Assessment of Pollinators in Indigenous Farming Systems in Garhwal Himalaya, Uttarakhand

THESIS

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Under the Supervision of

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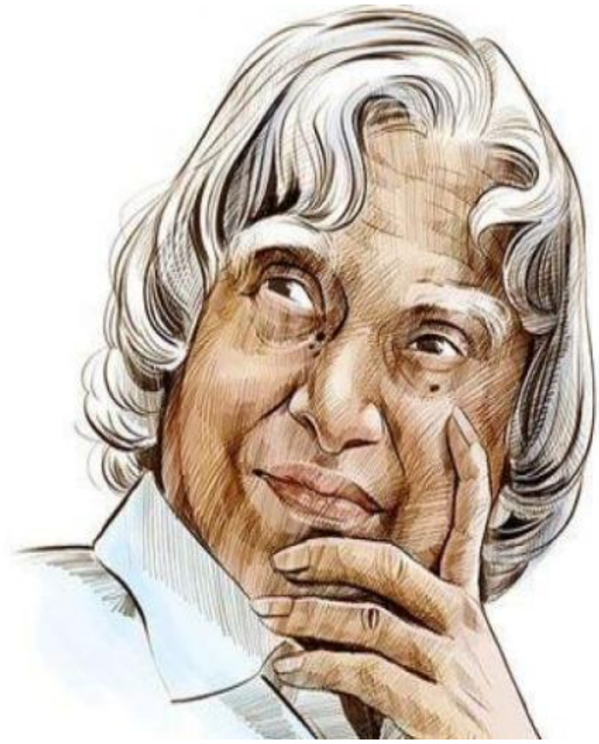
Dedicated to...



(1931-2015)

Dr. A.P.J. Kalam

A visionary who envisioned India as a developed country capable of self-sufficiency by 2020..!

If the farmer's hands slacken,
even the ascetic's state will fail.

- ***Thirukkural, 104:6***

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ACRONYMS

GP	Gram Panchayat
H_0	Null Hypothesis
HYVs	High Yielding Varieties
IHR	Indian Himalayan Region
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPM	Integrated Pest Management
IUCN	International Union for Conservation of Nature and Natural Resources
IWPA	Indian Wildlife (Protection) Act, 1972
LiDAR	Light Detection and Ranging
LULC	Land Use Land Cover
mb	Millibar (SI unit for pressure)
mm	Millimetre (SI unit for temperature)
Msl	Mean Sea Level
NGO	Non-governmental Organization
NTFPs	Non-Timber Forest Products
PRA	Participatory Rural Appraisal
SDG	Sustainable Development Goals
AN	Andaman & Nicobar Islands
AP	Andhra Pradesh
AR	Arunachal Pradesh
AS	Assam
BH	Bihar
CH	Chandigarh
CT	Chhattisgarh
DL	Delhi
GA	Goa

GJ	Gujrat
HR	Haryana
HP	Himachal Pradesh
JK	Jammu & Kashmir
JH	Jharkhand
KA	Karnataka
KL	Kerala
LD	Lakshadweep
MP	Madhya Pradesh
MH	Maharashtra
MN	Manipur
ME	Meghalaya
MI	Mizoram
NL	Nagaland
OD	Odisha
PY	Pondicherry
PB	Punjab
RJ	Rajasthan
SK	Sikkim
TN	Tamil Nadu
TS	Telangana
TR	Tripura
UP	Uttar Pradesh
UK	Uttarakhand
WB	West Bengal
DV	Doon Valley
MV	Mandakini Valley
UNDP	United Nations Development Program

Papers published/accepted in Journals:

- ❖ Need of Invertebrate Research in Mountain Agroecosystem: Special emphasis on Pollinators' Conservation in relevance to current Climate Change trend (Paper submitted as chapter/article for an edited book, New education policy 2020: an overview on 18th Sep, 2020)
- ❖ Indigenous Seed Conservation Practices in Western Himalaya: A Case Study of Mandakini Valley, Uttarakhand, India (Paper accepted as article in Springer Nature journal on 14th Dec, 2020)
- ❖ Preliminary assessment and conservation of insect pollinators through community participation in the Lahaul and Spiti district of Himachal Pradesh, India (Paper published in CURRENT SCIENCE, VOL. 120, 2021) https://www.currentscience.ac.in/Volumes/120/05/0883.pdf. DOI: https://doi.org/10.18520/cs/v120/i5/883-887
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- ❖ Conservation of Bees through Community Participation in the Indian Trans Himalayan Region: Climate Change Perspective (BEE-CON-211) - Conference Proceedings, Online International Conference: Bee Pollination Under Climate Change Scenario (May, 2021)
- ❖ Traditional mud-wall hives in the Mandakini valley, Uttarakhand: Current Scenario (Aug, 2021) ISBN:978-93-91535-07-0
- ❖ Himalayan Perspective of Indigenous Seed Preservation Practices in Mandakini Valley, Uttarakhand, India (ID-26) – 25th International Forestry and Environment Symposium 2020 for oral presentation. (Dec, 2020)

Webinars and Workshops attended:

- ❖ Bumble bee ecology and conservation (June, 2020)
- ❖ Discovering how cover crops impact cropland habitat for pests: Voles, slugs and other pests (June, 2020)
- ❖ Role of agroforestry in supporting pollinators (June, 2020)
- ❖ Trees for bees: pollinator habitat in urban forests (July, 2020)
- ❖ National online conference on Post-Covid Opportunities and Challenges in Zoological sciences (29-30th June, 2020)
- ❖ Environment and Climate change (20-23rd July, 2020)
- ❖ National webinar on Forest, Environment and Wildlife-Status and Developments in the 21st Century (Aug, 2020)
- ❖ Inventory and Design opportunities for pollinator habitat on working lands (Aug, 2020)
- ❖ Online workshop on "Agro-tourism through underutilized ethnic foods" (Sep, 2020)
- ❖ National webinar on Conservation talks (28-29th Nov, 2020)
- ❖ Certificate of completion of Basic module on Geospatial applications for disaster management (Oct, 2020)
- ❖ Role of Botanical survey of India in taxonomic Research in India (Feb, 2021)
- ❖ Webinar on Women farmers and sustainable mechanization: Improving lives and livelihoods in Hindu Kush Himalaya (Mar, 2021)
- ❖ Webinar on managing soil to enhance biodiversity, mitigate climate change and safeguard agriculture (Mar, 2021)
- ❖ Webinar on International Day for Biological Diversity (May, 2021)
- ❖ Online International Conference: Bee Pollination Under Climate Change Scenario (May, 2021)
- ❖ Online 93rd IIRS Outreach Programme on Geo-informatics for Biodiversity Conservation Planning (Dec 06th-17th, 2021)
- ❖ Diversity within the Giant Honey Bees (*Apis*, subgenus *Megapis*). This event is part of the Bee Biogeography and Systematics Talks series, was organized by the Packer Lab and the Centre for Bee Ecology, Evolution, and Conservation at York University, Toronto, Canada (Jan, 2022)
- ❖ Pollinators role in sustaining Agro-ecosystems and Entrepreneurship: A way forward (7th -8th March, 2022)

SUMMARY

"Everything can wait, but not agriculture"
— J.L. Nehru

Overview

This piece of work explores the indigenous farming systems that revolve completely or partially around pollinators!

The indigenous Garhwal Himalayan farming system is a complex system of food production that is interconnected with crops, livestock, and forests. Kharif (April–October) and Rabi (October–April) are the two major cropping seasons. The traditional practice of *barahnaja*—a two-year rotation in the mountains—exemplifies the advanced nature of subsistence farming in the Garhwal Himalaya. The regional crops *bhat*, *gahath* (horse gram), *lobiya* (French beans), *rajma* (common kidney beans), *ogal* (buckwheat), *mandua/koda* (finger millets), *ramdana/marchhu* (amaranthus), *urad* (green gram), *moong* (black gram), *naurangi* (mix of pulses), *kheera* (cucumber), and *bhang* (cannabis) are cultivated together in a finely balanced mixture to maximize output and soil fertility while also catering to a wide range of household needs. The traditional crop rotation system also helps conserve rainwater, improve soil health, increases crop yield, and protects small-scale farmers in the event of crop failure. Multiple crops growing in close proximity often turn out to be the saviours and secure the financial security of the farming communities. The out-migration of natives and the practice of conventional mono-cropping in the region are posing serious threats to this traditional practice.

Mountain farming lacks intensive agricultural operations because of the difficult terrain. The crops are sparsely grown. Furthermore, because of significant soil erosion, agricultural areas are limited to low-lying river valleys and foothill plains, which account for a very small area. Landholdings are mainly small in size and consequently limited to family farms, while tenant farming and sharecropping are uncommon. Each family in the Mandakini valley splits their plots into two parts, each of which is cropped for two to four years before being left fallow. Sari is a type of terrace farm that is used for crop production during a specific season. Two Saris are commonly identified based on their presence in the village. Terrace farms can be found

above and below the villages as "*Mallasari"* and "*Mullasari"* respectively. Indigenous farming is the sole means for native farming groups in the Garhwal Himalayas to meet their subsistence-oriented needs. Practices such as organic farming, mixed cropping, mulching, and the use of farmyard manure are prevalent in the region. Practices of growing ornamental and medicinal plants around their kitchen gardens, poly-houses to tackle the menace of climate change and erratic weather irregularities, and mud-walled hives were also documented in the study area through PRA and surveys. Divulging and sharing of traditional indigenous knowledge by the oldest member of the family is common in the region. Indigenous farming in the Garhwal Himalayas has undergone tremendous changes over recent years in terms of agricultural productivity, resulting in the search for other livelihood options and out-migration in the region.

The research work explores the major trends in mountain agriculture, livelihood options, adoption and non-adoption of organic farming, crop diversification, and key pollinators. The study also investigates the influence of different cropping systems on the diversity of insect pollinators, species richness, and their activities in the Mandakini and Doon valleys of Uttarakhand, India.

Objectives of the Study

The purpose of the study is to describe the insect pollinators and agrobiodiversity in the croplands of the Mandakini and Doon valleys in light of their role as ecosystem service providers. This study attempts to compile a list of entomofauna pollinators in organic and non-organic agro-ecosystems in different cropping sites of the Mandakini and Doon valleys irrespective of their altitudinal gradient. This methodical approach will overlay a better understanding of the pollinators and their interactions in the mountain agroecosystem. Thus, the study envisages the following objectives:

1) To assess the species richness of pollinators in organic and non-organic agro-ecosystems.
2) A comparative study of different cropping systems practised in the Mandakini and Doon valleys with respect to their socio-economic impact on the richness of pollinators.
3) A comparative study of different farming systems adopted in different study sites and their impact on the richness of pollinators.

Study areas and Methodology

Regardless of their elevational gradient, I chose two completely different sets of study locations to investigate the possibilities of my research study. The rationale behind selecting these study sites was to compare the existence, diversity, and variation of insect pollinators in different types of environments. The first study site is undoubtedly located in the Doon Valley up to an elevation of 600-1000mts, and has an organic mode of cultivation, i.e., Navdanya Agrobiodiversity Conservation & Ecological Farm, Ramgarh, Dehradun district of Uttarakhand. It has embraced natural methods of cultivation dealing with soil infertility, low yield, insect pest infestation, and seed preservation techniques. The second site, comprised of three gram panchayats (Ushara, Hudu, Barangali), is located in the hilly terrain of the Mandakini Valley in the Rudraprayag district of Uttarakhand, up to an elevational gradient of 1400-2200mts, and practices non-organic mountain agriculture.

This study used multi-stage stratified random sampling. Sampling has three stages. Stage I finalized the study selection. Stage II chose three gram panchayats in the Ukhimath block at random for this study. The seven villages were chosen above and beneath the cemented road so that the two distinct agricultural modes of the region, i.e., *Mullasari* and *Mallasari*, could be understood. These sample villages are randomly distributed so that the study's results represent all villages in the Mandakini valley. In other words, they represented other villages in the region that practiced indigenous agriculture, mud wall-hived beekeeping, or polyhouses or bee boxes. Stage III involved selecting the sample population. Primary data was collected from the sample farmers, especially women and elderly men, in the sample villages for this thesis. Besides, the socio-economic aspects have also been explored to get first-hand information regarding the causes of out-migration in the region.

A replicated trial was carried out to determine insect pollinator foraging preferences in different cropping systems as well as farming systems having diverse crop families. Seven sampling plots (5m x 5m dimension) in each transect were studied in each type of agroecosystems. The diversity and foraging behaviour of insect visitors in various farming systems were visually recorded at different times of the day (at 10.00, 12.00, and 15.00 hours), with observations taken every alternate day beginning with the first day of flowering. The observations were recorded from the bloom of every treatment replicated three times. Simultaneously, weather parameters were also recorded. The collected insects were killed, preserved, and identified by comparing them with the reference collection maintained at the laboratory.

Main Findings

Objective 1: Pollinator Diversity

Collectively, 177 species of primary insect pollinators belonging to 119 genera under 53 subfamilies of 32 families were recorded from the organic (Navdanya agrobiodiversity & ecological farm, Dehradun district) and non-organic (Mandakini valley, Rudraprayag district) study sites of Uttarakhand. In both datasets, pollinator species from the orders hymenoptera, lepidoptera, diptera, and coleoptera showed their presence in organic (32 families) and non-organic (31 families) agro-ecosystems. A total of 107 genera of pollinator diversity were reported from organic study sites and 100 from non-organic study sites. The diversity account of these primary pollinators is 177, and the maximum was recorded from the Navdanya Agrobiodiversity Conservation & Ecological Farm (organic), i.e., 162 species, and relatively less from the villages of the Mandakini valley, i.e., around 146 species (non-organic). Lepidoptera (72) exhibited the highest species richness, followed by hymenoptera (65), diptera (28) and then coleoptera (28). Genus-wise, all four orders exhibited a similar trend with lepidoptera (52), followed by hymenoptera (36), diptera (20), and coleoptera (11). Hymenoptera (12) emerged with the highest number of families, followed by diptera (9), lepidoptera (7) and coleoptera (4).

Various primary insect pollinators include a wide array of honey bees, flies, wasps, beetles, ants, moths, and butterflies, which are the most efficient pollinators. While most lepidopterans are beneficial pollinators, many are also agricultural pests that visit blossoms mainly to meet their food requirements, which include pollen and nectar. Butterflies were abundant in cropping, wild floral strips, and forest edges, mud puddles, grasslands, and open forest or bushes because of abundant nectar sources, and were reported more often at puddles near rivulets or water sources.

Objective 2: Impact of Cropping Systems on Pollinators

The investigation found that there was a significant difference present in the mean number of species richness of pollinators between mono-cropping and multiple-cropping of organic agro-ecosystems ($t=10.345$, $p < 0.05$) and non-organic agro-ecosystems ($t=5.715$, $p < 0.05$). Crop patches in mono-cropping systems, in particular, had a different pollinator assemblage than crop patches in multiple-cropping systems. The box plot signifies the higher species richness of primary pollinators in the multiple-cropping of organic agro-ecosystems than those of non-organic agro-ecosystems. Likewise, the box plot signifies the higher species richness of primary pollinators in the mono-cropping of organic agro-ecosystems than those of non-organic agro-ecosystems. Possible explanations include (i) the higher availability of foraging options in multiple-cropping agro-ecosystems, (ii) the generalist species can congregate around any crop plant regardless of floral habitat, and (iii) the specialist species prefer specific plants for their pollen preferences.

Socioeconomic Aspects:

Three gram panchayats of Ukhimath block of Rudraprayag district, having a total population of 1340 individuals and 266 households scattered in seven villages, were chosen. Of those 395 respondents, particularly women farmers, from 224 households were randomly selected for primary data generation. In Huddu GP, 77 out of 85 households, 67 out of 96 Ushara GP households, and 80 out of 85 households in Barangali GP were taken into account. A total of 87 sampling sites have been considered for the collection of pollinators, of which 37 from Huddu GP, 34 from Ushara GP, and 16 from Barangali GP from Ukhimath block in Rudraprayag district of Uttarakhand state.

Village: Social segregation was prominent and clearly distinguishable. The villages lying in the upper regions were more economically stable than those lying below the roads, lower regions.

Farming System:

- Mono-cropping as well as multiple-cropping systems (saviour from hunger in the worst scenario of crop failure)
- Prevalence of kitchen gardens (each household has small or big kitchen gardens where spices and seasonal vegetables were grown)
- Subsistence-oriented (paddy and wheat are the major food crops)
- Traditional farming (without the use of tools and farm machinery)

Division of Labour: Women played a substantial role, from household chores to farming activities.

Landholdings (1 Nali=200 m² and 50 Nali=1 ha) *and Secondary livelihood options:* Farmlands, were generally scattered and terraced fields. Cow dung, urine from livestock, and ashes from burnt fuel wood are often used as manure. A total of 115 farmers were interviewed. Of these, only 36 (31.3%) supported the indigenous farming system and wished to continue it in the future. Interestingly, out of these 36 respondents, 69.4% were generally above the poverty line (APL) card holders and belonged to the general social group category. The desire to continue farming stemmed from the social prestige associated with traditionally practising agriculture as a household activity, which fits their identity as an agrarian family and also contributes to household food security. At least 79 (68.6% of respondents opposed the indigenous farming system and wanted it to be phased out in the foreseeable future. Mountain agriculture was considered more of a part-time than a full-time occupation. The main reasons behind this were: high risk of crop failure due to erratic rainfall, insect-pest infestation, crop raiding by wild animals (monkeys, langurs, porcupines, barking deers, and wild boars), poor income, migration, and labour scarcity. During the surveys studied and collated, confirmed that an average occupancy of 13 Nali of landholdings. 68% of respondents were dependent on land for subsistence farming, while 30% of respondents worked as seasonal labourers (MGNREGA), 25% as shop owners, and 21% as pony keepers or doli bearers (chardham yatras) on a temporary basis. Though the number of people switching to MGNREGA has increased dramatically in recent years.

Apart from their primary occupation, i.e., agriculture, rural folks are actively involved in the following livelihood options in order to get extra income. People who are unable to migrate due to a lack of resources engage in a variety of secondary activities, such as;

- Weaving Basketry (Kanda, Hathkandi- *Dendrocalamus* spp.)
- Sericulture: Oak Tasar and Mulberry silkworm rearing (*Quercus* spp.) and spinning silk thread from silkworm cocoons
- Apiculture (*Apis cerana indica*) and honey selling
- Juice Extraction (*Rhododendron* spp., *Citrus sinensis*)
- Spices and Food Grains (cereals, pseudo-cereals)
- Dairy and Poultry (milk, ghee, eggs, meat)
- Sheep Rearing (wool, meat)
- Traditional broom making
- Tailoring and knitting (NMHS-provided training centre)
- Farm produce sold under the tag of organic products (pseudo-cereals, pulses, garlic)

Family ownership, average income, and seed or chemical usage: At least 154 households had working farm tools (hand hoe, sickle, iron/wooden plough, axe, spade, neck yoke, harrow, etc.). Besides, 63 of them had their own poly houses. Average members in a family was 5, with an average annual income was one lakh. The seasonal loss of the farm yield was 1,500-3,500 INR. Around 123 households were into using treated seeds while 141 advocated the use of native seeds. Use of decomposed cow dung and burnt ashes in fields as manure to enhance their productivity. 119 families used chemical pesticides and fertilizers to get rid of insect pests or to get matured crops on time and enhance their productivity, which has a negative impact on pollinators.

Status of bee hives, bee colony and bee foraging resource:

- At least 95.08% of households were into traditional mud wall hives and bee keeping prior to 2017 and has seen a downfall by ten percent i.e., 84.37% in 2020
- Average number of wall hives per house: 3-5 in the year 2020 and >7 (prior to 2017)
- Number of traditional mud wall hives and colonies was decreasing in tandem with the increasing number of modern cemented houses
- Floral diversity ensured the availability of pollen-nectar (Amaryllidaceae, Apiaceae, Asteraceae, Brassicaceae, Cucurbitaceae, Rosaceae)

Status of Beekeepers:

- At least 79.41% of respondents: Ancestral knowledge and rest came from KVIC agencies or NGOs
- 15% of the total families engaged in beekeeping
- Only 7.95% of respondents: beekeeping as full-time job, rest as part-time
- 68.10% of respondents: pass on the indigenous knowledge of beekeeping to the next generation
- Male members: management and upkeep of wall hives and bee boxes, honey extraction.
- Older respondents-better knowledge and expertise
- Mandakini valley: the traditional wall hive-wall cavity left during house/cowshed construction, 150cm above ground level (>150 in cemented households)
- Entrance hole from outside (2 cm dia), plastered and covered with a wooden

block from inside (oaks, chir pines, or deodar woods)

- *Apis cerana* naturally descends in the cavity, forming a series of parallel combs
- The wall hive is opened twice only to extract the honey (Verma and Attri., 2006)
- Probabilities of low or no bee forage during the off season or instances of weather adversities
- Beekeepers manage bee colonies and sustain the bee population by feeding sugar or jaggery solutions

The declining trend of beekeeping due to increased migration and house conversion (Tiwari et al., 2013) was verified. There are chances of disturbed mountain agro-ecosystems, if the issue is not addressed seriously. In comparison to 45 cm wide mud and stone dwellings, cemented houses with a 25 cm wall width are insufficient to host conventional wall hives (lack of insulation). Abandoned or dilapidated houses and cattle sheds could be renovated to epitomize valuable nesting sites for managed bees, *Apis cerana* (Singh et al., 2013). Traditional beekeeping practices in the mountains must be preserved in order to support the bee population and preserve the cultural heritage of the beekeeper communities. Furthermore, scientific investigations are needed to harness the full potential of beekeeping in the valley.

Objective 3: Species composition and abundance of insects in different farming systems

This study discovered that farming systems with various combinations of crop preferences, as well as the size and location of cultivable farmlands, determine the diversity of species. Both the diversity of pollinators and the composition of crops in different farming systems were different. The insect pollinator diversity of the Garhwal Himalaya as reflected through investigation showed that the order lepidoptera was the most active group of pollinators during the day, followed by the hymenoptera, diptera, and coleoptera, which includes 177 species belonging to 119 genera in 32 families and 53 sub-families. The crop families that were the most preferred forage by the insect pollinators were Amaryllidaceae, Asteraceae, Rosaceae, Rutaceae, Solanaceae, Polygonaceae, Brassicaceae, Cucurbitaceae, and Fabaceae. The least preferred families were Apiaceae, Araceae, Lamiaceae, and Pedaliaceae. The families such as Amaranthaceae, Meliaceae, Moraceae, Myrtaceae, and Zingiberaceae were the moderately preferred ones.

Management actions and Key recommendations

In summary, my doctoral thesis generates inventorial knowledge on insect pollinators in different farming systems and a variety of habitats in the Garhwal Himalayas. Mountain agriculture, in coming years, is vulnerable due to the advent of chemical pesticides, encroachment, non-regulation of tourism in the region, habitat loss and land fragmentation, and extreme climatic conditions in the Garhwal Himalaya. Though this doctoral study did not engage in any population estimation, collected data shows there are a minimum of 177 crucial insect pollinator species from 32 families in this landscape. The key management actions and future recommendations that can be undertaken based on this study are described below:

- The findings of this doctoral work have identified a number of genera from the families Hesperiidae, Lycaenidae, Nymphalidae, and Pieridae (order Lepidoptera) that are already enlisted under Schedule I (Part-IV, I: Butterflies & Moths), Schedule-II (Part-II), and Schedule-IV) of the Wild Life (Protection) Act, 1972. This valley supports a considerable number of primary insect pollinators from the orders Diptera, Hymenoptera, and Coleoptera, which should be undoubtedly taken into consideration from a conservation point of view as under different schedules of the Wild Life (Protection) Act, 1972 based on other extended research studies.
- Recognition of Indian butterflies and bees as threatened species under IUCN's Red List or Red Data Book.
- Our surveys and data collection highlight the importance of the cropping systems prevailing in the region. Even the conversion of agricultural land to non-agricultural purposes such as animal rearing and husbandry, the construction of homestays, shops, and cemented houses, has caused continuous land fragmentation and habitat destruction of these tiny pollinator communities. Preliminary observations from primary and secondary data suggest that the overall cropping area has been reduced for a variety of reasons.
- Future studies in the Western Himalayas should focus on bridging the research gaps such as generation of distribution maps of primary pollinators, more taxonomically based studies, isolation and speciation based research at the molecular level, and genetic profiling of bumble bees. Also, how do the phenomena of climate change and seasonal variation in crop resources, landscape features (wild strips, vegetation cover), environmental covariates (snowfall and

precipitation) and anthropogenic covariates (human disturbance regimes) affect the whole existence of primary pollinators in this landscape?

- The migration patterns of bumble bees (*Bombus* sp.) or managed bees (*Apis mellifera, Apis cerana indica*) need to be explored. Such fine-scale data could help in identifying and preserving the pollinators' corridors and ensure their conservation during unfavourable weather conditions. The unmasking of the habitat suitability index of bees and butterflies can also be achieved through remote sensing and geo-informatics. Habitat models and species distribution based on LiDAR-driven structural variables can provide a better representation of the habitat. Habitat classifications based on land cover types, habitat suitability indices, and seasonality have made major contributions to animal migration studies and species distribution models.
- Promote integrated pest management (IPM) and design incentives or similar programs to enable farmers to gain from ecosystem services rather than agrochemicals.
- The acknowledgement and acceptance of pollination biology as an essential element in agricultural extension services.
- Endorse and support organic farming by sensitizing farmers to reduce their use of chemical fertilizers and pesticides. It is critical to launch a public awareness campaign against chemicals that harm bees and other pollinators. The National Bee Board, NABARD, and state agriculture departments must incorporate this into their programs.
- Pollinator-friendly activities such as organic farming or diversified farming systems, awareness generation programs, citizen science tools, and the establishment of a pollinator conservation resource centre for attracting native bees and butterflies, where one can quickly locate regional plant lists, habitat conservation guides, and other relevant resources.
- Maintaining community seed banks and conservation of gene pools at the village or gram panchayat level is important for maintaining a healthy mountain biodiversity.
- Finally, crop raiding wildlife necessitates ongoing attention and collaboration efforts that are organized and action-oriented.

Conservation Implications

The findings of this study emphasize the need for organic agriculture adoption and promotion to conserve insect pollinator diversity in mountain agriculture, where inorganic agriculture is prevalent. Although our findings suggest that both types of farming practices (organic as well as non-organic) may support similar levels of insect pollinator diversity as in the Garhwal Himalayas and Navdanya Agrobiodiversity Conservation & Ecological farms, at least for hymenoptera and coleoptera species, this does not mean that multiple-cropping systems are unimportant for conserving their diversity. Risks associated with pollinator decline can be mitigated by moving toward more sustainable agriculture and reversing the simplification of agricultural landscapes. The following three complementary techniques help keep pollinator communities healthy and agriculture productive: (a) ecological intensification, i.e., improving agricultural production and livelihoods while reducing environmental damage by controlling nature's ecological functions; (b) reinforcing diversified farming systems favouring heterogeneity in landscapes (including kitchen gardens, homesteads, agroforestry, mixed cropping, and livestock rearing) to foster pollinators and pollination through indigenous knowledge (e.g., Mallasari, Mullasari, Barahnaaja); and (c) investing in ecological infrastructure across agricultural landscapes to protect, restore, and connect natural and semi-natural habitat patches.

Lastly, I would like to infer that Zero Hunger under SDG-2015 can solely be achieved through resilient agricultural practices, native seed conservation, and protection of pollinator communities. Insect pollinators are popularly branded as hard-working, detail-oriented, and tenaciously determined allies of flowers and nectar fabricators who benefit the environment while also enriching human existence. These pollinators are also influential partners in achieving the SDGs by promoting biodiversity (Goal 15), fighting hunger (Goal 2), and providing decent jobs (Goal 8) in agriculture and allied sectors, therefore, advancing Goal 1, no poverty (UNDP, 2021).

Chapter 1: Introduction

1.1. Overview

A pollinator is anything that helps carry spores from the stamen to the stigma of the same or other flower for fertilization. In simple words, pollinators are the wildlife that shuffle pollen between flowers and are represented by a wide range of animal and bird species (IPBES, 2016). The majority of plants rely on insects for pollen transfer, with only a handful using alternate pollen transmission mechanisms such as self-pollination or wind-pollination.

These pollinating managers from the orders of hymenoptera, lepidoptera, diptera, coleoptera, certain mammals or birds, are indispensable for the continued breeding and the holistic existence of the plants (Kearns et al., 1998). Insect initiated crop pollination in recent years has started to receive acclaimed recognition (Klein et al., 2007). Countless drupes, berries, or ornamental plants grown in groves, orchards, estates, botanical gardens, and quasi-natural habitats rely on pollinators to reproduce. Pollination and pollinators have long been associated with Asian culture and traditional beliefs (Joshi et al., 1983). Insect pollinators, particularly bees and butterflies, have long served as sources of inspiration for artists, musicians, dancers, writers, and folklorists (de Gubernatis, 1872; Andrews, 1998; Kristsy and Cherry, 2000; Bastian and Mitchell, 2004; Werness, 2006).

Unsustainable agricultural practices impair the environment and jeopardize the livelihoods of millions directly or indirectly. One of the key ecosystem services provided by wild animals is pollination. It is one of the most critical mechanisms for the sustenance of the entire biodiversity on the Earth. It also has societal benefits that boosts food security and raises their living standards. Pollinator diversity is essential for maintaining overall biological diversity in certain habitats, notably agro-ecosystems (Eardley et al., 2006). Pollinators, primarily bees, are required for the successful harvest of 75% of crops cultivated for human consumption (Tracy and Jessica, 2015). Bees are the primary pollinators of crops, particularly those related to the growth of seeds and fruits (Rosemeire et al., 2009). There are approximately 20,000 species of pollinating bees, as well as a slew of other insect and vertebrate pollinators worldwide that are immensely diverse (Eardley et al., 2006). Additionally, Losey and Vaughan (2006) indicated that globally, the needs of insect-pollinated crops are often fulfilled by them as a pollination service provider and sustain an important ecosystem function

(Rosemeire et al., 2009). Inadequate pollination, other than agricultural inputs, is a major cause of low yields and fruit deformation (Nabhan et al., 1996). The majority of wild crop plants (McGregor, 1976; Crane and Walker, 1984; Free, 1993; Burd, 1994; Williams, 1994; Nabhan and Buchmann, 1997; Kearns et al., 1998; Westerkamp and Gottsberger, 2000; Larson and Barrett, 2000; Ashman et al., 2004) rely on these pollinating agents for reproduction, and this may also provide mankind with calories and nutrition (Sundriyal and Sundriyal, 2004).

Moreover, the extinction of pollinators may result in the extinction of various plant species (Biesmeijer et al., 2006). Insect pollination is considered a regulating ecological service provider. The diversity and abundance of pollinator species has plummeted across the globe (IPBES, 2016). We need to safeguard pollinators as they play a key role in conserving biological diversity, supporting ecosystem services for food availability, natural habitations, and, thus, maintaining a healthy economy. About 99 percent of wild flowering plants need pollinators to transmit pollen, with honeybees accounting for over 80% of all insect pollination. They contribute a variety of resources in the form of food, medicine, biofuels, fibres, habitats to many animal species and are responsible for much of the world's crop productivity. But there is a pollinating catastrophe, in which pollinators both wild and controlled perish due to habitat loss, toxicity, disease, and pests at frightening rates (USDA-ARS, 1991). Untenable agricultural practices damage the environment and threaten the livelihoods of millions of small-scale farmers.

1.2. Mountain Agroecosystem and farming trend in Uttarakhand

Agriculture in the Western Himalayas is often considered as an asset turning into a liability. Agrarian crises and widespread advancements over the last decade have led Indian agriculture into a dynamic shift. Besides, mountain agricultural practices are getting increasingly difficult and challenging due to changes in socio-economic and environmental conditions. As a result, rural livelihoods in the Himalayas are becoming increasingly de-linked with agriculture, leading to widespread out-migration and switching to other livelihood options. With the advent of modern agriculture, the Indigenous farming system is losing its sheen. Indigenous peoples have provided humanity with a plethora of ecological and cultural services over the centuries. Preserving traditional agricultural knowledge and practices contributes to the conservation of mountain biodiversity, protection of natural resources and enhanced food security.

As an entirely man-made ecosystem, the agroecosystem is designed to meet human needs. It comprises of crop-plant diversity, weed communities, animal populations (including insects), microbiota and the abiotic components they interact with. Due to the physiographical variation in the country, different regions experience distinct climates, affecting agricultural output in different ways. India is heavily reliant on its monsoon cycle for its crop productivity. Currently, it is the second-largest producer of agricultural products in the world. Agriculture and other sectors accounted for over 16% of India's GDP in 2007. Agriculture and associatted industries such as forestry, livestock rearing, and fisheries accounted for 17% of GDP in 2014 and employed 49% of the workforce. Despite the fact that agriculture's proportion to GDP has been steadily dropping from 1951 to 2011, agriculture is still the country's largest industry in terms of source of employment and also impacts its overall socio-economic development. In India, farming systems based on agro-climatic zones are strategically used in regions where they are most appropriate. Subsistence farming, organic farming, and industrial/commercial farming are important contributors to India's economy.

Farming practices vary throughout India and often embrace crop rotation, intercropping, mixed cropping, horticulture, aquaculture, agroforestry, plantation farming, shifting cultivation, animal husbandry and poultry, dry land farming, apiculture, sericulture, and mushroom rearing. Agricultural crops, horticulture, tea plantations, and nursery practices are all part of the Himalayan farming system (Sati, 2005). When compared to lowland agricultural systems, the diversity of domesticated crops in the highlands is significantly higher (Sati, 2009). Basically, there are two crop seasons, namely, Rabi, having a crop cycle between the period of November to April, and Kharif, from May till October (Sati, 2005). The main crops in the hilly terrain are wheat, barley, rye, mustard, peas, and gram, which are grown during the Rabi season, while rice and millets are the major Kharif season crops that are grown extensively. Because of the terrain's fragility, intensive agriculture operations are not possible. The Garhwal Himalayas have well-established subsistence agroforestry systems (Dadhwal et al., 1988). Farmers cultivate a variety of plants, including seasonal and biennial crops, as well as multipurpose trees, all on the same plot of land (Dadhwal, 1988). Due to regional constraints, technological innovations such as chemical fertilizers, pesticides, and HYVs that transformed low-land agricultural areas couldn't alter the farming system. Enterprise-based pollination services and NTFPs such as medicinal herbs, wild edible mushrooms or plants, essential oils, dyes, silks and natural fibres, bamboo, wax and honey products can aid in generating employment and improving rural livelihoods (Sati, 2009).

1.3. Need for Pollinator based Studies in Western Himalaya

In the Indian subcontinent, the Western Himalayas have a distinct ecosystem. Uttarakhand is located between 28° 43' & 31° 29' N latitude and 77° 36' & 81° 02' E longitude and is part of the Western Himalayan bio-geographical provinces, with a total geographical area of approx. 53,483 km^2. Across the globe, concerns pertaining to the decline of crop pollinators due to intensive land use change, modern agricultural practices, induced pests and diseases, and climate change have been highlighted. It eventually resulted in a response to the impending "*pollinator crisis*", especially by conservationists and political decision makers (IPBES, 2016). The crisis situation seems to be primarily driven by the extensive loss of managed honey bee, bumble bee and butterfly populations (Ghazoul, 2005). There is a scarcity of data on the condition and trends of wild pollinators around the world. Asian research revealed a correlation between dwindling insect populations and decreased crop yields, and thus, people began to regulate the associated biodiversity of pollinators and their biodiversity and maintain crop productivity. Farmers from India's northernmost state, Himachal Pradesh, use honeybees to pollinate their apples (Partap, 1999; Mattu and Mattu, 2010). Since the population of pollinators is dwindling and methods of cultivation are changing, numerous farmers throughout the globe are importing and breeding non-indigenous breeds and using paid pollination services for their assured crop output. The growing understanding of pollination as an important and essential ecosystem service for food security and ecosystem resilience has garnered ample support for its conservation and management (Poppy et al., 2014). Besides the social and managed honey bee pollinators, the pollination of major crops is greatly complemented by many wild and other non-Apis domesticated bees. It includes the use of eusocial bumble bees, solitary bees Nomia and Osmia (Batra, 1998), Megachile (Richards, 1987) and social stingless bees for pollination of tomatoes, horticulture crops, coffee, fodder and other crops. It is reported that in apple orchards, 600 solitary bees can pollinate as much as 30,000 honey bees (Delaplane and Mayer, 2000), and may act synergistically with other managed bees to increase yields. Since the use of hybrid crop varieties and the import of exotic bee species meant for managed pollination has escalated, there has been a lack of data on pollination biology and the necessity of specific pollinators for certain crops (Klein et al., 2007).

Indigenous knowledge of native individuals or communities about floral phenology and pollinators provides signals for predicting accurate weather forecasts. Pollinators, as has been established, contribute to a wide array of profits, such as cultural (e.g. source of inspiration), financial (e.g. profits from crops/NTFPs), health (e.g. medicinal herbs, calories and nutrition), human needs (e.g. jobs and income generation), and environmental (e.g. balancing ecosystems, maintaining biodiversity), apart from providing pollination services.

1.4. Pollinators: Threats and Conservation

Globally, insect pollinators of crops and wild plants are under threat and their decline could have profound economic and environmental consequences. Different habitat types in the Indian Himalayan Region (IHR) are under constant anthropogenic pressure that has not only modified the functioning of ecosystems but also jeopardized the existence of native flora and fauna (Sundriyal and Sharma, 1996; Khan et al., 2012; Tiwari and Joshi, 2014). According to the IUCN's Red List assessments, 16.5% of land pollinators and 30% of island pollinator species on planet earth are thought to be endangered with greater chances of extinction. Pollinators, both wild and managed, play an important role in crop pollination globally. Pollinators are frequently viewed as a significant association between forestry, agriculture, biodiversity, nutrition, and food security.

Assessment report by IPBES identified some of the major drivers of change affecting the richness, diversity and well-being of the pollinators. The Himalayan biogeography supports a diverse spectrum of species, which is currently threatened by a fast deteriorating environment. Pollinator loss is exacerbated by urban–industrial development, mining, hydropower projects, unethical timber extraction, and unrestrained tourism, parasites and diseases, invasive alien species, monoculture, and intensive farming methods. While the Himalayas have proven resilient to these stresses, global warming and rising temperatures threaten the habitats of some charismatic, keystone, and beneficial pollinator species. Overgrazing has wiped out multiple endemic plant species in alpine forests, compromising their migratory and nectar corridors, also endangering wildlife and disrupting the food chain. In response to perceived vagaries of nature, certain species of pollinator have changed their navigational routes, relocated their habitations, and budged their seasonal activities, affecting their populations and overall distribution. Pollinators that have diverged over a long time are diminishing at a rapid rate. At present, many important pollinators, in particular honeybees, have died worldwide in unprecedented ways, and experts have not proposed appropriate reasons for this declining trend. This persistent deterioration in the population of pollinators will, in the long run, have serious ecological and economic consequences as they form an integral part of the pollination of almost all farm, horticultural, and cash crops worldwide (Gallai et al., 2009; Mattu and Mattu, 2007, 2010).

Pollination management practices can also be used to reduce climate change while also promoting sustainable agriculture and livelihoods. Provision of growing more wild floral resources in the periphery of farmlands, such as cover or trap crops, strip crops, and hedgerows, may aid in providing forage for the pollinators even in times of non-availability of pollen. The diversity and relative abundance of the majority of pollinators was observed to be higher with enhanced floral diversity (Mattu and Bhagat, 2015). There’s a saying-"farmers have their own struggles and their own solutions". They rely on eco-friendly ways and means to deal with issues related to insect pest and disease outbreaks, soil health, low productivity, and climate change. For developing climate change coping mechanisms and adaptation, indigenous traditional knowledge and local people's perceptions of climate change are crucial (Mehta et al., 2010). Climate change has had a major impact on vegetation, the community and ecosystem dynamics for a long time (Negi et al., 2012). Any change in the phenology of plants, such as early budding, delayed flowering, fruit or seed malformation, can adversely affect the productivity of the ecosystem and, in the meantime, also impair the compositional attributes of high altitude species and habitats (Thuiller et al., 2008).

1.4.1. Decline of Domesticated and Wild Pollinators

Although no scientific evidence of pollinator decline exists, based on some personal observations and experiences, it might be deduced that pollinator populations, particularly insect pollinators such as honeybees, bumble bees, and dipterans, are dropping over the Indian subcontinent (Verma, 1990, 1992; Mattu and Mattu, 2003, 2007, 2010, 2014). Variability in climate parameters has led to an impact on biodiversity: geographical changes (Pounds et al., 1999), variation in the composition of community species (Easterling et al., 2000), variations in phenological times (Fitter and Fitter, 2002) and species extinction.

Aguilar et al. (2006) found a connecting link between local declines in pollinator abundance and diversity, and declines in wild plant pollination and seed production. Invasive plant species have a significant negative effect on visitation of pollinators and fertilization of co-flowering species (Morales and Traveset, 2009). Montero-Castao and Vila, (2012) found that habitat alteration and alien species invasions reduced pollinator visitation rates. Vertebrate and insect (excluding bees) visitation rates were most affected by altered landscapes. Pollinator population declines are one type of global change that has the ability to impact the layout and structure of terrestrial ecosystems as a whole. In many regions of the world, the reduction in pollinator numbers and diversity poses a severe threat to agricultural output as well as biodiversity protection and maintenance. Pollinator losses can lead to a loss of pollination services, which has serious ecological and economic consequences that could jeopardize the diversity of wild plants, threaten the stability of the ecosystem, yield output, food security, and the well-being of mankind (Abrol, 2009).

Because of their limited temperature tolerance, insects are the first victims of climate change (Connor, 2008). Low temperatures and excessive humidity have a dual effect on bee activity and pollen release, lowering bee activity and slowing pollen release (Joshi and Joshi, 2010). The quantity and concentration of nectar, as well as the flower's attraction to bees, are affected by temperature, relative humidity, and wind (Somerville, 1999). Honeybees must expend a large portion of their energy on heating the comb and brood (Kleinhenz et al., 2003), making them less efficient pollinators. Pollinator abundance will be impacted more severely in the long term. As a result, the government should take policy measures to expand extension facilities in order to educate small-scale farmers about the environmental implications of agrochemical use. To maintain the livelihoods of a large number of small and large farmers, it is necessary to promote the scientific and rational use of pesticides and other agro-chemicals to minimize environmental consequences and to promote the balanced use of fertilizers, including bio-fertilizers, to restore soil health.

1.5. Research Gaps and Future Potentialities

The majority of the research appears to be the product of random surveys conducted in IHR states. Taxonomically, several taxa of high altitude insect pollinators have been poorly investigated. However, recent technical advancements have resulted in a multifold increase in research-based studies on insect diversity in the Himalayan province. Butterflies and beetles are one of the most studied groups amongst insects. Butterflies have been researched methodically since the early 18th century, and there are 19,238 species reported globally (Heppner, 1998). The majority of the pollinator-based studies, are limited to specific locations and are confined to inventory checklists for beetles, butterflies, and bees.

Furthermore, these studies are attempts to identify IHR's Lepidopterans and Odonates, demonstrating that a significant amount of work has been done on butterflies and moths. Scientific studies based on pollinators influencing the productivity of mountain agriculture are scantily done. Thus, we ignore the scope of other important pollinators, such as wild bees, bumble bees, flies, and wasps. Aside from the order Lepidoptera, detailed studies focusing on other relevant pollinators, their ecology, and evolution are urgently needed in the Himalayan region. If we look at the literature on the IHR's fauna and invertebrates, we find that a large number of studies are confined to the ecology and behavioural aspects followed by their distribution and taxonomy. Whereas studies on themes like molecular biology, conservation, and climate change are still in their infancy (Fig. 1.1 & Table 1.1).

The entomofauna pollinators of IHR are quite diverse, but their conservation efficiency is impaired by the utter lack of taxonomic knowledge, inadequate distribution maps, and evolution and morphometry-based studies. There is also a need for an IUCN red list for declining populations of pollinators (bees, butterflies) as they are disappearing at a faster rate. A few holistic research projects on pollinators have been conducted in the Jammu & Kashmir, Himachal Pradesh, and Uttarakhand regions of the Western Himalayas (ZSI, 1995). The entomofauna must be nurtured and protected at a regional level, through execution of pollinator-based conservation programs.

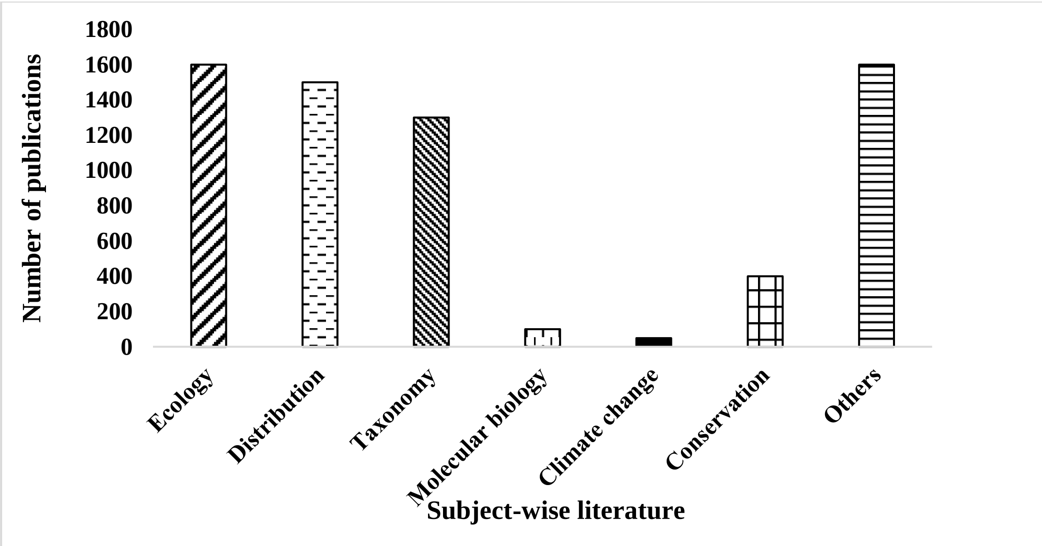


Fig 1.1: Distribution of subject-wise literature on the fauna and micro flora of the IHR (Source: ENVIS Bulletin, 2015-16)

Table 1.1: Subject area, key past research priorities and research gaps and future potentialities of pollinators in IHR

Subject Area	***Key past research priorities***	***Research gaps and future potentiality***
Ecology and Behaviour	Distribution	Inadequate distribution map of primary pollinators
	Stages of the life cycle	Biases in taxonomical studies
	Patterns of migration	Few studies (Bumblebees)
Taxonomy	Morphological Taxonomy (Butterflies, Beetles, Bees)	Other taxa (Bumblebees, wild bees, wasps, flies)
		Isolation and speciation research at the molecular level
Evolution	Not a single study, few hypothesis exist	Evolution and morphometry based study needs attention
Conservation	In few pockets and patches	Need for IUCN red list for disappearing pollinators (Bees, butterfly)
Climate Change	No single study but few geomorphic and diurnal variations observed	Phylogenetic affinities and past climate distribution based study

1.6. Objectives

The purpose of the study is to describe the agrobiodiversity in the croplands of the Mandakini and Doon valleys, in light of their role as ecosystem service providers. This study attempts to compile a list of entomofauna pollinators in organic and non-organic agro-ecosystems in different cropping sites of the Mandakini and Doon valleys irrespective of their altitudinal gradient. It also emphasizes the need for conservation of entomofauna pollinators of IHR by describing species diversity and highlighting the socio-economic state of mountain agriculture. This methodical approach will overlay a better understanding of the pollinators and their interactions in the mountain agroecosystem. The basic intent of this study is to address the following research questions:

- Is there any variability in the diversity of pollinators between two completely different sets of environmental conditions regardless of their physiographical differences?
- Does the adoption of different cropping techniques influence the diversity of pollinators in the field?
- Does the use of various farming strategies adopted by farmers attract more pollinators?

Keeping the above research questions in mind, the study envisages the following objectives:

1. To assess the species richness of pollinators in organic and non-organic agro-ecosystems.
2. A comparative study of different cropping systems practised in the Mandakini and Doon valleys with respect to their socio-economic impact on the richness of pollinators.
3. A comparative study of different farming systems adopted in different study sites and their impact on the richness of pollinators.

1.7. Present Study and Scope

The present study throws light on the diversity of pollinators in organic and non-organic agro-ecosystems in Mandakini as well as the Doon valley. Nature and the extent of their impact on different cropping and farming systems in the Garhwal Himalaya. The findings of the study will provide policymakers with the information they need to safeguard traditional mountain agricultural practices and to strengthen other livelihood options (beekeeping, sericulture, wax making, honey extraction) in the region. This will help in diversifying the income generation mechanism in the region and avert the issue of hill out-migration. The study may also assist the government in taking appropriate steps to diversify the cropping pattern in order to achieve developmental goals such as job creation, income growth, poverty alleviation, and so on. It would be a mistake to not recognize the importance of mountain agrobiodiversity in this changing climate scenario. Climate change adaptation plans should include agrobiodiversity protection as a key component. Ex-situ conservation must be supplemented by in-situ protection of agricultural biodiversity.

1.7.1. Period of the study

In order to study the diversity of pollinators in the region, research was conducted for the period from 2018-2020, from adoption of sampling designs to generation of primary/secondary data and laying of field experiments.

1.7.2. Choice of the study area

In the Mandakini and Doon valleys, the current study was conducted. The aim of this research was to discuss the pollinators' diversity, their distribution patterns, and farming practices, including crops, crop patterns, and ecological aspects of the mountain agroecosystem. Three gram panchayats in the Rudraprayag district of Ukhimath block were purposefully chosen for the present study. This area was selected because:

- No such study based on pollinators or comparative study for organic and non-organic agroecosystems has been conducted before.
- The area under these gram panchayats has vast terrace farming that represents the traditional way of mountain agriculture.
- Ease of conducting studies due to the availability of accommodation in the vicinity of Mandakini valley in Garhwal Himalaya.

1.8. Organization of Chapters

The thesis is organized into six chapters and are discussed in the following order:

Chapter I: (Introduction) - The first chapter describes the rationale for the study and specifies the objectives and scope of the study.

Chapter II: (Study Area and Methodology) - The second chapter discusses the study area, focusing mainly on its geographical area, physical attributes, and flora-fauna, apart from giving concise details of the sampling strategies adopted to collect and preserve the samples.

Chapter III: (Pollinator diversity in organic and non-organic agro-ecosystems) - The third chapter deals with my first objective, which is to provide a comprehensive inventory of the primary pollinator diversity documented from organic and non-organic agro-ecosystems with detailed taxonomic information and interactive keys to families and genera for this region.

Chapter IV: (Impact of different cropping systems on the richness of pollinators) - The fourth chapter discourses my second objective, which is to talk about the impact of mono-cropping and multiple-cropping systems on the richness of pollinators.

Chapter V: (Impact of different farming systems on the richness of pollinators) - The fifth chapter deals with the third objective, assessing the impact of different farming systems on the richness of pollinators. Here, I again explore how species composition changes across different farming systems.

Chapter VI: (Key findings and Recommendations) - The sixth chapter discusses the overall results of the study. Here, I summarize my key findings and conclude the study with constructive recommendations.

Chapter 2: Study Area and Methodology

2.1. Overview

Regardless of their elevational gradient, I chose two completely different sets of study locations to investigate the possibilities of my research study. The rationale behind selecting these study sites was to compare the existence, diversity, and variation of insect pollinators in different types of environments. The first study site is undoubtedly located in the Doon Valley up to an elevation of 600-1000mts, having an organic mode of cultivation, i.e. Navdanya Agrobiodiversity Conservation & Ecological Farm, Ramgarh, Dehradun district of Uttarakhand. It has embraced natural methods of dealing with soil infertility, low yield, insect pest infestation, and seed preservation techniques.

While the second site comprises of three gram panchayats (Ushara, Hudu, Barangali), located in the hilly terrain of the Mandakini Valley in Rudraprayag district of Uttarakhand up to an elevational gradient of 1400-2200mts, has a non-organic mode of mountain agriculture. This study used multi-stage stratified random sampling. Sampling has three stages. Stage I finalized the study selection. Stage II chose three gram panchayats in the Ukhimath block at random for this study. The seven villages were chosen above and beneath the cemented road so that the two distinct agricultural modes of the region, i.e., *Mullasari* and *Mallasari*, could be understood. These sample villages are randomly distributed so that the study's results represent all villages in the Mandakini valley. In other words, they represented other villages in the region who practiced indigenous agriculture, beekeeping, or polyhouses or bee boxes. Stage III involved selecting the sample population. Primary data was collected from the sample farmers, especially women and elderly men, in the sample villages for this thesis (Appendix 1 & 2).

2.2. Topography, Geology & Pedology

2.2.1. Mandakini valley

Different habitat types in the Indian Himalayan Region (IHR) are constantly under anthropogenic strain, which has altered ecosystem functioning and compromised the survival of local flora and wildlife (Khan et al., 2012; Sundriyal and Sharma, 1996; Tiwari and Joshi, 2014). Kumaon (6 districts) and Garhwal (7 districts) are the two geographical divisions of Uttarakhand state. The Mandakini valley lies in the

Rudraprayag district of the Garhwal division. The Rudraprayag district lies between 29° 55’ 37" and 31° 27’ 3" N latitude and 78° 54’ 3" to 80° 2’ 3" E longitude, and consists of three blocks, viz. Ukhimath, Rudraprayag, and Jakholi. The Ukhimath region of this district is often referred to as the Cherapunji region of Garhwal. The term Mandakini is a synonym for *"she who flows calmly"* and originates near Kedarnath, from the Chorabari glacier. Mandakini is fed by the Vasukiganga in Sonprayag. Hereafter, it joins the Alaknanda in Rudraprayag, and continues her journey till Devprayag, where she eventually merges with the holy Bhagirathi River to form the sacred Ganga.

The topography of the Mandakini Valley is characterized by a series of denudational hills and the vicinity is surrounded by moderate to dense forest (temperate broad leaf-wet deciduous/evergreen/mixed) and human settlements in hamlets or clustered forms can be seen. The research was carried out in seven villages of three Gram Panchayats (Elev. 1400 and 2200 mts), namely Taala, Ushara, Huddu, Karnadhar, Kanda, Barangali, and Semar, with a total area of 439.06 ha land. The soil in the region is endodynomorphic and dark brown to brown at the surface and brown to yellowish brown at the subsurface (Singh and Singh, 1992). The following table gives a full overview of their geographical locations, area, population, and number of households as of Census 2011 (Fig. 2.1; Fig. 2.2; Plate 1; Appendix1).

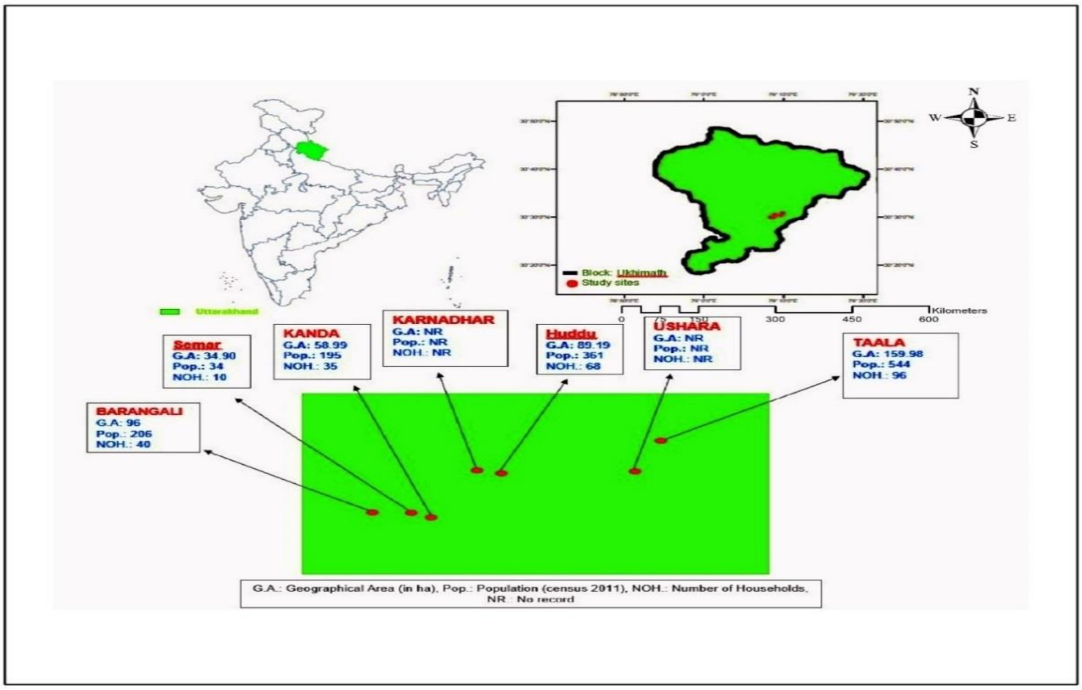


Fig 2.1: Study sites in the Ukhimath block of the Mandakini valley in Rudraprayag District, Uttarakhand

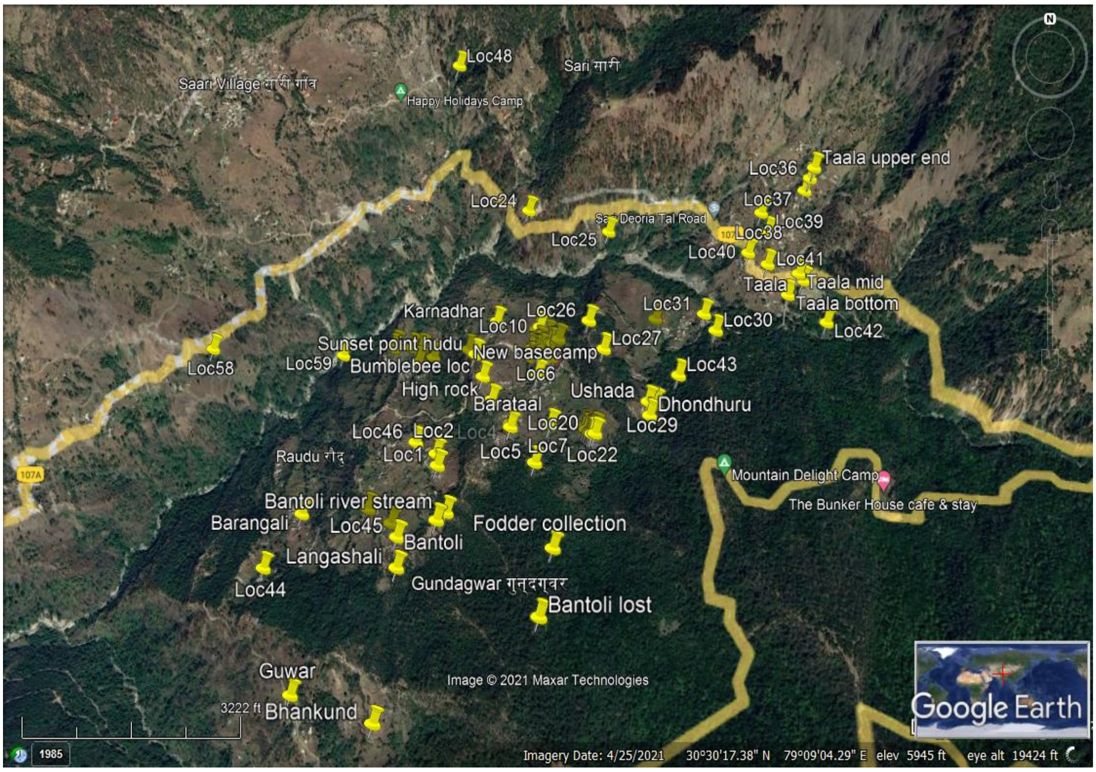


Fig 2.2: Sampling points in the study areas of the Mandakini valley

2.2.2. Navdanya Agrobiodiversity Conservation & Ecological Farm

'Bija Vidyapeeth' (School of the Seed) or 'Navdanya's learning centre' is a world-acclaimed institution dedicated to the revival and preservation of indigenous knowledge and culture through organic farming in the Doon valley. Navdanya agrobiodiversity conservation & ecological farm derives its essence from the word "Navdhanya", which connotes "Nine Crops", which symbolizes the gift of life, heritage & continuity. It lies adjacent to the foothills of the lower Himalayas, i.e., the Shiwaliks, located at Ramgarh, 21 kms away from Dehradun and is spread over 52 acres of land (30° 19' 38.78" N, 77° 52' 30.83" E; altitudinal range between 510-560mts asl). Dr. Vandana Shiva, an environmental activist, pioneered sustainable farming practices in the region in 1987 (Fig. 2.3 & Plate 2).

It's a huge network of seed savers and organic farmers who provide training in organic farming, saving and sharing indigenous varieties of seeds, adoption of environmentally friendly methods, use of pest repellent plants, green manure, and vermi/pit composting to protect the ancestral legacy of agro-biodiversity. They have various experimental farms, herbal gardens, a soil laboratory, and a community seed bank that upkeeps over 2000 seed varieties of food grains, fruits, vegetables, and medicinal plants (Appendix 3). The average temperature during the summer ranges from 25°C to 34°C, while winters lie between -2°C and 14°C. Rainfalls are frequent during the monsoon season and the average precipitation range is 80-135 mm. The area is surrounded by Temperate Broadleaf (moist deciduous/evergreen/mixed) types of vegetation. And the edaphic features tend to range from alluvial soil type to silty or clayey loam in composition and texture.

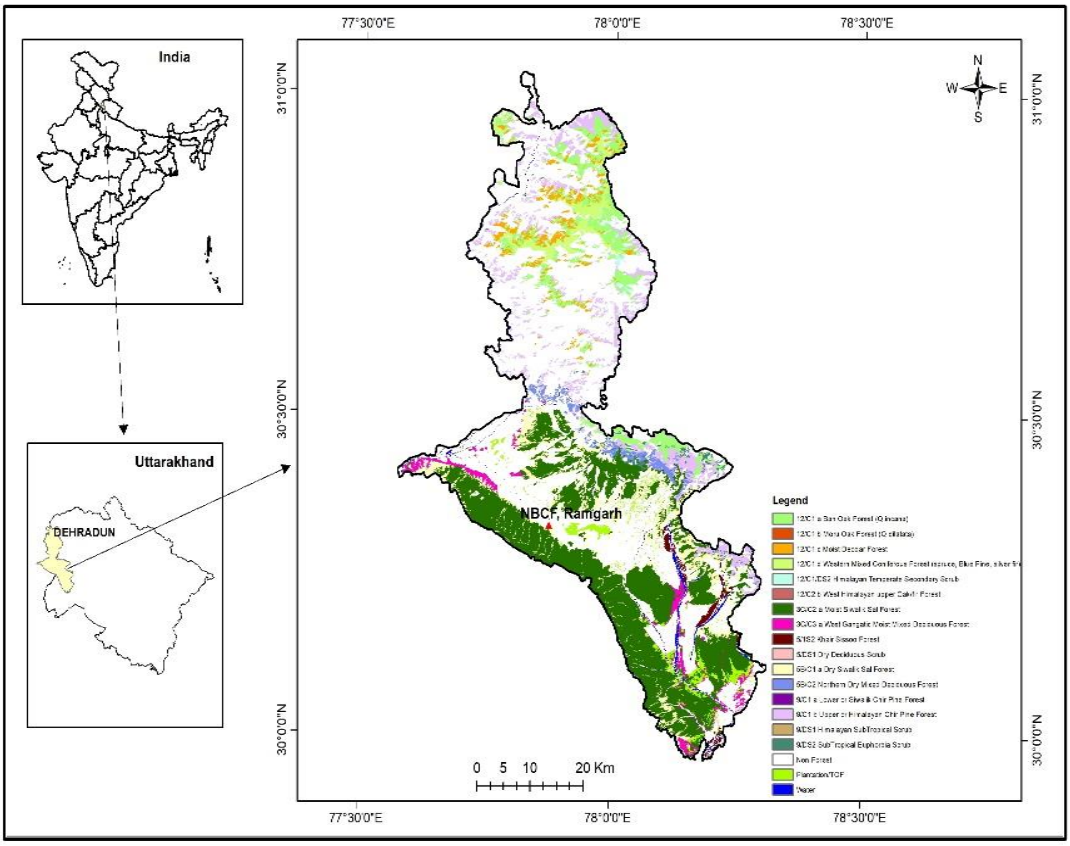


Fig 2.3: Study site Navdanya AgroBiodiversity Conservation & Ecological Farm in the Doon valley of Dehradun district

2.3. Climate: Temperature, Rainfall, Atmospheric Pressure, Snowfall

2.3.1. Mandakini Valley (Ukhimath)

The Himalayas are considered as the highest mountain range in the world and are covered with huge peaks and difficult terrain (Chevuturi et al., 2018). According to Dey and Kumar (1982), these ranges have a significant impact on climatic patterns at global, regional, local, and micro-scale levels. However, all these changes result in reversible effects on their own climate and vice versa (Dimri and Niyogi, 2013). Summers in this region are pleasant and clear, with greater precipitation during the monsoons, and severe downpours during this season can cause landslides and soil erosion. In the winter, temperatures at higher elevations drop below zero, resulting throughout snowfall in the months of November to March. The following four climate parameters (Fig. 2.3) are discussed on a monthly and decadal basis:

Temperature: The maximum average temperature in Ukhimath throughout the decadal period (2009-2021) ranges from 12° C to 16° C. The temperature reached its zenith in the years 2015 to 2018, and it never exceeded 20° C. Temperatures as low as -4° C to 2° C have been recorded as the minimum average temperature in the region over the last decade. When it comes to monthly average temperatures, the maximum temperatures ranged from 0° C to 16° C in June and July, respectively. The lowest monthly temperature ranges between -9° C to 8° C from January till March.

Precipitation: The maximum decadal rainfall in the region was reported in the months of July-September 2019, with 361mm of rainfall. This was closely followed by 305mm of rainfall in the year 2021 (April-June). On an annual basis, the month with the highest average rainfall was August (213mm), followed by July (189mm).

Snowfall: Following 2013's (74cm) record snowfall, more than 155cm of snow fell in the months of November to March in 2020, setting a new record. The months of January and February are the ones that get the most snow each year (59-64cm).

Atmospheric Pressure: The highest pressure was recorded in February 2020 at approximately 1024mb, and the lowest pressure was recorded in July 2012 (around 1005mb). In general, the highest readings were found between December and February, while the lowest readings were recorded between July and August.

2.3.2. Navdanya Agrobiodiversity Conservation & Ecological Farm (Doon Valley)

Dehradun has a subtropical to temperate climate (Mukesh et al., 2011). Summers are mild and pleasant and winters are cold and long in the Doon valley. Furthermore, because the area is located at the transition between the Gangetic Plains and the Himalaya, it experiences significant monsoons from mid-May to early October, and biodiversity is influenced by both biomes. The following three climate parameters (Fig. 2.4) are addressed below on a monthly and decadal scale:

Temperature: The average temperature for the decadal period (2009-2021); the highest temperature (11° C to 39° C); and the lowest temperature (3° C to 9° C) in Dehradun. The temperature reached its highest point in the year 2012, and then again in 2019, when it reached 39° C. For the months of June and July, the maximum monthly average temperature ranged from 18° C to 37° C and a minimum of 6° C to 22° C from December to February annually.

Precipitation: The maximum decadal rainfall in the region was reported in the months of July-September 2010, with 606mm of precipitation, followed by 569mm in 2012. The month with the highest monthly average rainfall was August (581mm), which was followed by July (523mm) on an annual basis. No instances of snowfall have been seen in the last ten years in Dehradun, according to historical records.

Atmospheric Pressure: The highest pressure was recorded in January 2019 at around 1020mb, and the lowest pressure was recorded in July 2021 at approximately 1001mb. In general, the highest readings were found between December and February, while the lowest readings were found between July and August.

For the years 2009-2021, climatological data for parameters for Ukhimath and Dehradun was retrieved from World Weather Online (Source: https://www.worldweatheronline.com/ukhimath-weather-averages/uttarakhand/in.aspx and https://www.worldweatheronline.com/dehradun-weather-averages/uttarakhand/in.aspx).

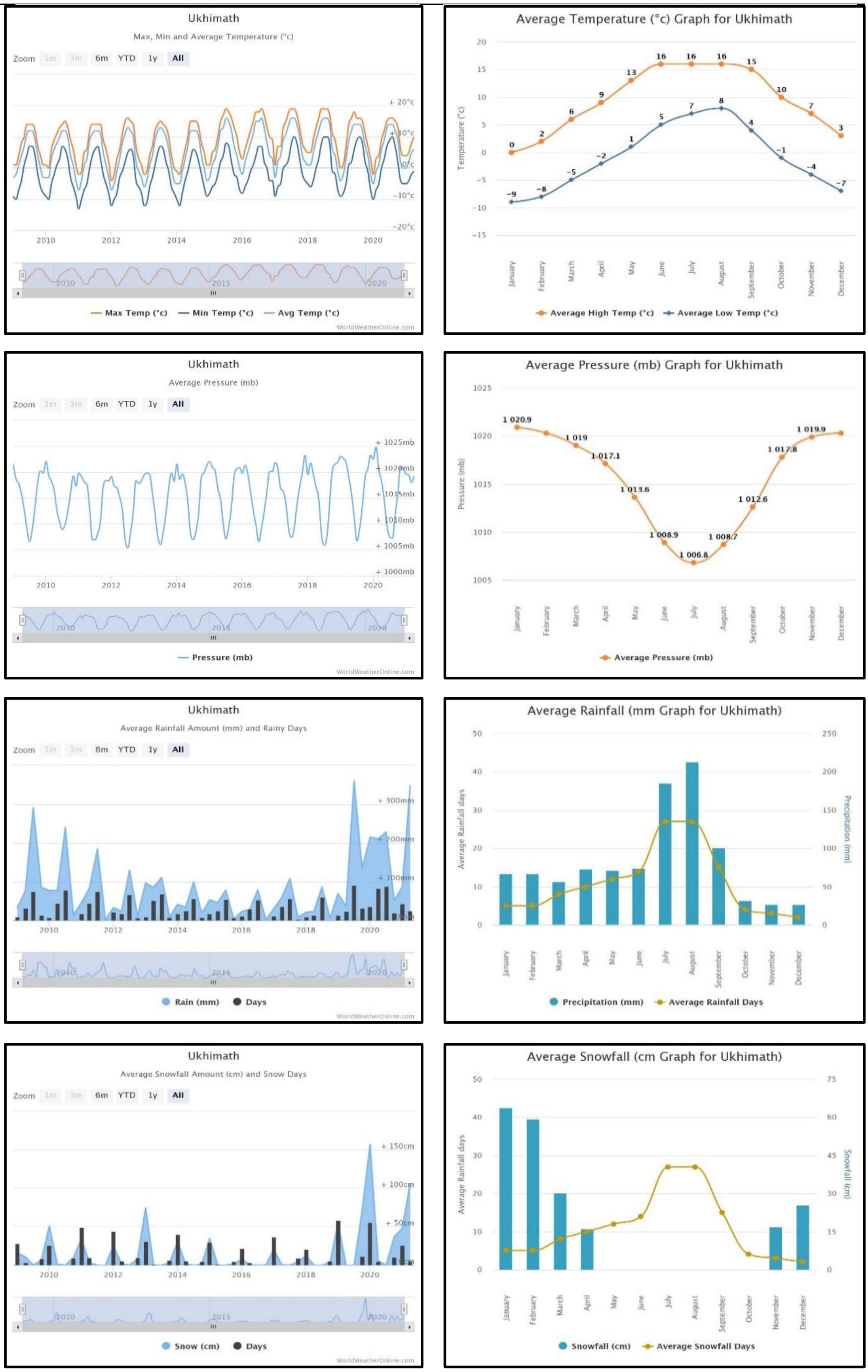


Fig 2.4: Climatological decadal and monthly average of Ukhimath (Source: world weather online)

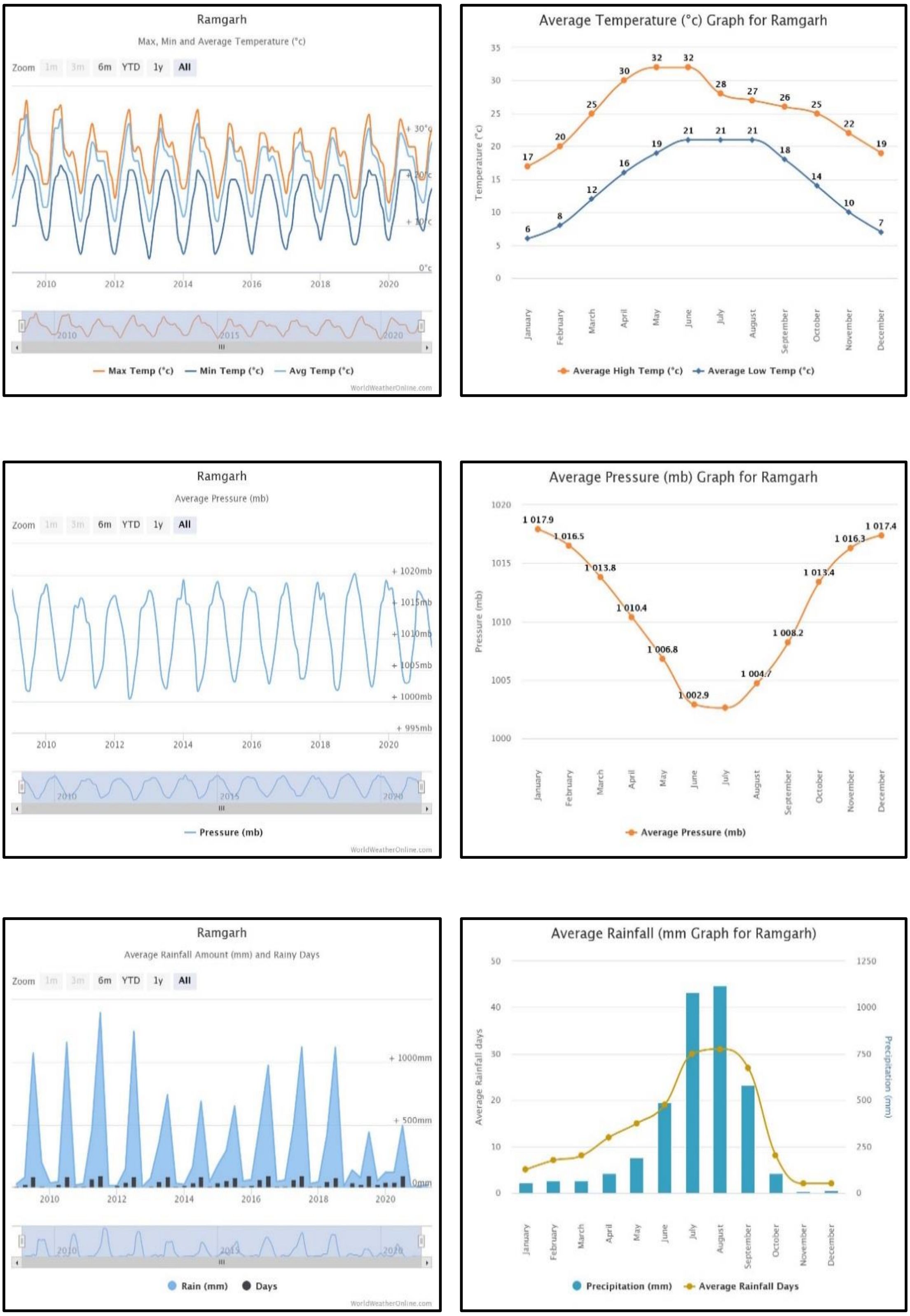


Fig 2.5: Climatological decadal and monthly average of Ramgarh (Source: world weather online)

2.4. Forest Types, Flora and Fauna

2.4.1. Mandakini Valley (Ukhimath)

The knowledge of a plant community's floristic composition is a precondition for understanding the whole ecosystem and its structure (Gairola et al., 2010). Plant exploration work in the Uttarakhand Himalaya has been done from time to time (Adhikari, 2003; Gaur, 1999; Rana, 2007; Rawat et al., 2001; Samant and Joshi, 2003). Champion and Seth, (1968) divided India’s forests into 6 major classifications and 16 major groups on the basis of climatic parameters, phenological and species compositional factors, edaphic, physiographic, and biotic factors.

The colourful floral diversity enhances the splendour of the Mandakini valley. Whether it is spring or monsoon, the flowering of wild herbs and bushes adds to the allure of each season. The picturesque landscape is bestowed with tall trees in mixed stands, such as *Acer caesium, Aesculus indica, Alnus nepalensis, Carpinus viminea, Daphniphyllum himalayense, Ficus auriculata,* Juglans regia, *Lindera pulcherrima, Lyonia ovalifolia, Myrica esculanta, Pinus roxburghii, Prunus cerosoides, Quercus floribunda, Quercus leucotrichophora, Quercus semecarpifolia, Rhododendron arboreum.* Common shrub species comprise *Asparagus racemosus, Berberis aristata, Berberis asiatica*, Cotoneaster spp., *Daphne papyracea, Debregeasia salicifolia, Desmodium* spp., *Woodfordia fructicosa, Urtica dioica*, and *Viburnum* spp. Herbal diversity consists of *Bergenia ciliata, Bidens pilosa, Cannabis sativa, Fragaria nubicola, Perilla frutescens, Potentilla* spp., *Reinwardtia indica, Rumex hastatus, Taraxacum officinale*, etc. Eight out of sixteen forest group types exist in Uttarakhand (ISFR 2019). As per Champion and Seth (1968), the principal forest categories of the Mandakini valley region are divided into four major groups:

(i) Group 9: Sub-Tropical Pine Forests

Subtropical chir pine forests are found between 1000 and 1800 metres in the central and western Himalayas; they are found in Haryana, Himachal, J & K, Punjab, and Uttarakhand. The main characteristics of these forests are *Pinus roxburghii* and broad-leaved species, while climbers and bamboo are absent.

(ii) Group 10: Sub-Tropical Dry Evergreen Forests

These can be found in the Bhabar tract, the Shiwaliks, and the western Himalayan foothills. Olea spp. grows on alluvial soil in the valleys of Punjab, Uttarakhand, and Himachal.

(iii) Group 12: Himalayan Moist Temperate Forests

These are concentrated in areas such as the central and western Himalayas, which receive more than 1000mm of precipitation. Kashmir, Himachal Pradesh, Punjab, Uttarakhand, West Bengal, Assam, and Sikkim are among the states where this type of forest is available. Several species, such as *Quercus leucotrichophora, Quercus floribunda, Quercus incana, Quercus semecarpifolia, Cedrus deodara, Rhododendron arboreum,* are common. Generally, deodar forests are pure stands with straight boles and a broad canopy. With a rise in elevation, the upper reaches witness the presence of *Abies pindrow* and *Picea smithiana*, along with scattered oaks and rhododendrons.

(iv) Group 13: Himalayan Dry Temperate Forests

Conifers are found at elevations ranging from 1700 to 3000 metres, and predominate in the Himalayan interior. Rainfall is typically less than 1000mm, with snow during the winters. Kashmir, Ladakh, Lahaul, Chamba, inner Garhwal, and Sikkim exhibit this type of forest. Coniferous forests generally have a tall (30-35m) canopy that is evergreen. These forests are made up of both coniferous and broad-leaved trees. *Pinus gerardiana*, *Cedrus deodara*, and Junipers are the dominant species in the western Himalaya. *Abies pindrow* and *Pinus wallichiana* can be found at higher elevations.

The valley area is unique in its diverse fauna and has a diverse range of mammals, assorted species of birds, insects, fish, and reptiles. The wild life found in and around the Mandakini valley are Himalayan Tahr, Blue Sheep or Bharal, Barking Deer, Black Beer, Yellow Chested Martens, Porcupine, Wild Boar, Himalayan Langurs, and avifaunal species such as Himalayan Rosefinch, Niltava, Nuthatch, Forktails, Fantails, Verditer Flycatcher, Minivets, Robins, Khaleej Pheasant, Redstarts and Woodpecker, Laughing Thrushes, Slaty headed Parakeets are common.

2.4.1. Navdanya Agrobiodiversity Conservation & Ecological Farm (Doon Valley)

Champion and Seth (1968), divided India's forests into 6 major classifications and 16 major groups on the basis of climatic parameters, phenological and species compositional factors, edaphic, physiographic, and biotic factors. The presence of a diverse range of colourful floral species enhances the natural attractiveness of the Doon valley. The blooming of wild herbs and bushes in Dehradun, whether in the spring or autumn, adds to the city's seasonal appeal. There are tall to medium-sized trees in mixed stands throughout the area, including *Albizia lebbeck, Anogeissus latifolia, Azardiracta indica, Bombax ceiba, Buchanania lanzan, Cassia fistula, Dalbergia sissoo, Ficus* spp., *Lagerstroemia parviflora, Mallotus philippinensis, Melia azedarach, Pongamia pinnata, Shorea robusta, Syzygium cumini, Tectona grandis, Terminalia* spp., and *Toona ciliata.* The shrubby vegetation is represented by *Adhatoda vasica, Bauhinia variegata, Carissa* spp., *Clerodendrum viscosum, Jasminum multiflorum, Jatropha curcas, Murraya koenigii,* and many others. *Boerhavia diffusa, Cymbopogon martini, Datura* spp., *Desmodium trifloum, Dryopteris* spp., *Oxalis* spp., *Parthenium hysterophorus* are some of the common herbal grass species.

Eight out of sixteen forest group types exist in Uttarakhand (ISFR 2019). As per Champion and Seth (1968), the principal forest categories of the Doon valley (Sheeshambara) region are divided into two major groups:

(i) Group 9: Sub-Tropical Pine Forests

The sub-tropical chir pine forest ranges across the central and western Himalayas between 1000 to 1800m; in Haryana, Himachal, J & K, Punjab, and Uttarakhand. *Pinus roxburghii* along with broad-leaved species such as *Shorea robusta, Dalbergia sissoo, Cassia fistula, Butea monosperma, Terminalia arjuna, Mallotus philippinensis, Syzygium cumini, Lagerstroemia parviflora, Melia azedarach* are the common species found in these forests. Climbers and bamboo are absent.

(ii) Group 10: Sub-Tropical Dry Evergreen Forests

They are distributed in the Bhabar tracts, the Shiwaliks, and the foothills of the western Himalayas. In Punjab, Uttarakhand, and Himachal Pradesh, Olea spp. grows in broad valleys on alluvial soil alongside climbers and bamboo.

The Doon Valley area is bestowed with a variety of wildlife species. In mammals, Asian palm civet, Leopard, Rhesus macaques, Asian Elephant, Striped Hyena, Jackals, Indian Porcupine, Barking Deer (Muntjac), Goral, Blue Bull, Spotted Deer, Wild Boar, Sambhar Deer, Rhesus Monkey, Common Langur, Jungle Cat, Himalayan Black bear, Nilgai are commonly seen. The avifauna is dominated by Woodpeckers, Rose-ringed parakeets, Rusty-cheeked Scimitar, Babbler, Goldenspectacled Warbler, Starlings, Orioles, Drongos, Cuckoos, Grey Hornbills, Barbets, Crested Kingfishers, Finches, and Thrushes.

2.5. Local Communities and Land Use practices

The mountain landscape in the Mandakini valley could be divided into different land cover-land use types, such as monoculture, agroforestry, home gardens, and village community forests (Nautiyal et al., 1998). Food or fodder crops are cultivated either in monoculture fashion or with scattered multipurpose tree species (for fruits, timber, firewood, and fodder) on terraced slopes. There are many kitchen gardens and homesteads in the region where people cultivate vegetables, spices, and ornamental and medicinal plants, among other things. The population is confined to natural streams or water sources. Farming practices are mostly limited to areas of low relief with proper fasal chakra based on the indigenous concept of Mullasari and Mallasari. Village community forests are the common forest lands managed by village communities for collective resource use and sustainable development. It basically runs on the principle of the people, by the people, and is based on their socio-economic, cultural, and religious beliefs in Uttarakhand (Mukherjee, 2003; Pala et al., 2014, 2015). The idea that community-conserved areas (CCAs) can save species from extinction has gained considerable traction in the past few decades (Bray et al., 2003; Kothri, 2006).

The Doon valley showed the commercialization of food crops or cash crops because of its physiography, unlike the mountains. Monoculture of wheat, paddy, lentils, sugarcane, maize, and fruit orchards were prevalent in the region. It was discovered that the Doon valley is primarily cultivated for paddy, sugarcane, and wheat crops. Sugarcane-fallow accounts for approximately 39.44% of the total crop area in the Dehradun valley, followed by paddy-wheat (28.97%). Whereas, the maize-wheat and sugarcane-wheat cropping systems account for approximately 7.2 and 6.2% of the total cropped area in the Doon Valley, respectively. There was also a significant amount of fallow land that existed all year (Patel, 2009).

PLATE 1: Pictorial representation of the first study site

Mandakini valley

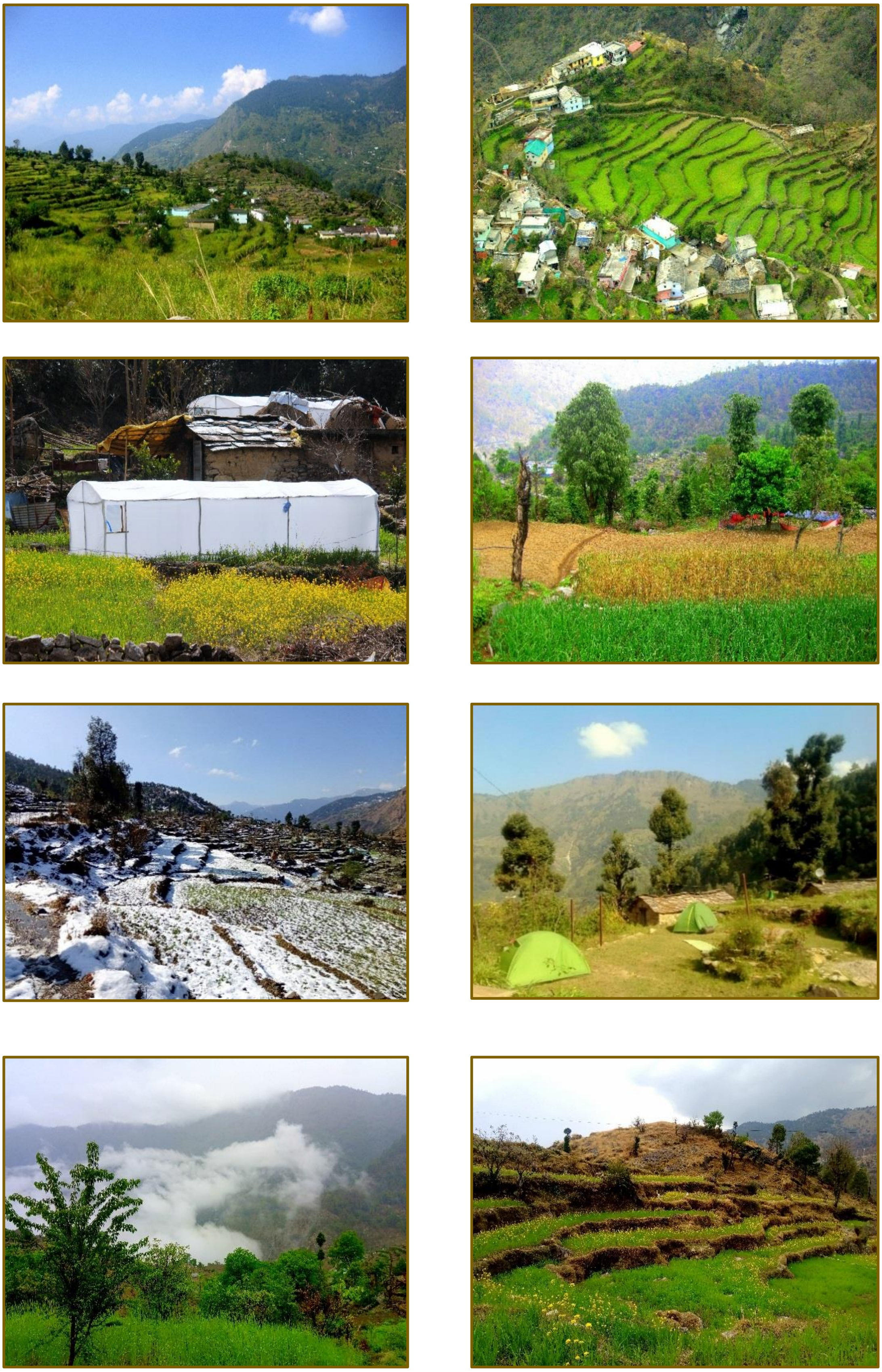


PLATE 2: Pictorial representation of the second study site

Navdanya AgroBiodiversity Conservation & Ecological Farm

2.6. Methodology

Both active and passive methods, such as aerial sweep netting in the case of pollinating insects, were extensively used for sampling. Ground-based arthropods and other pollinators were discovered using a variety of methods, including ground digging and hand picking, visual searches, vegetation beating and litter extraction, coloured pan traps, and pitfall traps, among others. For most of the pollinators, random and opportunistic sampling was conducted around nectar sources of different agricultural fields and croplands, and other microhabitats such as kitchen gardens, polyhouses, grasslands, forest edges, forest openings, bushes, wet mud puddles and rivulets, wild floral strips, etc.

Farms in seven villages in the Mandakini valley were studied for three years, with an approximate area of 439 ha, as well as 52 acres of cropland at Navdanya Agrobiodiversity Conservation and Ecological Farm. From 2017 to 2020, insect pollinators in farmland, kitchen gardens, and poly houses in the Mandakini valley were studied on a regular basis during the pre-monsoon (March-April-May) and post-monsoon (September-October-November) seasons.

In this study, a door-to-door survey was undertaken in randomly selected households of both the study sites using a semi-structured questionnaire set, to enumerate per household land holding size, livestock possession, manure application, area under cultivation, crop composition, and cropping pattern in agricultural fields, kitchen gardens, and polyhouses, and other sources of livelihood. Basic indigenous agricultural techniques, current farming trends, fertilizer and pesticide use, basic ideas about pollinators, potential reasons for their decline and seed sowing-flowering-harvesting related queries have also been discussed. Community-based strategic adaptations and mitigation actions taken to conserve these species and their ecosystems were also documented. The baseline information was acquired through informal conversations with family members, especially elderly people and women, who were well-versed in the subject. Three gram panchayats of the Ukhimath block of Rudraprayag district, having a total population of 1340 individuals and 266 households spread across seven villages, were chosen. For primary data collection, 395 respondents, mostly women farmers, from 224 homes were chosen at random. 77 out of 85 households in Huddu GP, 67 out of 96 homes in Ushara GP, and 80 out of 85 households in Barangali GP were considered.

Accessible research databases and relevant information were sought and exhaustively searched on Google Scholar and Web of Knowledge using the keywords "Western Himalaya", "Pollinators", “Bees”, “Butterflies”, “Wasps”, “Diptera”, “Lepidoptera”, “Hymenoptera”, “Mountain agriculture”, and “Cropping systems”. Web Resources in Entomology, Wildlife Ecology, and other insect pollinator-related databases, such as https://archive.org/; https://www.biodiversitylibrary.org/; and https://insect.inhs.illinois.edu/, were sought to gather the old literature.

2.7. Sampling Strategy for Pollinators

Visual observations and questionnaires were conducted to determine the abundance and diversity of pollinators at both organic and non-organic farms four times a day (a maximum three-hour gap), i.e., 8:30 am, 11:30 am, 2:30 pm, and 5:30 pm. In both mono-cropping and multiple-cropping systems, visual observations with direct counts were conducted with selected plant species from the Amaryllidaceae, Asteraceae, Brassicaceae, Cucurbitaceae, Fabaceae, Solanaceae, and Zingiberaceae families. The pollinators visiting the blooms were observed and tallied, and monitoring points near the blossoming crops were established.

2.7.1. Field Surveys

First and foremost, field surveys were conducted to identify different orders of pollinators and their host plants in both the mountain agroecosystems in the Mandakini valley and the organic farmlands of Navdanya Agrobiodiversity Conservation and Ecological Farm in the Doon valley.

(i) Hymenoptera: Active method of collection, such as sweeping vegetation using a triangular net (Noyes, 1982), and passive methods such as malaise traps (Darling and Packer, 1988), pan traps (Abrahamczyk et al., 2010; Saunders et al., 2013), and pitfall traps (Skvarla, 2014), and set in a variety of habitats yield enormous numbers of specimens representing wide range of species. There are two types of surveys that use nets; spot netting and sweep netting. For rookie netters, larger and more apparent bees are captured during the sweeping surveys than in the pan traps (Roulston et al., 2007). Bowl traps have been shown to successfully collect bees worldwide (Ortiz-Sanchez and

Aguirre-Holds, 1993; Westphal et al., 2008; Gollan et al., 2011; Popic et al., 2013; Wang et al., 2017).

Wasps, from the Vespidae family, are potential pollinating agents that feed on defoliating insect pests and play a crucial role in ecosystems (Clemente et al., 2012; Prezoto et al., 2019). The activities of most social wasps depend on the intensity of the sunlight, so they start foraging at dawn and cease at dusk, i.e., basically between 10 a.m. and 3 p.m. (Barbosa et al., 2014; Elisei et al., 2013). Sampling took place on bright, sunny and non-cloudy days between 11 a.m. and 4 p.m. Therefore, spot netting, sweep netting, coloured pan traps, pitfall traps, and vegetation beating were used to capture the pollinators of this order.

(ii) Lepidoptera: The transect method was widely used by researchers for the visual search for butterflies (Pollard, 1977; Pollard and Yates, 1993). Favourable weather conditions for butterfly activity were considered best for sampling. Identification of butterflies was done using Tolman and Lewington (2011) and Garcia-Barros et al. (2013) at the species level, and taxonomical studies by Van Swaay et al. (1999). A linear transect was used to calculate its abundance or density per km. We started by calculating annual butterfly abundance in each habitat (mean of 3 sampling dates). It was the basic metric for calculating mean abundance per site (mean of three habitats) or per region (mean of 5 sites).

(iii) Diptera: Over 200 years of research on Diptera has revealed little (Borkent et al., 2018; Brown et al., 2018; Jaschhof and Jaschhof, 2014; Srivathsan et al., 2019). Flies are predators, parasitoid parasitoids, herbivores, scavengers, and fungivores (Brown et al., 2009; Marshall, 2012; Marshall and Kirk-Spriggs, 2017). Fly pollination, decomposition, and insect population control are all crucial environmental services provided by flies (Larson et al., 2001; Raguso, 2020). The Diptera comprise over 8.05 percent of biodiversity and 15.3 percent of known insect diversity around the world (Chapman, 2009). There are 1,698 species reported from IHR, divided into 427 genera and 64 families, 329 of which are endemic to the region.

(iv) Coleoptera: Phytophagous beetles have diversified feeding habits (Bouchard et al., 2017). They feed upon different plant parts, such as leaves, pollen, seeds, wood, roots, etc. (Blanche and Cunningham, 2005; Bouchard et al., 2017; Jonason et al., 2013). Curculionidae, Chrysomelidae, and Cerambycidae, families of the order Coleoptera, are phytophagous that feed prolifically on angiosperms. Pollination, pest control, soil

aeration, and nutrient cycling are the foremost services provided by beetles (Losey and Vaughan, 2006; Nichols et al., 2008). Predator beetles from the Carabidae, Cantharidae, and Coccinellidae families are known for controlling pests that incur agricultural losses (Eitzinger and Traugott, 2011; Fonseca et al., 2017; Scheller, 1984). Finding and collecting insect specimens directly by hand or with the assistance of tools such as brushes, forceps, sweeping nets, or beating sheets (Gibb and Oseto, 2020).

2.7.2. Collection, Preservation and Identification

Standard protocols were used to detect and monitor the pollinator community (LeBuhn et al., 2016). Again, proper protocols were used for sampling techniques and strategies for pinning-labelling insects were followed (Grootaert et al., 2010). Bees have a nuanced visual physiology and can distinguish flowers with ultraviolet and iridescent patterns (Whitney et al., 2009). They have a trichromatic vision, with high sensitivities at 350 nm, 440 nm, and 525–570 nm (Peitsch et al., 1992; Skorupski et al., 2007), which we see as ultraviolet, blue, and green to yellow-green colours. Thus, three sets of coloured pan traps (white, yellow and blue bowls) were used to capture a diverse range of bees, wasps, flies and ground beetles.

The dimensions of these plastic built pan trap bowls were 2cm (depth) x 25cm (diameter) and were placed in each sampling plot (5m x 5m) in the morning and were collected in the evening just before sunset (Plate 3). These bowls were filled with a pinch of salt and soapy water. Since soap breaks the surface tension of water, the crawling arthropods tend to sink into the solution and die. While salt acts as a temporary preservative (Westphal et al., 2008). Later, the collected samples were cleaned with normal water to remove field impurities and then transferred to 70% alcohol or Ethanol (C_2H_6O) based vials for further identification.

The insects collected via sweeping net were kept in killing jars with ethyl acetate ($C_2H_8O_2$) or benzene (C_2H_6) for at least half an hour. Eventually, the specimens were spread on spreading boards, dry pinned, and stored in insect boxes after being photographed for identification and further research. Naphthalene balls ($C_{10}H_8$) and phenol (C_6H_6O) were used to store the samples in an insect box to prevent the incidence of any mould formation.

Michener's (2007) standard identification key was used to identify bees and morphospecies, whereas Kehimkar (2008) referred to the nomenclature of butterflies. Identification was done with the help of different published descriptions by Mitra et al. (2005, 2008), Bhardwaj and Uniyal (2011), Mahmood et al. (2012), Singh and Sondhi et al. (2016), Sengupta et al. (2016), Kumar et al. (2018), and Chandra et al. (2019), by comparing the specimens to those that have already been identified at the Zoological Survey of India, Kolkata, and the Entomology Museum of Forest Research Institute, Dehradun. Field crops and native wild plants were identified as species using relevant books and other online sources such as Exotic Bee ID, Amateur Entomologists' Society and Plants of the world, while the International Plant Names Index was used for plant nomenclature (IPNI, 2020). A Micap Microscope Camera, V3 version (5MP) was used to study the specimens.

2.8. Sampling Design

A stratified random sampling technique was used, and quadrats were established in different habitat types associated with crops and non-crops of semi-natural vegetation with microhabitats such as kitchen gardens, polyhouses, grasslands, forest edges, forest openings, bushes, wet mud and rivulets, wild strips, etc., and were distributed spatially to reduce autocorrelation in the vegetation.

Pollinators, especially bees and butterflies, were sampled along the transect belt with dimensions of 100x5m, obtaining an estimate of relative abundance in different habitats (mono-cropping/multiple-cropping and organic/non-organic agroecosystem) of both study sites at Mandakini and Doon valley. Each transect had seven sampling quadrats, measuring 5x5m separated by a 10m gap (Fig. 2.6). A total of 12 transects with four transects in each gram panchayat were laid, that equals 84 sampling plots in the Mandakini Valley, while in Navdanya organic farm, 3 transects were laid with 21 sampling plots. During the peak blooming seasons of Rabi and Kharif crops (Mar-Jun and Sep-Nov), systematic sampling was carried out in these plots for two consecutive years, with two duplicates of both active and passive components of the collection.

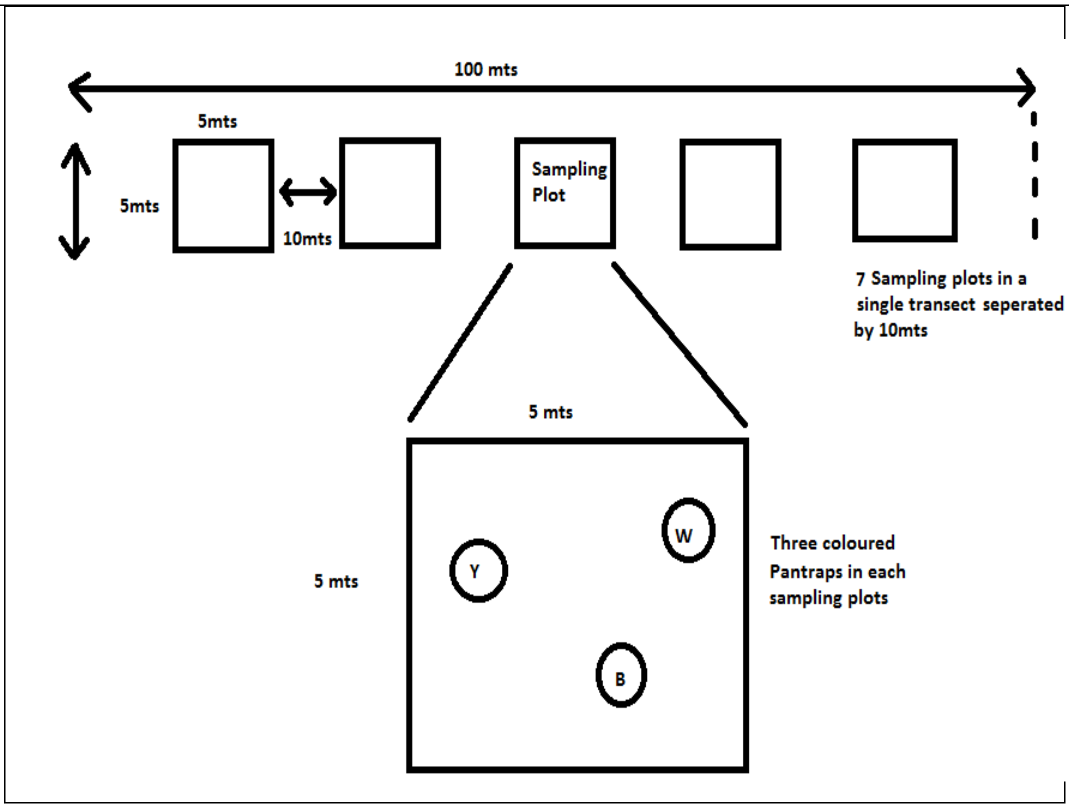


Fig 2.6: Belt transect for active (visual observation, sweep netting) and passive (pitfalls, coloured pan traps, YWB-yellow, white, blue) sampling methods used for pollinators.

Crop species were identified in the various cropping systems, and vegetation was quantitatively analysed for its abundance, density, frequency, and basal area using appropriate methods (Mishra, 1968; Phillips, 1959). The Simpson dominance index (Simpson, 1949), Shannon diversity index (Shannon and Wiener, 1963), and species richness (Margalef, 1958) were also calculated (Table 2.1, 2.2, & 2.3). Despite its efforts to account for sampling effects, the Margalef index is very sensitive to sample size and evaluates species richness (Magurran, 2004).

2.9. Statistical Analysis

To accomplish the first objective, I performed a t-test (Student, 1908) between pollinator species in organic and non-organic farming systems. To determine the species richness of pollinators, various indices such as Taxa (Pielou, 1975, 1982), Simpson (Simpson, 1949), and Shannon (Shannon, 1948; Shannon and Wiener, 1963) were calculated and analyzed using the PAST (version 4.03) software for organic and non-organic agro-ecosystems.

A t-test is an inferential statistics used to examine whether two related groups have statistically significant differences in their means. It's a technique for testing hypotheses that can be used to evaluate a population-based assumption. A t-test analyses the t-statistic, t-distribution values, and degrees of freedom to determine statistical significance. The following formula for t-test (Student, 1908) was used (Table 2.1):

Table 2.1: t-Test formula (Student, 1908)

$t = \frac{m - \mu}{s/\sqrt{n}}$
where, t= student's t-test, s= standard deviation, μ= theoretical value, m= mean, $\sqrt{n}$= variable set size.

In order to compute the data for the second objective, I performed a t-test again between the two cropping systems (mono-cropping and multiple-cropping) on both organic and non-organic farms, and the formula used is already discussed above.

The number of species found in a sample is measured by species richness (Scott et al., 1987). The greater the sample size, the more species we can expect to find. This particular measure of species richness is known as D, the Margalef/Menhinick's index (Margalef, 1958 and Menhinick, 1964). The Margalef index evaluates species richness and is significantly influenced by the sample size, despite its compensations for the sampling effects (Magurran, 2004). The following formulas are used to determine the species richness of the primary pollinators (Table 2.2):

Table 2.2: Diversity Indices (Margalef, 1958 and Menhinick, 1964)

Diversity Indices	
Margalef's Diversity Index (DMg)	Menhinick's Diversity Index (DMn)
D = $\frac{S-1}{\ln N}$ where, N = total number of species (individuals) in the sample S = total number of species identified	DMn = $\frac{S}{\sqrt{N}}$ where, N = total number of different species represented in the sample S = total number of species recorded

The observed species richness was also compared to the Chao 1 bias correction estimator for species richness in estimations, version 9.1, to assess the overall sampling effort (Chao, 1984; Colwell et al., 2004). The Chao 1 estimator (Chao 1984; Colwell and Coddington, 1994) uses the following equation to calculate the estimated true species diversity of a sample (Table 2.3):

Table 2.3: Species richness (Chao, 1984; Colwell and Coddington, 1994; Colwell et al., 2004)

$$S_1 = S_{obs} + \frac{F_1^2}{2F_2}$$

where,

S_1 = chao 1

Sobs = number of species in the sample

F1 = number of singletons (i.e., number of species in the sample with single occurrence)

F2 = number of doubletons (i.e., number of species in the sample with two occurrences)

A diversity index is a numerical representation of a community's species diversity. It is based on both species richness and species abundance. There are two types of indices: dominance indices and information statistic indices. The following two indices are used to determine the species richness of the primary pollinators in different agro-ecosystems (Table 2.4). Shannon's index (Shannon, 1948; Shannon and Wiener, 1963) is a statistical information index that assumes all species are represented in a sample and are sampled randomly. The Simpson index (Simpson, 1949) is a dominance index that gives common or dominant species more weightage. In that case, the diversity of a few rare species with only a few representatives will be unaffected.

Table 2.4: Shannon (Shannon, 1948) and Simpson Index formulas (Simpson, 1949)

Shannon Index	Simpson Index
$H = -\sum_{i=1}^{S} pi \ln pi$ where, H = shannon index p = proportion (n/N) n = one particular species found N = total number of individuals found ln = natural log Σ = sum of the calculations S = number of species	$D = \frac{1}{\sum_{i=1}^{S} pi^2}$ where, D = simpson index p = proportion (n/N) n = one particular species found N = the total number of individuals found Σ = sum of the calculations S = number of species

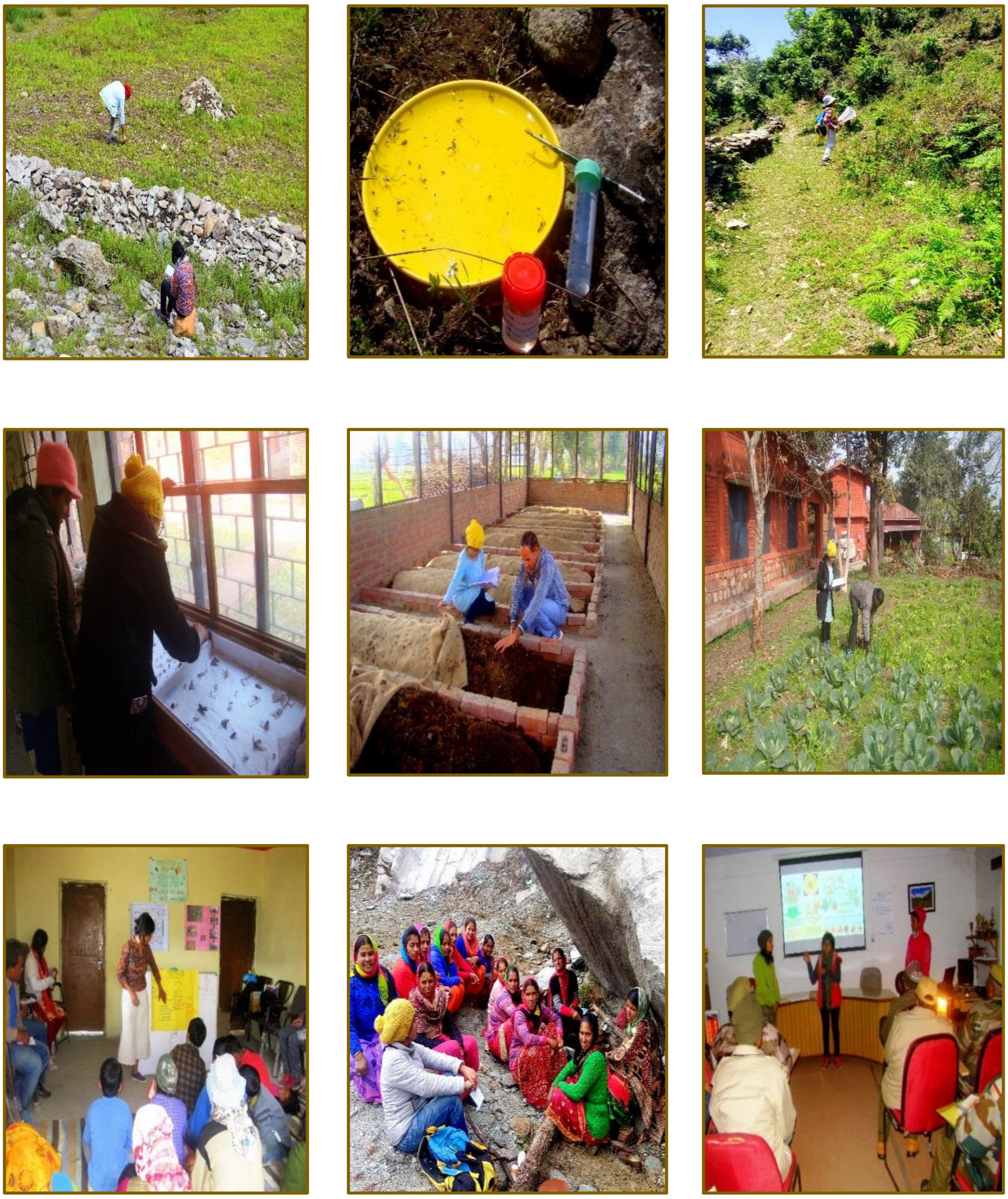
To achieve my third objective, I performed an ANOVA (Stahle and Wold, 1989) followed by a Tukey's pairwise test (Tukey, 1953; Smith, 1971) for different insect orders and crop families under the farming system.

ANOVA (Stahle and Wold, 1989) is used for separating observed variance data into different components using a statistical approach. A one-way ANOVA is used for data sets with three or more groups. Tukey's pairwise comparison statistical test (Tukey, 1953; Smith, 1971) is a one-step multiple comparison procedure that is frequently used in conjunction with ANOVA. It can be used to find mean that are immensely different from one another. The Tukey's null hypothesis says that the means being compared are taken from the same lot of population (i.e., μ1 = μ2 = μ3 = ... = μk), and thus the means should be distributed normally. This results in the normality assumption of the Tukey's test. The following formulas are used (Table 2.5):

Table 2.5: ANOVA (Stahle and Wold, 1989) and Tukey's Pair Wise Test formulae (Tukey, 1953; Smith, 1971)

ANOVA	Tukey's Pair Wise Test
$F = \frac{MST}{MSE}$ where, F = ANOVA coefficient MST = mean sum squares due to treatment MSE = mean sum of squares due to error	$qs = \frac{Y_A - Y_B}{SE}$ where, qs = tukey's pair wise test Y_A = larger value of the two means being compared Y_B = smaller value of the two means being compared SE = standard error of the sum of the means

PLATE 3: Pictorial representation of fieldwork, lab work, and workshops



Chapter 3: Pollinator diversity in Organic & Non-organic Agro-ecosystem

3.1. Background

Growing public cognizance of the well-being and environmental risks associated with widespread chemical use has sparked the pursuit of alternative agricultural techniques around the world. Organic agriculture is just one of the many environmentally friendly crop producing options available globally. In organic farming, agro-ecosystem health is promoted and enhanced by a holistic approach to agricultural production management. For centuries, organic agriculture has fed India, and it is now a prospering sector in the economy. It emphasises the use of on-farm management practises over off-farm inputs, recognising the need for regionally feasibly customized systems due to area variables. It is accomplished by using agronomic, cultural, and biological techniques to fulfil any specific function within the system, rather than synthetic materials (FAO/WHO Codex Alimentarius Commission, 1999). In organic farms, farmyard manure (FYM), vermicompost, green manures, bio fertilisers (neem cake, fish/bone meal), biodynamic preparations (Jeeva amrit and Panchagavya), plant extracts (*Aloe vera*, dhatura, pongamia, cassia, garlic, etc), effective microorganisms (Trichoderma, Pseudomonas and Verticillium), and minerals like gypsum and rockphosphate are employed to provide plant nutrients (Ramesh et al., 2010).

In India, approximately 2657889.33 hectares of cultivable land is under the organic mode (44,926 certified organic farms and rest under conversion) for the year 2020-21. This equates to roughly 0.3 percent of total agricultural land. India's organic agricultural sector is projected to be valued $78 million and is fully export-oriented. India exports organic products worth Rs. 301 million, according to the Agricultural and Processed Food Products Export Development Authority (APEDA), a central organization tasked with promoting Indian organic agriculture. There has been a 200 percent increase in certified area over the previous two years as a result of growing public awareness, burgeoning market demand, farmers' inclination towards organic, and institutional support.

Animal pollination occurs in 75% of blooming plants (Burger, 1982; Gullan and Cranston, 2010). Coleoptera, Hymenoptera, Lepidoptera, and Diptera are the four biggest orders classified by Proctor et al. (1996). Hymenopterans are the most beneficial insects for pollination. According to Buchmann and Nabhan (1996), the general public believes that the only pollinators are European honey bees (*Apis mellifera*) and bumble bees (*Bombus* sp.). Kerr (2001) disagreed, claiming that pollinators other than wasps and bees, include flies, moths, butterflies, and beetles. The basic modes of plant pollination by insects include Mellitophily (bee pollination), Phalaenophily (moth pollination), Psychophily (butterfly pollination), Myophily (fly pollination), Cantharophily (beetle pollination), and Myrmecophily (ant pollination), and among these, bees play a dominant role in the majority of plant species, according to Awasthi (2001). Stingless bees are just as important as honeybees in pollination, according to Abrol (2009), and they have advantages over honeybees due to their small size, shorter foraging range, and resistance to many diseases and parasites. Many insect visitor groups, including Lepidoptera, Coleoptera, Diptera, Hemiptera, Heteroptera, Ortoptera, Thysanoptera, and Hymenoptera, are also pollinators in the Oriental (Indomalayan) region, according to Corlett (2004). According to Delaney and Tarpy (2008), honeybees (*Apis mellifera*) have replaced other pollinators and emerged as the primary insect pollinator in agriculture due to the ease with which they can be transported from Europe. Another important honeybee species (*Apis dorsata*) in India, according to Tiwari et al. (2010), is an important pollinator and the country's main source of honey.

The results obtained during the investigations carried out in organic and non-organic farms and the abundance of insect pollinators in Navadanya AgroBiodiversity Conservation & Ecological Farm and the Mandakini valley are presented in this chapter. These have been dealt with under the following sub-headings:

- An overview of entomofaunal pollinator diversity in an Indian Himalayan context
- Divesity of insect pollinators in organic and non-organic agro-ecosystems
- Systematics & taxonomic accounts of insect pollinator diversity

3.2. Methodology and Approach

The first objective of the research work is partially based on the collection of primary data from organic and non-organic localities. For the agricultural years 2018-2020, primary data was acquired from the pesticide applicators of sample families using a pre-tested schedule and a personal interview approach. I have sampled primary pollinators from orders Lepidoptera (Butterflies), Hymenoptera (Bees and Wasps), Diptera

(Flies) and Coleoptera (Beetles) from the study areas (please refer to Chapter 2 for detailed methodology and sampling strategies applied). I have documented different families belonging to all four orders, and an inventory of all such species recorded from the primary study has been consolidated in a table, and, following Evans (1932) and Wynter-Blyth (1957), they were identified at the genus and species level. In this case, I used Kehimkar's nomenclature (2008). The study was conducted separately in different quadrates laid into different habitat types, around organic and non-organic croplands, kitchen gardens and polyhouses, wild floral strips, forest edges, wet mud and small rivulets.

The sample collected was sorted initially in the field itself, before being transported to the laboratory for further identification and examination. Special transparent killing jars were designed for the collection of these insects (bees, butterflies, flies, and wasps) in order to preserve the colour of the pubescence (for details, please refer to Chapter 2: Materials & Methodology). Because the colour of bumblebee pubescence is so important in species identification, proper care was taken during the collection period (Saini et al., 2012). Insects in the killing jar were regularly relocated to another jar (similar in size) to safeguard the delicacy and grace of pubescence. After arriving at the laboratory, the specimens were cautiously pinned and stretched, and were accordingly labelled with important information such as their location, elevation, date of collection, and collector's name. Later, these stretched specimens were transferred to the insect boxes and preserved with finely powdered naphthalene and cotton balls-soaked ethyl acetate. The species were further identified and species richness was calculated. The specimens have been deposited in the Department of Landscape Level Planning and Management, Wildlife Institute of India, Dehradun for future reference.

3.3. An Overview: Entomofaunal Pollinator Diversity in an Indian Himalayan Context

There are more than 2,00,000 pollinator species, the bulk of which are insects (Berenbaum, 2007). Insects are the most abundant animal category, not only in terms of worldwide diversity (10,53,578 species) and Indian diversity (65,047 species), but also in terms of IHR (Chandra, 2011a; 2011b; Chandra et al., 2017). Insects of the Himalayan region were studied by Chandra and Sidhu (2009). IH's insect fauna contains around 24,784 species/sub-species divided into 26 orders, accounting for 38.1 percent of India's recognised variety. Previous studies have reported various primary pollinators from the Indian Himalaya region (Table 3.1). These primary insect pollinators include a wide array of honey bees, flies, wasps, beetles, ants, moths, and butterflies.

With approximately 1,80,000 known species organised into 126 families and 46 superfamilies (Capinera, 2008), the order Lepidoptera is the world's most researched taxon and accounts for 10% of all living things (Mallet, 2007). Butterflies and moths have distinct niches, with butterflies active diurnally and moths being nocturnal. In both natural and managed ecosystems, they have emerged as an important pollinator of flowering plants. The IHR has around 6 families of Lepidoptera and over 800 species, out of a total of 1504 species in the country. According to van Nieukerken et al. (2011), there are approximately 18,732 butterfly species on the globe, excluding the Hedylidae family. On the Indian mainland, there are around 1,501 species of butterflies (Kehimkar, 2008). The Indian Himalaya harbours a diversity of about 1,013 species, and including subspecies, the diversity composition increases to 1,249 members of this group, falling into 343 genera under six families. The butterfly diversity of IH accounts for as much as 67% of the butterfly diversity known in the country.

According to Zhang (2013), the global diversity of hymenopteran fauna is estimated to be over 1,53,088 species, with approximately 10,605 species known from India. According to published data, 3,054 species of Hymenoptera have been identified from the Indian Himalaya, divided into 816 genera, 52 families, and 16 superfamilies.

With approximately 1,60,000 species (Marshall, 2012) classified into 188 families (Brake, 2017), Diptera accounts for roughly 10% of the world's biodiversity (Brown, 2005). There are 87 families in India, with about 6,000 species in each (Alfred et al., 1998). Diptera account for more than 8.05 percent of known global biodiversity and 15.3 percent of insect diversity (Chapman, 2009). There are 1,698 dipteran species discovered in IH, divided into 427 genera and 64 families.

In terms of species diversity, the order Coleoptera accounts for 47.3% of overall insect diversity in IH, with 10,533 species (of 22,299 Indian species) divided into 107 families.

Table 3.1: Overview of Entomofaunal Pollinator diversity in Indian Himalayan context (Chandra et al., 2018)

ORDER	GLOBAL			INDIA			INDIAN HIMALAYAN REGION (IHR)			PRESENT STUDY		
	F	**G**	**S**	**F**	**G**	**S**	**F**	**G**	**S**	**F**	**G**	**S**
HYMENOPTERA (Bees, Wasps)	116	7738	1,59,659	-	-	10,605	52	816	3,054	12	36	65
LEPIDOPTERA (Butterflies)	7	-	18,732	6	-	1,501	6	-	>800	7	52	72
DIPTERA (Flies)	188	-	1,60,000	87	427	>6,000	64	427	1,698	9	20	28
COLEOPTERA (Beetles)	176	29,500	3,89,487	113	2684	22,299	107	-	10,533	4	11	12
									TOTAL	**32**	**119**	**177**

F=Family, G=Genus, S=Species

3.4. Results and Discussions

3.4.1. Taxonomic Composition and Species Inventory

Objective 1: To assess the species richness of pollinators in organic and non-organic agroecosystems.

Hypothesis: There will be a significant difference in the species richness of pollinators in organic and non-organic agro-ecosystems.

Statistical Method: I performed a t-test between the species richness of pollinators in organic and non-organic agro-ecosystems.

Results: As per the t-test, there was a significant difference present in the mean number of pollinators between organic and non-organic agro-ecosystems ($t=15.853$, $p < 0.05$). The box plot signifies the higher species richness of primary pollinators in the organic agro-ecosystem than in the non-organic agro-ecosystem.

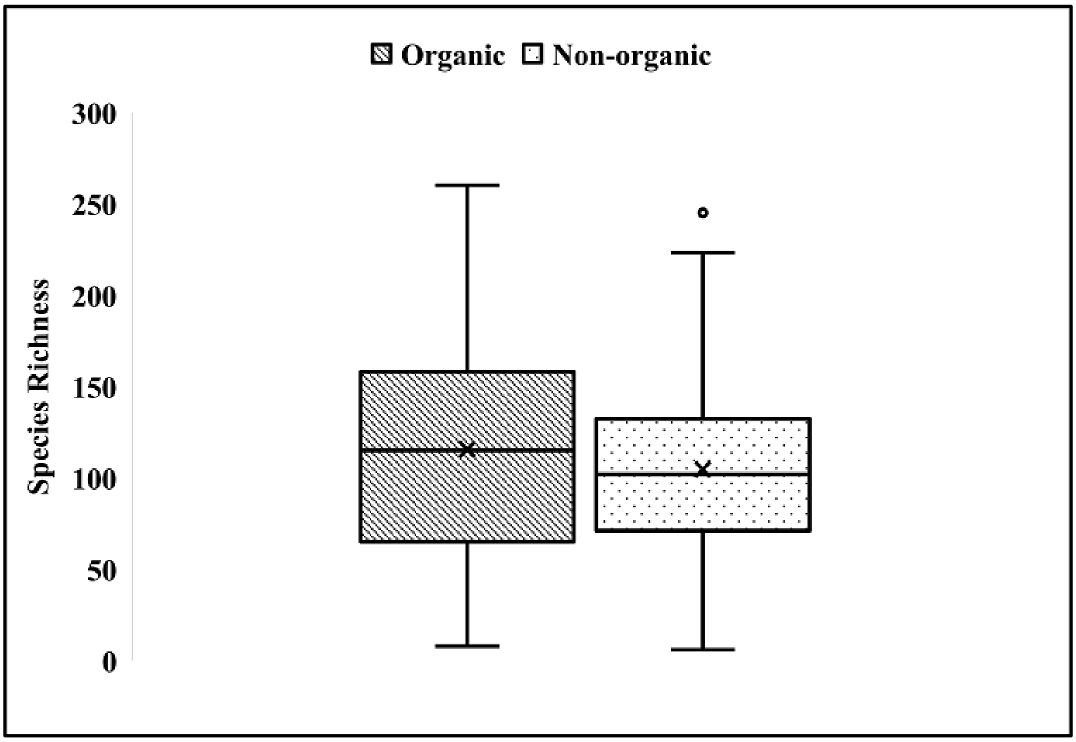


Fig 3.1: The box plot displays the mean species richness of pollinators in organic and non-organic agro-ecosystems

Two diversity indices, namely the Simpson's Index (Simpson, 1949) and Shannon-Weiner Index (Shannon and Wiener, 1963), are being used in the current investigation (Table 3.2). Simpson's Index calculated values ranged from 0.9936 (Organic) to 0.9929 (Non-Organic), indicating that primary pollinator diversity does not differ significantly across agro-ecosystems. Almost all hymenoptera, lepidoptera, diptera, and coleoptera species are found in abundance at both the Mandakini and Doon Valley study sites. The Shannon-Weiner Index ranged from 5.069 (Organic) to 4.966 (Non-Organic) in different agro-ecosystems. The non-organic agro-ecosystem had the lowest diversity (4.966) and the organic agro-ecosystem had the highest diversity (5.069). The calculated values of this index show that all the primary pollinators are more or less equally distributed across both the agro-ecosystems, as the calculated values did not show much difference between the organic (Navdanya Farm, Doon Valley) and non-organic (Mandakini Valley).

Table 3.2: Diversity indices of insect pollinators in organic and non-organic agro-ecosystems

	Organic	Inorganic	
Taxa_S	162	146	
Simpson_1-D	0.9936	0.9929	
Shannon_H	5.069	4.966	

In both datasets, a total of 32 families from orders hymenoptera, lepidoptera, diptera and coleoptera were recorded. And all of them showed their presence in organic and 31 in non-organic agro-ecosystems. A total of 119 genera of pollinator diversity were reported from both study sites, with 107 from organic study sites and 100 from non-organic study sites. The diversity account of these primary pollinators is 177, and the maximum was recorded from the Navdanya AgroBiodiversity Conservation & Ecological Farm (organic), i.e., 162 species, and relatively less from the villages of the Mandakini valley, i.e., around 146 species (non-organic). Lepidoptera (72) exhibited the highest species richness, followed by hymenoptera (65), diptera (28) and then coleoptera (28). Genus-wise, all four orders exhibited the similar trend with lepidoptera (52), followed by hymenoptera (36), diptera (20), and coleoptera (11). Hymenoptera (12) emerged with the highest number of families, followed by diptera (9), lepidoptera (7) and coleoptera (4) (Fig. 3.2 & Table 3.3).

Table 3.3: Taxonomic composition and Species Inventory

Order	**Number of Families**			**Genera**			**Species**		
	T	**ORG**	**NON**	**T**	**ORG**	**NON**	**T**	**ORG**	**NON**
Lepidoptera	7			52	45	44	72	62	60
Hymenoptera	12			36	31	28	65	57	49
Diptera	9			20	20	18	28	27	23
Coleoptera	4			11	11	10	12	12	12
Total	32	32	31	119	107	100	177	162	146

T=Total number, ORG=Organic agro-ecosystem, NON=Non-Organic agro-ecosystem

In organic agro-ecosystems, lepidoptera with seven families (62 species, 45 genera) accounted for the highest species and genetic diversity, followed by hymenoptera with twelve families (57 species, 31 genera) and diptera with nine families (27 species, 20 genera).

While in non-organic agro-ecosystems, lepidoptera (60 species, 44 genera) had the highest diversity, followed by hymenoptera (49 species, 28 genera), and diptera (23 species, 18 genera). Hymenoptera (11) had the maximum number of families, followed by diptera (9) and then lepidoptera (7) in non-organic study site (Fig. 3.3). A consolidated bio-inventory of pollinator species recorded from the primary study area with their distribution in Mandakini and Doon valley is given below (Table 3.4 & 3.5).

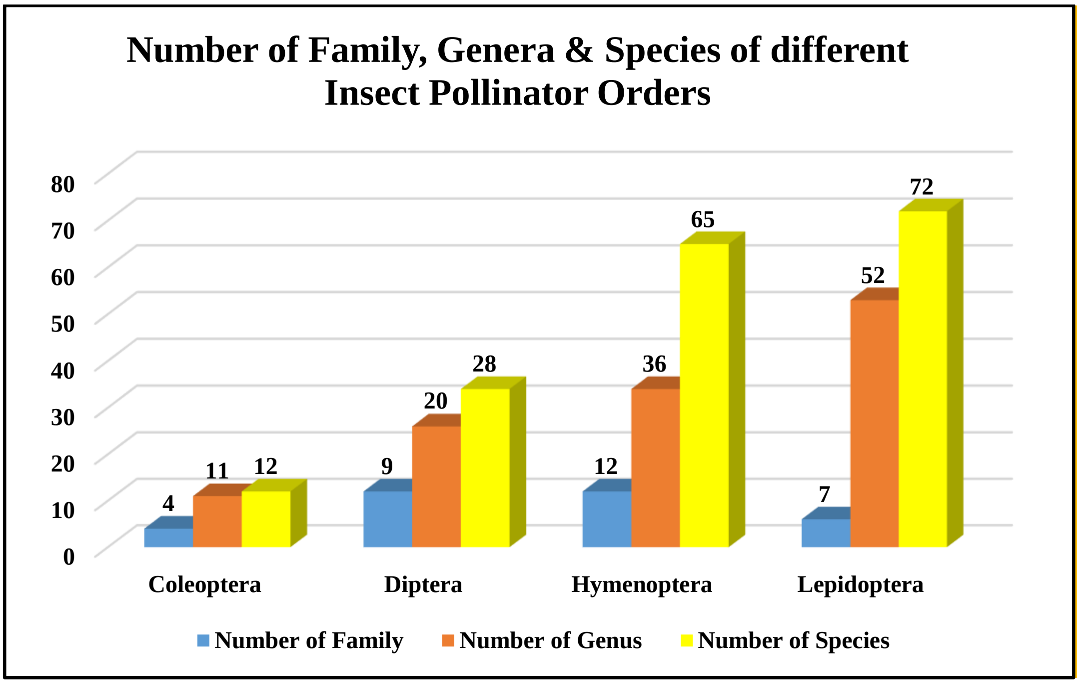


Fig 3.2: Total Entomofaunal pollinators recorded from the study sites

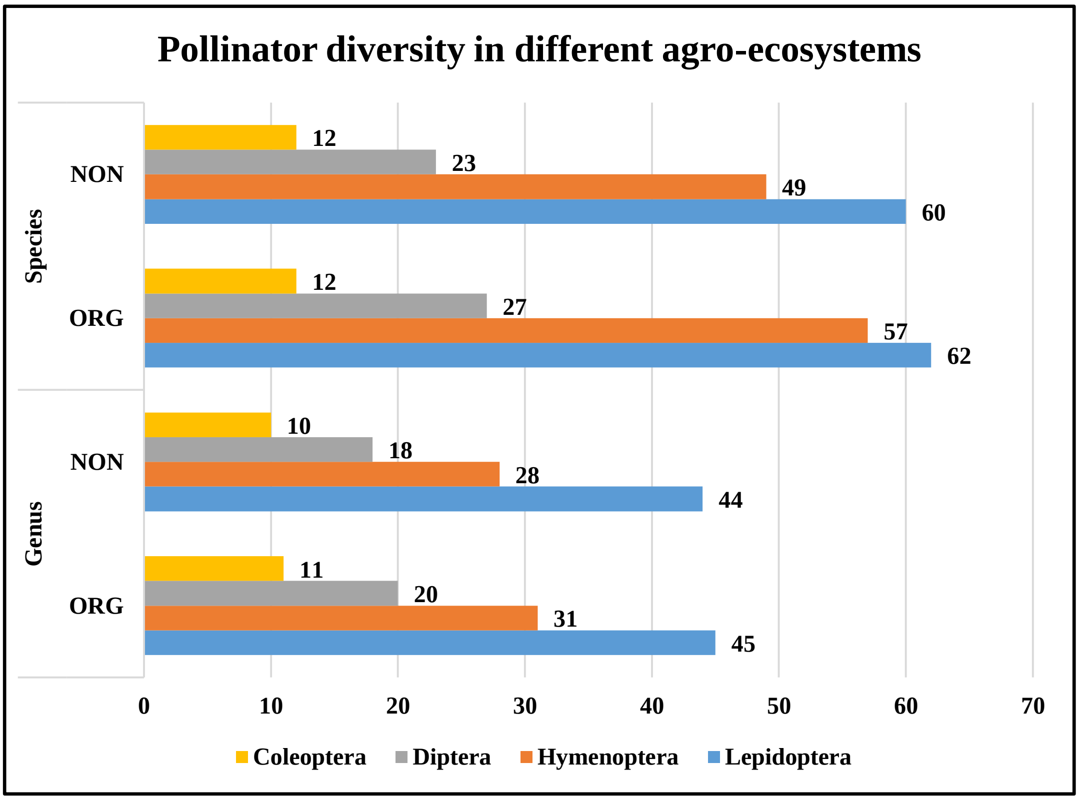


Fig 3.3: A clustered bar chart showing insect pollinators recorded in different agro-ecosystems

Table 3.4: Consolidated list of Pollinator taxa of Doon and Mandakini valley of Uttarakhand

S. No	Family	Subfamily	Scientific Name
	LEPIDOPTERA:		
1	Hesperiidae	Pyrginae Burmeister, 1878	*Oriens gola* (Moore, 1877)
2			*Pelopidas mathias* (Fabricius, 1798)
3			*Pelopidas* sp. Walker, 1870
4			*Pseudocoladenia* sp. Shirozu & Saigusa, 1962
5			*Tagiades litigiosa* (Fruhstorfer, 1910)
6	Lycaenidae	Lycaeninae Leach, 1815	*Heliophorus moorei coruscans* (Moore, 1882)
7			*Heliophorus sena* (Kollar, [1844])
8			*Heliophorus tamu tamu* (Kollar, [1844])
9			*Lycaena pavana* (Kollar, 1848)
10			*Lycaena phlaeas baralacha* (Moore, 1884)
11		Polyommatinae Swainson, 1827	*Acytolepis puspa gisca* (Fruhstorfer, 1910)
12			*Cupido argiades* (Pallas, 1771)
13			*Cupido* sp. Schrank, 1801
14			*Pseudozizeeria maha maha* (Kollar, [1844])
15			*Talicada nyseus* (Guerin, 1843)
16			*Zizeeria karsandra* (Moore, 1865)
17	Nymphalidae	Apaturinae Boisduval, 1840	*Sephisa dichroa* (Kollar, [1844])
18		Cyrestinae Guenée, 1865	*Cyrestis thyodamas ganesha* (Kollar, 1848)
19		Danainae Boisduval, 1833	*Tirumala limniace* (Cramer, 1775)
20			*Danaus chrysippus chrysippus* (Linnaeus, 1758)

21			*Danaus genutia genutia* (Cramer, [1779])
22			*Euploea core core* (Cramer, [1780])
23			*Euploea mulciber mulciber* (Cramer, [1777])
24			*Parantica sita sita* (Kollar, [1844])
25		Heliconiinae Swainson, 1822	*Argynnis hyperbius hyperbius* (Linnaeus, 1763)
26			*Cupha erymanthis* (Drury, 1773)
27			*Phalanta phalantha phalantha* (Drury, [1773])
28		Libytheinae Boisduval, 1833	*Libythea lepita lepita* (Moore, [1858])
29			*Libythea myrrha* (Godart, 1819)
30		Limenitidinae Behr, 1864	*Athyma opalina opalina* (Kollar, [1844])
31			*Neptis mahendra mahendra* (Moore, 1872)
32		Nymphalinae Rafinesque, 1815	*Aglais caschmirensis aesis* (Fruhstorfer, 1912)
33			*Hypolimnas bolina* (Linnaeus, 1758)
34			*Issoria lathonia* (Linnaeus, 1758)
35			*Junonia almana (Linnaeus, 1758)*
36			*Junonia iphita* (Cramer, [1779])
37			*Junonia orithya ocyale* (Huebner, [1819])
38			*Kaniska canace canace* (Linnaeus, 1763)
39			*Nymphalis polychloros* (Linnaeus, 1758)
40			*Symbrenthia lilaea* (Moore, [1875])
41			*Vanessa cardui* (Linnaeus, 1758)
42			*Vanessa indica indica* (Herbst, 1794)
43		Satyrinae Boisduval, 1833	*Callerebia annada* (Moore, 1858)

44			*Lasiommata schakra schakra* (Kollar, [1844])
45			*Lethe verma verma* (Kollar, [1844])
46			*Orinoma damaris damaris* (Gray, 1846)
47			*Ypthima nikaea* (Moore, [1875])
48			*Ypthima* sp. Hubner, 1818
49		Satyrinae Boisduval, 1834	*Mycalesis perseus* (Fabricius, 1775)
50	Papilionidae	Papilioninae Latreille, 1802	*Atrophaneura aidoneus* (Doubleday, 1845)
51			*Byasa dasarada* (Moore, 1857)
52			*Graphium sarpedon sarpedon* (Linnaeus, 1758)
53			*Papilio bianor* Cramer, [1777]
54			*Papilio polytes* (Linnaeus, 1758)
55			*Papilio machaon asiatica* (Menetries, 1855)
56			*Papilio protenor protenor* (Cramer, [1775])
57	Pieridae	Coliadinae Swainson, 1827	*Catopsilia pomona* (Fabricius, 1775)
58			*Catopsilia pyranthe pyranthe* (Linnaeus, 1758)
59			*Colias erate* (Esper, 1805)
60			*Colias fieldii fieldii* (Menetries, 1855)
61			*Eurema blanda silhetana* (Wallace, 1867)
62			*Eurema hecabe hecabe* (Linnaeus, 1758)
63			*Gonepteryx rhamni* (Linnaeus, 1758)
64		Pierinae Swainson, 1820	*Pareronia valeria* (Cramer, [1776])
65			*Belenois aurota aurota* (Fabricius, 1793)
66			*Delias belladonna horsfieldii* (Gray, 1831)

67			*Pieris brassicae nepalensis* (Gray, 1846)
68			*Pieris melete* (Moore, 1865)
69			*Pieris rapae* (Linnaeus, 1758)
70			*Pontia daplidice* (Linnaeus, 1758)
71	Riodinidae	Nemeobiinae	*Dodona durga durga* (Kollar & Redtenbacher, 1844)
72	Sphingidae	Macroglossinae Harris, 1839	*Macroglossum* sp. Scopoli, 1777
	HYMENOPTERA:		
73	Andrenidae	Andreninae Latreille, 1802	*Andrena flavipes* (Panzer, 1799)
74			*Andrena* sp. Fabricius, 1775
75	Apidae	Apinae Latreille, 1802	*Amegilla zonata* (Linnaeus, 1758)
76			*Amegilla confusa* (Smith, 1854) Syn. *Anthophora confusa*
77			*Anthophora* sp. Latreille, 1803
78			*Apis cerana indica* (Fabricius, 1798)
79			*Apis dorsata* (Fabricius, 1793)
80			*Apis laboriosa* (Smith, 1871)
81			*Apis florea* (Fabricius, 1787)
82			*Apis mellifera* (Linnaeus, 1758)
83			*Bombus haemorrhoidalis* (Smith, 1852)
84			*Bombus orientalis* (Smith, 1854)
85			*Bombus tunicatus* (Smith, 1852)
86		Nomadinae Latreille, 1802	*Epeolus* sp. Latreille, 1802
87		Xylocopinae Latreille, 1802	*Ceratina* sp. Latreille, 1802
88			*Xylocopa* sp. Latreille, 1802
89	Chrysididae	Chrysidinae Latreille, 1802	*Chrysis* sp. Linnaeus, 1767
90			*Chrysura* sp. Dahlbom, 1845

91	Colletidae	Colletinae Lepeletier, 1841	*Colletes* sp. Latreille, 1802
92	Crabronidae	Bembicinae Latreille, 1802	*Bembix* sp. Fabricius, 1775
93	Halictidae	Halictinae Thomson, 1869	*Halictus* sp. Latreille, 1804
94			*Lasioglossum* sp. Curtis, 1833
95		Nomiinae Robertson, 1904	*Nomia* sp. Latreille, 1804
96	Ichneumonidae	Gelinae Viereck, 1918	*Cryptus* sp. Fabricius, 1804
97		Ichneumoninae Latreille, 1802	*Ichneumon* sp. Linnaeus, 1758
98		Ophioninae Shuckard, 1840	*Ophion* sp. Fabricius, 1798
99		Xordinae Shuckard, 1840	*Odontocolon* sp. Cushman, 1942
100	Leucospidae	-	*Leucospis* sp. Fabricius, 1775
101	Megachilidae	Megachilinae Friese (1911b)	*Megachile* sp. Latreille, 1802
102	Scoliidae	Scoliinae Latreille, 1802	*Colpacampsomeris* sp. Betrem, 1967
103			*Megacampsomeris* sp. Betrem, 1928
104			*Phalerimeris* sp. Betrem, 1967
105	Sphecidae	Ammophilinae André, 1886	*Ammophila* sp. W. Kirby, 1798
106			*Chalybion* sp. Dahlbom, 1843
107		Sceliphrinae Ashmead, 1899	*Podalonia* sp. Fernald, 1927
108		Sphecinae Latreille, 1802	*Prionyx* sp. Vander Linden, 1827
109			*Sphex* sp. Linnaeus, 1758
110	Vespidae	Eumeninae Latreille, 1802	*Ancistrocerus* sp. Wesmael, 1836
111			*Eumenes* sp. Latreille, 1802
112			*Parancistrocerus* sp. Bequaert, 1925
113		Polistinae Lepeletier, 1836	*Parapolybia* sp. Saussure, 1854
114			*Polistes* sp. Latreille, 1802

115			*Polistes olivaceous* (DeGeer, 1773)
116		Vespinae Latreille, 1802	*Vespa basalis* (Smith, 1852)
117			*Vespa tropica* (Linnaeus, 1758)
118			*Vespa velutina* (Lepeletier de Saint Fargeau, 1836) Synonym as *V. auraria* (Smith, 1852)
119			*Vespula* sp. Linnaeus, 1758
	DIPTERA:		
120	Asilidae	Asilinae, Leach 1819	*Machimus* sp. Loew, 1849
121			*Promachus hinei* (Bromley, 1931)
122	Bibionidae	Bibioninae Newman, 1834	*Bibio* sp. Geoffroy, 1762
123		Pleciinae Duda, 1930	*Plecia* sp. Wiedemann, 1828
124	Bombyliidae	Anthracinae Latreille, 1804	*Villa* sp. Lioy, 1864
125		Bombyliinae Latreille, 1802	*Anastoechus* sp. Osten Sacken, 1877
126			*Bombylius major* (Linnaeus, 1758)
127			*Bombylius minor* (Linnaeus, 1758)
128	Calliphoridae	Calliphorinae	*Calliphora vomitoria* (Linnaeus, 1758)
129		Luciliinae	*Lucilia* sp. Robineau-Desvoidy, 1830
130	Muscidae	Muscinae Latreille, 1802	*Musca domestica* (Linnaeus, 1758)
131	Scathophagidae	Scathophaginae Robineau-Desvoidy, 1830	*Cordilura* sp. Fallen, 1810
132	Syrphidae	Eristalinae Newman, 1834	*Ceriana* sp. Rafinesque, 1815
133			*Episyrphus balteatus* (De Geer, 1776)
134			*Eristalinus* sp. Rondani, 1845
135			*Eristalis horticola* (De Geer, 1776)
136			*Eristalis* sp. Latreille, 1804

137			*Eristalis tenax* (Linnaeus, 1758)
138			*Eumerus* sp. Meigen, 1822
139			*Sphaerophoria* sp. Le Peletier & Serville, 1828
140	Tabanidae	Tabaninae Latreille, 1802	*Tabanus* sp. Linnaeus, 1758
141	Tachinidae	Tachininae	*Tachina* sp. Meigen, 1803
142			*Nowickia* sp. Wachtl, 1894
	COLEOPTERA:		
143	Buprestidae	Agrilinae Laporte, 1835	*Agrilus* sp. Curtis, 1825
144	Coccinellidae	Coccinellinae Latreille, 1807	*Adalia* sp. Mulsant, 1850
145			*Coccinella septempunctata* (Linnaeus, 1758)
146			*Coccinella* sp. Linnaeus, 1758
147			*Halyzia* sp. Mulsant, 1846
148		Epilachninae Mulsant, 1846	*Henosepilachna* sp. Li & Cook, 1961
149	Meloidae	Meloinae Gyllenhal, 1810	*Epicauta* sp. Dejean, 1834
150			*Hycleus* sp. Latreille, 1817
151			*Lytta* sp. Fabricius, 1775
152	Scarabaeidae	Cetoniinae Leach, 1815	*Clinteria* sp. Burmeister, 1842
153			*Gametis* sp. Burmeister, 1842
154			*Protaetia* sp. Burmeister, 1842

Table 3.5: Consolidated Inventory of species recorded from study area [Doon (DV-Organic) and Mandakini valley (MV-Non-organic)] (Source: Kumar, 2008; Chandra et al., 2019; Mahmood et al., 2012; Kumar and Pham, 2015; Parui et al., 2006; and Mitra et al., 2005, 2008; Insecta.pro)

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
	I. LEPIDOPTERA				**Global**	**India**		
1	Papilionoidea	Hesperiidae Latreille, 1809	Pyrginae Burmeister, 1878	*Oriens gola* (Moore, 1877)	Europe, Northern Asia, China, Japan, British Isles	HP, UK, SK, WB, AR, AS, MH, AP, KA	DV	1
2				*Pelopidas mathias* (Fabricius, 1798)	China, Japan, Mongolia, North and South Korea, Taiwan	HP, UK, SK, WB, AR, AS, ME, NL, MI, MN, TR, JH, GJ, MH, AP, KA, TN, KL, GA, OD	MV, DV	1
3				*Pelopidas* sp. Walker, 1870	Pakistan, Nepal, Myanmar, Srilanka	JK, HP, UK, PB, HR	MV, DV	1
4				*Pseudocoladenia* sp. Shirozu & Saigusa, 1962	Pakistan, Nepal		MV, DV	1
5				*Tagiades litigiosa* (Fruhstorfer, 1910)	Nepal, China, Bhutan, Bangladesh, Myanmar, Laos, Thailand	HP, UK, SK, WB, AR, AS, JH, OD, ME, NL, MI, MN, TR, GJ, MH, AP, KA, TN, KL, GA	MV	1

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
6		Lycaenidae Leach, 1815	Polyommatinae Swainson, 1827	*Acytolepis puspa gisca* (Fruhstorfer, 1910)	Cambodia, New Guinea, Taiwan, Sri Lanka, Philippines Myanmar,, Sulawesi, Borneo	HP, UK, SK, WB, AR, AS, MH, AP, KA, TN, KL, GA, AN	MV, DV	1
7				*Cupido argiades* (Pallas, 1771)	Japan, Europe, Myanmar	UK, HP, JK, BH, JH, MP, CG	MV, DV	1
8				*Cupido* sp. Schrank, 1801	Europe, Asia, Russia	JK, HP, UK	MV, DV	1
9				*Pseudozizeeria maha maha* (Kollar, [1844])	Pakistan, Nepal, Laos, Bhutan, Bangladesh, Myanmar, China, Vietnam, Thailand	SK, WB UK, AR, AS, ME, NL, MI, MN, TR, PB, HR, GJ, RJ, MP, CG, MH, OD, JK, HP	MV, DV	1
10				*Talicada nyseus* (Guerin, 1843)	Sri Lanka, North Myanmar	JK, MP, CG, AP, HP, UK, KA, TN, KL, SK, WB, AR, AS, ME, NL, MI, MN, TR, BH, JH, UP, DL, CH, HR, PB, GJ, RJ, TL, MH, , GA, OD, PY, AN	MV	1
11				*Zizeeria karsandra* (Moore, 1865)	Pakistan, Nepal, Bhutan, Bangladesh, Sri Lanka, Laos, Myanmar, China, Taiwan, New Guinea, Australia, Vietnam, Thailand, Malaysia		MV, DV	1

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
12			Lycaeninae Leach, 1815	*Heliophorus moorei coruscans* (Moore, 1882)	Nepal	JK, HP, UK	MV	1
13				*Heliophorus sena* (Kollar, [1844])	Pakistan, Nepal	JK, HP, UK, AR, PB	MV, DV	1
14				*Heliophorus tamu tamu* (Kollar, [1844])	Nepal, Bhutan	UK, SK, WB, AR	MV	1
15				*Lycaena pavana* (Kollar, 1848)	Pakistan, Nepal	JK, HP, UK	MV, DV	1
16				*Lycaena phlaeas baralacha* (Moore, 1884)	Pakistan, Nepal, Bhutan	JK, HP, UK	MV, DV	1
17		Papilionidae Latreille, 1802	Papilioninae Latreille, 1802	*Atrophaneura aidoneus* (Doubleday, 1845)	Nepal, Bhutan, China, Bangladesh, Myanmar, Laos, Vietnam, Thailand	UK, SK, WB, AR, AS, ME, MN, NL, MI	MV, DV	3
18				*Byasa dasarada* (Moore, 1857)	Nepal, Bhutan	SK, UK, WB, AR, AS, ME, NL, MN	MV	3

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
19				*Graphium sarpedon sarpedon* (Linnaeus, 1758)	Pakistan, Thailand, Nepal, Bhutan, Bangladesh, Cambodia, Malaysia, Sri Lanka, Myanmar, China, Taiwan, Laos, Vietnam, Japan, Indonesia, Australia, Korea	JK, SK, AR, AS, ME, NL, WB, MN, MI, TR, BH, DL, PB, HP, UK,	MV, DV	3
20				*Papilio bianor* Cramer, [1777]	Pakistan, Nepal	JK, HP, UK	MV, DV	3
21				*Papilio polytes* (Linnaeus, 1758)	Nepal, Bhutan, China, Pakistan, Bangladesh, Sri Lanka, Myanmar, Taiwan, Vietnam, Philippines	JK, TL, KA, TN, HP, UK, MH, AP, SK, CG, MI, WB, AR, AS, ME, NL, GA, OD, MN, TR, BH, JH, UP, DL, AN, PB, HR, CH, GJ, RJ, MP, KL	DV	3
22				*Papilio machaon asiatica* (Menetries, 1855)	Pakistan	JK, HP, UK	DV	3
23				*Papilio protenor protenor* (Cramer, [1775])	Pakistan, Nepal	JK, HP, UK	MV	3

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
24 25		Pieridae Swainson, 1820	Coliadinae Swainson, 1827	*Catopsilia pomona* (Fabricius, 1775)	Pakistan, Nepal, Laos, Bhutan, Bangladesh, Sri Lanka, Myanmar, China, Taiwan, Vietnam, Cambodia, Thailand, Malaysia, Indonesia	JK, MP, CG, AP, HP, UK, AR, AS, ME, NL, MN, TR, UP, DL, PB, SK, MH, KA, WB, GJ, RJ, , TL, TN, KL, GA, AN	MV, DV	4
26				*Catopsilia pyranthe pyranthe* (Linnaeus, 1758)	Pakistan, Nepal, Laos, Bhutan, Bangladesh, Sri Lanka, Japan, Indonesia, Myanmar, China, Taiwan, Vietnam, Cambodia, Thailand, Philippines	JK, AR, UK, GA, OD, SK, WB, AS, ME, NL, MN, TR, UP, DL, PB, GJ, RJ, MP, CG, AP, TL, MH, KA, TN, KL, HP	MV, DV	4
27				*Colias erate* (Esper, 1805)	Pakistan, Nepal, Bhutan	JK, HP, UK	MV, DV	4
28				*Colias fieldii fieldii* (Menetries, 1855)	Pakistan, Nepal, Laos, Bhutan, Myanmar, Vietnam, Thailand	WB, DL, AP, MH, HP, SK, AR, UK, AS, ME, NL, MN, BH, UP, JK,	MV, DV	4
29				*Eurema blanda silhetana* (Wallace, 1867)	Pakistan, Nepal, Laos, Bhutan, Bangladesh, Myanmar, Vietnam, Thailand	HP, UK, SK, WB, AR, AS, ME, NL, MN, TR, BH, JH, GJ, RJ, MP, TL MH, KA, TN, OD, AP	MV, DV	4

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
30				*Eurema hecabe hecabe* (Linnaeus, 1758)	Pakistan, Nepal, Laos, Bhutan, Myanmar, Japan, China, Vietnam, Thailand, Malaysia, Indonesia, Sri Lanka, Philippines	JK, HP, UK, SK, WB, AR, AS, ME, NL, MN, BH, JH, UP, DL, PB, HR, CH, GJ, RJ, MP, CG, AP, TL, MH, KA, TN, KL, GA, OD, AN	MV, DV	4
31				*Gonepteryx rhamni* (Linnaeus, 1758)	Pakistan, Nepal, Bhutan, Tibet	JK, HP, UK, SK, WB	MV, DV	4
32			Pierinae Swainson, 1820	*Belenois aurota aurota* (Fabricius, 1793)	Pakistan, Nepal, Bangladesh	JK, HP, UK, SK, WB, BH, JH, UP, MP, MH, KA, TN, KL, OD	MV, DV	3
33				*Delias belladonna horsfieldii* (Gray, 1831)	Pakistan, Nepal	JK, HP, UK, SK, WB	MV, DV	4
34				*Pareronia valeria* (Cramer, [1776])	Pakistan, Nepal, Laos, Bhutan, Bangladesh, Myanmar	HP, UP, UK, WB, AS	DV	4
35				*Pieris brassicae nepalensis* (Gray, 1846)	Pakistan, Nepal, Laos, Bhutan, Bangladesh, Myanmar, China, Vietnam, Thailand	JK, HP, UK, SK, WB, AR, AS, ME, NL, MI, MN, TR, BH, UP, DL, PB, HR, RJ	MV, DV	4

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
36				*Pieris melete* (Moore, 1865)	Pakistan, Nepal, China, Bhutan, Myanmar, Korea, Japan, Bangladesh, Thailand	JK, HP, UK, SK, WB, AR, AS, ME, NL, MN, BH, JH, UP, DL, PB, HR, CH, GJ, RJ, MP, CG, AP, TL, MH, KA, TN, KL, GA, OD, AN	MV, DV	4
37				*Pieris rapae* (Linnaeus, 1758)	China, Vietnam, USA, Australia, Russia, UK, Kazakhstan, Morocco, Algeria, Italy, Germany, France, Netherlands, Spain, Norway, Canada, Romania, Switzerland, Austria	JK, HP, UK, SK, WB, AR, AS, ME, NL, MI, MN, TR, BH, UP, DL, PB, HR, RJ	MV, DV	4
38				*Pontia daplidice* (Linnaeus, 1758)	Asia, Europe, Afganistan	JK, HP, UK, SK, WB	MV, DV	4
39		Riodinidae Grote, 1895	Nemeobiinae	*Dodona durga durga* (Kollar & Redtenbacher, 1844)	Pakistan, Nepal, Bhutan	JK, HP, UK	MV, DV	3
40		Nymphalidae Rafinesque, 1815	Heliconiinae Swainson, 1822	*Argynnis hyperbius hyperbius* (Linnaeus, 1763)	Pakistan, Nepal, Laos, Bhutan, China, Taiwan, Myanmar, Vietnam, Thailand, Japan, Korea	JK, HP, UK, SK, WB, AR, AS, ME, NL, MI, MN, UP, DL, PB, GJ, RJ, MP, OD	MV	1

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
41				*Cupha erymanthis* (Drury, 1773)	Pakistan, Nepal, Laos, Bhutan, China, Taiwan, Myanmar	JK, HP, UK, SK, WB, AS, UP, BH, JH, MP, CG, AP, TL, MH, KA	DV	2
42				*Phalanta phalantha phalantha* (Drury, [1773])	Myanmar, Pakistan, Nepal, Laos, Bhutan, Japan, China, Sri Lanka, Taiwan, Vietnam, Thailand, Philippines, Bangladesh, Malaysia, Indonesia	WB, JK, CG, AP, UK, AS, ME, NL, MI, MN, TR, BH, JH, UP, DL, CH, HR, PB, GJ, RJ, HP, MP, MH, KA, TN, KL, GA, OD, AN, SK, AR	MV, DV	3
43			Limenitidinae Behr, 1864	*Athyma opalina opalina* (Kollar, [1844])	Pakistan, Nepal, Bhutan, China	JK, HP, UK, SK, WB, ME, MN	MV, DV	2
44				*Neptis mahendra mahendra* (Moore, 1872)	Pakistan, Nepal	JK, PB, UK, AS, SK, AR, HP, WB	MV, DV	2
45			Cyrestinae Guenée, 1865	*Cyrestis thyodamas ganescha* (Kollar, 1848)	Pakistan	JK, HP, UK	MV, DV	2

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
46				*Danaus chrysippus chrysippus* (Linnaeus, 1758)	Pakistan, Indonesia, Nepal, Laos, Bhutan, China, Bangladesh, Italy, Vietnam, Thailand, Malaysia, Myanmar, Japan, Algeria, Philippines, South Africa, Kenya, Madagascar, Taiwan, Sri Lanka	SK, AS, ME, NL, MI, MN, TR, BH, JH, UP, DL, WB, AR, CH, HR, PB, GJ, RJ, MP, CG, AP, TL, TN, KL, GA, OD, PY, AN, JK, HP, UK, MH, KA	MV, DV	2
47			Danainae Boisduval, 1833	*Danaus genutia genutia* (Cramer, [1779])	Pakistan, Bhutan, Laos, Bangladesh, Myanmar, China, Taiwan, Vietnam, Thailand, Philippines, Nepal, Malaysia, Sri Lanka,	JK, TR, BH, JH, HP, PB, GJ, UK, SK, WB, AR, AS, ME, NL, MI, MN, UP, DL, CH, HR, RJ, MP, CG, AP, TL, MH, KA, TN, KL, GA, OD, PY, AN	DV	2
48				*Euploea core core* (Cramer, [1780])	Pakistan, Bangladesh, Nepal, Bhutan	MH, KA, JK, OD, PY, HP, UK, PB, MP, SK, GJ, RJ, WB, AP, AR, AS, ME, NL, BH, JH, UP, DL, CH, HR, CG, TL, , TN, KL, GA	MV, DV	2
49				*Euploea mulciber mulciber* (Cramer, [1777])	Nepal, Laos, Bhutan, Bangladesh, Myanmar, Vietnam, Cambodia, Thailand, Malaysia, China	PB, AN, JK, UK, WB, AS, ME, SK, NL, MI, MN, TR, BH, UP, DL, HP, AR	MV, DV	2

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
50				*Parantica sita sita* (Kollar, [1844])	Afghanistan, Pakistan, Laos, Nepal, Bhutan, Myanmar, Vietnam, China, Thailand	JK, HP, UK, WB, SK, AR, AS, NL, MN, ME, MI	MV, DV	3
51				*Tirumala limniace* (Cramer, 1775)	Sri Lanka,Bangladesh, Bhutan, China, Nepal, Myanmar Sumatra, Thailand, Vietnam	UK, PB, BH, JH, UP, DL, CH, HR, PB, GJ, RJ, MP, CG, TL, MH, KA, TN, KL, GA, OD, PY	DV	3
52			Nymphalinae Rafinesque, 1815	*Aglais caschmirensis aesis* (Fruhstorfer, 1912)	Nepal, Bhutan, Myanmar	HP, UK, SK, WB, AR, ME, NL, MN	MV, DV	1
53				*Hypolimnas bolina* (Linnaeus, 1758)	Bhutan, Nepal, Sri Lanka, Myanmar	UK, UP, PB, HP, BH, GJ, RJ, MP, TL, CG	DV	2
54				*Issoria lathonia* (Linnaeus, 1758)	Nepal and Myanmar	HP, UK, SK, WB, AR, AS, ME, NL, MI, MN	MV, DV	2
55				*Junonia almana* (Linnaeus, 1758)	Sri Lanka, Myanmar	WB, JH, JK, UP, UK, BH, HP	DV	2
56				*Junonia iphita* (Cramer, [1779])	Thailand, Nepal, China, Malaysia, Pakistan, Sri Lanka, Bhutan, Bangladesh, Myanmar, Laos, Vietnam, Cambodia	AS, ME, HP, MH, KA, UK, SK, BH, JH, WB, AR, MI, MN, TR, UP, DL, CH, HR, PB, GJ, RJ, MP, CG, AP, TL, TN, KL, GA, OD, AN, JK	DV	2

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
57				*Junonia orithya ocyale* (Huebner, [1819])	Nepal, China, Bhutan, Bangladesh, Myanmar, Vietnam, Laos, Cambodia, Thailand	HP, UK, SK, WB, AR, AS, ME, NL, MI, MN	MV	2
58				*Kaniska canace canace* (Linnaeus, 1763)	Vietnam, Thailand, China, Pakistan, Bhutan, Myanmar, Laos, Nepal	JK, HP, UK, SK, WB, AR, AS, ME, NL, MN, BH	MV, DV	2
59				*Nymphalis polychloros* (Linnaeus, 1758)	Pakistan, Nepal	JK, HP, UK	MV, DV	3
60				*Symbrenthia lilaea* (Moore, [1875])	Afghanistan, Pakistan, Nepal, Myanmar, Bhutan, Laos, China, Vietnam, Thailand, Singapore	HP, JK, UK, AS, SK	MV, DV	3
61				*Vanessa cardui* (Linnaeus, 1758)	Pakistan, China, USA, Vietnam, Russia, Peru, Algeria, Morocco, Italy, Germany, Kenya, Spain, Austria, Canada, France, Switzerland, Norway, Romania, Mexico, Brazil	TL, MH, HP, UK, WB, AR, ME, MI, MN, TR, BH, JH, UP, DL, CH, HR, PB, GJ, RJ, SK, MP, CG, AP, KA, TN, KL, GA, OD, PY, AN JK, AS	MV, DV	3
62				*Vanessa indica indica* (Herbst, 1794)	Pakistan, Nepal, Bhutan, Myanmar, China, Taiwan, Vietnam, Laos, Thailand,	PB, JK, HP, WB, AR, AS, ME, UK, NL, MI, MN, SK,	MV, DV	3

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
					Philippines, Japan, Korea, Russia			
63			Satyrinae Boisduval, 1833	*Callerebia annada* (Moore, 1858)	Nepal, Pakistan, Bhutan, Bangladesh	JK, HP, UK	MV, DV	2
64				*Lasiommata schakra schakra* (Kollar, [1844])	Nepal, Pakistan, Bangladesh	JK, HP, UK, WB	MV, DV	2
65				*Lethe verma verma* (Kollar, [1844])	Pakistan, Nepal, Bhutan	JK, HP, UK	DV	2
66				*Mycalesis perseus* (Fabricius, 1775)	Myanmar, Nepal, Bhutan	HP, UK,	MV, DV	
67				*Orinoma damaris damaris* (Gray, 1846)	Nepal, Bhutan, Laos, Myanmar, Vietnam, China, Thailand	HP, UK, SK, WB, AR, AS, ME, NL, MN	MV	3
68				*Ypthima nikaea* (Moore, [1875])	Pakistan, Nepal	JK, HP, UK, PB	MV, DV	3
69				*Ypthima* Hubner, 1818	Africa, Afghanistan, Pakistan, Nepal, Bhutan, Myanmar		MV, DV	3

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
70			Libytheinae Boisduval, 1833	*Libythea lepita lepita* (Moore, [1858])	Pakistan, Nepal, China, Bhutan, Myanmar, Laos, Vietnam, Thailand	JK, HP, UK, SK, WB, AR, AS, ME, NL, MN, OD	MV, DV	2
				Libythea myrrha (Godart, 1819)			MV, DV	2
71			Apaturinae Boisduval, 1840	*Sephisa dichroa* (Kollar, [1844])	Pakistan, Nepal, Bhutan, China	JK, HP, UK	MV	3
72	Bombycoidea	Sphingidae Latreille, 1802	Macroglossinae Harris, 1839	*Macroglossum* Scopoli, 1777	Nepal, Bhutan, China, Bangladesh, Vietnam, Indonesia, Hong Kong, Taiwan, Japan, Thailand, Philippines, Korea, Russia	HP, UK, SK, WB, AR, AS, ME, KA	MV, DV	1
II. HYMENOPTERA					**Global**	**India**		
73	Apoidea	Andrenidae Latreille, 1802	Andreninae Latreille, 1802	*Andrena flavipes* (Panzer, 1799)	Central and Southern Europe, Central Asia, North Africa	UK, HP, JK, SK	MV, DV	5
74				*Andrena* sp. Fabricius, 1775			Sp.1 & Sp.2 (both)	5

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
75				*Amegilla zonata* (Fabricius, 1775)	Australia, Indonesia, Malayasia, Asia	UK, HP, JK, SK	MV, DV	5
76				*Amegilla confusa (Smith,*1854) Syn. *Anthophora confusa*	Australia, Indonesia, Malayasia, Africa, Asia	UK, JK, HP, PB,	DV	5
77				*Anthophora* sp. Latreille, 1803	North Africa, Eurasia, North America	UK, HP, JK, WB	Sp.1 & Sp.2 (both)	5
78		Apidae, Latreille, 1802	Apinae Latreille, 1802	*Apis cerana indica* (Fabricius, 1798)	Pakistan, Nepal, Myanmar, Bangladesh, Srilanka, Thailand, Mainland Asia	JK, HP, UK, SK, WB, AR,AS, ME, NL, MI, MN, TR, BH, JH, UP, DL, CH, HR,PB, GJ, RJ, MP, CG, AP, TL, MH, KA, TN, KL, GA, OD, PY, AN	MV, DV	5
79				*Apis dorsata* (Fabricius, 1793)	China, Nepal, Malayasia, Indonesia, Pakistan, Srilanka, Phillippines	Terai region of UP, UK, HP, WB, HR, BH	DV	5
80				*Apis laboriosa* (Smith, 1871)	Terai of Nepal, China (Western yunnan), Laos, Bhutan, Vietnam, Northern Myanmar	JK, UK, WB, AS, AR, MN, ME, NL, MI	MV	5

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
81				*Apis mellifera* (Linnaeus, 1758)	Every continent except Antarctica	JK, HP, UK, SK, WB, AR, AS, ME, NL, MI, MN, TR, BH, JH, UP, DL, CH, HR, PB, GJ, RJ, MP, CG, AP, TL, MH, KA, TN, KL, GA, OD, PY, AN	Both	5
82				*Apis florea* (Fabricius, 1787)	Asia, Africa, Thailand, China, Middle east	JK, HP, UK, SK, WB, AR, AS, ME, NL, MI, MN, TR, BH, JH, UP, DL, CH, HR, PB, GJ, RJ, MP, CG, TL, MH, KA, TN, KL	DV	5
83				*Bombus haemorrhoidalis* (Smith, 1852)	Pakistan, China, Nepal, Myanmar, Bangladesh	HP, UK, WB	MV, DV	5
84				*Bombus orientalis* (Smith, 1854)	China, Laos, Indonesia, Philippines, Myanmar, Korea, Japan, Singapore, Thailand, Vietnam, Mongolia, Malaysia	HP, UK, AR, AS, ME	MV, DV	5
85				*Bombus tunicatus* (Smith, 1852)	Afaganistan, Pakistan, Nepal	HP, UK, JK, WB	MV	5

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
86			Nomadinae Latreille, 1802	*Epeolus* sp. Latreille, 1802	Canada, Europe, Middle East, North Africa, Pakistan	JK, HP, UK, SK, AR	DV	5
87			Xylocopinae Latreille, 1802	*Xylocopa* sp. Latreille, 1802	Afghanistan, Iran, UAE, Pakistan, Germany, Java, Lebanon, USA, Malaysia, Saudi Arabia, Singapore, Thailand, Russia	JK, HP, UK, SK, WB, AS, BH, JH, UP, DL, CH, HR, PB, GJ, RJ, MP, CG, AP, TL, MH, KA, TN, KL, OD, PY	Sp.1 & 2 (both MV, DV)	5
				Ceratina sp. Latreille, 1802	Ethiopia, Kenya, Mali, Mauritania, North Africa, Iran, southern, Pakistan, Afghanistan, Srilanka	PB, GJ, TN, RJ, OD, UK	MV, DV	5
88		Sphecidae Latreille, 1802	Ammophilinae André, 1886	*Ammophila* sp. W. Kirby, 1798	Present in warm Tropical regions except Antarctica	UK, WB, AS, ME, NL, MI, MN, TR, BH, JH, UP, DL, CH, HR,PB, GJ, RJ, MP, CG, AP, TL, MH, GA, KA, TN, OD, KL	Sp. 1 (both), Sp.2 (DV only)	7
89				*Padalonia* sp. Fernald, 1927	Present worldwide except South America		MV, DV	
90			Sceliphrinae Ashmead, 1899	*Chalybion* sp. Dahlbom, 1843	Eastern coasts of Africa, Sinai Peninsula, Japan, Australia, Iraq, Oman, Philippines, China, USA, Indonesia, New Guinea		MV, DV	7

S. No.	**Super-Family**	**Family**	**Subfamily**	**Scientific Name**	**Distribution**		**Area**	**Plate No.**
91			Sphecinae Latreille, 1802	*Prionyx* sp. Vander Linden, 1827	Afghanistan, Africa, Middle East, China, Greece, Iran, Israel, Italy, Japan, Russia, Sri Lanka, Kazakhstan, Thailand, Vietnam	TN, KL, JK, HP, KA, GA, UK, TL, MH, SK, PY, AN, WB, AR,AS, ME, NL, MI, MN, TR, BH, JH, UP, DL, CH, HR, PB, GJ, RJ, MP, CG, AP, OD	DV	7
92				*Sphex* sp. Linnaeus, 1758	Australia, China, Spain, Djibouti, Indonesia, Japan, New Guinea, Philippines, Taiwan		MV, DV	7
93		Colletidae Lepeletier, 1841	Colletinae Lepeletier, 1841	*Colletes* sp. Latreille, 1802	Austria, France, Western Palaearctic, Morocco	PB, RJ, UK, UP, HP, GJ	MV, DV	6
94		Crabronidae Latreille, 1802	Bembicinae Latreille, 1802	*Bembix* sp. Fabricius, 1775	Australia, Central Europe, Southern Africa, Central Asia	JK, HP, UK, AS, WB	DV	6
95		Halictidae Thomson, 1869	Halictinae Thomson, 1869	*Halictus* sp. Latreille, 1804	Afghanistan, Myanmar, Nepal, Pakistan, Sri Lanka, Thailand, Iran	AP, HR, MH, PB, TN, WB, SK, UK, UP	MV, DV	6
96				*Lasioglossum* sp. Curtis, 1833	Germany, Nepal, Sri Lanka, South East Asia	AS, HP, MH, SK, PB, UK, UP, WB	Sp. 1 & 2 (both)	6

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
97			Nomiinae Robertson, 1904	*Nomia* sp. Latreille, 1804	Laos, Malaysia, Myanmar	PB, UK, TN	Sp.1 (both), Sp.2 & 3 (MV only)	6
98		Megachilidae	Megachilinae Friese (1911b)	*Megachile* sp. Latreille, 1802	China, Madagascar, South East Asia, Pakistan	PB, UK, SK, TN, RJ, HP, HR	Sp. 1 (both), Sp.2 (MV only)	6
99	Chalcidoidea	Leucospidae	-	*Leucospis* sp. Fabricius, 1775	All Continent, except Antarctica	JK, HP, UK, PB, HR, UP, BH, JH, SK, AR, AS, NG, ME, MI, MN	MV, DV	6
100	Chrysidoidea	Chrysididae Latreille, 1802	Chrysidinae Latreille, 1802	*Chrysis* sp. Linnaeus, 1767	Arabian Peninsula, Europe, Palaearctic, Oriental region	HP, UK, PB, HR, UP, SK, AR, AS, NG, ME, MI, MN	MV, DV	6
101				*Chrysura* sp. Dahlbom, 1845	Eurasia, North Africa	JK, HP, UK, SK, AR, AS, NG, ME, MI, MN	MV, DV	6
102	Ichneumonoidea	Ichneumonidae Latreille, 1802	Gelinae Viereck, 1918	*Cryptus* sp. Fabricius, 1804	Neoarctcic, Palearctic, Oriental countries	HP, UK, UP	MV, DV	6

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
103			Ichneumoninae Latreille, 1802	*Ichneumon* sp. Linnaeus, 1758	All Continent, except Antarctica	UK, HP, UP, KA, KL	Sp. 1 (both), Sp.2 (DV only)	6
104			Xordinae Shuckard, 1840	*Odontocolon* sp. Cushman, 1942	Europe, China, Nepal, Pakistan, Bhutan	UK, HP, UP, KA, KL	Sp. 1 & 2 (both)	6
105			Ophioninae Shuckard, 1840	*Ophion* sp. Fabricius, 1798	Europe, China, Nepal, Pakistan, Bhutan	HP, UK, UP, KA, KL	MV	6
106	Vespoidea	Vespidae Latreille, 1802	Eumeninae Latreille, 1802	*Ancistrocerus* sp. Wesmael, 1836	Afghanistan, America, New Zealand, Pakistan	JK, UK, HP, SK, WB, AS, AR, ME, MI, NL, MN	MV, DV	7
107				*Eumenes* sp. Latreille, 1802	Neoarctcic, Palearctic, Oriental countries	JK, UK, HP, SK, WB, AS, AR, ME, MI, NL, MN	DV	7
108				*Parancistrocerus* sp. Bequaert, 1925	North and South America, Asia, Northern Europe, South East Asia	DL, CH, HR, PB, JK, SK, GJ, RJ, UP, MP, WB, AR, AS, ME, NL, MI, MN, TR, BH, JH, CG, AP, TL, MH, KA, TN, HP, UK	Sp. 1, 2, 3 (DV only)	7

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
109			Polistinae Lepeletier, 1836	*Polistes olivaceous* (DeGeer, 1773)	Madagascar, Mauritius, Africa, Nepal, Srilanka, Southern China, Myanmar, Indonesia, Singapore	JK, AS, HP, UK, TR, WB	MV, DV	7
110				*Polistes* sp. Latreille, 1802	China, Hong Kong, Indonesia, Malaysia, Myanmar, Philippines, Singapore, Thailand, Nepal	UK, WB, AS, ME, NL, MI, MN, TR, BH, JH, UP, DL, CH, HR,PB, GJ, RJ, MP, CG, AP, TL, MH, KA, TN	Sp. 1, 2, 3 & 4 (both)	7
111				*Parapolybia* sp. Saussure, 1854	Iran, Afghanistan, Asia, Australia, New guinea (Melanesia)		MV, DV	7
112			Vespinae Latreille, 1802	*Vespa basalis* (Smith, 1852)	China, Indonesia, Laos, Myanmar, Pakistan, Nepal, Taiwan, Thailand, Vietnam, Bhutan	AR, AS, HP, ME, MI, OD, PB, SK, UK, WB	MV, DV	7
113				*Vespa velutina* (Lepeletier de Saint Fargeau, 1836) Synonym as *V.auraria* (Smith, 1852)	Bhutan, China, Laos, Indonesia, Malaysia, Myanmar, Pakistan, Thailand, Taiwan, Vietnam	UK, HP, AS, WB, ME	MV, DV	8

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
114				*Vespa tropica* (Linnaeus, 1758)	Bhutan, China,Laos, Indonesia, Pakistan, Malaysia, Myanmar, Nepal, Sri Lanka, Papua New Guinea, Afghanistan, Thailand, Philippines, Vietnam, Cambodia	UK, WB, AS, ME, NL, MI, MN, TR, BH, JH, UP, DL, CH, HR,PB, GJ, RJ, MP, CG, AP, TL, MH, KA, TN	MV, DV	8
115				*Vespula* sp. Linnaeus, 1758	China, United Kingdom, Germany, New Zealand, Australia	JK, HP, UK, SK, WB, AR, AS, ME, MI, MN, TR, BH, JH, UP, DL, CH, HR, PB, GJ, RJ, MP, CG, AP, TL, MH, KA, TN, KL, GA, OD, AN	Sp.1, 2 & 3 (both)	8
116				*Megacampsomeris* sp. Betrem, 1928	Bhutan, Myanmar, Nepal	MN, ME, SK, UK, WB, KA, KL	MV, DV	7
117		Scoliidae Latreille, 1802	Scoliinae Latreille, 1802	*Phalerimeris* sp. Betrem, 1967	Bhutan, China, Indonesia, Nepal, Malaysia, Myanmar, Taiwan, Thailand	AP, JH, BH, DL, GJ, RJ, KA, KL, MH, OD, PY, TN, UK, UP, WB	DV	6
118	Scolioidea			*Colpacampsomeris* sp. Betrem, 1967	Bangladesh, Myanmar, Bhutan	AR, CG, HP, MH, ME, SK, UK	MV, DV	7

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
	III. DIPTERA				**Global**	**India**		
119	Asiloidea	Asilidae, Leach 1819	Asilinae, Leach 1819	*Machimus* sp. Loew, 1849	Neoarctcic, Palearctic, Oriental countries	JK, HP, UK, SK, WB, AR, AS, ME, MI, MN, TR, BH, JH, UP, DL, CH, HR, PB, GJ, RJ, MP, CG, AP, TL, MH, KA, TN, KL, GA, OD, PY	Sp.1 (both MV & DV), Sp.2 (DV)	9
120				*Promachus hinei* (Bromley, 1931)			MV, DV	9
121		Bombyliidae Latreille, 1802	Bombyliinae Latreille, 1802	*Anastoechus* sp. Osten Sacken, 1877	Northern Himalayan foothills, Northern and Central parts of the Arabian Peninsula, northern Africa, Europe	HP, UK, WB, AR, SK	MV, DV	9
122				*Bombylius major* (Linnaeus, 1758)	Temperate regions of Europe, Asia, North America	JK, HP, SK, AR, UK	MV, DV	9
123				*Bombylius minor* (Linnaeus, 1758)	Eurasia, North of foothills of Himalaya, North Africa		MV, DV	9
124			Anthracinae	*Villa* sp. Lioy, 1864	All Continent, except Antarctica	WB, AP, UK, TN, AR	DV	9

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
125	Bibionoidea	Bibionidae	Pleciinae Duda, 1930	*Plecia* sp. Wiedemann, 1828	Worldwide in distribution, with the exception of Antarctica	BH, JH, HP, UP, DL, UK, CH, HR, SK, MP, CG, WB, AR, AS, ME, MI, MN, TR, PB, GJ, RJ, AP, TL, MH, KA, TN, OD, PY, JK, KL, GA	Sp.1 (both MV & DV), Sp.2 (MV only)	9
126			Bibioninae Newman, 1834	*Bibio* sp. Geoffroy, 1762			MV, DV	9
127	Muscoidea	Muscidae Latreille, 1802	Muscinae Latreille, 1802	*Musca domestica* (Linnaeus, 1758)	Neoarctcic, Palearctic, Oriental countries	BH, JH, HP, UP, DL, UK, CH, HR, SK, MP, CG, WB, AR, AS, ME, MI, MN, TR, PB, GJ, RJ, AP, TL, MH, KA, TN, OD, PY, JK, KL, GA	MV, DV	9
128		Scathophagidae Robineau-Desvoidy, 1830	Scathophaginae Robineau-Desvoidy, 1830	*Cordilura* sp. Fallen, 1810	Distributed primarily in the Holarctic, Nearctic, Palaearctic, and Oriental Region	BH, JH, HP, UP, DL, UK, CH, HR, SK, MP, CG, WB, AR, AS, ME, MI, MN, TR, PB, GJ, RJ, AP, TL, MH, KA, TN, OD, PY, JK, KL, GA	DV	9

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
129	Syrphoidea	Syrphidae Latreille, 1802	Syrphinae Latreille, 1802	*Sphaerophoria* sp. Le Peletier & Serville, 1828	Nepal, Afghanistan, China, Algeria , Egypt, Europe (widespread), Greenland, Mongolia, Morocco, Syria	AR, BH, HP, KA, KA, MH, MN, ME, MI, SK, WB, UP, UK	MV, DV	10
130			Eristalinae Newman, 1834	*Eristalinus* sp. Rondani, 1845	Bhutan, China, Indonesia, Nepal, Malaysia, Myanmar, Taiwan, Thailand, Australia	AR, JK, UK, GJ, MH, KA, KL, UP, BH, MP, ME, OD, SK, TR, WB	MV, DV	10
131				*Eumerus* sp. Meigen, 1822		WB, HP, UK, AS, JK, AN	DV	10
132				*Episyrphus balteatus* (De Geer, 1776)	Oriental, Australian, Palaearctic region	AR, BH, HP, JK, KA, KL, MN, ME, MI, NL, OD, SK, TN, UK, WB	MV, DV	10
133				*Ceriana* sp. Rafinesque, 1815	Spain, Portugal, France, Italy, Albania, Greece, Romania, Turkey, Israel, Lebanon, North Africa, Netherland	JK, BH, UP, UK, WB	MV, DV	10
134				*Eristalis horticola* (De Geer, 1776)	Eurasia, Central Asia, Northern foothills of the Himalayas, North Africa, Mediterranean Basin	JK, HP, UK, SK, AS, AR	MV, DV	10

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
135				*Eristalis tenax* (Linnaeus, 1758)	Bhutan, China, Indonesia, Nepal, Malaysia, Myanmar, Taiwan, Thailand, Australia	AR, MN, ME, MI, NL, SK, WB, UK, HP, PB, JK	MV, DV	10
136				*Eristalis* sp. Latreille, 1804			Sp.1 (both), Sp.2 & Sp.3 (DV only)	10
137	Tabanoidea	Tabanidae Latreille, 1802	Tabaninae Latreille, 1802	*Tabanus* sp. Linnaeus, 1758	Europe, Asia, Middle East	AS, HP, JK, UK, WB	MV, DV	9
138	Oestroidea	Tachinidae Bigot, 1853	Tachininae	*Tachina* sp. Meigen, 1803	Entire Palearctic realm, Europe, Israel, North Asia, China, Korea, Japan, North Africa	AR, MN, ME, MI, NL, SK, WB, UK, HP, PB, JK	MV, DV	10
139				*Nowickia* sp. Wachtl, 1894			MV, DV	9
140		Calliphoridae Brauer & Bergenstamm, 1889	Calliphorinae	*Calliphora vomitoria* (Linnaeus, 1758)	Neoarctcic, Palearctic, Oriental countries	BH, JH, HP, UP, DL, UK, CH, HR, SK, MP, CG, WB, AR, AS, ME, MI, MN, TR, PB, GJ, RJ, AP, TL, MH, KA, TN, OD, PY, JK, KL, GA	MV, DV	9

S. No.	**Super-Family**	**Family**	**Subfamily**	**Scientific Name**	**Distribution**		**Area**	**Plate No.**
141			Luciliinae	*Lucilia* sp. Robineau-Desvoidy, 1830		AR, AS, JK, HP, UK, SK, WB	Sp. 1 & 2 (both MV,DV)	9
IV. COLEOPTERA					**Global**	**India**		
142	Buprestoidea	Buprestidae Leach, 1815	Agrilinae Laporte, 1835	*Agrilus* sp. Curtis, 1825	Korea, Cambodia, Myanmar, China, Thailand, Japan, Indonesia, Malaysia, Singapore, Vietnam, Philippines	BH, JH, HP, UP, DL, UK, CH, HR, SK, MP, CG, WB, AR, AS, ME, MI, MN, TR, PB, GJ, RJ, AP, TL, MH, KA, TN, OD, PY, JK, KL, GA	MV, DV	11
143	Coccinelloidea	Coccinellidae Latreille, 1807	Coccinellinae Latreille, 1807	*Adalia* sp. Mulsant, 1850	Europe, North America, Africa, Northern Russia, Western Asia	UK, PB, UP, HR, WB, AS	MV, DV	11
144				*Coccinella septempunctata* (Linnaeus, 1758)	North America, Pakistan, Palaearctic region, Sri Lanka	JK, UK, HR, HP, PB, BH, UP, JH, WB, CH, GJ, RJ, MP, CG, KL, KA	MV, DV	11

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
145				*Coccinella* sp. Linnaeus, 1758	USA, Canada, Europe, Brazil, Northern Africa, Georgia, Asia, Armenia, Kazakhstan, Azerbaijan, Belarus, Turkmenistan	JK, HP, UK, SK, WB, AR, AS, ME, MI, MN, TR, BH, JH, UP, CH, HR, PB, GJ, RJ, MP, CG, AP, TL, MH, KA, TN, KL, OD	MV, DV	11
146				*Halyzia* sp. Mulsant, 1846	Europe, Siberia, Belarus, the Russian Far East, Japan, Ukraine, Asia Minor, Mongolia, Kazakhstan, Northern China		MV, DV	11
147			Epilachninae Mulsant, 1846	*Henosepilachna* sp. Li & Cook, 1961	Australia, Indonesia, Bhutan, China, Japan, Myanmar, New Guinea, Nepal, Sri Lanka, Pakistan, Philippines Fiji,, Thailand, Vietnam	AN, GA, HR, HP, KL, MP, MH, MN, ME, PB, SK, TN, TR, UP, UK, WB	MV, DV	11
148	Tenebrionoidea	Meloidae Gyllenhal, 1810	Meloinae Gyllenhal, 1810	*Epicauta* sp. Dejean, 1834	Present worldwide except Australia and Antarctica	JK, PB, HP, UK, UP, BH, AS, SK, AR, AS, KA, WB, RJ, GJ, MH, KL	MV, DV	11
149				*Hycleus* sp. Latreille, 1817	Everywhere in Asia and Africa	HR, PB, JK, KA, TN, HP, SK, OD, AR, AS, ME, MI, MN, TR, BH,	MV, DV	11

S. No.	Super-Family	Family	Subfamily	Scientific Name	Distribution		Area	Plate No.
150				*Lytta* sp. Fabricius, 1775	North America, Asia, Africa, Europe	JH, UP, CH, GJ, RJ, MP, AP, MH, KL, UK	MV, DV	11
151	Scarabaeoidea	Scarabaeidae Latreille, 1802	Cetoniinae Leach, 1815	*Clinteria* sp. Burmeister, 1842	China, Saudi Arabia, Iran, Japan, Thailand, Laos, Bangladesh, Nepal, Sri lanka, Bhutan, Maldives, Pakistan, Myanmar	CG, HR, HP, MH, KA, MP, OD, UP, UK	MV, DV	11
152				*Gametis* sp. Burmeister, 1842	Afghanistan, Pakistan, Bangladesh, Bhutan, Nepal, Mauritius, Siberia,, China, Madagascar, Sri Lanka, Japan, Myanmar, S. Korea	HR, HP, MN, ME SK, WB, MH, UK, AP, TN, CG, MP, DL	MV, DV	11
153				*Protaetia* sp. Burmeister, 1842	Afghanistan, Pakistan, Myanmar, Sri Lanka, Tibet, Nepal	BH, HR, GJ, JH, KA, MP, MH, SK, TN, UK, UP, WB, NL, MN, ME, JK, AR	MV, DV	11

Indian states given in abbreviation (please refer to Acronyms) in distribution column of table above and arranged according to Biogeographic Zones and Provinces of India.

3.4.2. Systematics & Taxonomic accounts of Insect pollinator diversity

One of the most significant qualities of a biological community is diversity, and determining it is a prerequisite for studying or managing a system. The diversity of insect pollinators from all the four orders across the study area are identified and listed in Table 3.6 to 3.9.

3.4.2.1. ORDER I - Lepidoptera (7 families): Diversity of Butterflies

Butterflies are regarded as "flagships" (Samways, 1995; Simberloff, 1998) in the insect world and are often taken into account as models in ecological entomology and habitat conservation based research investigations.

Historical Review

Fabricius and Cramer conducted the first ever studies on Indian butterflies in 1775, and later researchers such as Horsfield (1828-29), Moore and Swinhoe (1890-1913), Bingham (1905), and Bell (1890-1913) continued the research (1909-1927). Evans (1932) and Yates (1935 & 1946) have contributed significantly to our understanding of these insects. The first ever records of butterflies of Uttarakhand were documented by Hutton (1847) and Doherty (1886). Mackinnon and de Niceville (1897-98) detailed the discovery of more than 300 butterflies in and around Mussoorie. Mackinnon's eleven-year field collection resulted in the world's largest collection of Western Himalayan species, according to the study. Later, Hannyngton (1910-1911) published Kumaon butterflies in the Journal of the Asiatic Society of Bengal. Arora and Mandal (1977) identified 45 species in the Garhwal Himalaya. From the Valley of Flowers, Chaturvedi (1981) issued an entomological note. Mandal (1984) discovered 17 species in the forests of Garhwal and Tons Valley. According to Baindur (1993), Nanda Devi National Park was home to 27 different species. According to Arora (1994), Rajaji National Park was home to 68 different species. Singh compiled a list of 148 butterfly species found at Dehradun's New Forest Campus in 1999. According to Singh and Bhandari (2003), Doon Valley was home to 183 species. Uniyal (2004) compiled a list of 35 species from Nanda Devi National Park. Singh (2009) produced a 147-species butterfly inventory from the Kedarnath Wildlife Sanctuary. Bhardwaj et al. discovered 79 butterfly species in the Tons valley along an elevational gradient in 2012. Uniyal et al. (2013) identified few butterflies in the Gangotri region. Das and Parida (2015) identified 42 species on the Forest Research Institute (FRI) campus. Singh and

Sondhi (2016) collated existing material and their data on 349 Uttarakhand species to generate a cohesive account of 407 species. Bhardwaj et al. (2017) and Bhardwaj and Uniyal (2018) also studied butterflies in the sacred Gangotri area. The Nymphalidae and Papilionidae are the most studied families because of their large size and colour (Chandra, 2011).

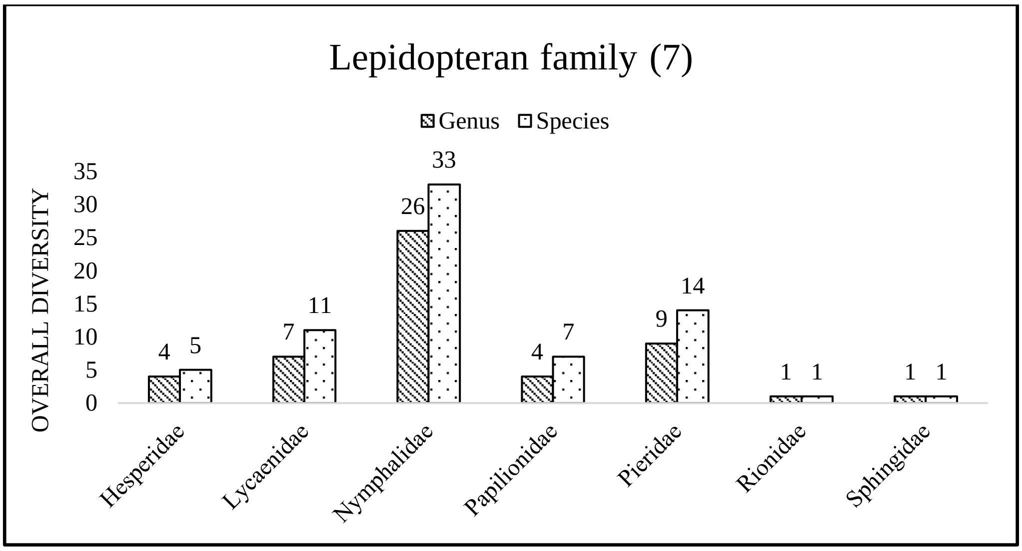


Fig 3.4: Overall family-wise diversity of Lepidoptera in both study areas

A total of 72 butterfly species were identified as flower visitors/pollinators of diverse crop plants from different sampling locations in the Mandakini Valley (Non-Organic) and Doon Valley (Organic), representing 16 subfamilies of 7 families. During the current course of study, all recorded butterfly species were placed under two super families, namely, Papilionoidea (true butterflies) and Bombycoidea. The superfamily Papilionoidea consisted of 6 families (Papilionidae, Pieridae, Nymphalidae, Lycaenidae, Hesperiidae, and Riodinidae), while the family Sphingidae was separated from the rest and placed under the superfamily Bombycoidea. There were 16 sub-families reported from the seven families of lepidoptera (Table 3.4 & 3.5). Of these Nymphalidae accounts for 7 sub-families, of which Danainae, Nymphalinae and Satyrinae were most diverse with *Aglais cashmirensis, Argynnis hyperbius, Cyrestis thyodamas, Danaus chrysippus, Danaus genutia, Euploea core, Euploea mulciber, Issoria lathonia, Junonia iphita, Kaniska canace, Neptis mahendra, Nymphalis polychloros, Parantica sita, Phalantha phalantha, Vanessa cardui, Vanessa indica, Ypthima* sp. as dominant species. The familes Lycaenidae (Lycaeninae, Polyommatinae) and Pieridae (Coliadinae, Pierinae) had two sub-families each with *Acytolepis puspa, Cupido argiades, Heliophorus moorei, Heliophorus sena, Heliophorus tamu, Lycaena phlaeas, Pseudozizeeria* sp., *Zizina kasandra, Anaphaesis aurota, Catopsilia pomona, Catopsilia pyranthe, Colias erate, Colias fieldii, Delias belladonna, Eurema blanda, Eurema hecabe, Gonepteryx nepalensis, Pareronia valeria, Pieris brassicae, Pieris melete, Pontia daplidice* as dominant species. The families Hesperiidae (Pyrginae), Papilionidae (Papilioninae), Riodinidae (Nemeobiinae) and Sphingidae (Macroglossinae) had minor representation (single sub-familes each) with *Oriens gola, Pelopidas mathias, Pseudocoladenia* sp., *Tagiades littigiosa, Atrophaneura aidoneus, Byasa dasarada, Graphium sarpedon, Papilio bianor, Papilio demoleus, Papilio machaon, Papilio protenor, Dodona durga, Macroglossum* sp. as dominant butterfly species.

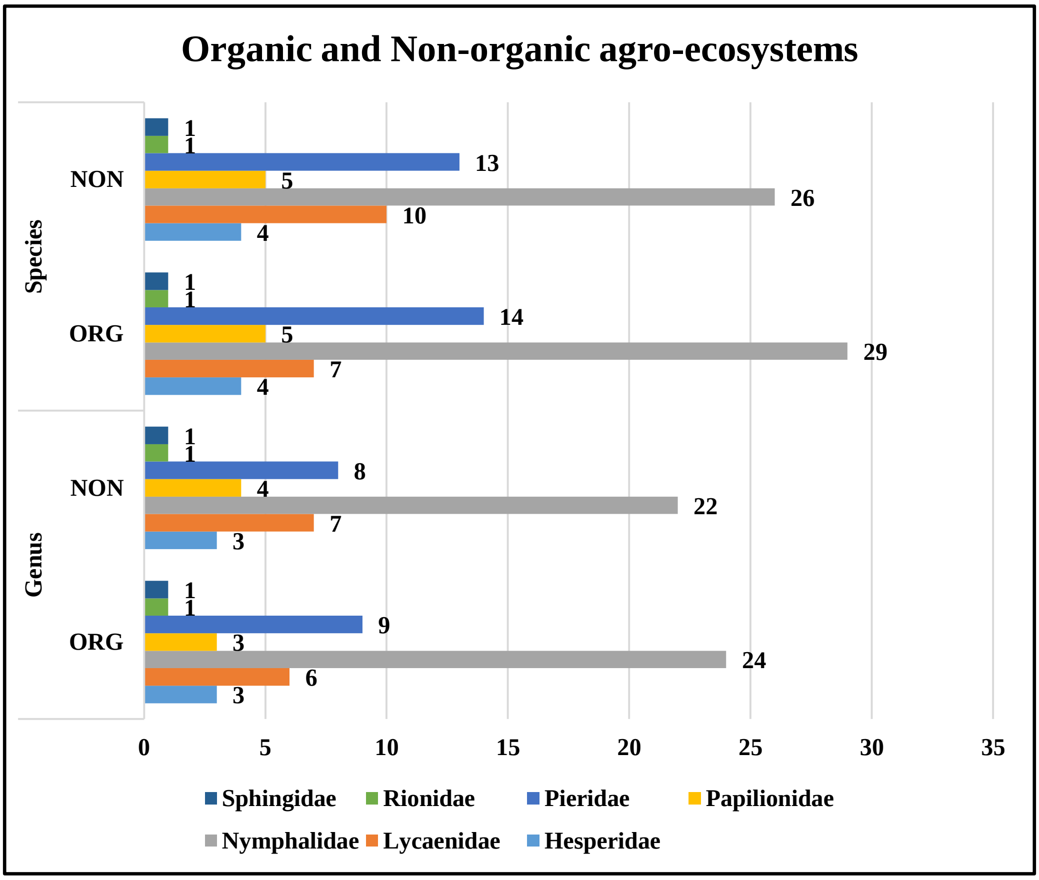


Fig 3.5: A clustered bar chart showing family-wise diversity of Lepidoptera in Organic and Non-organic agro-ecosystems

In organic agro-ecosystems, it was found that the highest number of species diversity occurred in the family Nymphalidae (29), followed by Pieridae (14), and Lycaenidae (7). While the families Papilionidae (5) and Hesperiidae (4) showed moderate species diversity. The families Riodinidae and Sphingidae have the least species diversity with a single species representation. In terms of genus diversity, the family Nymphalidae (24) had the most, followed by Pieridae (9) and then Lycaenidae (6). The families Riodinidae and Sphingidae had the least genus diversity of all the seven lepidopteran families.

In non-organic agro-ecosytems, the families Nymphalidae (26), Pieridae (13), and Lycaenidae (10) had the most species diversity.The families Papilionidae (5) and Hesperiidae (4) showed moderate species diversity, while Riodinidae and Sphingidae had the least species diversity with a single species representation. In terms of genus diversity in non-organic agro-ecosystems, the family Nymphalidae (22) was once again reported as the most diverse one, followed by Pieridae (8), Lycaenidae (7) and Hesperiidae (3). The families Riodinidae and Sphingidae had the least genus diversity of all the seven lepidopteran families (Fig. 3.13).

Table 3.6: Number and percentage of genus, species along with dominant species in the Lepidopteran family

SNo	**Family**	**No. of Genera**	**% of Genera** (round off)	**No. of Species**	**% of Species** (round off)	**Dominant Species**
1	Hesperiidae	4	8	5	7	*Pelopidas mathias* *Tagiades litigosa*
2	Lycaenidae	7	13	11	15	*Heliophorus* sp. *Lycaena phaleus*
3	Nymphalidae	26	50	33	46	*Aglais cashmirensis* *Vanessa cardui*
4	Papilionidae	4	8	7	10	*Papilio bianor*
5	Pieridae	9	17	14	19	*Papilio brassicae*
6	Riodinidae	1	2	1	1	-
7	Sphingidae	1	2	1	1	-
	Total	**52**	**100**	**72**	**100**	

Table 3.6 and Fig. 3.6 reveal the relative abundance of each family of Lepidoptera from the distinguished agro-ecosystems. The relative abundance of the families showed that Nymphalidae, with 26 genera had a 50% contribution, and was the most dominant, followed by Pieridae with 9 genera and a 17% contribution, Lycaenidae with 7 genera and 13%, and Hesperiidae and Papilionidae with 4 genera each and a contribution of 8%. While the families Sphingidae and Riodinidae were the least dominant ones, with a single genus and only a 2% contribution.

Upon analysing the species numbers, it was observed that the family Nymphalidae (33) was most diverse, with a relative abundance of 45%. It was followed by Pieridae (14), contributing 19%, Lycaenidae (11) and 15% contribution, Papilionidae with 7 species and 10% contribution while Hesperiidae (7) with only 5% contribution. The families Sphingidae and Riodinidae each contributed the least.

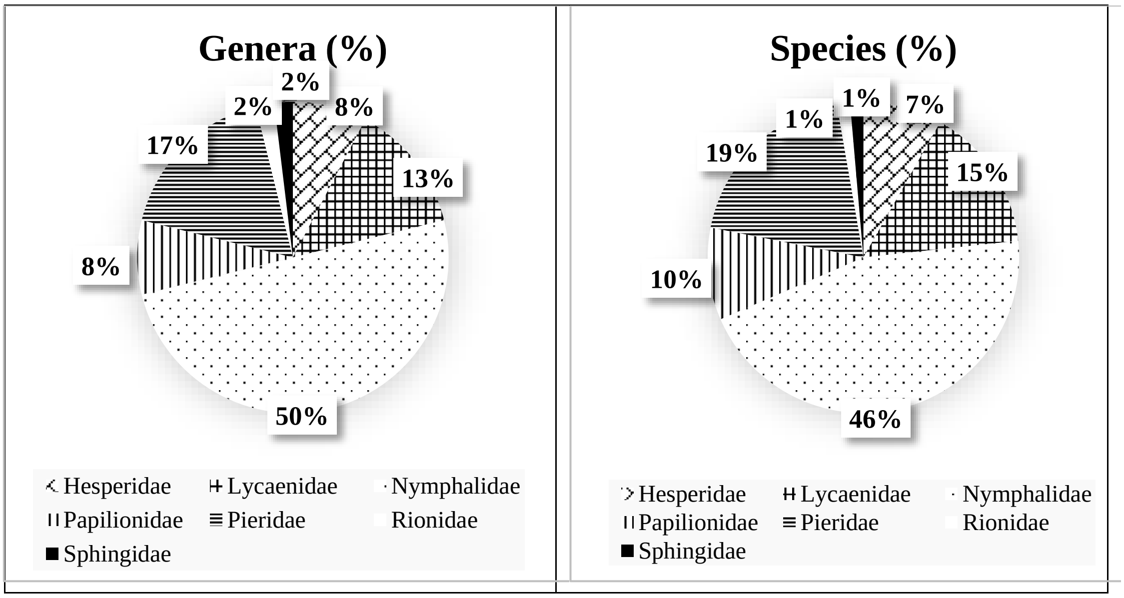
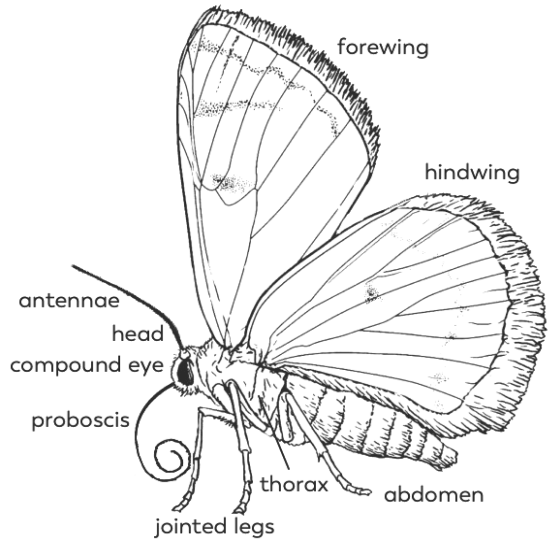
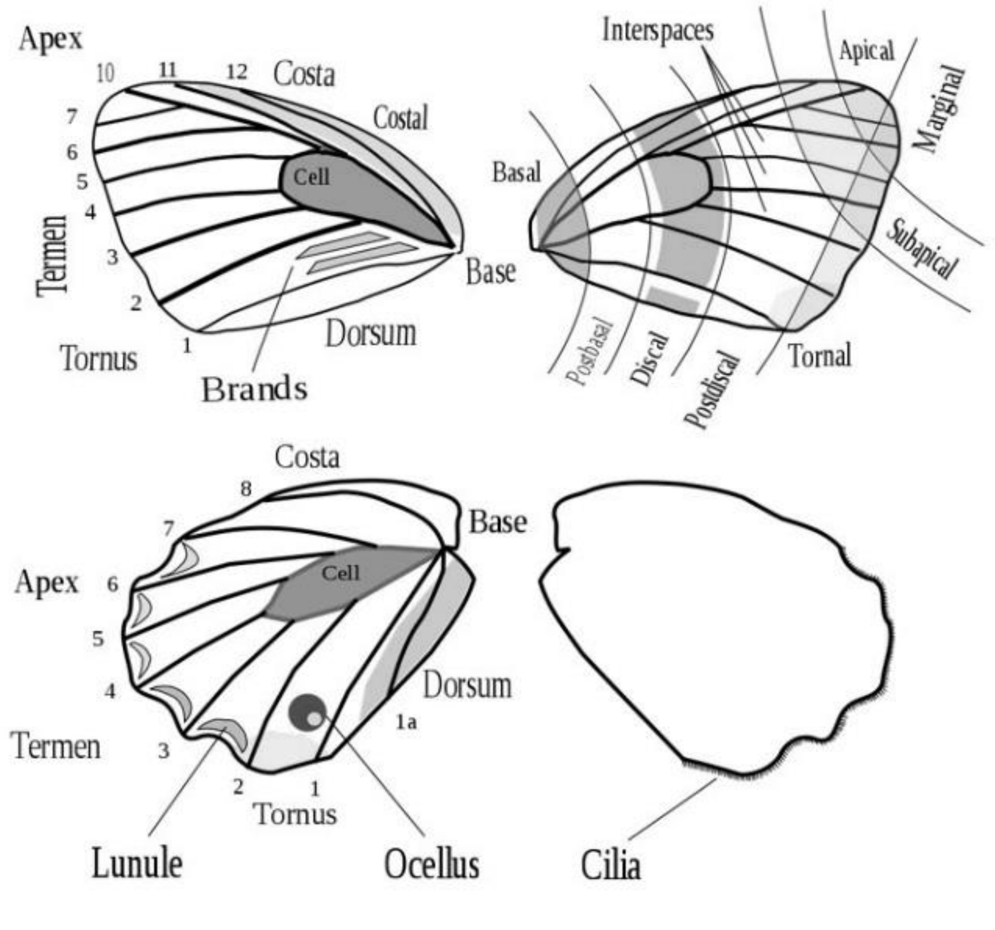


Fig 3.6: Percentage contribution of genera and species in the family of Lepidoptera

The following is a list of the distinctive features of lepidoptera found in the study area, along with their body parts (Fig 3.7 & Table 3.7).



(a)



(b)

Fig 3.7: (a) Diagram of Adult Butterfly (b) Parts of forewing and hindwings in Butterfly (created by L. Shyamal, 2006)

Table 3.7: Diagnostic characters of Lepidoptera (7 families) recorded from the study site (Chandra et al., 2019)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
Hesperiidae **(Skippers)**	- Presence of hooked antenna - Antennae are apically dilated to form a gradual club and are widely separated at the base (hooked antennae) - Wings are comparatively small and during rest its partially opened - Erratic and darting flight pattern - Large and constricted larval head - The larvae taper towards both ends - Larvae concealed under host foliage - Fore wing and hind wing with all the veins present and arising separately from the cell or base of the wing	*Oriens* Evans, 1932	-	*Oriens gola* (Moore, 1877) aka Common Dartlet	- 22-27mm wingspan - dark chocolate brown in colour (UP) - presence of tawny yellow markings on hind and forewings - orange hindwing with black spot (UN)
		Pelopidas Walker, 1870	-	*Pelopidas mathias* (Fabricius, 1798) aka Small Branded Swift	- olive brown colour (UP) - ♂ (3) and ♀ (4-5) semi-transparent discal spots - pale and distinct markings (UN)
		Pseudocoladenia Shirozu & Saigusa, 1962	- similar male and female - rufous-brown in colour - 3 semi-hyaline tiny white sub-apical dots near costa on forewing (UP) - paler in colour and forewing similarly marked (UN)	-	-
		Tagiades Hubner, 1819	-	*Tagiades litigiosa* (Fruhstorfer, 1910) aka Water Snow Flat	- black forewing - one spot below cell spot at vein 5 and other at first median interspace (♂) - black spots on hindwing, semi-hyaline spots on forewing (♀)
Lycaenidae **(Blues, Coppers, Sapphires and Hairstreaks)**	- 2nd largest family - Gossamer-winged butterflies - Small sized-butterlies (<5cm) - Brightly coloured often with metallic gloss	*Acytolepsis* Horsfield, 1828	-	*Acytolepis puspa gisca* (Fruhstorfer, 1910) aka Common Hedge Blue	- ♂ (13) and ♀ (12) antennal segments - violaceous blue wings (UP) - bluish white, large dusky black markings (UN) - white cilia - antenna, head, thorax and dusky black

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
	- Presence of hairy antennae-like tails - Surface of upper wing is metallic blue or coppery - Antennae banded with white rings - Eyes of adults indented near antennae and face is narrow between eyes - White rimmed compound eyes - Simple radial veins of forewing, not forked - Hindwing often with thread-like extensions that resemble antennae (typical of "hairstreaks") - Coloration often bright, iridescent - Hind wing with a precostal vein				abdomen
		Cupido Schrank, 1801	-	*Cupido argiades* (Pallas, 1771) aka Short-tailed Cupid	- violet forewing and hindwing with brown edging (♂) (UP) - dark grey blue with broader edging (♀) - black spots on wings - black tail with white tip - white to brownish grey wings (UN)
		Heliophorus Geyer, 1832	-	*Heliophorus moorei coruscans* (Moore, 1882) aka Azure Sapphire	- wing span (30-35mm) - dark brownish in colour with a patch of metallic blue on both fore- and hind wing (UP) - orange coloured tail with a small white tip (UP) - yellow coloured fore- and hind wing (UN) - hindwing has orange, white and black colured margin (UN)
				Heliophorus sena (Kollar, [1844]) aka Sorrel Sapphire	- wing span (28-33 mm) - wings brown with bluish metallic colour (UP) - hindwings with red reddish orange spots along the margin (UP) - hindwing having one black spot on costa (UN) - wings clothed with white cilia

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
				Heliophorus tamu tamu (Kollar, [1844]) aka Powdery Green Sapphire	- dark brown forewing with greenish blue shiny metallic patch and hindwing with orange border at the margins (♀) (UP) - dark brown hindwing with orange border at the margins (♂) - black tail with white tip - yellow coloured forewing with black spot and hindwing with orange border at the margins (UN)
		Lycaena Fabricius, 1807	- Identical male and female	*Lycaena pavana* (Kollar, 1848) aka White-bordered Copper	- 32-38mm (wingspan) - forewing rich copper red - outer black margin has white border - three black spots in the discoidal cell - dull orange forewings and pale fawn-grey hindwings (UN) - purplish shine along the margins and reddish copper in the cell and basal region (♂) - brown upper hindwings and discal area and cell orange-copper in upper forewings (♀)
				Lycaena phlaeas baralacha (Moore, 1884) aka Common Copper	- dark shining copper colour forewing with black spots (UP) - dark brown hindwing with small bluish discal spots and copper coloured marginal band (UP) - grey brownish forewing and hindwing with minute spots (UN) - females more brighter

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Pseudozizeeria Bueret, 1955	-	*Pseudozizeeria maha maha* (Kollar, [1844]) aka Pale Grass Blue	- wingspan: 23 (♀) and 20 mm (♂) - wings purplish blue with brownish black wing margins (UP) - larger margins in (♀) than ♂ - body covered with white or grey hairs and is pale brownish grey with bands and spots (UN)
		Zizeeria Chapman, 1910	-	*Zizeeria karsandra* (Moore, 1865) aka Dark Grass Blue	- purple-brown wings (UP) - greyish-brown wings (UN) - forewing with discocellular streak and a spot - hindwing with 12 black spots in series
Nymphalidae **(Brush footed)**	- Largest family - Short and functionless forelegs - Larva has numerous spines on the body - Forewings have the unbranched sub-medial vein - Forelegs with imperfect and brush-like tarsi in one or both sexes - Medial vein has three branches - Subcostal vein has four branches - Hindwings have internal and pre-costal veins	*Aglais* Dalman, 1816	-	*Aglais caschmirensis aesis* (Fruhstorfer, 1912) aka Indian Tortoiseshell	- wingspan (52–63 mm) - both wings chestnut coloured - forewing with a quadrate black bar with pale yellow and black bar (UP) - small bluish-white costal spot (UP) - apex cut off at the tip and produced and angulated at vein 6 - hindwing with a basal area blackish-inner margin paler in basal half (UN) - outer margin black, bearing prominent bluish lunules
		Argynnis Fabricius, 1807	-	*Argynnis hyperbius hyperbius* (Linnaeus, 1763) aka Large Silver Stripe or Indian Fritillary	- wingspan (50-60mm) - tawny coloured wings with black spots - forewing with the tawny base, costa and inner margin (UP) - dark coloured scale on basal and abdominal area of hindwing (UP)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
	- Cell in both wings is closed (forewing) or open (hindwing) - Includes the fritillaries, admirals, emperors, and tortoiseshells				- paler forewing with the sub-marginal series of black spots pupilled with silver (UN) - hindwing yellowish brown with a large silver spot (UN)
		Athyma Westwood, 1850	-	*Athyma opalina opalina* (Kollar, [1844]) aka Himalyan Sergeant	- wingspan (55-70 mm) - wings black with broad creamy-white markings (UP) - forewing with a narrow streak and two spots at its outer end in the cell and two sub-marginal wavy pale lines - hindwing brownish black with broad creamy markings - discal white band and sub-marginal series of white lunules present - reddish brown forewing (UN) - hindwing suffused with pale lilac - dorsal margin of hindwing greenish-blue
		Callerebia Butler, 1867	- Identical male and female	*Callerebia annada* (Moore, 1858) aka Pallid Argus	- dark brown (UP) and greyish brown in colour (UN) - forewing with a subapical black ocellus having two white pupils and a dark ferruginous ring (UP) - hindwing with a subtornal single white pupilled black ocellust (UP) - forewing with discal portion maroon brown, large ocellus (white dot below it) and yellow ringed (UN) - hindwing with a postdiscal row of white dots; usually a small tornal ocellus (UN)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
					- females are comparatively larger, paler
		Cupha Billberg, 1820	- Identical male and female	*Cupha erymanthis* (Drury, 1773) aka Rustic	- wings yellowish brown, 50-60mm wingspan (UP) - forewing with broad-rounded black apex and two yellowish irregular spots - 3 black spots on a brilliant yellow transverse discal band - An irregular wavy line crosses the wing towards the cell's apex, followed by a discal sequence of five black spots in the interspaces - pale ochraceous coloured (UN) - forewing apical area brownish - chest-nut brown lunular line bordered by series of dark spots
		Cyrestis Boisduval, 1832	- Identical male and female	*Cyrestis thyodamas ganesha* (Kollar, 1848) aka Common Mapwing	- white to pale ochraceous (♂) and yellowish ochraceous (♀) wings irregular in outline - transparent map like markings (UP/UN) - forewing with costal margin oeraceous at base and fuscous beyond - four slender and irregular sinuos transverse black lines - hindwing with three to four transverse black lines

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Danaus Kluk, 1802	- Identical male and female	*Danaus chrysippus chrysippus* (Linnaeus, 1758) aka Plain Tiger	- tawny fore wing with white spots on black apical area, costal, subapical and postdiscal area 2 (UP) - black outer margin with white spots and dots prominent in the middle (UP) - hindwing yellowish brown, with narrow outer black border crenulate on its inner edge (UP) - forewing with apical area ochraceous and subapical band of 5 white spots (UN) - hindwing ground colour ochraceous with white markings and prominent spots - costa bearing 3 white and 4 black spots (UN) - females have 3 black spots around end of cell
				Danaus genutia genutia (Cramer, [1779]) aka Common Tiger	- reddish brown wings - forewing with a subapical white band, half black apical - hindwing with veins broadly black (UP) - scent patch at vein 2 (in ♂ only) - outer margin with black border with inner edge crenulate (UP) - few submarginal and a complete marginal row of white dots (UP) - forewing apex dusky brown and paler hindwing (UN)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Euploea Fabricius, 1807	- Identical male and female	*Euploea core core* (Cramer, [1780]) aka Common Indian Crow	- black or glossy brown wings - a submarginal and marginal row of white dots on the forewing (UP) - hindwing with short stripes below vein 5 and row of white spots (UP) - both wings usually with a few discal spots and a spot in apex of cell (UN)
				Euploea mulciber mulciber (Cramer, [1777]) aka Striped Blue Crow	- dark brownish, forewing glossed with blue and white or violet-white spots (UP) - hindwing unmarked (♂) but with white streaks (♀) brown and distinct spots (UN) - forewing with incomplete submarginal and marginal series of spots apically (UN) - hindwing with discal spots in areas 3 and 5 (UN)
		Hypolimnas Hubner, 1819	-	*Hypolimnas bolina* (Linnaeus, 1958) aka Great Eggfly	- black forewing with an obliquely placed white maculated spot in areas 3-5 at or beyond of cell, this spot margined with bright bluish, two preapical elongate white spots (UP) - large medial bright bluish spot on hind wing broadly centred with white (♂) - dark brown forewing paler towards outer margin, a few small bluish subcostal spots above the cell ♀ (UP) - deep purple forewing with a few minute white specks on the costal edge below

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		GENUS		SPECIES	
					the basal half (UN)
		Issoria Hubner, 1819	-	*Issoria lathonia* (Linnaeus, 1758) aka Queen of Spain Fritillary	- wing span (38-46mm) - deep orange in colour with rounded black spots arranged in regular rows (UP) - large pearly nacreous patches adorn the hindwings, which are crossed by a postdiscal row of black eyespots with pearly pupils (UN)
		Junonia Hubner, 1819	-	*Junonia almana (*Linnaeus, 1958) aka Peacock Pansy	- wingspan 54-62mm - exhibits seasonal polyphenism (both the sexes are variable in colour and markings) - wings rich orange yellow, fore wing with 3 black lines in the cell and 4th one at end of cell - both wings with ocelli in areas 2 and 5 - forewing with the ocellus larger in area 2 and hindwing with the ocellus larger in area 5
				Junonia iphita (Cramer, [1779]) aka Chocolate Pansy	- wing span (50-60mm) - brown hues of varied intensities (UP) - two pairs of subbasal and apical transverse sinuous fasciae on each forewing. (UP) - Beyond vein 4 is a short, broad, black, oblique fascia - Both the inner and outer margins are

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
					diffused and defined sharply - row of faint ocelli is visible - narrow blackish loop towards the cellular area's apex and a well-defined short discal fascia on the hindwing (UP) - mostly brown in colour with broad darker brown transverse fasciae (UN) - hindwing dark brown and has a curved short fasciae near base (UN)
				Junonia orithya ocyale (Hubner, [1819]) aka Blue Pansy	- wingspan (40-6.0 mm) - basal two-thirds of forewing blue black (♂) - basal half area of hindwing being entirely black (♀) (UP) - shining blue hindwing with two ocelli near outer margin - dull ochraceous with white markings and wavy lines - female larger than male
		Kaniska Moore, 1899	- Identical male and female	*Kaniska canace canace* (Linnaeus, 1763) aka Blue Admiral	- wingspan (60–70 mm) - forewings and hindwings deep indigo-blue black (UP) - blue band runs along the wavy outer margin of the forewing (UP) - a larger blue transverse band with a row of small black spots and a narrow blue band at the outer wavy edge can be found on hindwings - brownish black in colour and covered with short transverse black striae (UN) - hindwing with a white speck at the cell's

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
					apex and a continuation of the forewing's light discal band (UN)
		Lasiommata Westwood, 1841	- exhibits slight sexual dimorphism	*Lasiommata schakra schakra* (Kollar, [1844])	- wingspan (56-58mm) - ground colour silky brown (♂) and orange spot bearing the ocellus on the forewing (♀)(UP) - both wings have whitish cilia (UP) - transverse row of 4 orange dots on the forewing bears a black, white-centred eyespot (UP) - uniform hindwing earing a postdiscal row of 3-6 black, white-centred, orange-ringed eyespots (UP) - pale greyish white (UN) - orange disc at outward forewing and a subapical ocelli (UN) - hindwing has two sinuous curved slender lines (UN)
		Lethe Hubner, 1819	-	*Lethe verma verma* (Kollar, [1844]) aka Western Straight-banded Treebrown	- wingspan (50-60mm) - dark brown to lighter in shade - forewing has a broad white line at the discal area - hindwing has 2 white spots at the tornal area (UP) - paler forewing has a broad white line at the discal area with two ocelli (UN) - paler hindwing with 6 ocelli at the termen (UN)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Libythea Fabricius, 1807	- Identical male and female - head with a prominent beak - dark brown and angular forewing - yellow club shaped streak from base to beyond cell and an apical band - hindwing with a broad yellow band	*Libythea lepita lepita* (Moore, [1858]) Common Beak	- ground is somewhat darker brown coloured - In cell, the forewing has a thinner orange-yellow streak (UP) - lower discal spot missing, and the top bigger discal spot is diamond-shaped; the subcostal and preapical spots are angled outwards - subapical spot is orange-yellow at the bottom, while the subcostal spot is white at the top (UP) - upper postdiscal orange patch on the hindwing is thinner, producing a short band that runs from vein 2 to vein 6 and is not curled (UP) - forewing vinous brown, paler at the costal and dorsal borders, while the hindwing irrorated with minute dark striae and dots (UN) - hindwing with or without any markings (UN)
				Libythea myrrha (Godart, 1819) aka Club Beak	- forewing without dark yellow spot in area 1b; with a tawny club shaped streak from base of wing outside the confines of the cell to near the outer margin, 2 preapical double white or tawny spots separated or forming a band a small white spot at extreme apex may be present (UP) - hindwing from vein 1 to vein 5 with a slightly oblique discal band, wide and diffused towards inner margin but

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
					narrowed towards and not reaching apex (UP) - apex and dorsal border of the forewing are extensively tinted with pale grey and irrorated with minute black dots and transverse short striae (UN) - hindwing greyish brown (UN) - females paler and tawny with larger markings
		Mycalesis Hubner, 1818	- Identical male and female - exhibits seasonal polyphenism (both the sexes are variable in colour and markings)	*Mycalesis perseus* (Fabricius, 1775) aka Common Bushbrown	- wingspan (42-54mm) - dark brown to paler in colour (UP) - In interspaces 2 and 5, the forewing has a white-centred, fulvous-ringed, black ocellus (UP) - 2-3 postmedian obscure ocelli present on hindwing (UP) - similar subterminal and terminal lines on the wings (UP/UN) - 3 posterior ocelli present in a straight line on hindwing (UN)
		Neptis Fabricius, 1807	-	*Neptis mahendra mahendra* (Moore, 1872) aka Himalayan Sailor	- wingspan (40-50mm) - dull black in colour with prominent white markings - On the forewing, the discoidal stripe is clavate, obliquely truncate at the apex, and the spot beyond it is large, cone-shaped, and sharp at the apex - fairly large subbasal transverse band, increasing slightly towards costa (♂), broader and more evenly spaced (♀) - rich golden brown, the white markings

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
					as on the upperside but broader (UN) - cilia white alternated with black
		Nymphalis Kluk, 1780	-	*Nymphalis polychloros* (Linnaeus, 1758) aka Large Tortoiseshell	- wingspan (68–72mm) - wings that are orange to red with black and yellow patches - yellowish sub-marginal lunules on both wings, followed by a black band and bears small blue spots on the hindwing (UP) - wings smoky brown with darker shades and black (UN)
		Orinoma Gray, 1846	-	*Orinoma damaris damaris* (Gray, 1846) aka Tigerbrown	- wingspan (75-80mm) - creamy white with broadly dark brown veins spread all over (UP) - bright orange basal half of cell on the forewing with two black dots (UP) - underside similar to upperside but is paler
		Parantica Moore, 1880	-	*Parantica sita sita* (Kollar, [1844]) aka Chestnut Tiger	- wingspan (85-110mm) - fuliginous black with bluish white sub-hyaline patterns on the forewing (UP) - cell and three-fourths of the basal area is filled with broad bluish-white streak - 5 large quadrate discal spots present - hindwing is chestnut-red coloured, with sub-hyaline streaks and spots, streak from the base in area 1a, 1b, not reaching the margin

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
					- 2 scent pouches present (♂) - similar and clear markings on the underside
		Pareronia Bingham, 1907	- Female exhibits dimorphism	*Pareronia valeria* (Cramer, [1776]) aka Common Wanderer	- deeper blue wing with well-defined black veins (UP) - forewing has a broad black costa, apex and terminal margin, which narrowed towards the tornus - borders dorsal and costal terminal margin: widely whitish on the hindwing, it's mostly black (UP) - sub terminal, extremely subtle (UN), transverse series of whitish lunulated dots traverses the wings' terminal margins, which are obscurely fuscous - both forewing and hindwing cilia are quite thin and white. (UN)
		Phalanta Horsfield, 1829	-	*Phalanta phalantha* (Drury, [1773]) aka Common Leopard or Spotted Rustic	- wingspan (50-60mm) - brilliant yellowish brown wings with wavy lines and a row of black dots - 4 slender wavy fasciae run along the apical half of the costal border on the forewing - hindwing with some transversely wayed linear fasciae on basal area - underside similar as above but most of dark markings very paler and glossy

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Sephisa Moore, 1882	-	*Sephisa dichroa* (Kollar, [1844]) aka Western Courtier	- wingspan (60-75mm) - both wings dark brown above (UP) - forewing with two tawny, irregular broken bands, crossed by black veins - preapical and sub-terminal spots tawny (♂) and whitish (♀) - hindwing with black vein and black outer discal band (UP) - paler and marginal series of lunules more conspicuous on hindwings (UN)
		Symbrenthia Hubner, 1819	-	*Symbrenthia lilaea* (Moore, [1875]) aka Jester	- wingspan (60-65mm) - black with orangish yellow toned markings (♂) and orange markings broader and somewhat paler (♀)(UP) - continuous patch at the base of interspace 3; from the middle of the dorsum, a short, outwardly oblique band is constricted in the middle - hindwing with a broad sub-basal transverse band narrows at the costal border (UP) - myriad spots and ferruginous lines of ochraceous orange colour on hindwing and a continuous sub-basal transverse streak (UN)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Talicada Moore, 1881	-	*Talicada nyseus* (Guerin, 1843) aka Red Pierrot	- wingspan (3-3.5cm) - brown forewing with large orange spot on hindwing (UP) - forewing white with blackspots and orange spot on hind wings (UN)
		Tirumala Moore, 1880	- Identical male and female	*Tirumala limniace* (Cramer, 1775) aka Blue Tiger	- wingspan (90-100mm) - forewing black with irregular white or pale blue spots and streaks(UP/UN) - hindwing black with irregular bluish-white spots and streaks(UP) - streaks in the cell broad and forked (UP) - forewing (dusky black), hindwing (olive brown) - male with sex pouch in interspace
		Vanessa Fabricius, 1807	-	*Vanessa cardui* (Linnaeus, 1758) aka Painted Lady	- basal areas, reddish-ochreous in colour (UP) - cilia black and white - on forewing, an oblique black irregularly formed broken band crosses from the middle of the cell to the disc over the submedian vein - on the hindwing, a blackish patch from the costal vein runs across the cell's end - pale and dark outer ring between the discal band and sub-marginal lunules - brighter reddish-ochreous forewing (UN)
				Vanessa indica indica (Herbst, 1794) aka Indian Red Admiral	- wingspan (55-65mm) - dark brown forewing with a broad medial oblique red band having 3 large black dots (UP)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
					- posterior edge and basal area brown golden; apical half black, with a sub-apical series of white quadrate spots (UP) - hindwing golden brown, with marginal red band having small black spots in the center (UP) - forewing with 3 small blue spots beyond the cell (UN) - hindwing with dark brown, marginal area pale ochraceous (UN)
		Ypthima Hubner, 1818	-	*Ypthima nikaea* (Moore, [1875]) aka Moore's Fivering	- wingspan (45-52mm) - dark brown with golden shine (UP) and grey with numerous short brown strigae (UN) - forewing has sub-apical ocellus, oval and bi-pupilled (UP) - hindwing has 2 sub-anal ocelli, pre-apical and tornal ocelli are frequently absent or faintly marked (UP) - 5 ocelli, 2 large apical ocelli have an intervening yellow band between them (UN) - posteriorly, 3 ocelli are organized in a linear sequence, with the tornal ocellus bi-pupilled (UN)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
Papilionidae **(Swallow tails)**	- Generally, huge and vividly coloured - Prothoracic legs has Tibial epiphysis - Hind wings have tail-like extensions - Wing coupling is of the amplexiform type - Body of the larvae is either smooth or tuberculated - Prothoracic tergum of the caterpillar has retractile osmeteria - Hind wing with inner margin channelled to receive the abdomen; modified and upturned - Vein la usually absent	*Atrophaneura* Reakirt, 1865	-	*Atrophaneura aidoneus* (Doubleday, 1845) aka Lesser Batwing	- wingspan (112–162mm) - a white scent patch in a square dorsal fold, which is pink or red on its marginal border, is bluish black and unmarked (♂) - greyish brown in colour and has dark stripes between the veins (♀)
		Byasa Moore, 1882	- Identical male and female	*Byasa dasarada* (Moore, 1857) aka West Himalayan Windmill	- wingspan (110-140mm) - In 1a, 2a, and 3a, there are irregular red crescents on the hindwing, as well as a little white spot. In 4a, there is a small white speck (UP) - there's a black-white pattern with a pronounced swallowtail - red bodied and red tipped tail - black forewings (UP/UN) - hindwings crenulated deeply twice on each side - huge white oblong discal spot in 5 (UP/UN)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Graphium Scopoli, 1777	-	*Graphium sarpedon sarpedon* (Linnaeus, 1758) aka Common Bluebottle	- wingspan (80-90mm) - wings brownish-black with a short tail (UP) - pale blue or greenish blue discal band runs from the inner border to the apex of the forewing, diminishing anteriorly towards the apex - hindwing with white band scaled (UP) - brownish-black, with a bluish stripe on the lower side (UN) - before the tornus, the forewing has sub-marginal dots (UN) - disc has 5 red spots and the hindwing has a red mark near the base (UN)
		Papilio Linnaeus, 1758	- predominantly black or black-brown - with or without tails - fully developed forewings - hind wings with the pre-costal spur present, vein 1 b absent - caterpillars of most of the species feed on pungent citrus plants	*Papilio bianor* Cramer, [1777] aka Common Peacock	- wingspan (90-130mm) - dark black wings and tailed - woolly scent stripes on forewing (♂) - forewing with diffuse golden green irroration, becoming bluish anteriorly (UP) - hindwing with less dense golden-green irroration (UP) - forewing chocolate brown, somewhat thinly irrorated with yellowish scales (UN) - hindwing without discal patch; sub-marginal series of claret-red crescents (UN)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
			belonging to family Rutaceae (citrus, orange, lime)	*Papilio polytes* (Linnaeus, 1758) aka Common Mormon	- wingspan (75-94mm) - black forewing with marginal series of white or pale yellow spots decreasing in size towards the apex (UP) - complete discal band of elongate white spots, ending in red lunules in the tornal region and sub~marginal series of crimson lunules (♀) - paler and dull in colour (UN)
				Papilio machaon asiatica (Menetries, 1855) aka Common Yellow Swallowtail	- wingspan (75-90mm) - black forewing dusted with yellow-scales, rest of cell yellow with a black bar (UP) - lower half of the hindwing is creamy yellow with black veins, while the upper half is black with diffused blue spots and a creamy-yellow big crescent spots on the edge (UP) - blue-topped red spot at tornus (UP) - pale-cream colour forewing with 2 transverse short bands across the cell (UN) - hindwing veins prominently black (UN)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
				Papilio protenor protenor (Cramer, [1775]) aka Spangle	- wingspan (100-140mm) - tail-less black-bodied - black with blue scaling on hindwing (UP) - white costal streak of specialized scales and tornal black-centered red spot (♂) - hindwing with additional black-centered red spot in area 2; cell irrorated with bluish scales (♀) - basal red stripe does not reach the base of the hindwing (UN)
Pieridae **(White and Sulphurs)**	- White, yellow, or orange forewings with black markings (UN) - Green coloured larval body segments have annulates and finely covered with hairs - Black scales are softly pressed into the cell and cost - The apex is slightly tinted with ochraceous yellow - Hind wing pale, almost white, to dark ochraceous - Antennae are black with a few white spots on them - Long greenish grey hairs on the head and thorax, black hairs on the abdomen, and white hairs beneath the head, thorax, and abdomen - Hind wing with inner margin not channelled to	*Chrysis* Linnaeus, 1767	-	*Belenois aurota aurota* (Fabricius, 1793) aka Pioneer	- wingspan (40-55mm) - white forewing with a prominent curved (hockey-stick mark) black discocellular bar (UP) - hindwing with a black marginal border bearing 4 round white spots in areas 2 to 5 (UP) - forewing similar but the markings prominent and the apical spots larger (UN) - veins on the hind wing are extensively edged with black, and regions 1, 2, 6, and 7 have black cross bars (UN)
		Catopsilia Hubner, 1819	-	*Catopsilia pomona* (Fabricius, 1775) aka Lemon/ Common Emigrant	- wingspan (55-75mm) - white coloured wings with yellow at the proximal areas (♂) or sulphur yellow to white (♀) - at the apex of the forewing, the costal edge is black, and the outer marginal narrow border is macular (UP)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
	receive the abdomen; neither modified nor upturned - Vein la always present				- greenish white with a disco cellular silvery patch surrounded in reddish brown on each wings (UN)
				Catopsilia pyranthe pyranthe (Linnaeus, 1758) aka Mottled Emigrant	- wingspan (50-70mm) - chalky white-greenish (♂) or greenish-white to greenish-yellow (♀) in colour - forewing with apical and marginal narrow black border; a black disco-cellular spot, which may be absent - hindwing with marginal black dots (UP) - both sexes greenish, with reddish-brown strigae and disco-cellular spots (UN)
		Colias Fabricius, 1807	-	*Colias erate* (Esper, 1805) aka Pale Clouded yellow	- wingspan (45-55mm) - forewing with oval, disco-cellular black spot - outer margin and apex black in colour, widest at the apex and shrinking to tornus - deep orange-yellow hindwing with disco-cellular and broken marginal black spots (UP) - base and costa of forewing and basal half of hindwing lightly dusted with black (UN) - forewing with disco-cellular spot as on upper side (UN)
				Colias fieldii fieldii (Menetries, 1855) aka Dark Clouded Yelow	- wingspan (45-65mm) - forewing deep orange with broad pale yellow (inner margin) and broad black (outer margin) - paler in colour and narrow costal margin (UN) - Hindwing overlaid with pale dull green and large disc-cel1ular spot (UN)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Delias Hubner, 1819	-	*Delias belladonna horsfieldii* (Gray, 1831) aka Hill Jezebel	- wingspan (70-96mm) - wings black with white to pale cream coloured spots - forewing with cell spot at the end white; post-discal and sub-marginal series of white spots (UP) - hindwing with a large basal yellow spot; a tornal yellow patch and white inner area, post discal and sub-marginal series of white spots ((UP) - cell stripes on both wings are conspicuous, and large markings, more defined on the lower side than on the upper side (UN)
		Eurema Hubner, 1819	-	*Eurema blanda silhetana* (Wallace, 1867)	- wingspan (35-45mm) - lemon yellow in colour (UP) with ordinary markings on both wings (UN) - forewing with the outer marginal broader black band (posterior end) and shorter and oblique at inner edge (posterior end) (UP) - forewing with 3 marks in the cell (UN)
				Eurema hecabe hecabe (Linnaeus, 1758)	- wingspan (40-50mm) - bright yellow wings (UP) and paler (UN) - excavation between veins 2 and 4 on the forewing, which has a black broad border (UP) - conspicuous reddish-brown patch on the forewing (UN) - hindwing with a slightly curved sub-basal series of 3 spots (UN)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
					- at the vein ends of both wings, there are minute reddish-brown costal and outer marginal terminal flecks (UN)
		Gonepteryx Leach, 1819	-	*Gonepteryx rhamni* (Linnaeus, 1758) aka Common Brimstone	- wingspan (60-70mm) - sulphur yellow (♂) or creamy white (♀) with an orange disco-cellular spot on both wings - forewing with apex more falcate (♂) and marginal dots more distinct (♂) (UP) - hindwing toothed at vein 3 with dark orange spot present at the end of cell in each wing (UN) - pale yellowish green (♂) and yellowiah white or greenish (♀) (UN)
		Pieris Schrank, 1801	-	*Pieris melete* (Moore, 1865) aka Himalayan green-veined	- wingspan (45-50 mm) - creamish white with black apex and costa - black spot at sub-apical of forewing (UP) - hindwing white with a small patch of black on apex 7 (UP) - forewing white with two spots at postdiscal and 4th termen and prominent green veins (UN) - hindwing yellowish with dark yellow at the base and greenish prominent veins all over (UN)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
				Pieris brassicae nepalensis (Gray, 1846) aka Large Cabbage White	- forewing is irrorated (sprinkled) with black scales, and the wings are creamy white (UP) - hindwings are uniform, irrorated with black scales at base (UP) - forewing is white with black scales at the base of the cell and along the costa (UN) - white hairs cover the head, thorax, and abdomen, while the underbelly is whitish - antennae are black and white at apex
				Pieris rapae (Linnaeus, 1758) aka Small Cabbage White	- wingspan (32–47mm) - smaller version of *Pieris brassicae* - creamy white with black tips on the forewings (UP) - 2 black spots in the center of the forewings (UP) - yellowish with black speckles (UN)
		Pontia Fabricius, 1807	-	*Pontia daplidice* (Linnaeus, 1758) aka Bath White	- wingspan (52-56mm) and white in colour - costa's basal half is faintly irrorated with black scales, with a black mark across the discocellulars in the forewing (UP) - hindwing has a costal spot before the apex and irrorated black scaling indicates anterior terminal marks (UP) - forewing identical to the upperside, except there is irroration of green scales near the cell's base (UN) - in the outer half of interspace 1, there is a black or greenish-black patch, as well as a

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
					black discocellular mark that extends to the costa (UN) - green patches with a yellow costal edge and slightly yellow veins can be found on the hindwing (UN)
Riodinidae **(Metalmarks)**	- Vibrant structural colouring - Golden or silvery metallic spots on the wings - Humeral vein in the hindwings - Thickened costa	*Dodona* Hewitson, 1861	-	*Dodona durga durga* (Kollar & Redtenbacher, 1844) aka Common Punch	- wingspan (30-42mm) - dark brown with numerous yellow spots - forewing with 3 dark yellow bars-one each in the cell, at the end of cell also beyond the cell (UP) - hindwing with a tornal lobe but without tail (UP) - wings with large pale yellow spots (UN) - hindwing with two small black spots near the apex (UN)
Sphingidae **(Hawk moths, Sphinx moths, Horn worms)**	- Distinct flying pattern (swing hovering/ side slipping) - Narrow wings and streamlined abdomen - Lack tympanal organ - Frenulum and retinaculum are present to connect the hindwings and forewings - Scales are extensively covered on the thorax, abdomen, and wings	*Macroglossum* Scopoli, 1777	- black or dark brown - wingspan (40-52mm) - sides of middle abdomen and hindwing has yellow markings at the frenulum till medial patch (UP) - forewing dark brown with orange tint (UN) - hindwing has small patch of yellow colour near the dorsum (UN)	-	-

UP= Upperside, UN=Underside

PLATE 4: Species account of Lepidoptera

1. *Pelopidas* sp.

2. *Oriens gola*

3. *Pelopidas mathias* ♀

4.*Pseudocoladenia* sp.

5. *Tagiades littigiosa*

6. *Acytolepis puspa*

7. *Cupido argiades*

8. *Cupido* sp.1

9. *Heliophorus moorei*

10.*Heliophorus sena*

11.*Heliophorus tamu* ♀

12.*Heliophorus tamu* ♂

13. *Lycaena phlaeas* ♂

14. *Lycaena pavana*

15. *Talicada nyseus*

16.*Pseudozizeeria maha*

17. *Macroglossum* sp.

18. *Zizeeria karsandra*

19.*Aglais cashmirensis*

20. *Argynnis hyperbius*

PLATE 5: Species account of Lepidoptera


21. ***Athyma opalina***


22. ***Callerebia annada***


23. ***Cupha erymanthis***


24. ***Cyrestis thyodamas***


25. ***Danaus chrysippus*** ♀


26. ***Danaus genutia***


27. ***Euploea core***


28. ***Euploea mulciber*** ♀


29.***Hypolimnas bolina*** ♂


30. ***Issoria lathonia*** ♂


31. ***Junonia almana***


32. ***Junonia iphita***


33. ***Junonia orithya***


34. ***Kaniska canace***


35.***Lasiommata schakra***


36. ***Lethe verma***


37. ***Libythea lepita***


38. ***Libythea myrrha***


39. ***Mycalesis perseus***


40. ***Neptis mahendra***

PLATE 6: Species account of Lepidoptera

41.*Nymphalis polychloros*

42. *Orinoma damaris*

43. *Dodona durga*

44. *Parantica sita*

45.*Phalantha phalantha*

46. *Sephisa dichroa*

47. *Symbrenthia lilaea*

48. *Tirumala limniace*

49. *Vanessa cardui*

50. *Vanessa indica*

51. *Ypthima nikaea*

52. *Ypthima* sp.

53.*Atrophaneura aidoneus*

54. *Byasa dasarada*

55.*Graphium sarpedon*

56.*Papilio bianor*

57. *Papilio polytes* ♂

58. *Papilio machaon*

59. *Papilio protenor*

60. *Belenois aurota*

PLATE 7: Species account of Lepidoptera


61. ***Catopsilia pomona***


62. ***Catopsilia pyranthe***


63. ***Colias erate***


64. ***Colias fieldii***


65. ***Delias belladonna***


66. ***Eurema blanda***


67. ***Eurema hecabe***


68.***Gonepteryx rhamni*** ♂


69. ***Pareronia valeria*** ♂

70. ***Pieris brassicae***


71. ***Pontia daplidice***


72. ***Pieris melete***


73. ***Pieris rapae***

3.4.2.2. ORDER II- Hymenoptera (12 families): Diversity of Honey bees-wild/domesticated, bumble bees, wasps)

There are two broad subdivisions in order Hymenoptera; suborder Symphyta (most primitive or basal taxa) and suborder Apocrita (highly evolved). The abdomen of the Symphyta (sawflies and horntails) is extensively attached to the thorax, whereas the Apocrita (ants, bees, wasps, braconids, ichneumons, chalcids) has a conspicuous constriction at the waist. Taxonomically, the latter is more diversified. Bees form the largest of entomofaunal pollinators (Berenbaum, 2007), which are social as well as solitary. One of the most diverse insect orders is Hymenoptera (Goulet and Huber, 1993) and as parasitoids, predators, and pollinators, they play a substantial role in almost every terrestrial ecosystem and are economically significant (Grimaldi and Engel, 2005). However, because most of the world's diverse locations have yet to be thoroughly inventoried, it's difficult to put a specific number on this insect order (LaSalle and Gauld, 1993). In India, too, such estimations are fairly inaccurate, and numerous new taxa are identified on a regular basis. According to latest research, India has 19 super families, 68 families, and 12,605 Hymenoptera species (Chandra, 2011).

Historical Review

Hymenoptera can be found in all terrestrial and some aquatic habitats (Bennett, 2008b). As stated by Gauld et al. (1990), Hanson and Gauld (1995, 2006), and, LaSalle and Gauld (1993), they play critical ecological roles (2009). Grissell (2001) spoke articulately on the relevance of insects, including Hymenoptera, in homesteads, where they are likely to be observed by a large number of people. The most useful role of the Hymenoptera is pollination by bees, fig wasps, and pollen wasps, without which many plants, including most crops, would perish. Many Hymenoptera species engage in parasitism and insect predation, preventing numerous insect species from becoming forest and agriculture pests. Many Hymenoptera are found to be involved in food webs when they are thoroughly researched, and the webs can be difficult to navigate (Eveleigh et al., 2007). The larvae of butterflies and moths, beetles, and flies are the most common hosts for Braconidae, but other orders of insects have been reported to be parasitized as well. They might be endoparasitoids or ectoparasitoids, solitary or gregarious, polyembryonic, hyper parasitoids, or phytophagous (Wharton, 1993). According to Bennett (2015), around 30% of ichneumonid species are ectoparasitoids and 70% are endoparasitoids. Despite their abundance and widespread distribution throughout most habitats (with woods being more abundant than grasslands and agricultural settings), ichneumonids have only been used in biological control on a few occasions.

"Fauna of British India–Hymenoptera" was the first book authored by Bingham in 1903 that covered the Hymenoptera of India in detail. There has been very little or no work done in India since Morley (1913) released his "Fauna of British India, Hymenoptera", Volume III, about four decades ago (Narayanan and Lal, 1954). Mani and Sharma (1982) published a review of Proctotrupoidea (Hymenoptera) from India, while Narendran (1989, 1994, 2007, and 2011) released many monographic works on Chalcidoidea that provide useful information on account of Indian Hymenoptera. Several advances on taxonomic studies have been made by the scientists from various national institutes and universities that contributed to the Indian Hymenoptera later in the post-British era (1950-2021), including Batra (1977, 1996), Bohart and Menke (1976), Gupta and Maheshwari (1977), Jonathan (1980), Gupta and Gupta (1983), Singh and Singh (1986), Das and Gupta (1989), Carpenter and Kojima (1996), Gupta (2003b, 2013), Girish Kumar (2009a, 2009b), Aguiar et al. (2013), Bharti et al. (2016), Pramanik and Dey (2016), Rahman et al. (2018), Wachkoo and Akbar (2019), Carpenter et al. (2020), Viraktamath and Thangjam (2021).

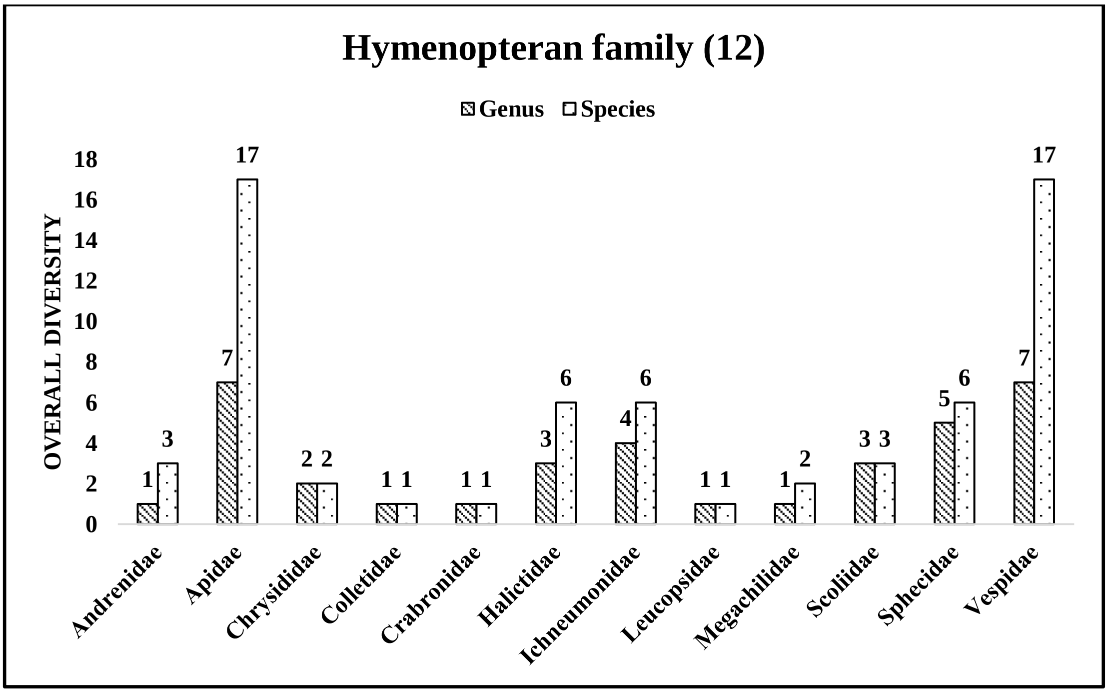


Fig 3.8: Overall family-wise diversity of Hymenoptera in both study areas

From several sampling locations in the Mandakini Valley (Non-Organic) and Doon Valley (Organic), a total of 65 species of bees and wasps belonging to 36 genera, representing 22 subfamilies of 12 families, were documented as flower visitors/pollinators of diverse crop plants. During the current course of study, all recorded bee species were placed under six super families, namely, Apoidea, Chalcidoidea, Chrysidoidea, Ichneumonoidea, Scolioidea, and Vespoidea. The superfamily Apoidea was the largest, consisting of 7 families (Andrenidae, Apidae, Colletidae, Crabronidae, Halictidae, Megachilidae, and Sphecidae), while the other super families consisted of single families; Chalcidoidea (Leucopsidae), Chrysidoidea (Chrysididae), Ichneumonoidea (Ichneumonidae), Scolioidea (Scoliidae), and Vespoidea (Vespidae). There were around 22 sub-families reported from the 12 families of hymenoptera (Table 3.4 & 3.5). Ichneumonidae has the maximum number of 4 sub-families (Gelinae, Ichneumoninae, Ophioninae, and Xordinae) with *Cryptus* sp., *Ichneumoninae* sp., *Odontocolon* sp., *Ophion* sp. as the dominant species. Veijalainen et al. (2012, 2013) demonstrated that the family Ichneumonidae is more diverse than what was assumed previously, because of the underestimated inventory of the species of the tropics. Apidae (Apininae, Nomadinae, Xylocopinae), Sphecidae (Ammophilinae, Sceliphrinae, Sphecinae), and Vespidae (Eumeninae, Polistinae and Vespinae) has the maximum number of 3 sub-families each, with *Amigella* sp., *Anthophora confusa*, *Apis cerana indica*, *Apis dorsata*, *Apis laboriosa*, *Apis florea*, *Apis mellifera*, *Bombus haemorrhoidalis*, *Bombus orientalis*, *Bombus tunicatus*, *Ceratina* sp., *Epeolus* sp., *Xylocopa* sp., *Ammophila* sp., *Chalybion* sp., *Prionyx* sp., *Sphex* sp., *Ancistrocerus* sp., *Eumenes* sp., *Parancistrocerus* sp., *Polistes* sp., *Vespa basalis*, *Vespa tropica*, *Vespa veluntina*, *Vespula* sp. as dominant species.

Apis laboriosa is one of the largest honey bee species currently known. Its range is limited, with unique nesting behaviours. The presence of this bee species was confirmed in the mountainous regions of Bhutan, Nepal, India, and China's Yunnan province (Batra, 1995; Ahmad and Roy, 2000). There have been no reports of races or variations for this species so far. *Apis laboriosa* was previously thought to be a subspecies of *Apis dorsata*. *Apis laboriosa* is a polylectic (bees that collect pollen from the flowers of a variety of unrelated plants) bees that visits a wide range of flora for foraging. Bumble bees are the crucial pollinators known to appear early during the flowering season, particularly in alpine or high-altitude areas (Kevan and Baker, 1983;

Yu et al., 2012). Bumble bees (*Bombus* sp.) can be used for pollination services in greenhouses for they are highly efficient pollinators and are easy to handle. Because of their unique "buzz pollination" behaviour, bumble bees outperform other pollinator species in pollination efficiency (Buchmann, 1985).

Members of the Vespidae family are pollinators of fruit and vegetable crops. Adults have yellow or white patches on their bodies and are predominantly black or brown in colour (Goulet and Huber, 1993). Vespidae are the family of wasps that are best known for their spectacular paper nests (Wenzel, 1998) and their ability to defend them with stings. Carpenter and Kojima (1997) divided the social wasps into three subfamilies: Vespinae, which includes yellowjackets and hornets, Polistinae, which includes paper wasps (Carpenter, 1996a, 1996b; Kojima and Carpenter, 1997; Carpenter, 2015a, 2015b), and Stenogastrinae, which includes hoverwasps (Carpenter and Kojima, 1996; Turillazzi, 2012). Only strongly eusocial species are found in Polistinae and Vespinae, but Eumeninae, Euparagiinae, and Masarinae are all solitary wasps; Stenogastrinae are primitively eusocial wasps (Mahmood et al., 2012).

The family Halictidae is comprised of two subfamilies (Halictinae and Nomiinae) with *Halictus* sp., *Lasioglossum* sp., and *Nomia* sp. as dominant species. While the families Andrenidae (Andreninae), Colletidae (Colletinae), Crabronidae (Bembicinae), Chrysididae (Chrysidinae), Megachilidae (Megachilinae) and Scoliidae (Scoliinae) had minor representation with *Andrena flavipes*, *Andrena* sp., *Chrysis* sp., *Chrysura* sp., *Colletes* sp., *Bembix* sp., *Megachile* sp., *Elis* sp., *Megacampsomeris* sp., *Phalerimeris* sp. as dominant bee and wasp species. The Chrysididae and several Chalcidoidea are the “peacocks” of the Hymenoptera world (Mahmwd, 2017). The majority of species are opalescent blue, green, or coppery red, or a combination of colours. Rosa and Xu (2015) depicted some of their vibrant hues. The majority of species live in the nests of bees and other wasps as parasitoids or cleptoparasitoids, hence the name cuckoo wasp. Adults have the ability to roll into a ball.

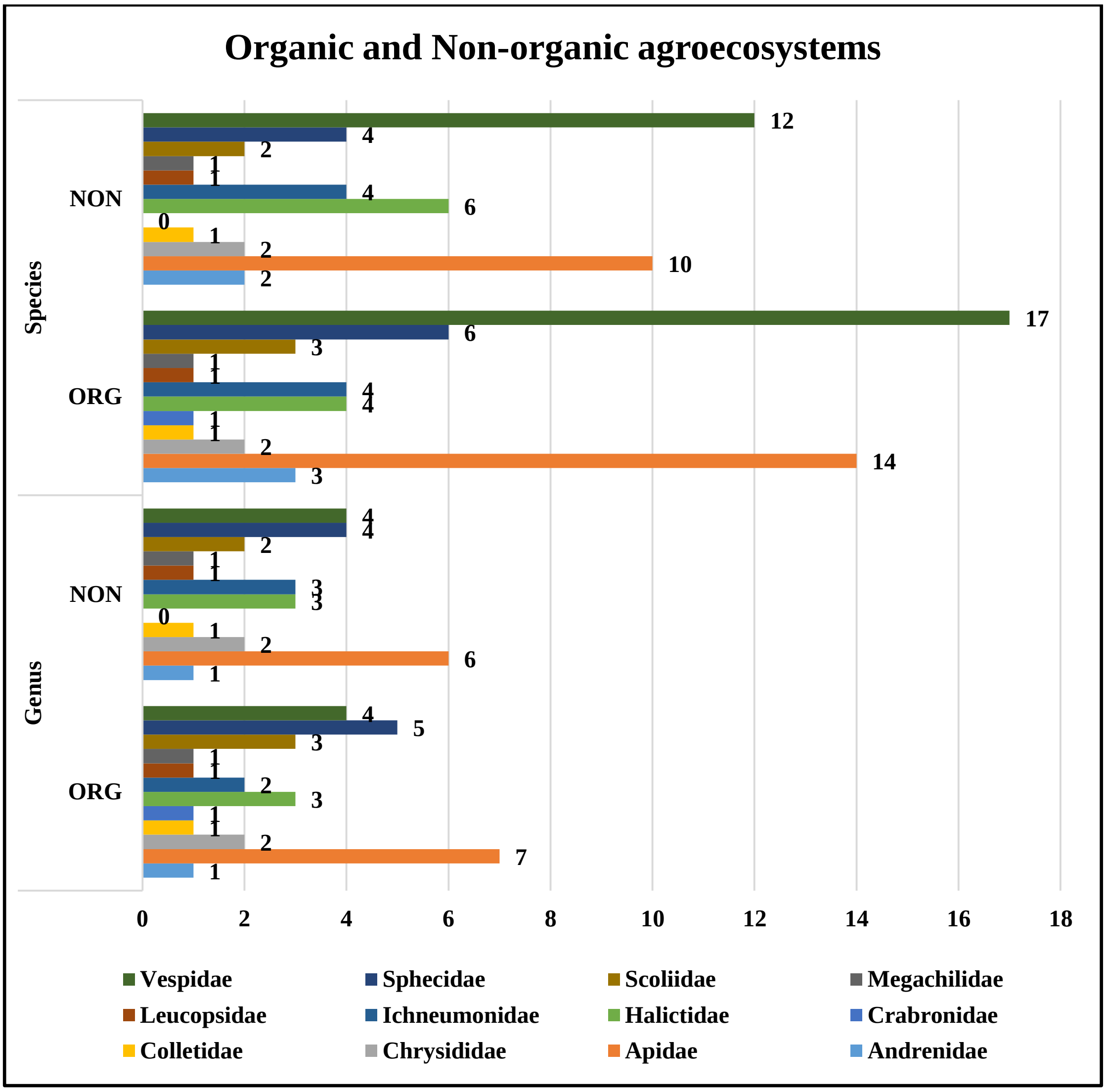


Fig 3.9: A clustered bar chart showing family-wise diversity of Hymenoptera in Organic and Non-organic agro-ecosystems

In organic agro-ecosystems, it was found that the highest species diversity occurred in the family Vespidae (17), followed by Apidae (14), and then Sphecidae (6). The Ichneumonidae (4), Halictidae (4), Andrenidae (3), and Scoliidae (3) exhibited a moderate diversity of species. The families of Chrysididae (2), Colletidae (1), Crabronidae (1), Leucopsidae (1), and Megachilidae (1) have the least species diversity. In terms of genus diversity, the family Apidae (7), followed by Sphecidae (5), and Vespidae (4), was the most diverse. The families Halictidae and Scoliidae had three genera each, while the Chrysididae and Ichneumonidae had only two genera. The families Andrenidae (1), Colletidae (1), Crabronidae (1), Leucopsidae (1), and Megachilidae (1) had the least genus diversity among all the 12 hymenopteran families.

In non-organic agro-ecosytems, Vespidae (12), followed by Apidae (10), and Halictidae (6), showed the highest species diversity. The families of Sphecidae (4) and Ichneumonidae (4) exhibited a moderate diversity of species. Andrenidae (2), Chrysididae (2), Colletidae (1), Leucopsidae (1), Megachilidae (1) and, Scolidae (2), have the least species diversity. No species from the family Crabronidae was recorded from the non-organic site. In terms of genus diversity in non-organic agro-ecosystems, the family Apidae (6) was the most diverse, followed by Sphecidae (4), and Vespidae (4). Halictidae (3) and Ichneumonidae (3) showed a moderate diversity of genera. The families of Chrysididae (2), Andrenidae (1), Colletidae (1), and Megachilidae (1) had the least genus diversity among all the families (Fig. 3.9).

The relative abundance of each family of the order Hymenoptera from the distinguished agro-ecosystems is shown in Table 3.8 and Fig. 3.10. The relative abundance of the families shows that both the families Apidae and Vespidae, with 7 genera each, had a 19% overall contribution, followed by Sphecidae (5) with a 14% contribution, Ichneumonidae (4) with 11%, Scoliidae and Halictidae, with 3 genera each, had an 8% contribution, and Chrysididae (2) with a 6% contribution. While the families Andrenidae, Colletidae, Crabronidae, Megachilidae, and Leucopsidae were the least dominant ones, with a single genus and only a 3% contribution.

Upon analyzing the species numbers, it was observed that the families Apidae and Vespidae, with 17 species each, were dominant, with a relative abundance of 26%. It was followed by the Ichneumonidae and Sphecidae with 6 species each, contributing around 9%. Andrenidae and Scoliidae, with 3 species each, had a 5% contribution. Megachilidae and Chrysididae have only 2 species each, contributing 3%. While the Colletidae, Crabronidae, and Leucopsidae all contributed at least 1%.

Table 3.8: Number and percentage of genus/ species along with dominant species in the Hymenopteran family

SNo	**Family**	**No. of Genera**	**% of Genera** (Round off)	**No. of Species**	**% of Species** (Round off)	**Dominant Species**
1	Andrenidae	1	3	3	5	-
2	Apidae	7	19	17	26	*Apis cerana indica* *Bombus haemorrhoidalis*
3	Chrysididae	2	6	2	3	-
4	Colletidae	1	3	1	1	-
5	Crabronidae	1	3	1	2	-
6	Halictidae	3	8	6	9	*Lasioglossum* sp.
7	Ichneumonidae	4	11	6	9	*Ichneumon* sp. *Odontocolon* sp.
8	Megachilidae	1	3	2	3	-
9	Leucopsidae	1	3	1	2	-
10	Scoliidae	3	8	3	5	-
11	Sphecidae	5	14	6	9	*Ammophila* sp.
12	Vespidae	7	19	17	26	*Polistes olivaceus* *Vespa basalis*
	Total	**36**	**100**	**65**	**100**	

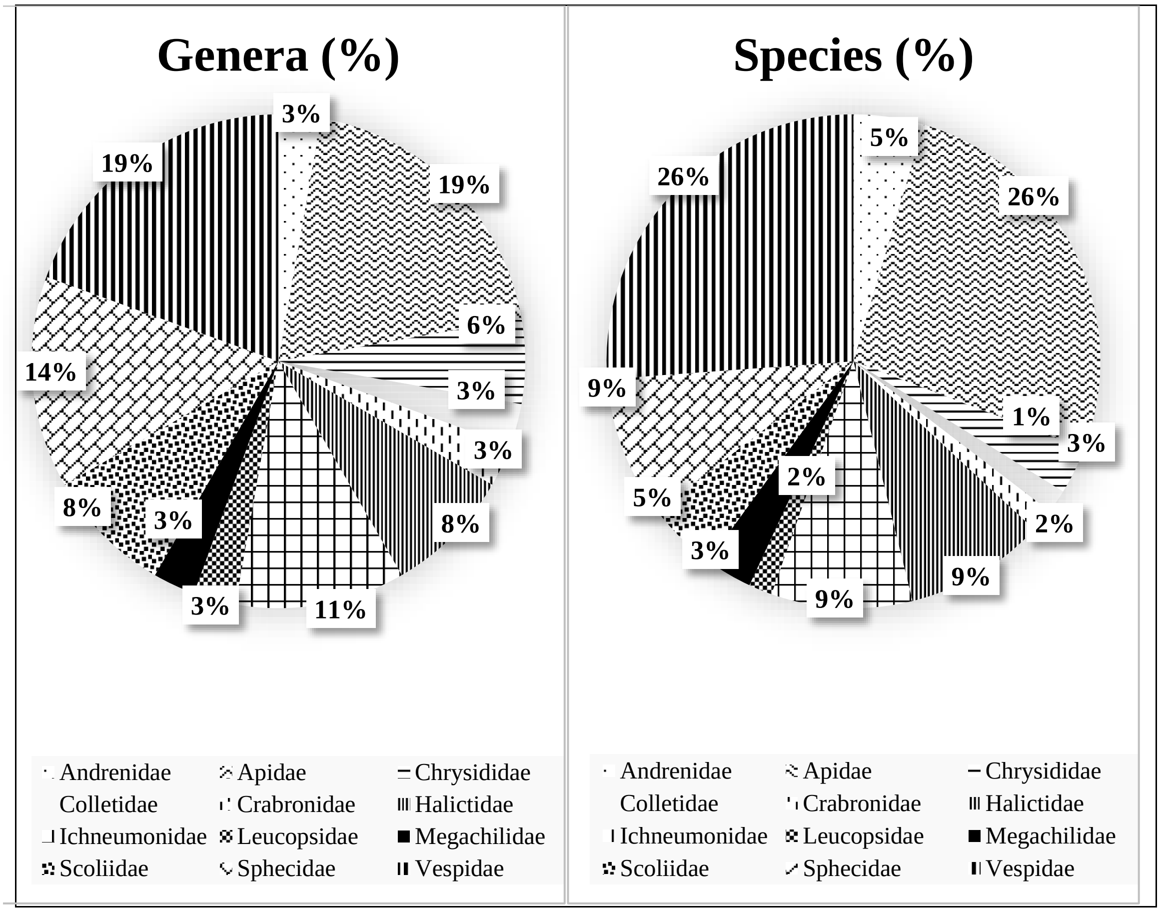


Fig 3.10: Percentage contribution of genera and species in each family of Hymenoptera

The following is a list of the distinctive features of hymenoptera found in the study area, along with their body parts (Fig 3.11 & Table 3.9).

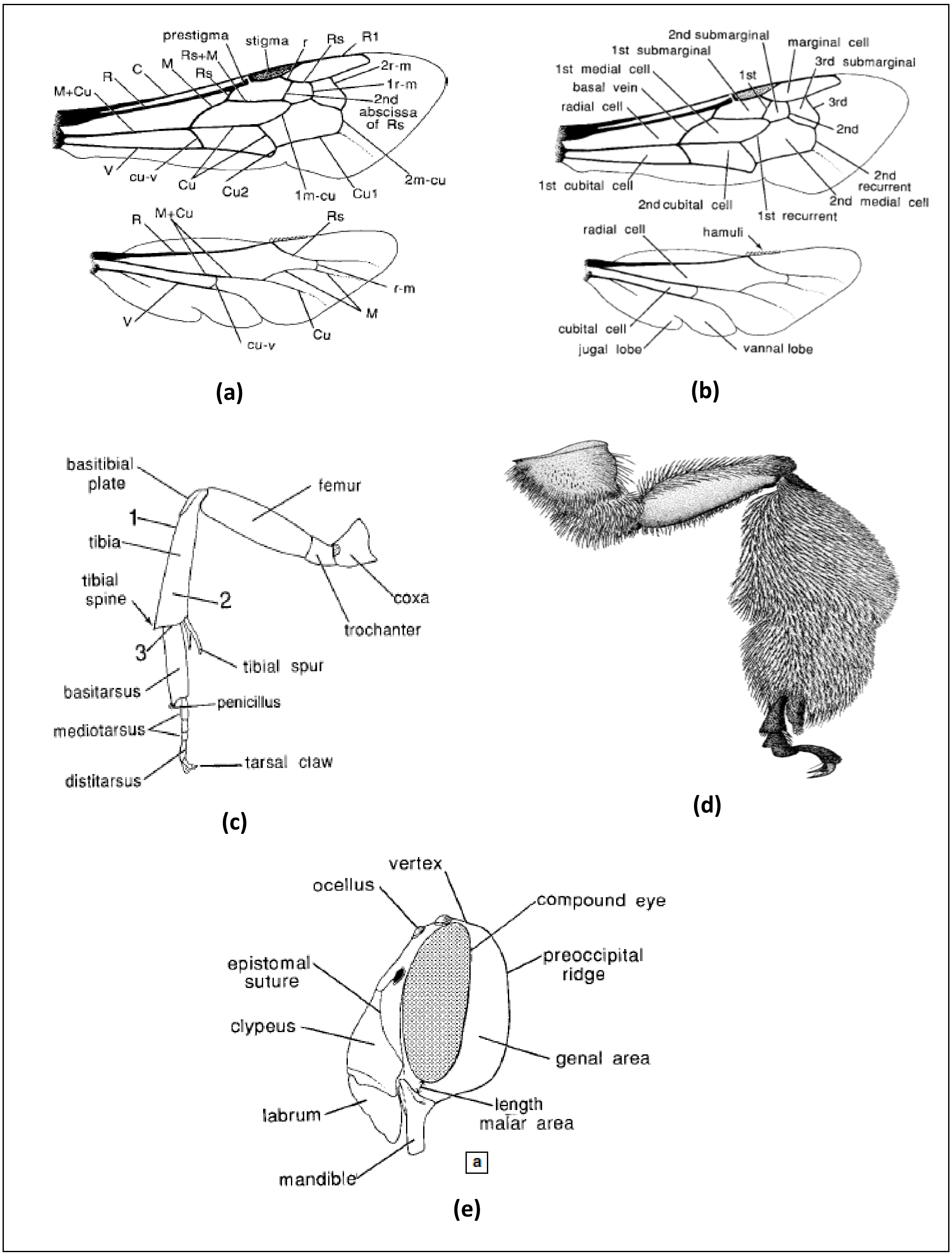


Fig 3.11: (a) A diagram of a bee's wings, demonstrating Michener's vein terminology (1944). (b) Diagram of the wings of a bee, showing the terminology of cells and morphologically noncommital terms for certain veins. (c) Hind leg of a bee, hairs omitted except those that form the penicillus {a-c Modified from Michener, McGinley, and Danforth, 1994}. (d) Hind leg of a bee, showing the femoral corbicula and scopa (patch of hair) for transporting dry pollen on the tibia and basitarsus (Drawing by D.J. Brothers from C.D. Michener). (e) Diagrammatic lateral view of a bee's head

Pictorial key to Hymenopteran families *(Scott and Stojanovich, 1966).*

1. Presence of wings (Fig. 1 A)……………………………………………………..2
   Absence of wings (Fig. 1 B)………………………………………………….…32

Fig. 1 A

Fig. 1 B

2. Node like first (and sometimes second) segment of the abdomen, distinctively separated from the rest of the abdomen above and below (Fig. 2 A). Nesting sites include the ground, wood, and structures (Family Formicidae)..………………ANT

   Abdomen with or without constriction of the first abdominal segments, but no genuine formation of nodes in the basal abdominal segments. (Fig. 2 B)……..…...3

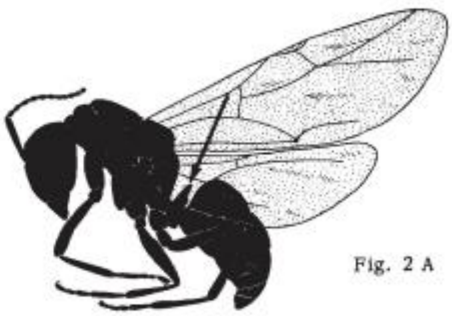


Fig. 2 A

Fig. 2 B

3. The first abdominal segments may be constricted or not, but there is no true creation of nodes in the basal abdominal segments. (Fig. 3 A). (Super families Vespoidea and Sphecoidea). Wasps and Hornets…………………………………………………………………..…...4

   At least some hairs of the thorax are branching or plumose; the first segment of the hind tarsus is widened and thickened, and it is often densely hairy. (Fig. 3 B). (Superfamily Apoidea). Bees…………………………………………………….……27

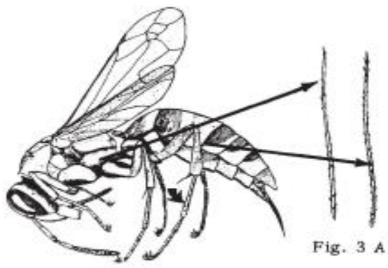


Fig. 3 A

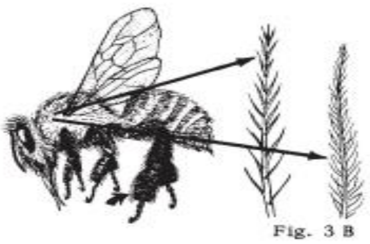
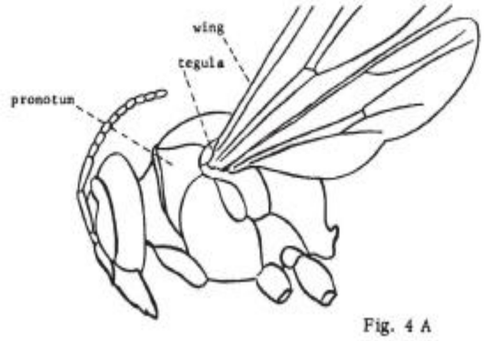
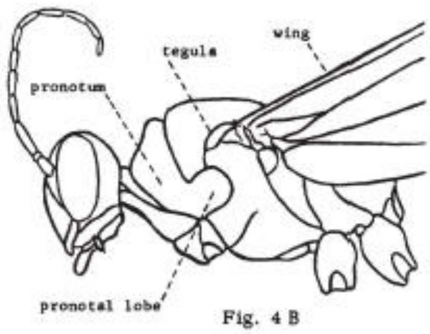


Fig. 3 B

4. Entirely extended black pronotum, to the tegula (the scale covering base of fore-wing), its hind angles not lobed (Fig. 4 A). (Superfamily Vespoidea). ….………..5

   Pronotum shortened, more or less collar-like, not extending back to tegula, its hind angles often produced into lobes (Fig. 4 B). (Superfamily Sphecoidea)……..…..22





5. When in rest, the forewing is almost always folded; lengthy first discoidal cell is very, as a rule much longer than the submedian cell (Fig. 5 A). Both solitary and colonial species (Family Vespidae)……..……………………….…………..…….6

   Forewing very rarely folded; first discoidal cell shorter than submedian cell (Fig. 5 B). Solitary species……………………...…………..……………………........…21

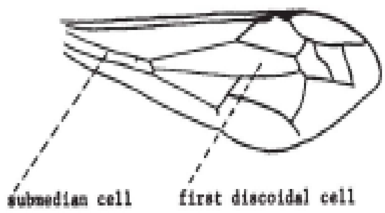


Fig. 5 A

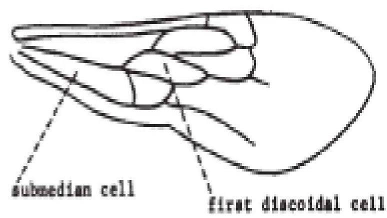
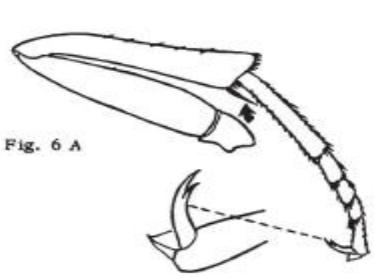
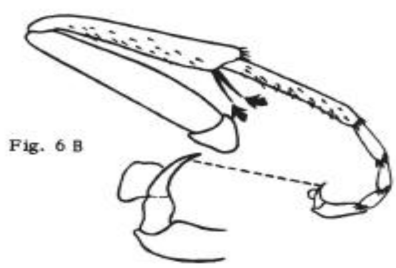


Fig. 5 B

6. One spike at the point of the middle tibia; bifid claws with a split at the tip (Fig. 6 A). (Subfamily Eumeninae)………..Solitary Wasps……..……………….…….....18
   Bifid claws with a split at the tip; one spike at the point of the middle tibia (Fig. 6 B)……………………………………………………………………….………….7





7. One spike at the apex of the middle tibia; bifid claws with a split at the tip (Fig. 7 A); hindwing without a lobe at anal angle (Fig. 7 B). (Subfamily Vespinae). Hornets, Yellow Jackets……………………….……………………….................8

Clypeus somewhat pointed at apex (Fig. 7 C); hindwing with a lobe at anal angle (Fig. 7 D). (Subfamily Polistinae). Paper Wasps…………………….…..…........15

Fig. 7 A

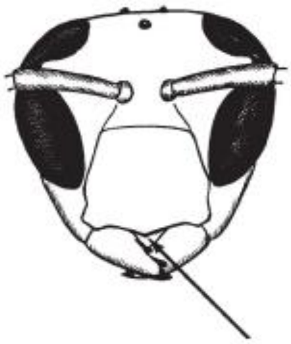


Fig. 7 C

Fig. 7 B

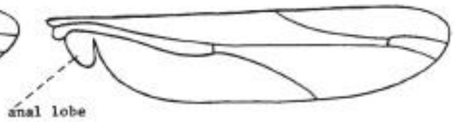


Fig. 7 D

8. Elongated oculo-malar space, more than half the length of next to last antennal segment; vertical carina on pronotum (Fig. 8 A)………………………………….…..9

   Short oculo-malar space, less than half the length of next to last antennal segment; no vertical carina on pronotum (Fig. 8 B)………………………………………...11

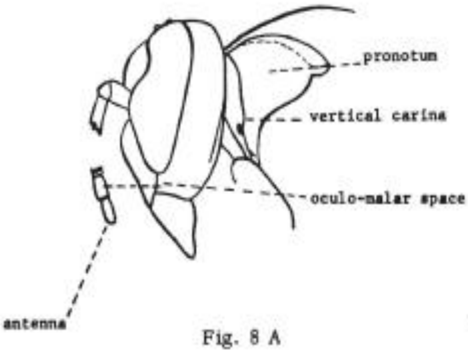


Fig. 8 A

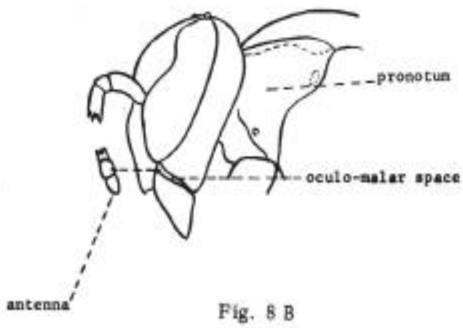


Fig. 8 B

24. Petiole of abdomen two-segmented (Fig. 24 A). Nest in holes in ground. (*Sphex* sp.) ……….…….………………………………..…..…...SOLITARY WASP

    Petiole of abdomen one-segmented (Fig. 24 B)……….…………………………25

25. Species with a bright metallic-bluish hue (Fig. 25 A). Constructs mud nests provisioned with spiders…(*Chalybion caliornicum*)...........BLUE MUD-DAUBER

    Species darker with orange or yellowish patterns (Fig. 25 B)…..……….……......26

27. Spurs absent on hind tibia (Fig. 27 A). In bee hives, buildings, and trees, the colony creates wax combs (*Apis mellifera*)……………...…..............……..HONEY BEE

    One or two spurs on hind tibia (Fig. 27 B)……………..……………………..……28

28. Oculo-malar gap is longer than the antenna's second segment; large hairy species with blackish and yellowish (occasionally reddish) piles (Fig. 28 A). The colony makes wax combs in ground or log nests, frequently in existing mouse nests. (Family Bombidae; *Bombus* sp.)……………………………..........…BUMBLEBEES

    Oculo-malar gap is narrow, with the eye reaching (or nearly reaching) the mandible's base (Fig. 28 B)…………………..………………………......………29

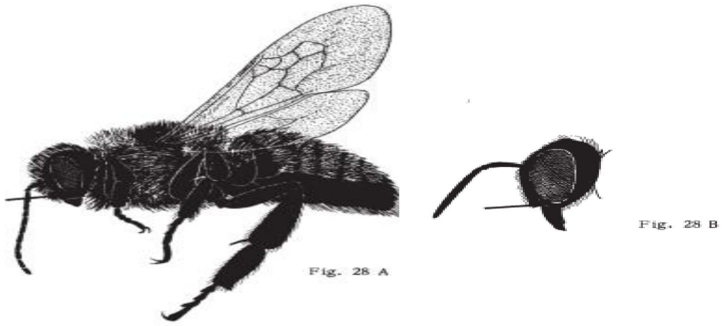


Fig. 28 A Fig. 28 B

29. Huge species, 15-25mm in length, with a long, bluish top abdomen that is almost hairless; second submarginal cell anteriorly strongly narrowed (Fig. 29 A). Nest in wood-bored holes. (*Xylocopa virginica*)……………………………….…………...…...CARPENTER BEE

Smaller species 2-14mm, long usually with some hairs on upper surface of abdomen, shiny greenish species; second submarginal cell not narrowed anteriorly (Fig. 29 B & C)…………………………………………...………30

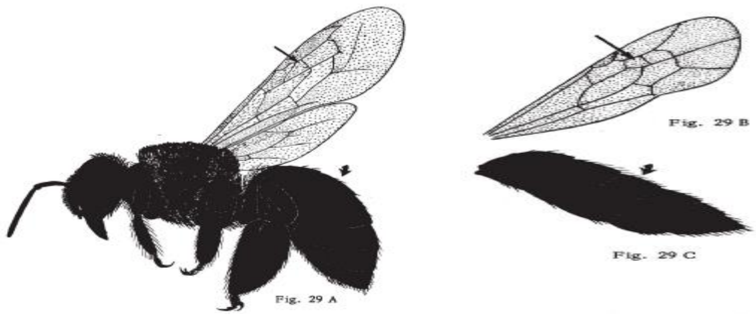


Fig. 29 A Fig. 29 B Fig. 29 C

30. Female abdomen has dense hairy patches on the underside; forewing has two submarginal cells (Fig. 30 A). Builds nest out of leaves in tree holes (Megachile species)..LEAFCUTTER BEES

Forewing with three submarginal cells; abdomen without dense hairy patches on underside (Fig. 30 B & C)..31

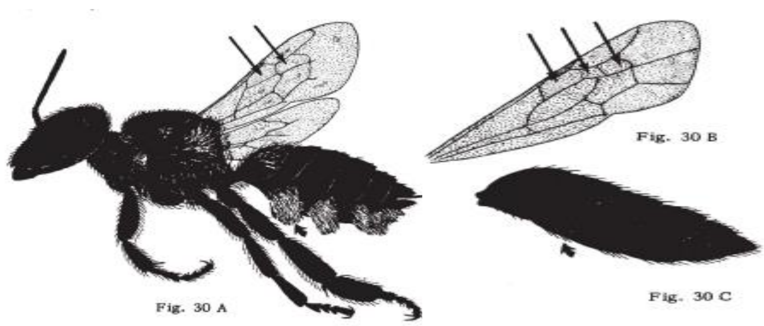


Fig. 30 A Fig. 30 B Fig. 30 C

Table 3.9: Diagnostic characters of Hymenoptera (12 families) recorded from the study site (Michener, 2007; Gupta, 2013; Kumar and Pham, 2015; Kumar et al, 2018)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
Andrenidae	- Presence of scopae on basal segment of legs, in addition to the tibia - Presence of two subantennal sutures on the face - Typically small to moderate-sized bees - Cosmopolitan family of solitary and ground-nesting bees - Presence of enlarged Ocelli	*Andrena* Fabricius, 1775	- Andrena, Halictus, or Colletes have similar body forms - ♂ metasoma is thin and more parallel-sided than that of ♀ - hairy bees that are black or dull metallic blue or green - ♂ with black triangle (the "pygidial plate") at the abdominal apex and have two subantennal sutures and a straight basal vein in the fore wing. - compound eyes, antennal base	*Andrena flavipes* (Panzer, 1799)	- long scopal hairs on hind leg - presence of facial fovea - presence of 3 sub-marginal cells in the fore wing - shiny abdomen with white markings - body length (8 and 17 mm) - presence of scopal hairs
Apidae **(Honey bees, Bumble bee, Carpenter bees)**	- Presence of enlarged Ocelli and pronotal collar without projections - Branched or plumose body hairs - Larger and flattened metatarsus - 3-submarginal cells on the front wing - Jugal lobe of the hind wing is shorter than the sub median cell	*Amegilla* Friese, 1897	- blue-banded bees with blue metallic bands on abdomen - non-aggressive but can sting for defense - *Amegilla* does not possess arolia - pygidial plate is missing in adults, with yellowish white marks on their faces (♂) - upper edge of the hind tibial scopa has a strip of plumose hairs	*Amegilla zonata* (Brooks, 1988)	- ♂ (13) and ♀ (12) antennal segments - adults have dense pubescence on head and thorax and are finely punctured, while on the clypeus, the basal portion of metasomal segments, and the face below the antennae is thinner - clypeus, labrum and base of mandibles are yellowish - on the head and thorax, there is a pale grey pubescence with a mixture of black hairs - metasoma with thin black hairs and metallic blue pubescence in transverse bands - dark brown tegulae and fusco-hyaline wings

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
				Amegilla confusa (Smith, 1854) Syn. *Anthophora confusa*	- comparatively pale and lighter bands - thorax and upper half of the head are coarsely perforated - base of the mandibles and labrum are profusely pubescent - vertex and thorax are pale yellowish, with ash grey pubescence occasionally intermixed with black pubescence. - white pubescence metasoma coated with fine black hairs on the hind femora and cheeks - wings fusco-hyaline
		Anthophora Latreille, 1803	- males have pale white or yellow markings on face - modified leg armature and hairs - arolium found between the tarsal claws	-	-
		Apis Linnaeus, 1758	-“long-tongue” bees - labial palpi's first two segments are elongated, flattened, and sheath-like.	*Apis cerana indica* (Fabricius, 1798) aka Asian Honey Bee	- moderate body size (forewing 7–9 mm) - rusty coloration in legs - tan pubescence of the body sting - on the sting apparatus, there are 4–5 pairs of stylets and 10 lancet barbs - distance between the tip of the lancet and the first barb is 49.87 µm - generalist visiting wide range of flora for foraging

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
				Apis dorsata (Fabricius, 1793) aka Giant Honey Bee	- 17-20mm long - forewing length (12–15 mm) - vein M's distal abscissa is present in the hind wing and fuscous forewings - brownish-black or reddish-brown scutellum of the worker - T3–T4 of the worker metasomal is a dark brown to black in colour - drones have condensed frond-like setae on mesotarsi and metatarsi - workers have more or less raised ocelli - 11 lancet barbs and 2–4 pairs of stylet barbs on the sting apparatus - 77.92 µm from the tip of the lancet to the first barb - a generalist visiting a wide range of flora
				Apis laboriosa (Smith, 1871) aka Himalayan Honey Bee or Cliff Honey Bee	- forewings fuscous (>12 mm) - vein M's distal abscissa is present in the hind wing - nest composed of single comb built under overhangs on vertical cliffs - distribution restricted to the Himalayas (2500-4000 m amsl) - workers with scutellum black and metasomal T3–T4 reddish-brown - foragers don't produce sound during waggle dance - polylectic bees that collect pollen from the flowers of a variety of unrelated plants

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
				Apis mellifera (Linnaeus, 1758) aka European Honey Bee	- adult worker size (10–15 mm), larger queens (18–20 mm), drones without metabasitibial process (15–17 mm) - forewing length (7.5–10 mm) - dark to light reddish-brown in colour - presence of dark bands in the metasoma - distal abscissa of vein M in hind wing absent - mesoscutum light to dark brown - The vestigial form of a sting mechanism with 10 lancet barbs and 2–4 pairs of stylet barbs: really small - 55.18 µm from the tip of the lancet to the first barb - a generalist visiting a wide range of flora
				Apis florea (Fabricius, 1787) aka Red Dwarf Honey Bee	- smallest honey bees (7–10 mm body size, 6.8 mm forewing) - a generalist visiting a wide range of flora - female worker with metatibia and dorsolateral margin of metabasitarsus with white setae - metasomal T1 and T2 reddish-orange to reddish-brown - 10 lancet barbs and 4–5 pairs of stylet barbs on the sting apparatus - 42.59 µm from the tip of the lancet to the first barb

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Bombus Latreille, 1802 aka Bumble bee	- round and plump body - pump and densely furry usually with black, yellow, and/or red coloration - comparatively broader and stouter-body than honeybees - abdomen tip is more rounded with broad bands of colour and are covered in black fur - longer proboscis to collect nectar from tubular flowers	*Bombus haemorrhoidalis* (Smith, 1852)	- body length (16-21 mm) - dark fuscous wings - pubescence conspicuously blackish - little pubescent on tarsi - creamish pubescence at the base - 2 abdominal fragments, bright rufi-fulvous on the apical 4 - pubescence on abdominal segments ♂ whitish fulvous red than ♀
				Bombus orientalis (Smith, 1854)	- 20mm (body length) and 36mm (body width with spread wings) - dark fuscous wings - two abdominal fragments with bright yellow and rust orange densely arranged hairs - hairy tibia and femur
				Bombus tunicatus (Smith, 1852)	- black pubescence on head, mesonotum and 3rd abdominal tergum - 1st abdominal tergum, pronotum and metanotum are white - 4th and 5th abdominal tergites are red brick, black band between wings

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Ceratina Latreille, 1802 aka Small Carpenter bee	-	-	- 7mm (body length) and 11mm (body width with spread wing) - dark, shining metallic blue green - fairly sparse body hairs - weak scopa on the hind tibia
		Epeolus Latreille, 1802 aka Variegated Cuckoo-bees	-	-	- variegated cuckoo-bees and are cleptoparasites - bright bluish white parallel lines with a vertical as well as horizontal gap on abdomen - scopa absent - short, pale pubescence forming a conspicuous pattern - mandible usually with preapical tooth - S7 usually lacking median margination on distal margin
		Xylocopa Latreille, 1802 aka Carpenter bee	-	-	- primarily black with some yellow or white pubescence - shiny abdomen without any fur - hind leg of ♀ is entirely hairy - wing venation: front wing's marginal cell is narrow and elongated, with an apex that bends away from the costa, and the front wing's stigma is small - short mandibles conceal the labrum when closed and the clypeus is flat

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
Chrysididae **(Cuckoo Wasps)**	- Thorax is pitted and the colour is green or blue-green - 3-5 apparent terga on metasoma - Head not elongate - Do not sting - Antennae with 12 (♀) or 13 segments (♂) - Pointed thorax's rear corners - Teeth-like projections protrude from the tip of the abdomen - No closed cells on the hindwings - Chrysidids curl up into a ball when disturbed	*Chrysis* Linnaeus, 1767 aka Cuckoo wasp	-	-	- 10mm (body length) and 12mm (body width with spread wing) - metallic emerald green - two distinct golden bands on the abdomen - last metasomal tergum dentate apically - presence of tooth-like projections at the end of abdomen
		Chrysura Dahlbom, 1845	-	-	- 8mm (body length) and 8mm (body width with spread wing) - metallic green body - one prominent golden band at the metasoma - presence of tooth-like projections at the end of abdomen
Colletidae **(Plasterer or polyester bees)**	- Ground nesting solitary bees - Presence of scopae - Presence of bilobed glossa (♀) - Presence of enlarged Ocelli - Mouth secretes cellophane-like plastic secretion	*Colletes* Latreille, 1802	-	-	- 9mm (body length) and 12mm (body width with spread wing) - black head and abdomen with white bands, orange thorax - glossal lobes present - glossal brush contains coarser annuli with pointed annular hairs, and there are glossal lobes - one subantennal suture runs beneath each antenna and is directed toward the inner margin of the antennal socket.

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
Crabronidae **(Digger wasps)**	- Medium to large in size - Body is long and usually black, yellow and orange - Spiny-legged - Deformed ocelli	Bembix Fabricius, 1775	- large cosmopolitan genus and brightly coloured predatory wasps	-	- 16mm body length - have very syynchronized movements of forelegs while digging - abdomen with a distinctive yellow and black striped pattern - In some species, the labrum extends into a narrow beak
Halictidae **(Sweat bees)**	- Small sized, ground nesting eusocial or solitary bees - Metallic and dark-coloured in appearance (red or green) - Males have yellow markings - Adults often have yellow faces - Presence of enlarged Ocelli - Arcuate basal veins on wings	*Halictus* Latreille, 1804	- metallic greenish-tinted - head and thorax densely covered with hairs	-	- 13mm (body length) and 16mm (body width with spread wing) - black or dark brown in colour - presence of white abdominal bands on terga - presence of basal abdominal hair bands
		Lasioglossum Curtis, 1833	-	-	- 8-11mm (body length) and 13-15mm (body width with spread wing) - shiny black body with round abdomen having yellow bands on terga - yellow proboscis and legs - highly variable in size and colour - strong-veined forewings

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Nomia Latreille, 1804	- presence of opalescent bands on metasoma	-	- 12mm (body length) and 18mm (body width with spread wing) - moderate sized solitary bees - wings has 3 sub-marginal cells and 2nd one is shorter than the 1st and 3rd one at the abdomen has greenish-blue bands - of ivory or pearl
Ichneumonidae **(Parasitoid Wasps)**	- Slender waisted - "Horsehead" cell in forewing - Wing venation: 2 recurrent m-cu cross veins present - 16 or more antennal segments - Ovipositor long, often longer than body - Front wing with 2 recurrent veins	*Cryptus* Fabricius, 1804	-	-	- 10mm (body length) and 14mm (body width with spread wing) - black head and thorax, long antennae - legs and abdomen rust orange - tip of slender abdomen black and a white spot on thorax
		Ichneumon Linnaeus, 1758	-	-	- 15mm (body length) and 20mm (body width with spread wing) - black body and long antennae - transparent wing with black patch at the costa - yellow and black shaded legs
		Odontocolon Cushman, 1942	-	-	- 22mm (body length) and 20mm (body width with spread wing) - black head, thorax and antennae - legs and slender abdomen reddish brown - either 1 or 2 or 3 long tails at the ovipositor

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Ophion Fabricius, 1798	-	-	- 10mm (body length) and 15mm (body width with spread wing) - orangish-brown body with transparent wing - long legs, antennae and slender abdomen - 2 short and one long ovipositors
Leucospidae **(Wasp mimicking bee)**	- Brightly coloured - Enlarged femurs on the hind leg with lower margin toothed - Long ovipositor	*Leucospis* Fabricius, 1775	-	-	- yellow black pattern around the abdomen - 18-20mm (body length) - enlarged femurs - wings have longitudinal fold - long ovipositor is bent over their backs above the metasoma
Megachilidae **(Leaf cutter bees, Mason bees)**	- Two equal length sub-marginal cells - Front wing with two submarginal cells - On the ventral aspect of the metasoma, there are scopae - Labrum not large and free, if the clypeus is visible, it is usually completely hidden; if it is visible, it is firmly inflexed - Pygidial area absent	*Megachile* Latreille, 1802	- 2^{nd} largest bee family - with pollen, the underside of the abdomen resembles light yellow to deep gold in colour - tarsal claws simple or bifid - ventral abdominal pollen-collecting brush (♀) - Circular shaped cut leaves	-	- moderate sized and stout-bodied black bees (5-24 mm) - arolia absent on all legs - unlike other bees, females transport pollen on hairs on the underside of the abdomen rather than on the rear legs

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
Scoliidae **(Scoliid wasps)**	- Often black, marked with orange or yellow - Tips of wings are distinctively corrugated - Males are slender and elongated than females - Middle and hind coxae covered by a continuous flat plate formed by the mesosternum and metasternum - Males have three spines between the last exposed tergite and the sternite at the apex of their abdomen	*Megacampsomeris* Betrem, 1928	-	-	- 20mm (body length) and 30mm (body width with spread wing) - stiff hairs all over the body - metallic blue abdomen with 5 creamish yellow rings - long legs covered with hairs
		Phalerimeris Betrem, 1967	-	-	- 15mm (body length) and 22mm (body width with spread wing) - head and thorax covered with golden yellow hairs - black abdomen covered with 4 yellow hairy rings - wings yellow with black patch at the radial cell
		Colpacampsomeris Betrem, 1967	-	-	- 28mm (body length) and 40mm (body width with spread wing) - black body and wings with bluish tint - thorax densely covered with white patch of hairs - rest body parts scarcely covered with hairs

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
Sphecidae **(Mud daubers, Thread-waisted and Sand wasps)**	- Predatory or parasitoidal wasps - First segment of hind tarsi not dilated - Absence of plumose hairs - Females lacking corbicula (pollen baskets) on the posterior tibia	*Ammophila* W. Kirby, 1798 aka thread-waisted sand wasps	-	-	- 26mm (body length) and 22mm (body width with spread wing) - medium-sized wasps - antennae as long as head plus thorax - small and stronger jaws for digging - orange abdomen with a black tip attached to the thorax with a long petiole
		Podalonia Fernald, 1927	-	-	- 18mm (body length) and 20mm (body width with spread wing) - similar to Ammophila, but have shorter petiole - orange abdomen with a black tip - black body and legs
		Chalybion Dahlbom, 1843 aka Blue Mud Dauber wasps	-	-	- 18mm (body length) and 22mm (body width with spread wing) - metallic and shiny body with slender abdomen - transparent wing, darker at the marginal and sub-marginal cell

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Prionyx Vander Linden, 1827	-	-	- 16mm (body length) and 25mm (body width with spread wing) - saw-like endings on their claws - head and thorax black - slender waisted with long legs - rust orange abdomen - tibia spur present - antennae long and black
		Sphex (Linnaeus, 1758) aka digger wasps	-	-	- 20mm (body length) and 32mm (body width with spread wing) - black body with orange antennae - black wings and abdomen with purple tint
Vespidae **(Paper and potter wasps, Hornets, Yellow jackets)**	- Both eusocial and solitary wasp - Medium-sized (9-25 mm), black, and yellow, white, or red-hued - Predatory in nature - Long curved slender antennae - Pronotum extends laterally to the tegulae - Wings with usually long discoidal (M-4) cell	*Ancistrocerus* Wesmael, 1836 aka potter wasp	-	-	- 12mm (body length) and 20mm (body width with spread wing) - nonpetiolate eumenine wasps - black head and thorax with 3 yellow bands on abdomen - black and yellow legs
		Eumenes Latreille, 1802	-	-	- 16mm (body length) and 22mm (body width with spread wing) - black body and black-yellow shaded legs - head, thorax and abdomen has yellow bands and rings

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
	- Wings folded longitudinally when the insect is at rest - "Felt lines" (i.e., very dense pubescence arranged in two rows, the pubescence of each row lying nearly at right angle to the other - The front wings' first discoidal cell is longer than the sub-median cell When at repose, the wings are folded longitudinally	*Parancistrocerus* Bequaert, 1925	-	-	- 15mm (body length) and 20mm (body width with spread wing) - black bodied - legs black with lighter tarsus - tibia spur absent - slender waisted - abdomen tapering towards the tail with two orange rings around the tergum
		Polistes Latreille, 1802	- largest genus within the family - prefer human habitation for nest-building which is single-layered nests like an umbrella - yellow, reddish-brown and black in colour - many species aggregate and undergo hibernation in winters	*Polistes olivaceous* (DeGeer, 1773)	- body length (13-20mm) - Yellow body with varying black patterns and a few reddish marks - Clypeus's basal and apical margins have black patterns and mandibular teeth - on raised part of interantennal space short line drawn - mark on pronotum ventrally towards propleuron - T1 is thin at the base (sometimes absent) - bisinuate markings on gastral tergites and sternites
		Parapolybia Saussure, 1854 aka paper wasp	-	-	- 9-10mm (body length) - Shallow median groove of propodeum - T2 at base has yellow mark - head width longer than petiole - incomplete occipital carina

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Vespa Linnaeus, 1758	- basically the hornets - eusocial wasps - large head and rounded abdomen	*Vespa basalis* (Smith, 1852)	- 14–22 mm (body length) - coffee brown with yellow ring around the abdomen, tibia spur present - yellow head, orange to reddish orange antennae, light yellow brownish legs - body scarsely covered with hairs
				Vespa velutina (Lepeletier de Saint Fargeau, 1836) Syn as V. auraria (Smith, 1852)	- 18.5–25.5mm (body length) - fore wing length 18.5–27 mm - orange face and antennae - tibia spur present - yellow-brown dual shaded legs - velvety body, yellow patched thorax - abdomen half yellow half brownish orange
				Vespa tropica (Linnaeus, 1758)	- body length (20.5mm) - reddish brown antenna and head - reddish brown scutellum - mesoscutum anteriorly with two short reddish brown lines - female thick and larger, coated with thick and stiff hairs - coarsely punctate clypeus - hairy apical margin, and has a triangular apico-lateral angle - pronotum features strong - transverse ridges in the lower vertical section.

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
		Vespula Linnaeus, 1758	- basically the yellow jackets - adult body size 12–17 mm - long, yellow and black coloured body - yellow pronotal bands on abdomen - shorter oculomalar space	Sp. 1,2,3	- yellow black thorax and head - yellow and black striped abdomen - slender waist - tibia spur present

PLATE 8: Species account of Hymenoptera


1. *Andrena flavipes*


2. *Andrena* sp.1


3. *Andrena* sp.2


4.*Amegilla zonata*


5. *Amegilla confusa*


6. *Anthophora* sp.1


7. *Anthophora* sp.2


8. *Apis cerana indica*


9. *Apis dorsata*


10. *Apis laboriosa*


11. *Apis florea*


12. *Apis mellifera*


13.*Bombus haemorrhoidalis*


14. *Bombus orientalis*


15. *Bombus tunicatus*


16. *Ceratina* sp.1


17. *Ceratina* sp.2


18. *Epeolus* sp.


19. *Xylocopa* sp.1


20. *Xylocopa* sp.2

PLATE 9: Species account of Hymenoptera


21. *Chrysis* sp.1


22. *Chrysura* sp.1


23. *Colletes* sp.


24. *Bembix* sp.


25. *Halictus* sp.1


26.*Lasioglossum* sp.1

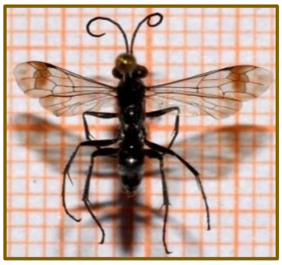

27. *Lasioglossum* sp.2


28. *Nomia* sp.1


29. *Nomia* sp.2

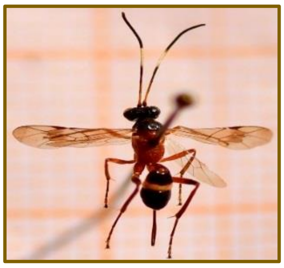

30. *Nomia* sp.3


31. *Cryptus* sp.


32. *Ichneumon* sp.1


33. *Ichneumon* sp.2


34. *Odontocolon* sp.1


35. *Odontocolon* sp.2


36. *Ophion* sp.


37. *Leucospis* sp.


38. *Megachile* sp.1


39. *Megachile* sp.2


40. *Phalerimeris* sp.

PLATE 10: Species account of Hymenoptera


41.*Megacampsomeris* sp.


42.*Colpacampsomeris* sp.


43. *Ammophila* sp.1


44. *Ammophila* sp.2


45. *Chalybion* sp.


46. *Prionyx* sp.


47. *Podalonia* sp.


48. *Sphex* sp.1


49. *Ancistrocerus* sp.1


50. *Eumenes* sp.1


51.*Parancistrocerus* sp.1


52.*Parancistrocerus* sp.2


53.*Parancistrocerus* sp.3


54. *Polistes olivaceus*


55. *Polistes* sp.1


56. *Polistes* sp.2


57. *Polistes* sp.3


58. *Polistes* sp.4


59. *Parapolybia* sp.


60. *Vespa basalis*

PLATE 11: Species account of Hymenoptera

61. *Vespa tropica*

62. *Vespa veluntina (syn V.auraria)*

63. *Vespula* sp.1

64. *Vespula* sp.2

65. *Vespula* sp.3

3.4.2.3. ORDER III - Diptera (9 families): Diversity of flies, hoverflies, and syrphids

From an ecological standpoint, the order Diptera is one of the most diverse groups and plays an essential role in the environment (Ssymank et al., 2008). In tropical areas, dipteran diversity rivals or surpasses hymenoptera diversity (Inouye, 2001). They are often considered the most crucial pollinators after bees (Irshad, 2014). These are universal in nature and can be found everywhere, except Antarctica. They have suctorial or lapping mouthparts, and are often thought to be primitive pollinators (Kevan and Baker 1983). The existence of one pair of functional wings, mouth parts, and antennae distinguishes the group from other flying insects (Hutson, 1984).

Historical Review

The Himalayan diptera has been widely studied during the British Era, when Shimla-Darjeeling were the summer capitals of British colonisers from the late 1900s to the early 1930s. Stalwarts like Wiedemann (1821), Westwood (1835), and Bigot (1890, 1891), who analysed the dipteran specimens from the Himalayas and deposited them in museums abroad. Giles (1900) and Brunetti (1917, 1923) brought in the Diptera collection for the research. The baton was transferred to a number of naturalists working in India and abroad. Bromley (1935, 1945), Theodor (1956), Sabrosky (1961), Emden (1965), and Maa (1969) were some of the prominent workers who worked on the Himalayan fauna. During that time, surveys were limited to the hill stations of Shimla, Kullu, Manali, Rohtang, Mussoorie, Nainital, Dehradun, Srinagar, Jammu, Gangtok, Darjeeling, Kalimpong, Kurseong, and Tsangu. Mani (1954), Nayar (1977), Nandi (2002), Ghorpade (1981), Hazra et al. (2002) were among the scientists from several national institutes and universities who contributed to the Himachal fauna. Between 1970 and 2021, the Dipterists of ZSI conducted extensive faunistic surveys on the Himalayas under the guidance of many contributors to the fly fauna, including Joseph (1970), Joseph and Parui (1986), Datta (1992), Parui et al. (2006), Mitra and Banerjee (2007), Mitra and Parui (2010), Parui and Mukherjee (2000), Parui and Mitra (2004), Mitra et al. (2004b, 2005, 2008, 2015), Sengupta et al. (2016), Naskar et al. (2019) and, Hussain et al. (2021).

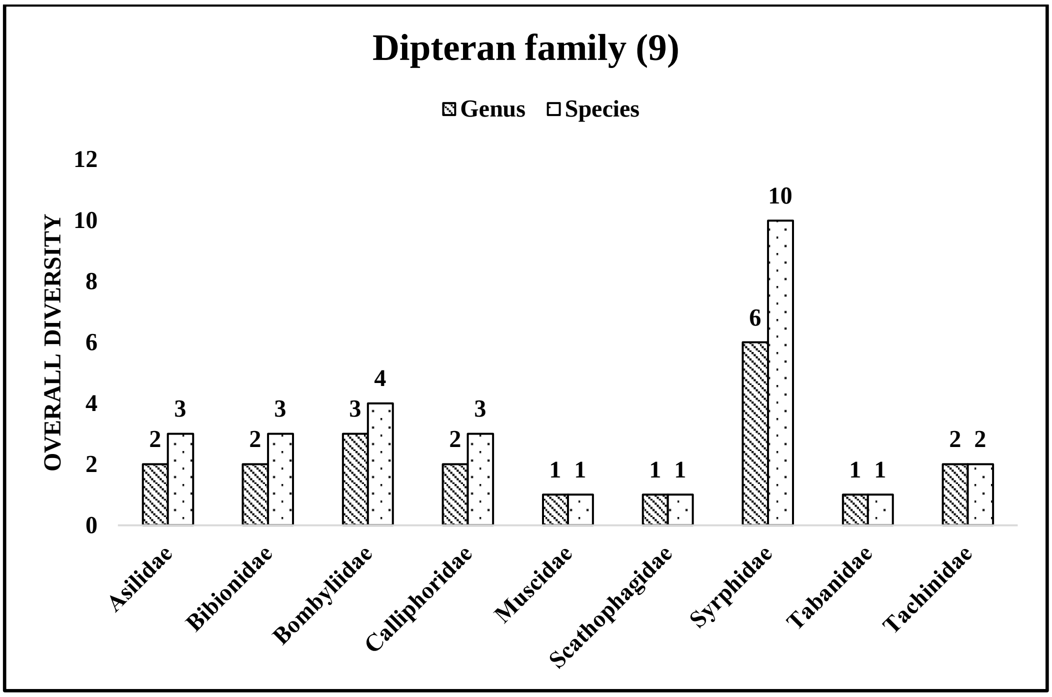


Fig 3.12: Overall family-wise diversity of Diptera in both study areas

28 species of dipteran flies belonging to 20 genera, representing 12 subfamilies of 9 families, were reported as flower visitors/pollinators of various crop plants from different sampling localities of Mandakini Valley (Non-Organic) and Doon Valley (Organic). During the current course of study, all recorded dipteran fly species were placed under 6 super families, namely, Asiloidea, Bibionoidea, Muscoidea, Syrphoidea, Tabanoidea, and Oestroidea. The superfamily Asiloidea consists of 2 families (Asilidae and Bombyliidae). The superfamily Muscoidea is comprised of the Muscidae and Scathophagidae families. The families Calliphoridae and Tachinidae belonged to the superfamily Oestroidea. Other families were placed under the superfamilies Bibionoidea (Bibionidae), Syrphoidea (Syrphidae), and Tabanoidea (Tabanidae). There were around 12 sub-families reported from the nine families of diptera (Table 3.4 & 3.5). Syrphidae has the highest number of species under 2 sub-families (Eristalinae, Syrphinae) with *Ceriana* sp., *Episyrphus balteatus*, *Eristalinus* sp., *Eristalis horticola*, *Eristalis tenax*, *Eumerus* sp., and *Sphaerophoria* sp. as dominant species. The families Bibionidae (Pleciinae, Bibioninae), Bombyliidae (Anthracinae, Bombylinae) and Calliphoridae (Calliphorinae, Lucilinae) also had 2 sub-families each with *Bibio* sp., *Plecia* sp., *Anastoechus* sp., *Bombylius major*, *Bombylius minor*, *Villa* sp., and *Musca domestica* as dominant species. The families Asilidae (Asilinae), Muscidae (Muscinae), Scathophagidae (Scathophaginae), Tabanidae (Tabanine), and Tachinidae (Tachininae)

are comprised of a single sub-family with *Machimus* sp., *Machimus* sp., *Promachus hinei*, *Cordilura* sp., *Tabanus* sp., *Nowickia* sp., and *Tachina* sp. as dominant dipteran species.

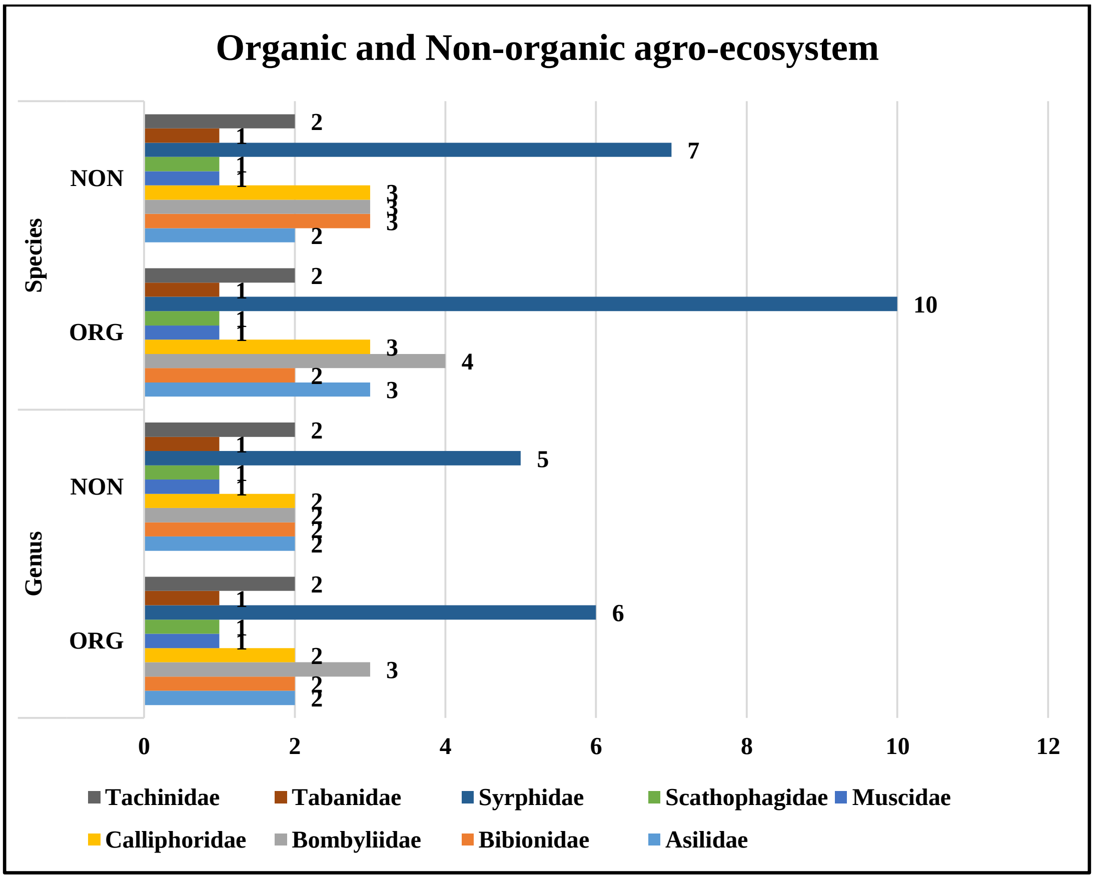


Fig 3.13: A clustered bar chart showing family-wise diversity of Diptera in Organic and Non-organic agro-ecosystems

In organic agro-ecosystems, the family Syrphidae (10) had the most number of species, followed by Bombyliidae (4), and then Asilidae and Calliphoridae with 3 species each. While the Tachinidae and Bibionidae each had 2 species, the families of Calliphoridae, Muscidae, Tabanidae, and Scathophagidae have the least species diversity with a single species representation. In terms of genus diversity, the family Syrphidae (6) had the most, followed by Bombyliidae (3).The families Ailidae, Bibionidae, Calliphoridae, and Tachinidae had 2 species each. While the Muscidae, Tabanidae, and Scathophagidae had the least genus diversity of all the 9 dipteran families.

In non-organic agro-ecosytems, Syrphidae had the most species (7), followed by the trio of Bibionidae, Bombyliidae, and Calliphoridae, with 3 species each. The families Asilidae and Tachinidae had 2 species each, while the families of Muscidae, Tabanidae, and Scathophagidae had the least species diversity, with a single species representation. In terms of genus diversity in non-organic agro-ecosystems, the family Syrphidae (5) was once again reported as having the highest genera. The families of Asilidae, Bibionidae, Bombyliidae, Calliphoridae, and Tachinidae had two species each. While the Muscidae, Scathophagidae, and Tabanidae had the least genus diversity of all the 9 dipteran families (Fig. 3.13).

Table 3.10: Number and percentage of genera/genus, species along with dominant species in the Dipteran family

SNo	**Family**	**No. of Genera**	**% of Genera** (Round off)	**No. of Species**	**% of Species** (Round off)	**Dominant Species**
1	Asilidae	2	10	3	11	*Machimus* sp.
2	Bibionidae	2	10	3	11	*Plecia* sp. *Bibio* sp.
3	Bombyliidae	3	15	4	14	*Anastoechus* sp. *Bombylius major*
4	Calliphoridae	2	10	3	11	*Calliphora vomitoria* *Lucilia* sp.
5	Muscidae	1	5	1	3	*Musca domestica*
6	Scathophagidae	1	5	1	3	-
7	Syrphidae	6	30	10	36	*Eristalis* sp. *Eristalinus* sp.
8	Tabanidae	1	5	1	4	-
9	Tachinidae	2	10	2	7	*Nowickia* sp.
	Total	**20**	**100**	**28**	**100**	

Table 3.10 and Fig. 3.14 reveal the relative abundance of each family of Diptera from the distinguished agro-ecosystems. The relative abundance of the families showed that the family Syrphidae, with 6 genera, had the highest contribution (30%), followed by Bombyliidae (3) with a 15% contribution. The families Asilidae, Bibionidae, Calliphoridae, and Tachinidae had 2 genera each contributing 10%. The Muscidae,

Scathophagidae, and Tabanidae families were the least dominant, accounting for only 5% of the total.

Upon analyzing the species numbers, it was observed that the family Syrphidae (10) had the highest contribution with 36%, followed by Bombyliidae (4) with a 14% contribution. It was further followed by the Asilidae, Bibionidae, and Calliphoridae, with 3 species each and an 11% contribution, and the Tachinidae (2) contributed 7% to the overall diversity. The Muscidae, Scathophagidae, and Tabanidae families contributed the least, accounting for only 4% of the total.

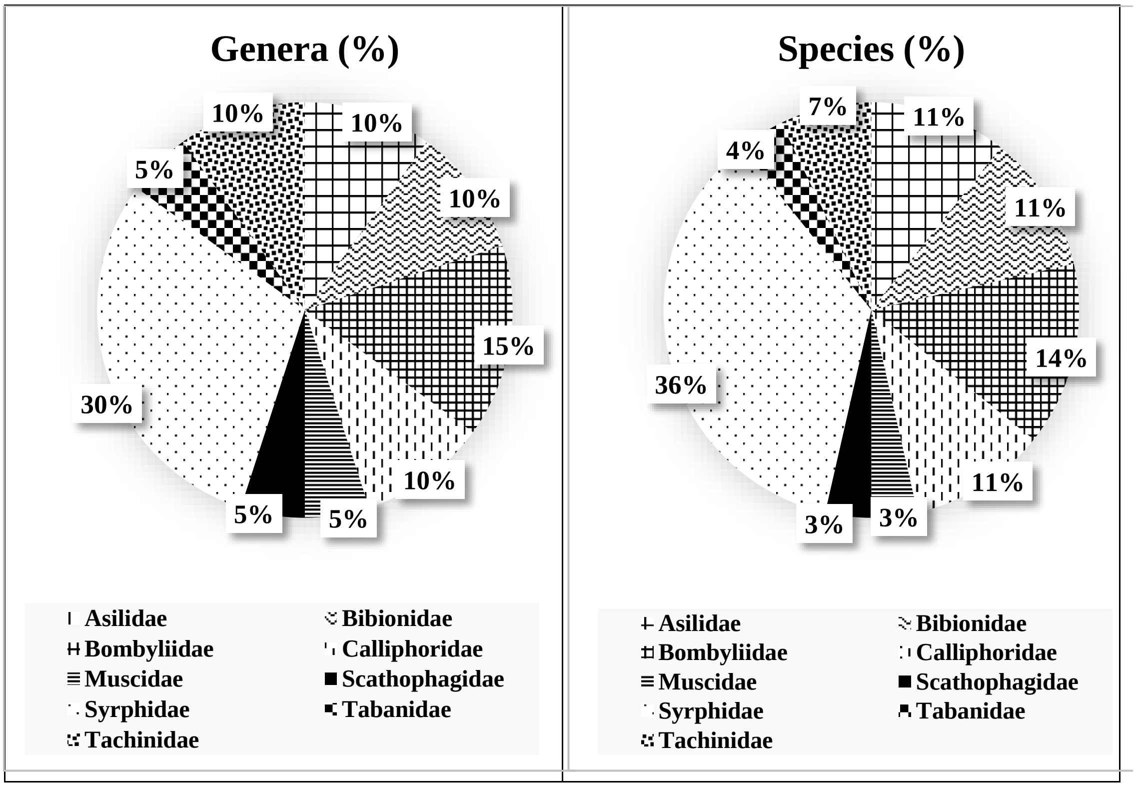


Fig 3.14: Percentage contribution of genera and species in each family of Diptera

The following is a list of the characteristic features of diptera found in the study areas (Table 3.11).

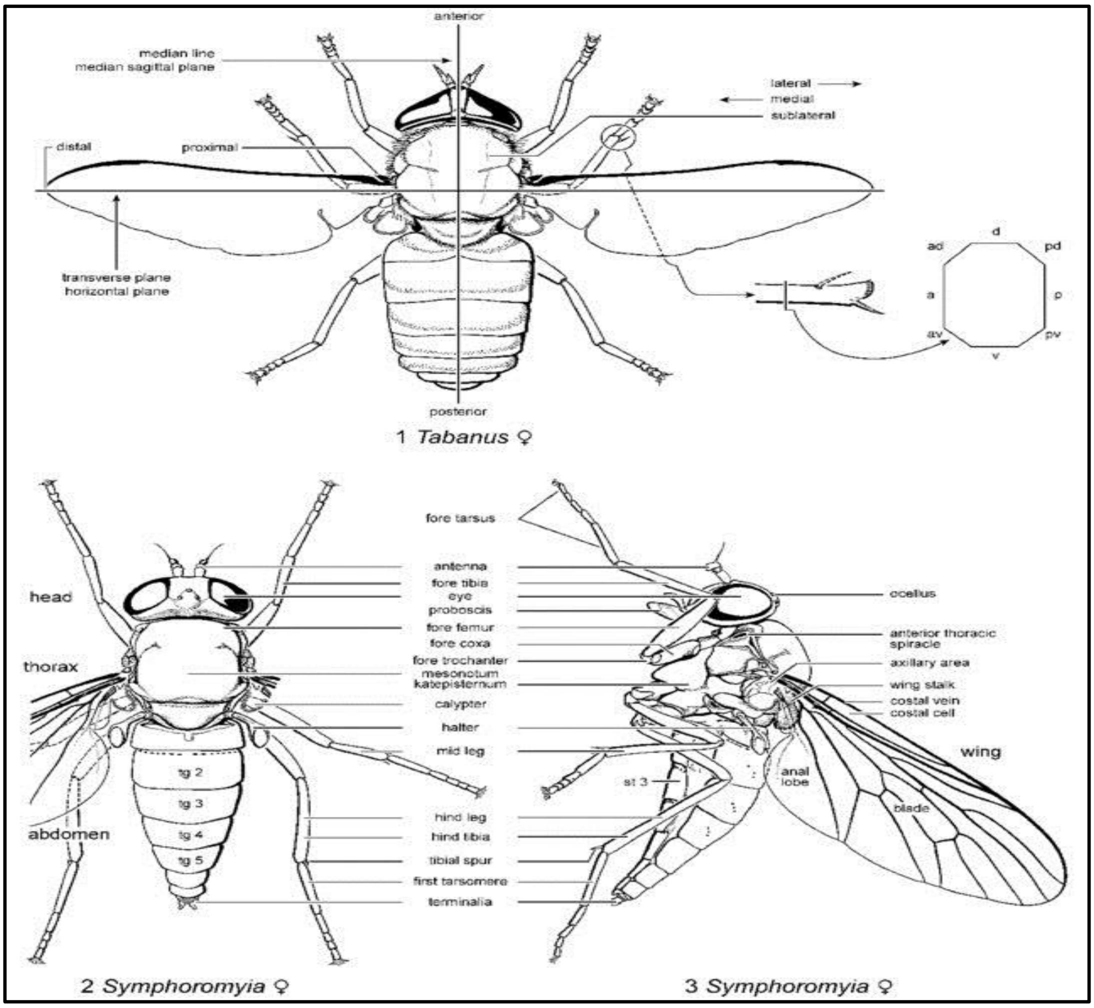


Fig 3.15: Anatomical divisions and parts of adult flies: (1) dorsal view of Tabanus americanus Forster (Tabanidae) ♀, to show orientation and anatomical planes (inset of vertical section through distal portion of right mid tibia showing external surfaces); (2) Symphoromyia montana Aldrich (Rhagionidae) ♀, dorsal view; (3) same, lateral view (both non-Afrotropical). Figs 1–3 (after McAlpine 1981, figs 1–3).

Abbreviations: a-anterior; ad-anterodorsal; av-anteroventral; d-dorsal; p-posterior; pd-posterodorsal; pv-postero-ventral; st-sternite; tg-tergite; v-ventral.

Key to Dipteran families *(Parui et al., 2006).*

1. Adult has antennae with more than 5 segments that aren't fused together to form a solid structure……..…………………………………….............................2
— Adult has antennae with less than 5 segments (usually three) or flagellum segments united together to form a solid structure, enclosed by a style……………………..3
2. On the mesonotum, there is a V-shaped suture; ocelli are absent. …….TIPULIDAE
— No V-shaped suture in the thorax, and ocelli are present. …..........….BIBIONIDAE
3. There is no frontal lunule on an adult's head……………....……………….……..4
— Distinct frontal lunule or a ptilinium on adult head…. …………..……..…………….7
4. Spurious vein present between veins R and M on wings; dorsal antennal arista ……...……………………………………………………….…….……SYRPHIDAE
— Spurious vein absent on wings; terminal antennal arista …………………………5
5. Pad-like arolium, as large as two pulvilli; mid tibia invariably with spur……………………………………………………………TABANIDAE
— Primitive hair-like empodium has replaced the arolium. …….………………….6
6. Flies with dense hairs, a slightly depressed vertex between the eyes, and a lengthy proboscis not suitable for piercing. …………………..……..…BOMBYLIIDAE
— Long-bristled flies with a prominent vertex between the eyes and a strong proboscis suitable for piercing …….……..……………………………….……...ASILIDAE
7. Theca not developed at the base of proboscis; antennal segment 2 above lacks a pronounced groove externally…….…………………………….……….………...8
— Theca formed near the proboscis's base; antennal segment 2 has a prominent external groove. ………………………………..…………………………..….11
8. Long wing with Cu2 that reaches or almost reaches wing margin…..…………..…9
— Short wing with Cu2 that does not reaches wing margin……..................………10
9. Cell Cu2 pointed……………………………………………………….….OTITIDAE
— Cell Cu2 bulbous……………………..…………………………...CONOPIDAE
10. Scutellum with two long spines; eyes and antennae carried on a short or long stalk……………………..…………………………...….………....DIOPSIDAE
— Ant like flies, normally located eyes and antennae; vibrissae present…..SEPSIDAE
11. Hypopleura without a row of strong bristles below spiracle……….….MUSCIDAE
— Hypopleura with one or more vertical series of bristles below spiracle……........12
12. Antennae aristae pubescent that does not extend much beyond the middle; greyish or dull black and black striped body...………...…………...….SARCOPHAGIDAE
— Arista has a feathery tip and a shiny blue or green body……....CALLIPHORIDAE

Table 3.11: Diagnostic characters of Diptera (9 families) recorded from the study site (Parui et al., 2006; Mitra et al., 2008; Sengupta et al., 2016)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
Asilidae **(Robber flies or Assassin flies)**	- Arista's body is a gleaming blue or green with a feathery tip - Arista's body is sparkling blue or green with a feathery tip - When viewed from the front, the vertex dipped between the eyes, forming a noticeable groove - Ocelli raised on a little island - Both sexes have well-separated eyes - Females have a variety of ovipositors	*Machimus* Loew, 1849	- body covered with fine golden brown hairs - abdomen long and slender with tapering end - short and stiff proboscis - dark wings and segmented abdomen	-	- 21mm (body length) - 30mm (body width with spread wings)
		Promachus Loew, 1848	-	*Promachus hinei* (Bromley, 1931)	- black to dark brownish in colour and hairy body - At the end, the abdomen begins to taper. prominent and straight proboscis - black compound eyes and legs - transparent wings and segmented abdomen
Bibionidae **(March flies or Love bugs)**	- The flagellum is divided into segments that are constricted but distinct - Palpi with many segments and a tendency to droop - The anal cell of the wing is nearly never shortened as it approaches the wing-margin - Antennae short, flagellar segments closely contracted and placed well below compound eyes	*Bibio* Geoffroy, 1762 aka March fly	- complete black body (head, thorax, abdomen) - dark translucent wing with black costa - short antennae and long legs	-	- 12mm (body length) - 26mm (body width with spread wings)
		Plecia Wiedemann, 1828 aka Lovebugs	- brown or black body with brown thorax - dark translucent wing with black costa - long black legs	-	- 12mm (body length) - 22mm (body width with spread wings)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
Bombyliidae **(Bee flies)**	- Hairy resembles like-bee - Frequently has a long proboscis - R2+3 and R4 often sinuate - Four posterior cells - Furry species with a distinctive pattern of vividly coloured scales - Head globular - Highly movable	*Anastoechus* Osten Sacken, 1877	- large compound eye - body densely covered with silky golden hairs all over - long black legs and rigid black proboscis - black wings	-	- 10–12mm (body length)
		Bombylius Linnaeus, 1758	- mimic bumblebees	*Bombylius major* (Linnaeus, 1758) aka Greater Bee Fly	- 6.3–12mm (body length) - dark body densely covered with golden hairs - short and pointed antennae - long legs and rigid black probosis
				Bombylius minor (Linnaeus, 1758) aka Heath Bee Fly	- smaller than *B. major* (7-8.5mm body length) - long spear-like proboscis - furry body is dull gold - pale yellow femora (3rd segment of the legs)
		Villa Lioy, 1864	- abdomen black, thorax dull black and rounded head - antennal tip pointed ended with bristle - scutellum with closely adhering black scales - clear iridescent wings	-	- 5-17mm (body length) - 1st and 2nd segment rufous laterally - 7th segment with whitish pubescence laterally
Calliphoridae **(Blow flies, Blue Bottle Flies or Green Bottle Flies)**	- Postscutellum absent or very weakly developed	*Calliphora* Robineau-Desvoidy, 1830	-	*Calliphora vomitoria* (Linnaeus, 1758) aka Blue Bottle Fly	- 10-14mm (body length) - shiny blue body and bigger than houseflies - dull grey head and thorax, long yellow-orange setae present at the back of the head

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
					- black bristly hairs cover the body and legs - antennae short and clubbed with four tarsi each - red eyed
		Lucilia Robineau-Desvoidy, 1830	- small green to purple coloured fly - third antennal segment 5 times of second - wing tinged brown - subcostal sclerite with stiff black hairs - squama dark brown	-	-
Muscidae **(House fly and relatives)**	- Small to medium to in size - Hypopleural bristles are missing, but there may be extremely minute hairs arranged in an uneven pattern	*Musca* Linnaeus, 1758	-	*Musca domestica* (Linnaeus, 1758) aka Housefly	- adult (6-7mm) - wingspan (13-15mm) - head convex from front while it is flat and conical from behind - 3 ocelli and short antennae - non-functional maxillae - flexible proboscis
Scathophagidae	- Small sized, ground nesting eusocial or solitary -	*Cordilura* sp. Fallen, 1810	- black or dark brown in colour - metallic greenish-tinted - presence of white abdominal bands on terga - presence of basal abdominal hair bands	-	-

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
Syrphidae **(Hover flies)**	- Often seen hovering at flowers - Spurious vein in the wing bisects the radio-medial cross - R5 cell and frequently M2 closed - Many mimic bees or appear similar to bombyliid flies - Larvae are either predate on aphids or live in decaying vegetation - Their abdomens and thoraces have glossy cuticular body surfaces	*Ceriana* sp. Rafinesque, 1815 aka Dandelion fly	- mimic wasps with yellow black markings on body - rounded abdomen - long and joint antennae	-	- 10-11mm (body length)
		Episyrphus Matsumura & Adachi, 1917	-	*Episyrphus balteatus* (De Geer, 1776) aka Marmalade fly	- the only genus possessing lengthy hairs on the upper surface of the calypter's lower lobe. larvae feed on aphids - mesonotum is dull unlike other tribes - ♂ have the eyes meeting on the top of the head, whilst ♀ have widely separated eyes
		Eristalinus sp. Rondani, 1845 aka Band-eyed dronefly	- mimic yellow-black markings similar to bees - metallic yellow-brown thorax and densely yellow hairy - yellow-brownish scutellum - abdomen is reddish-yellow with black transversal streaks - 5 distinct vertical dark stripes on compound eyes	-	- 11-14mm (body length)
		Eristalis Latreille, 1804 aka Drone fly	- resembles to honeybee drones - Short brownish-yellow hairs cover the thorax and the first segment of the abdomen - on their thorax, the pupa contains 2 pairs of cornua (horn-like bumps)	*Eristalis horticola* (De Geer, 1776)	- wing length (8-11 mm) - face pale dusted - antenna mere brownish black - dull tergite on the yellow spots - yellowish abdominal spots - dark clouding wing developed more in ♀ - at the base 3 pale femur (♂) and half basal (♀)

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
			- a syphon on the larvae's back end serves as a breathing system and also serves as a tail - males tend to have lighter patterns than females	*Eristalis tenax* (Linnaeus, 1758)	- average wing length (9.75–13 mm) and wingspan (15 mm) - eyes are marbled in black - stouter in appearance, just like bees - abdomen varies from dark brown to orange - have dark front tarsi and broad dark facial stripe
		Eumerus Meigen, 1822	- black coloured hoverflies with cylindrical smooth body - powerful hind legs - fine hairs cover the majority of the head, with compound eyes. (♂) and are divided across the forehead (♀) - flat face with hairs directed downwardly - longitudinal stripes on the back of thorax	-	- body size ranges from 5–12 mm - yellowish, or white and black legs
		Sphaerophoria Le Peletier & Serville, 1828	- body is long and narrow, with yellow and black bands - transparent wings - short yellow antennas - yellow face and scutellum - thorax is a bit dull, copper colored with broad yellow side stripes	-	- body size (7-12mm) - wingspan (5-7mm) - lateral scutellum stripe ends at the transverse suture and faint or strong stripe extending past the suture
Tabanidae **(Horse flies)**	- Large and conspicuous Squam - At least on the middle legs, tibiae with spurs	*Tabanus* Linnaeus, 1758	- small, slender flies - yellowish abdomen with inverted black markings on tergum 2	-	- body size (30mm) - wingspan (65mm) - wing with a broad hyaline region up to the hind edge in posterior cell 5

DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED					
FAMILY		**GENUS**		**SPECIES**	
	- Antennae and veins are separating into a broad fork across the wingtip - Flies with a huge fiat head and eyes that are frequently brightly coloured patches or bands in life				- never swollen tibia
Tachinidae **(Bristle flies)**	- Brilliantly coloured to dull coloured and resemble blow-flies - More bristler and more robust - Three-segmented antennae present - Bare or plumose aarista - Calypters are large - Their fourth long vein sharply bends - Postscutellum present, strongly convex	*Tachina* Meigen, 1803	- thread-waisted sand wasps - medium-sized wasps - antennae as long as head plus thorax	-	-
		Nowickia Wachtl, 1894	-	-	- a yellow-red abdomen with a black longitudinal pattern in the middle and a black hairy thorax - at the end, there are a lot of long straight bristles wings are hyaline (glass like), base yellowish - palps' bottom half is brown or blackish - dorsal centre of men is slightly concave - in the abdomen, only 7 and 8 segments are hairy

PLATE 12: Species account of Diptera

1.*Machimus* sp.1

2. *Machimus* sp.2

3. *Promachus hinei*

4. *Bibio* sp.

5. *Plecia* sp.1

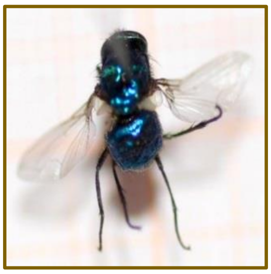
6. *Plecia* sp.2

7. *Anastoechus* sp.

8. *Bombylius major*

9. *Bombylius minor*

10. *Villa* sp.



11. *Lucilia* sp.1

12. *Lucilia* sp.2

13.*Calliphora vomitoria*

14. Unidentified

15. *Musca domestica*

16. *Cordilura* sp.

17. *Ceriana* sp.

18. *Eumerus* sp.

19. *Tabanus* sp.

20. *Nowickia* sp.

PLATE 13: Species account of Diptera

21. *Episyrphus balteatus*

22. *Eristalinus* sp.

23. *Eristalis tenax*

24. *Eristalis horticola*

25. *Eristalis* sp.1

26. *Eristalis* sp.2

27. *Eristalis* sp.3

28. *Sphaerophoria* sp.

29. *Tachina* sp.

3.4.2.4. ORDER IV - Coleoptera (4 families): Diversity of beetles and coccinellids

Presently, beetles are the most common group of insect fauna rich in species-groups on this planet (Gupta et al., 2018). Beetles, unlike most other pollinators, visit flowers to ingest pollen (a protein) rather than nectar. They were among the first insects to visit flowers, and they continue to play an important role in pollination today. They have evolved with chewing mouthparts as part of their physiology. Pollinating beetles primarily travel around collecting pollen that adheres to their bodies and "accidentally" depositing it on the stigma of the flower to complete pollination. Some beetles devour petals and other floral elements, making them pests in gardens and agriculture. Many species of Epicauta, Lytta, Clinteria, Gametis, and Protaetia are notorious as agricultural pests all over the world, earning them the sobriquet "*mess and soil*" pollinators (Erhardt, 1993). The Himalayas are home to 75% of the Indian species, Epicauta (Saha, 1979).

Historical Review

"*Systema Naturae*" (Vol.10) outlines 50 insects from India, with roughly 41 of them attributed to the Himalayas (Linnaeus, 1758). Between 1906 and 1949, the first comprehensive collection of order Coleoptera from India was published in the form of 19 booklets titled "Fauna of British India, including Ceylon and Burma." Cerambycidae, Chrysomelidae, Scarabaeidae, Curculionidae, Carabidae, Passalidae, and other key families were covered in this series. The taxonomic studies of different families of IH have been extensively studied by Jeannel (1949), Sengupta (1976, 2005), and Hartmann (2016). Gupta et al. (2016, 2017) documented an annotated checklist of Aphodiinae (Scarabaeidae) from India, and his Scarabaeidae checklist from Himachal Pradesh appeared in 2005. Chandra (2011a, 2011b) studied Sikkim's insects and India's states and union territories. Veer (2011) studied dermestid beetle diversity in India and supplied identification keys for adults. Pal and Dasgupta (2014), and Dasgupta and Pal (2016) have described all new species of Nitidulidae from the Indian Himalaya recently. Dryocoetes and Scolytus (Curculionidae, Scolytinae) were described by Mandelshtam and Petrov (2010a, 2010b) from Afghanistan and northern India. Indomias, Baris, Acythopeus, and Pachynotus were updated by Ramamurthy and Ayri (2010).

Staphylinidae, Scarabaeidae, Dermestidae, and Curculionidae were documented in Kargil, Ladakh by Feroz et al. (2015). In Tawang, Arunachal Pradesh, Poorani and Sambath (2017) discovered 11 different species of ladybird beetles.

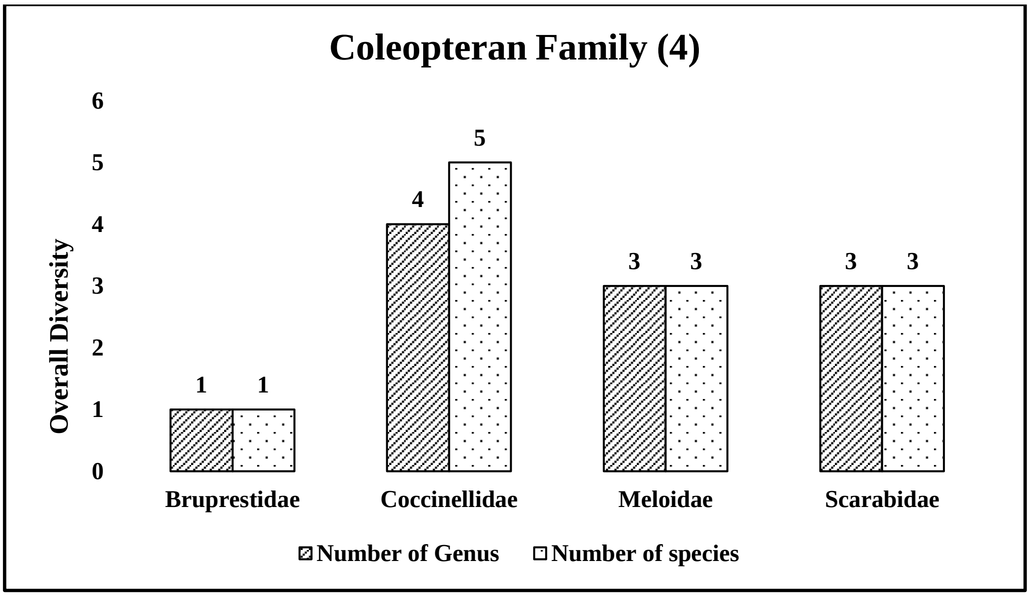


Fig 3.16: Overall family-wise diversity of Coleoptera in both study areas

From several sampling locations in the Mandakini Valley (Non-Organic) and Doon Valley (Organic), a total of 12 beetle species from 11 genera, representing 5 subfamilies from 4 families, were documented as flower visitors/pollinators of various crop plants. During the current course of study, all recorded beetle species were placed into 4 super families, namely, Buprestoidea, Coccinelloidea, Scarabaeoidea, and Tebrionoidea, with one family each. The superfamily Buprestoidea consisted of the family Buprestidae, which had one sub-family (Agrilinae). Another superfamily, Coccinelloidea, consisted of the Coccinellidae, having 2 sub-families, Coccinellinae and Epilachninae. The superfamily Scarabaeoidea consisted of the Scarabaeidae, having a single sub-family (Cetoniinae). Lastly, the superfamily Tebrionoidea also has a single family of Meloidae with a Meloinae sub-family. There were around 5 sub-families reported from the 4 families of lepidoptera (Table 3.4 & 3.5). Coccinellidae is comprised of 2 sub-families, Coccinellinae and Epilachninae, in which *Adalia* sp., *Coccinella septempunctata*, *Halzia* sp., and *Henosepilachna* sp. are dominant in nature. The sub-families Agrilinae, Meloinae, and Cetoinae consisted of *Agrilus* sp., *Epicauta* sp., *Hycleus* sp., *Lytta* sp., *Clinteria* sp., *Gametis* sp., and *Protaetia* sp. as beetle dominant species.

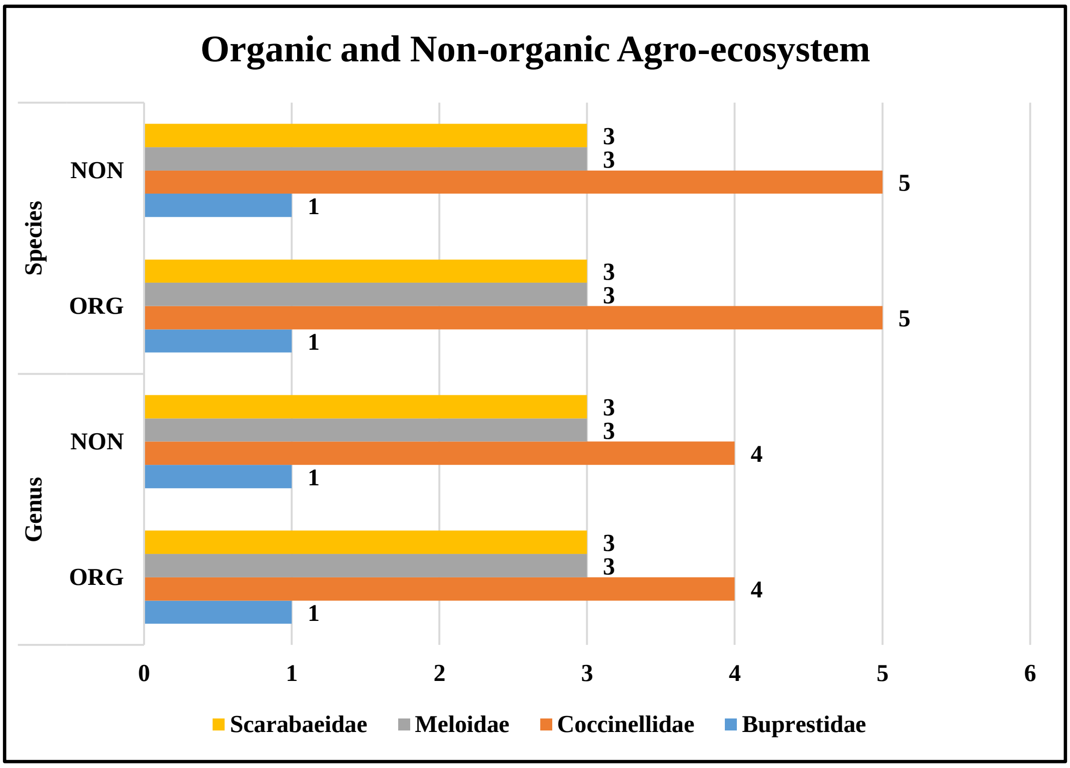


Fig 3.17: A clustered bar chart showing family-wise diversity of Coleoptera in Organic and Non-organic agro-ecosystems

In the case of both organic and non-organic agro-ecosystems, it was found that the maximum number of species occurred in the family Coccinellidae (5), followed by Meloidae and Scarabaeidae with 3 species each, and Buprestidae with a single species representation. In terms of genera, again, Coccinellidae (4) exhibited the highest degree of diversity among all families, followed by Meloidae (3), Scarabaeidae (3), and Buprestidae (1) (Fig. 3.16).

Table 3.12 and Fig. 3.17 reveal the relative abundance of each family of Coleoptera from the distinguished agro-ecosystems. The relative abundance of the families showed that the Coccinellidae, with 4 genera, contributed 37%, followed by the Meloidae and Scarabaeidae with 3 genera each and a 27% contribution. Buprestidae were the least dominant, contributing only 9%. Upon analyzing the species numbers, it was observed that the Coccinellidae (5) were dominant, with a relative abundance of 42%. It was followed by Meloidae and Scarabaeidae (3 species each), contributing 25%. Buprestidae had the lowest percentage of contributions, at 8%.

Table 3.12: Number and percentage of genus/ species along with dominant species in the Coleopteran family

SNo	**Family**	**No. of Genera**	**% of Genera** (Round off)	**No. of Species**	**% of Species** (Round off)	**Dominant Species**
1	Buprestidae	1	9	1	8	-
2	Coccinellidae	4	36	5	42	*Coccinella septumpunctata*
3	Meloidae	3	27	3	25	-
4	Scarabaeidae	3	27	3	25	*Gametis* sp. *Clinteria* sp.
	Total	**11**	**100**	**12**	**100**	

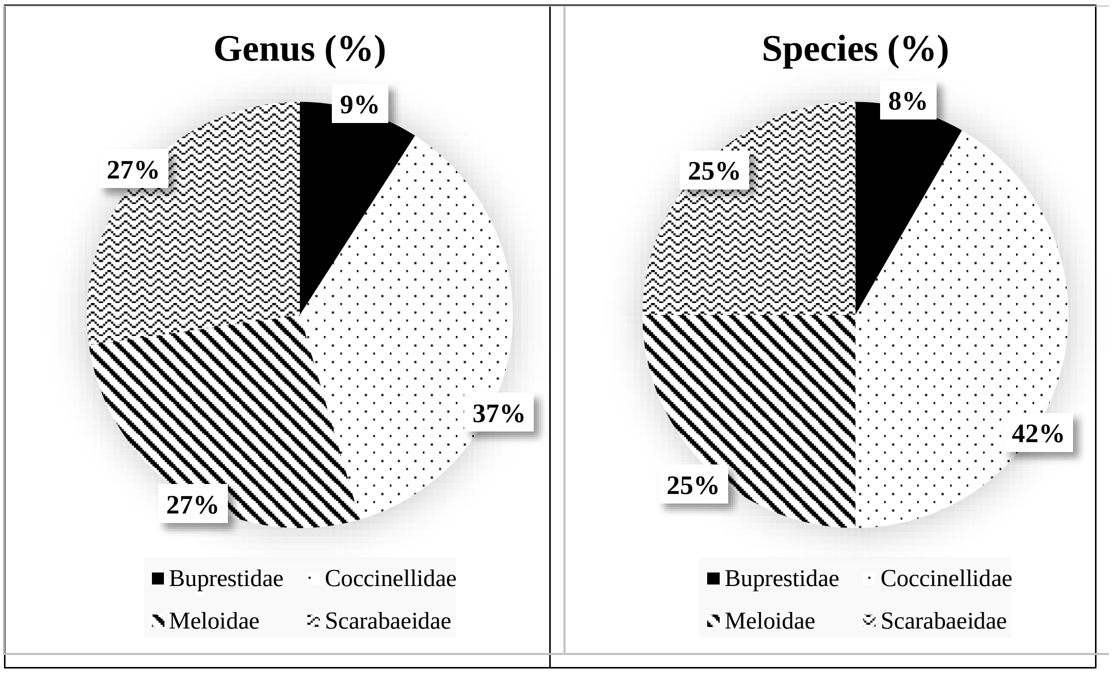


Fig 3.18: Percentage contribution of genera and species in each family of Coleoptera

The following is a list of the distinctive features of Coleoptera found in the study area, along with their body parts (Fig 3.18 & Table 3.13).

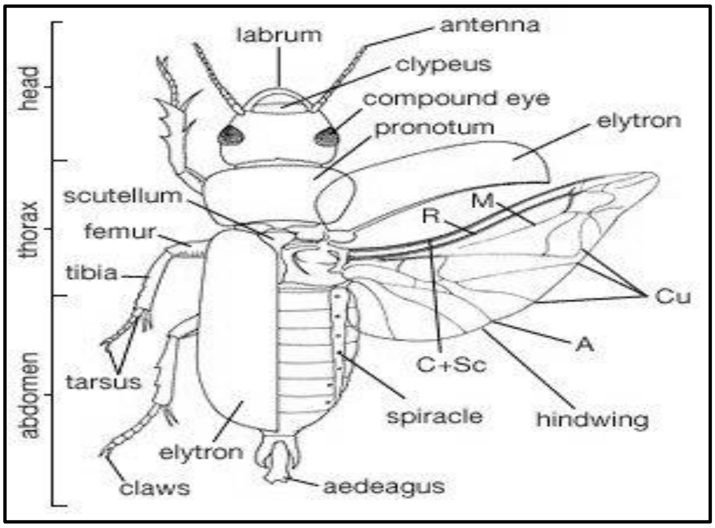


Fig 3.19: Body plan of Coleoptera (Weber, 1966). The veins of wing shown (with their abbreviations) are anal (A), cubitus (Cu), media (M), radius (R), and costa + subcosta (C + Sc).

Table 3.13: Diagnostic characters of Coleoptera (4 families) recorded from the study site (Gupta et al., 2018)

FAMILY		**DIAGNOSTIC CHARACTERS OF GENUS/SPECIES REPORTED**			
		GENUS		**SPECIES**	
Buprestidae **(Jewel beetles or metallic wood-boring beetles)**	- 7.5-60mm (body size) - Jewel beetles or metallic wood-boring beetles - Iridescent colours with a glossy sheen	*Agrilus* Curtis, 1825	-	-	- 5mm (body length) and 1mm (width) - shiny copper body with a tint of green colour
Coccinellidae **(Ladybugs)**	- 0.8-10mm (body size) - Ladybugs or ladybird beetles - Word coccineus (in Latin) means scarlet (colour) - Bright shining colour - Spot or patch patterns - Black head, legs and antennae - Round to elliptical, dome-shaped body - natural predators or bio-control	*Adalia* Mulsant, 1850	- 2 white spots at the adjoining of black pronotum and elytra - 2 white patch at the base of antennae	-	- 7mm (body length) and 5mm (body width) - light orange coloured body - large black spots interconnected to each other
		Coccinella Linnaeus, 1758	- red or orange colour, punctuated with black spots or bands - adults and larvae are voracious predators of aphids	*Coccinella septempunctata* (Linnaeus, 1758) aka Ladybird beetle	- 7mm (body length) and 5mm (body width) - red with 7 spots, 3 each on elytra and one in middle - 2 white patch at the base of eye
		Halyzia Mulsant, 1846	- pronotum lighter in colour	-	- bright brownish yellow in colour - 7 mm (body length) and 5 mm (body width) - several cream colored oval shaped spots present all over in a form of network
		Henosepilachna Li & Cook, 1961	- rust orange body with white glossy elytra	-	- 7mm (body length) and 5mm (body width) - black pronotum - 6 black spots on each elytra

Meloidae **(Blister Beetles)**	- Secrete defensive blistering agent (Cantharidin) - Hypermetamorphic and aposematically colourful - Hind coxae large and prominent - Tarsal claws cleft or toothed	*Epicauta* Dejean, 1834	- head and pronotum comparatively smaller to abdomen	-	- 1mm (body length) and 6mm (body width) - metallic greyish - velvety body
		Hycleus Latreille, 1817	-	-	- 13mm (body length) and 7mm (body width) - metallic blue body with 3 vertical yellow band
		Lytta Fabricius, 1775	-	-	- 12mm (body length) and 3mm (body width) - tan brown shiny elytra - head, thorax and legs black
Scarabaeidae **(Scarab beetles)**	- 2.5-100mm (body size) - Stout bodied - Metallic coloured - Some are fossorial - Some have prominent horns on their pronotum - Plates composing antennal club flattened and capable of close apposition	*Clinteria* Burmeister, 1842	- underneath of abdomen hairy - two yellow spots on the elytra	-	- 14mm (body length) and 5mm (body width) - metallic green body
		Gametis Burmeister, 1842	- underneath of abdomen and femur hairy - light yellow spots present on elytra	-	- 15mm (body length) and 5mm (body width) - rust red and green non-metallic body
		Protaetia Burmeister, 1842	- rough elytra with vertical engravings	-	- 18mm (body length) and 6mm (body width) - black bodied and non-hairy

PLATE 14: Species account of Coleoptera

1. *Agrilus* sp.

2. *Adalia* sp.

3.*Coccinella septempunctata*

4. *Coccinella* sp.1

4. *Halzia* sp.

6. *Henosepilachna* sp.

7. *Epicauta* sp.

8. *Hycleus* sp.

9. *Lytta* sp.

10. *Clinteria* sp.

11. *Gametis* sp.

12. *Protaetia* sp.

3.5. Conclusion

In addition to having considerable land and perennial water supplies, the Garhwal Himalaya exhibits a diverse range of species. A diverse range of endemic flora, wild life, and insects are supported by topography, vegetation, and unique environmental variables. The Mandakini valley and Navdanya Agrobiodiversity Conservation & Ecological Farm in the Garhwal Himalayas are rich in floral and faunal diversity. The climates of both study sites are favourable for traditional mountain cultivation. Jiju (2011), Jiju et al. (2017), and Kumar et al. (2019) conducted investigations based on pollinators, spiders, organic farming, and seed conservation in the Navdanya farms. But, traditional mountain-based farming systems in the villages of three gram panchayats (Huddu, Barangali, and Ushara) of Ukhimath block was a pioneer work. Previous works have been done by Sati (2005, 2009), Singh (2009), Tiwari (2013), Singh and Sondhi (2016), Saini (2021) that basically dealt with farming systems, bee forage, bee keeping, and butterfly checklists in the Garhwal Himalaya.

The present study documented the presence of 32 families, 119 genera, and 177 species of primary pollinators belonging to the orders Hymenoptera, Diptera, Lepidoptera, and Coleoptera from both the study areas. Lepidoptera (72) exhibited the highest species richness, followed by hymenoptera (65), diptera (28) and then coleoptera (12). Genus-wise, all four orders exhibited the same trend with 52 genera of lepidoptera, followed by 36 genera of hymenoptera, 20 genera of diptera, and 11 genera of coleoptera. Hymenoptera with a total of twelve families topped the list of primary pollinators, followed by Diptera (9), then Lepidoptera (7) and Coleoptera (4).

In organic agro-ecosystems, it was found that the maximum number of species occurred in the order lepidoptera (62), followed by hymenoptera (57) and then diptera (27). In terms of genera, again, lepidoptera (45) had the highest number of genera from seven families, followed by hymenoptera (31) from twelve families, and diptera with 20 genera from 9 families. While in non-organic agro-ecosystems, lepidoptera had the highest species diversity (60) and genera (44), followed by hymenoptera (49 species, 28 genera), and finally diptera (23 species, 18 genera). Hymenoptera (11) had the maximum number of families, followed by diptera (9) and then lepidoptera (7) in non-organic study sites.

Organic agro-ecosystems demonstrated a higher species richness of primary pollinators than non-organic agro-ecosystems at the agricultural field level. This corresponds to an overall positive effect of organic farming on crop diversity, regardless of pollination method (Gabriel et al., 2007). Pollinator abundance and diversity have been reported to benefit from organic farming (Weibull et al., 2000; Menalled et al., 2001; Morandin and Winston, 2005; Roschewitz et al., 2005; Gabriel et al., 2006; Hyvonen, 2007). Many crops can be pollinated by wild bees and other insects. However, their importance in crop pollination has been overlooked for decades. More emphasis is being placed on the proper supervision of regional agro-ecosystems and the conservation of natural or semi-natural suitable pollinator habitats in adjacent landscapes as their ecosystem services have become more widely recognised (O'Toole, 1993; Cane, 1997b; Kevan and Phillips, 2001; Klein et al., 2003a; Slaa et al., 2006).

Chapter 4: Impact of different Cropping system on Richness of Pollinators

4.1. Overview

Because India is primarily an agricultural country, previous studies were limited to economically and commercially important plant species in order to apply data to improving seed yields through pollination manipulation and pollinator management. As a result, improved plant varieties have been developed, leading to the growth of mono-cropping systems, which ultimately resulted in a tragic situation: the destruction of forests for extended areas of agricultural land; large-scale indiscriminate use of pesticides, insecticides, and herbicides; and the loss of plant gene pools and reduced genetic diversity. Further, such operations result in the loss of nesting sites of wild insect species that have a beneficial role in the conservation of plant species, pollination of cultivated crops, and the maintenance of genetic diversity (Aluri, 1990). Experiencing this situation, biologists have slowly started to investigate the pollination system and breeding structures of agricultural crops.

Pollination biology studies began only after the advent of volumes of literature in Europe and North America. Honeybees and megachilid bees are more appropriate for management and manipulation of agricultural crop pollination (Aluri, 1990). In natural conditions, wild bees require native plants for sustenance when their primary cultivated forage crops are out of bloom. Their success depends on the availability of particular wild insect species. Insects reported as pollinators include flies, bees, wasps, moths, and butterflies.

4.2. Understanding the Cropping pattern in Garhwal Himalaya

The cropping system describes the types and sequence of crops grown in a specific area over the course of time. It could be the growing of different crops on the same plot of land in a rotational manner throughout the year (Johnson and Peter, 1984). A cropping pattern is a scientific tool for analyzing the spatial distribution and relationship between crops and the land on which they are grown (Das, 1990). Cropping patterns can be used to better understand current agricultural conditions, regional land use patterns, and crop planning in the future (Mandal, 1982).

Cropping systems refer to the arrangement in which crops are planted or cultivated on a piece of land during a set period of time. It is a repetitive form of cropping system in which only one major crop is cultivated on the same piece of land year after year.

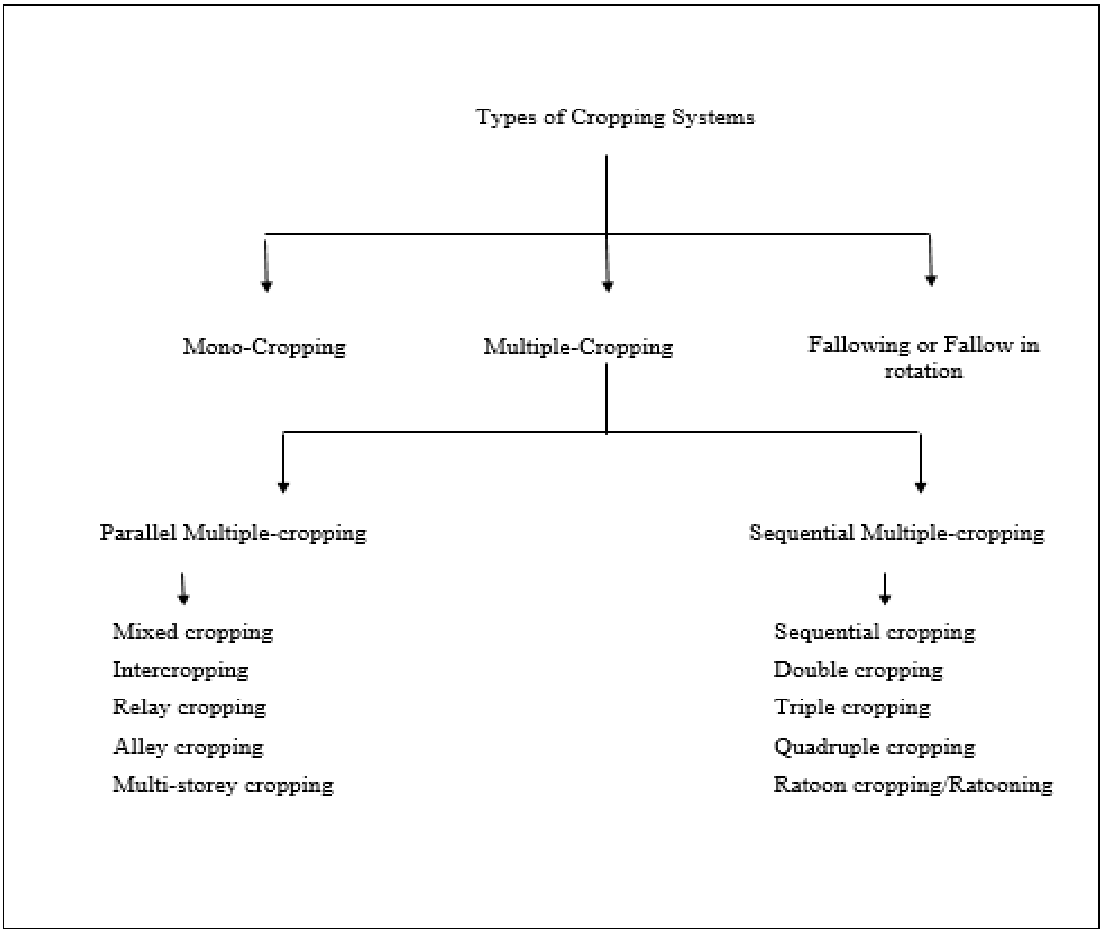


Fig 4.1: Prevalent Cropping Systems in India

For example, rice-rice, bajra-bajra. Basically, they are classified into three types of cropping systems: mono-cropping, multiple-cropping, and fallowing. There are certain advantages and disadvantages to mono-cropping practises in the mountain region. Crop growers find it convenient at the times of sowing, harvesting, or other farm operations. For that reason, farmers often overlook the problems generated by mono-cropping, such as soil deterioration and low fertility, as well as increased insect pest infestation. Multiple cropping is a cropping system in which two or more than two crops are cultivated on the same farmland in a year in succession, sequence, or association over the entire or portion of their life cycles. For example, green gram + wheat + sorghum or black gram + linseed + wheat. It has its own advantages and disadvantages. In other words, it can also be referred to as the cultivation of a variety of crops rather than concentrating on a particular crop or simply crop diversification in agriculture. It has been acknowledged as a viable method for attaining the goals of food and nutrition security, income progression, reduction of poverty, job creation, and the sensible use of land-water resources, as well as sustainable development and improvement of agriculture and the environment (FAO, 2001).

Traditionally, four cropping systems are upheld in the Garhwal Himalayas. These are kitchen garden or homestead-based cropping systems in which seasonal vegetables and fruits are grown exclusively for subsistence; the irrigated mode of land cropping system with staple food crops of rice and wheat; the upland or unirrigated cropping system, with dominant crops of millets and pulses; and the summer camp cropping system with cultivation of pseudo cereals and beans (Singh 1996, 1998b, 2005; Shiva et al., 2005; Singh et al., 2014). Local farmers created and managed the various cropping systems in accordance with differing micro-ecological niches suitable for the development of specific crops and crop combinations.

4.2.1. Sari System

Agriculture influenced and, accordingly, moulded the evolution of humans. It was devised and improved over years at several cradling sites and has spread globally. Different ethnic groups adopted different farming practises as per the local climate and cultivated crops suitable for their areas. Rain-fed agriculture accounts for 85% of all cultivated land, whereas irrigated agriculture accounts for only 15% (Maikhuri et al., 1996). Both systems have exclusive agricultural processes and crop compositions. Wheat and paddy are the main crops on irrigated land, whereas traditional crops such as *Amaranthus viridis, Eleusine coracana, Panicum miliaceum, Setaria italica, Perilla frutescense, Hordeum vulgare, Secale cereale*, and numerous legumes are grown in rainfed agriculture. The Himalayan region has a rich agrobiodiversity. The farming communities of the Western Himalayas practice low-input agriculture with a strong emphasis on maintaining diversity of crops at both the species and intra-species levels (Bisht et al., 2006). Mountain farming lacks intensive agricultural operations because of its difficult terrain. The crops are sparsely grown. Furthermore, because of significant soil erosion, agricultural areas are limited to low-lying river valleys and foothill plains, which account for a very small area. Landholdings are mainly small in size and consequently limited to family farms, while tenant farming and sharecropping are uncommon. Each family in the Mandakini valley splits their plots into two parts, each of which is cropped for two to four years before being left fallow for two to four years (Nautiyal et al., 1998). This system was created to provide moisture and nutrients to the soil. Similar observations were made by Cornish and Pratley (1991) and Greb et al. (1979).

Sari is a type of terrace farm that is used for crop production during a specific season (Fig. 4.2 and 4.3). Two Saris are commonly identified based on their presence in the village. Terrace farms can be found above and below the villages of Mallasari and Mullasari, respectively. Terrace farms in Uttarakhand are divided into two kinds based on their elevation. *"Danda"* refers to the highland areas, whereas *"Gangarh"* refers to the lower elevated hill parts. In terms of rainfall and snowfall, the Danda region receives more than Gangarh. As a result, the Gangarh region is receiving rainwater (Chandra et al., 2020). Under the Himalayan rain-fed agroecosystem, the cultivable land has a lot of tree cover on the field boundaries along with the crops. The cropped area is usually divided into two equal parts, locally referred to as *"Mullasari"* and *"Mallasari"* (Dangwal et al., 2007). Here, crops are managed through a biannual crop rotation system and are rotated every two years (Fig. 4.1). A two-year rotation is used in the Baranaaja system (Zardhari, 2000). Rabi crops such as *Hordeum vulgare*, Lens culinaris, and *Triticum aestivum* are sown while *Oryza sativa* is mixed with *Echinochloa frumentacea* during the Kharif season of the first year of crop rotation. During the Rabi season the following year, the land is left fallow, and nearly a dozen crops, or "barahnaja," are intercropped in the Kharif season (Fig. 4.1). In this method, millets and amaranth culms support growing legumes, while legumes fix atmospheric N_2 and nourish other crops. The traditional crop rotation system also helps conserve rainwater, improve soil health, increases crop yield, and protects small-scale farmers in the event of crop failure. Multiple crops growing in close proximity often turn out to be the saviours and secure the financial security of the farming communities. The out-migration of natives and the practice of conventional mono-cropping in the region are posing serious threats to this traditional practice.

The traditional practice of *barahnaja* in the mountains exemplifies the advanced nature of subsistence farming in the Garhwal Himalaya. It is often considered a sophisticated rain-fed hill farming intercropping system. The regional crops *bhat* (soybean), *gahath* (horse gram), *lobiya* (French beans), *rajma* (common kidney beans), *ogal* (buckwheat), *mandua/koda* (finger millets), *ramdana/marchhu* (amaranthus), *urad* (green gram), *moong* (black gram), *naurangi* (mix of pulses), *kheera* (cucumber), and *bhang* (cannabis) are cultivated together in a finely balanced mixture to maximize output and soil fertility while also catering to a wide range of household needs. Farmers spend no or a meagre amount of money on farm inputs in the case of indigenous farming, since the seeds, compost manure, and bio-pest control are virtually free. They would begin planting as soon as they realized the conditions were favourable. Mountain farming is diverse in every way, but the fragility of the terrain does not allow for intensive agronomic activities and growing crops. Furthermore, soil fertility is extremely low as a result of severe soil erosion.

4.2.2. Seasonality of Crops (Rabi and Kharif)

Kharif, or the summer crop season (April to September), and Rabi, or the winter crop season (October to March), are the two main agricultural seasons in this region. The Sari system of agriculture is unique to the Uttarakhand Himalayas (Chandra et al., 2020). Almost all of the crops are planted throughout the region, but the intensity and yield differ by district. Wheat, grams, and peas are produced copiously in the plains of *Bhabar, Doon, Dwar,* and *Tarai,* predominantly in some portions of Haridwar, Dehradun, Pauri, and Udham Singh Nagar districts, where wheat, gram, and peas are extensively grown. Rabi or the winter crop season (October to March) and Kharif or the summer crop season (April to September) are the two main agricultural seasons in the region. The Sari system of agriculture is unique to the Uttarakhand Himalayas (Chandra et al., 2020).

The commencement of the Kharif season varies according to several elevational gradients. The Kharif season lasts from May-June to September-October in low-altitudinal regions, but it begins in early June-July and lasts till October-November in high-elevation areas. Paddy is the chief crop this season. Here, in the hilly terrain, traditional crops such as millets and pseudo-cereals are extensively grown. It is found that millets help to reduce soil erosion by being grown on slopy land. Paddy is extensively cultivated in the "*Danda"* (irrigated) rather than "*Gangarh"* land (Sati, 1993). Potatoes are grown extensively in most of the Danda regions with gentle slopes, and in some regions, potatoes are exported to regional markets. Various kinds of crops, cereals and pseudo-cereals, lentils, and vegetables such as chilli peppers, coriander, capsicum, brinjal, squash, and cucurbits.are grown throughout the year in kitchen gardens or homesteads and polyhouses.

Grain legumes are generally Kharif season crops that are rain-fed. Mustard, barley, wheat, peas, grams, and lentils are the principal food crops grown during the Rabi season. During the Rabi season, however, a few crops such as peas and lentils are grown. Some are grown on the bunds (field margins) of irrigated paddy fields, while others are restricted to trivial sections of kitchen gardens. In the region of Garhwal Himalaya, legumes are traditionally grown by mixing them with non-legume crops such as amaranthus, eleusine, echinochloa, and maize, a method known as "Barahnaja." Literally, the phrase refers to the growing of roughly 10-12 crops in tandem in order to maximise and diversify production per unit space (Shiva and Vanaja, 1993; Ghosh and Dhyani, 2005). Growing legumes with non-leguminous crops provides climbing support for the latter, decreases chances of insect infestation, makes management of weed easier, and mitigates the harmful impacts of intense, long-term farming on soil fertility.

Crop rotations promote a wide range of food crops, fodder, and underutilized plants, which, in addition to enhancing overall farm output and fertility, may aid in plant genetic resource conservation on the farm. Integration of livestock into the farming system generates additional sources of income through eggs, meat, dairy products, wool, fur, and draught power. Tree crops and on-farm forestry integrated into the farming system provide shade and windbreaks while providing food, income, fodder, and fuel wood. Shade and windbreaks are provided by tree crops and on-farm forestry, which also supply food, fodder, fuel wood, and income. Gaining financial returns are not the sole objective of farmers. Their intent is typically to improve land-animal-plant interactions, protect natural nutrient and energy flows, and boost biodiversity, all of these factors contribute to the larger goal of sustainable agriculture: preserving natural resources and ecosystems for future generations.

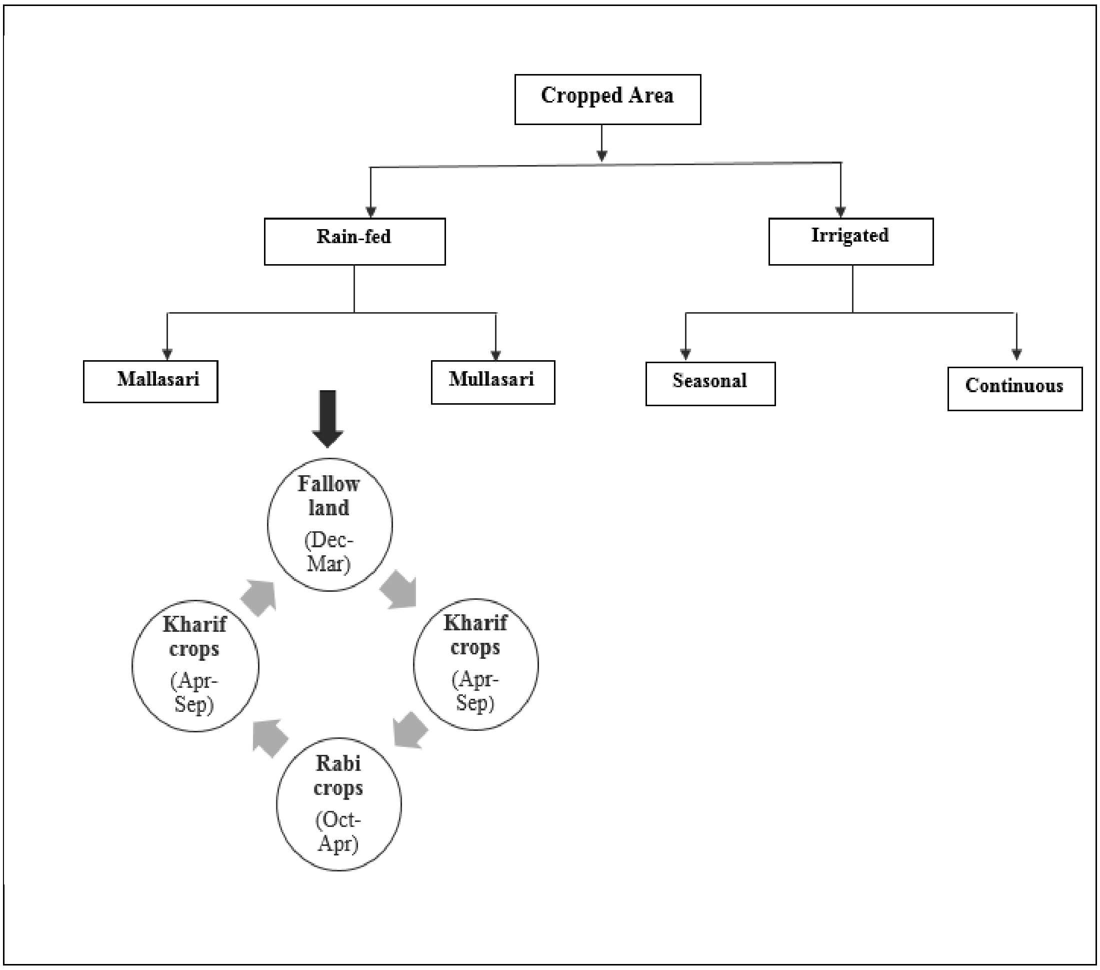


Fig 4.2: Crop cultivation in traditional Himalayan rain fed agro-ecosystems (Dangwal et al., 2007)

4.3. Methodology

A replicated trial was carried out to determine pollinator foraging behaviour in both mono-cropping and multiple-cropping systems. Seven sampling plots (5m x 5m dimension) in each transect were studied in each type of cropping system (for details, please refer to chapter 2). The diversity and foraging behaviour of insect visitors in various cropping systems were visually recorded at different times of the day, namely at 10.00, 12.00, and 15.00 hours, with observations taken every alternate day beginning with the first day of flowering. The observations were recorded from the bloom of every treatment replicated three times. Simultaneously, weather parameters were also recorded. The collected insects were killed, preserved, and identified by comparing them with the reference collection maintained at the laboratory.

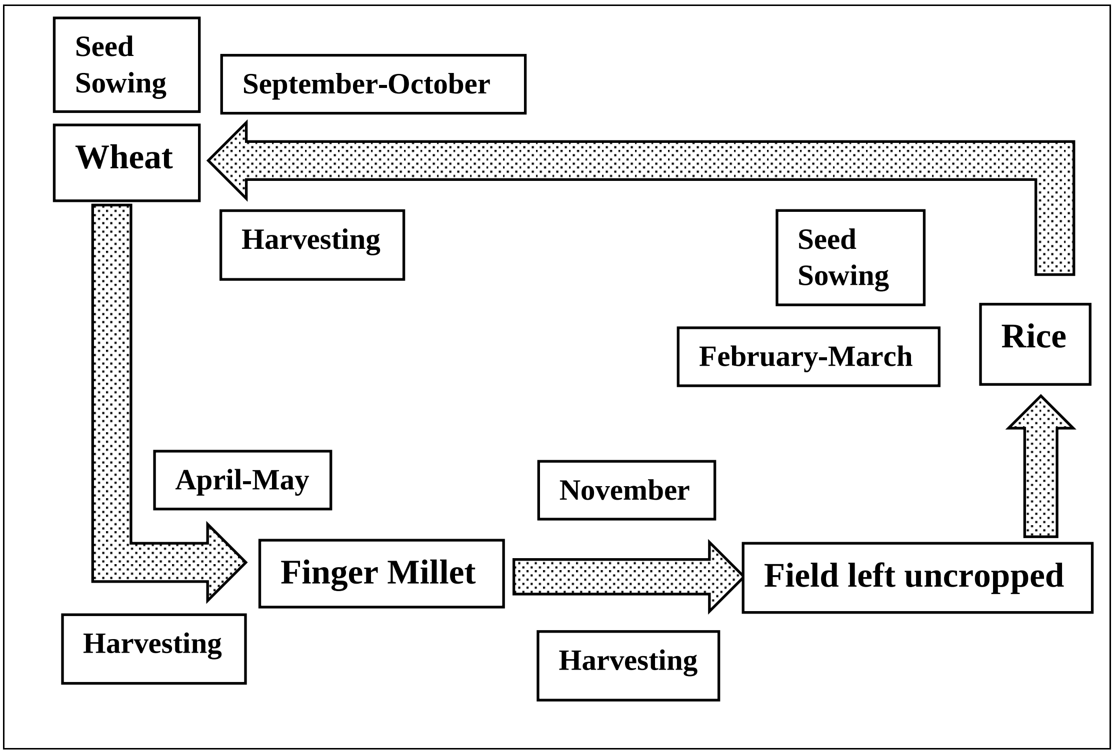


Fig 4.3: Biannual crop rotation system with dominant crops of a Sari system (Chandra et al., 2020)

Fig 4.4: Sari system followed in Garhwal Himalaya (Mallasari and Mullasari)

4.4. Results and Discussions

I performed a t-test (Student, 1908) between the two cropping systems (mono-cropping and multiple-cropping) on both organic and non-organic farms (for details please refer to chapter 2). A t-test is an inferential statistic that is used to examine whether two related groups have statistically significant differences in their means. It is a hypothesis testing technique that can be used to assess an assumption that is applicable to a population. To evaluate statistical significance, a t-test examines the t-statistic, t-distribution values, and degrees of freedom.

For socio-economic aspect, I interviewed 187 households out of 249 and inference were drawn from the primary as well as secondary data. Natives of Garhwal Himalayas were actively involved in occupations other than agriculture in order to get extra income. Instances of migration and reason behind was also explored. Besides, status of bee hives, bee colony and bee foraging resources as well as beekeepers were also studied.

Objective 2: Comparative study of different cropping systems practiced in Mandakini and Doon valley with respect to socio-economic impact on richness of pollinator

Hypothesis: There will be significant difference present in the species richness of pollinators in different cropping systems

Statistical Method: t-test was performed between:

- Mono-cropping and multiple-cropping in organic agro-ecosystems
- Mono-cropping and multiple-cropping in non-organic agro-ecosystems

Results: As per the t test it was found that there was a significant difference present in the mean number of species richness of:

- pollinators between Mono-cropping and multiple-cropping of organic agro-ecosystems ($t=10.345$, $p < 0.05$)
- pollinators between Mono-cropping and multiple-cropping of non-organic agro-ecosystems ($t=5.715$, $p < 0.05$)

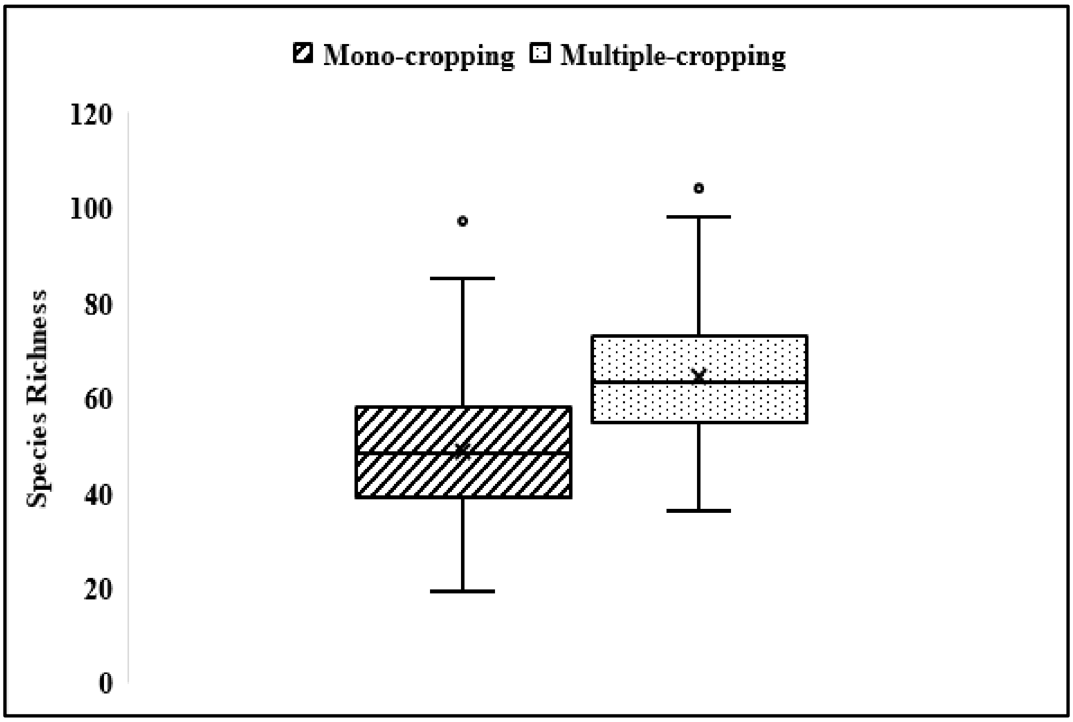


Fig 4.5: The box plot displays the mean species richness in organic agro-ecosystem comparing mono-cropping and multiple-cropping (Doon Valley)

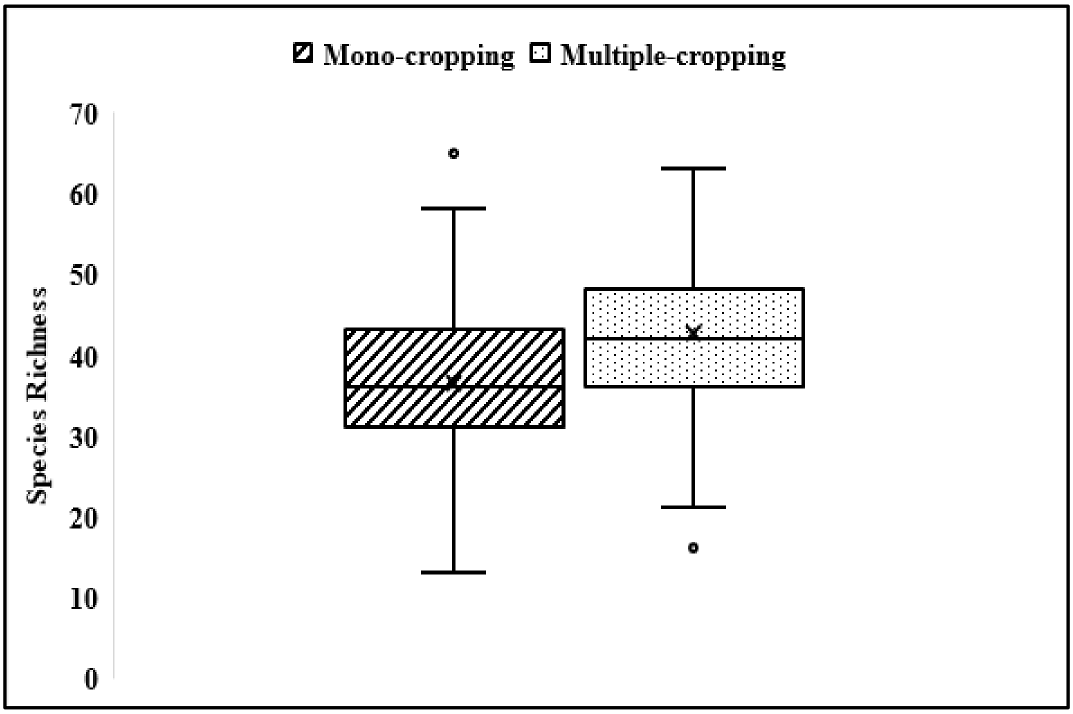


Fig 4.6: The box plot displays the mean species richness in non-organic agro-ecosystem comparing mono-cropping and multiple-cropping (Mandakini Valley)

The investigation found that there was a significant difference present in the mean number of species richness of pollinators between mono-cropping and multiple-cropping of organic agro-ecosystems ($t=10.345$, $p < 0.05$) and non-organic agro-ecosystems ($t=5.715$, $p < 0.05$). The box plot signifies the higher species richness of primary pollinators in the multiple-cropping of organic agro-ecosystems than those of non-organic agro-ecosystems. Likewise, the box plot signifies the higher species richness of primary pollinators in the mono-cropping of organic agro-ecosystems than those of non-organic agro-ecosystems. Possible explanations include (i) the higher availability of foraging options in multiple-cropping agro-ecosystems, (ii) the generalist species can congregate around any crop plants regardless of floral habitat and, (iii) the specialist species refer specific plants for their pollen preferences.

4.4.1. Cropping systems and their impact on richness of pollinators

Croplands have increased globally since the early 1960s, resulting in the gradual decline of grasslands and forests (Klein Goldewijk et al., 2004; FAO, 2016). The extent of agricultural land is predicted to expand by 10% by 2030, primarily in developing countries (Haines-Young, 2009). The composition (e.g., habitat loss) and spatial configuration (e.g., land fragmentation) of land-cover types are shifted as a result of anthropogenic-induced land-use alterations (Fahrig et al., 2011). The loss of nesting and feeding places, as well as essential floral resources, has been connected to declines in wild bees and butterflies (Burkle et al., 2013; Bommarco et al., 2014; Senapathi et al., 2015; Goulson et al., 2005; Biesmeijer et al., 2006; Potts et al., 2010; Scheper et al., 2014; Baude et al., 2016). Increased habitat loss and degradation have lowered the fruit set of insect-pollinated crops (Klein et al., 2002, 2012) and wild plants (Aguilar et al., 2006; Batáry et al., 2013; Clough et al., 2014) by eroding pollinator density or variety. Habitat fragmentation can also occur as a result of land-use changes, altering the extent and connectivity of habitat patches (Hadley and Betts, 2012; Hooke and Martn-Duque, 2012). This has the potential to limit pollinator gene flow and has long-term consequences for the persistence of their population (Darvill et al., 2010), as well as negatively affect wild plant sexual reproduction, particularly in species that are obligatory pollinators (Aguilar et al., 2006).

Many different ecological aspects of farmland habitat may be affected by agricultural practices such as monoculture and polyculture farming (Benton et al., 2003;

Holzschuh et al., 2007; Rundlöf et al., 2008; Savilaakso et al., 2014; Azhar et al., 2014b). In agricultural landscapes, habitat heterogeneity, is linked to higher biodiversity, whether measured on a small or large scale (Benton et al., 2003; Azhar et al., 2015a). Tews et al. (2004) found that habitat heterogeneity, which is intrinsically connected to vegetation structural complexity and floristic diversity, drives animal species diversification. The evolution of structural complexity and floristic diversity in an agricultural landscape may supply complementary vegetational components (Cunningham et al., 2008) and impact the faunal colonization of agricultural areas (Munro et al., 2009).

Multiple-cropping systems help to conserve biodiversity by offering habitat to a wide variety of species (Jackson, 2002; Jones and Gillett, 2005; Picasso et al., 2008; Elba et al., 2014). However, the current study established that insect pollinator species richness, abundance, and composition were similar in mono-cropping and multiple-cropping systems. This suggests that the existing multiple-cropping systems will not boost insect pollinator diversity. This could be attributed to the abundance of cover crops and ornamental plants grown along farmland or in kitchen gardens. We believe that, notwithstanding the slightly nonsignificant result, there is at least some evidence that the species richness of insect pollinators is statistically higher in multiple-cropping systems than in mono-cropping systems. According to a previous study, multiple-cropping systems can provide more diverse biota resources than mono-cropping, as polyculture have more structural complexity and floristic diversity (Azhar et al., 2014a; Ghazali et al., 2016; Syafiq et al., 2016). Mono-cropping can reduce overall diversity and, at the same time, allow insect species to thrive (Elliott al., 1998). Because of the limited spatial complexity of mono-cropping systems, the ensuing insect communities were simple and species-poor (Danielsen and Heegaard, 1995). Also, the resource quality varies with stand size since certain species have a restricted supply of food (Tscharntke et al., 2002). However, the current study's findings show that mono-cropping systems do not differ significantly from multiple-cropping systems in terms of butterfly variety, owing to the smallholding's patchiness (i.e., due to numerous ownership considerations) enhancing habitat heterogeneity (Azhar et al., 2015a). In polyculture, a low level of crop diversity is likely to provide a small amount of nectar supplies or a modest number of host plants for butterflies.

Common eusocial pollinators like honey bees and bumble bees are generalists who collect nectar and pollen from a variety of plant types. Honey bees and other wild bees pollinate approximately 100 different fruits and vegetables, making them the most crucial agricultural pollinators, whereas the vibration of bumble bees, while pollinating ("*buzz pollination*"), is helpful in pollinating plants such as tomatoes and brinjal (Buchmann and Hurley, 1978; Buchmann, 1983; Berenbaum, 2007). Native pollinators help pollinate native crops including blueberries, squash, pumpkin, cucumbers, and cranberries, but more research is needed to learn how to optimize pollination rates and promote healthy native pollinator populations.

Table 4.1. Crops cultivated in the Baranaaja system in Mandakini valley (dominant species; *associated species; **crops grown in kitchen garden)

S. No.	Cropping season	English name	Hindi/Local name	Scientific name	Family	Preferred Cropping system	Agents of pollination
1.	Rabi	**Wheat**	Gehun	*Triticum aestivum*	Poaceae	Mono-cropping	Self-pollination, Anemophily
2.		**Barley**	Jau	*Hordeum vulgare*	Poaceae	Mono-cropping	Self-pollination, Anemophily
3.		Red Lentil*	Masur	*Lens culinaris*	Fabaceae	Multiple-cropping	Entomophily
4.		Gram*	Chana	*Cicer arietinum*	Fabaceae	Multiple-cropping	Entomophily
5.		Kidney beans*	Rajmah	*Phaseolus vulgaris*	Fabaceae	Multiple-cropping	Entomophily
6.		Pea*	Matar	*Pisum sativum*	Fabaceae	Mono-cropping, Multiple-cropping	Self-pollination, Anemophily
7.		Beefsteak*	Bhangjeera	*Perilla frutescens*	Lamiaceae	Mono-cropping	Entomophily
8.		Brown Mustard*	Raai	*Brassica juncea*	Brassicaceae	Mono-cropping, Multiple-cropping	Entomophily
9.		Indian Mustard*	Gharia	*Brasssica nigra*	Brassicaceae	Mono-cropping, Multiple-cropping	Entomophily
10.		Indian Rapeseed*	Radu	*Brassica campestris* var. toria*	Brassicaceae	Mono-cropping, Multiple-cropping	Entomophily

11.	Kharif	Black Gram*	Urad/ Kali Dal	*Vigna mungo*	Fabaceae	Multiple-cropping	Entomophily
12.		Black eyed bean*	Lobia/ Suanta	*Vigna unguiculata*	Fabaceae	Multiple-cropping	Entomophily
13.		Rice bean*	Raiyans	*Vigna umbellata*	Fabaceae	Multiple-cropping	Entomophily
14.		Pigeon pea*	Tuar dal	*Cajanus cajan* var. *flavus*	Fabaceae	Mono-cropping	Entomophily
15.		Soybean*	Safed Bhat	*Glycine max*	Fabaceae	Multiple-cropping	Self-pollination & Entomophily both
16.		Black Soybean*	Kali Bhat	*Glycine soja*	Fabaceae	Multiple-cropping	Self-pollination & Entomophily both
17.		Horse gram*	Gahat	*Macrotyloma uniflorum*	Fabaceae	Multiple-cropping	Entomophily
18.		Amaranth*	Chaulai/ Marchhu	*Amaranthus caudatus*	Amaranthaceae	Mono-cropping, Multiple-cropping	Self-pollination, Anemophily
19.		Japanese Barnyard Millet	Jhangora	*Echinochloa frumentacea*	Poaceae	Mono-cropping	Self-pollination, Anemophily
20.		Asian spider flower*	Jakhiya	*Cleome viscosa*	Cleomaceae	Multiple-cropping	Entomophily
21.		Foxtail Millet	Kauni	*Setaria italica*	Poaceae	Mono-cropping	Self-pollination, Anemophily

22.		Finger Millet	Mandua/ Koda	*Eleusine coracana*	Poaceae	Mono-cropping	Self-pollination, Anemophily
23.		Rice	Dhaan/ Satti	*Oryza sativa*	Poaceae	Mono-cropping	Self-pollination, Anemophily
24.		Sorghum	Jowar	*Sorghum bicolor*	Poaceae	Mono-cropping	Anemophily, Entomophily
25.		Sesame*	Til	*Sesamum indicum*	Pedaliaceae	Multiple-cropping	Entomophily
26.	Zaid (Though many vegetables are grown in poly-houses irrespective of cropping season)	Maize**	Makka/ Mungari	*Zea mays*	Poaceae	Multiple-cropping	Anemophily
27.		Potato	Aloo	*Solanum tuberosum*	Solanaceae	Mono-cropping	Entomophily
28.		Tomato**	Tamatar	*Solanum lycopersicum*	Solanaceae	Mono-cropping, Multiple-cropping	Entomophily
29.		Cucurbits** (cabbage, cucumber, cauliflower, pumpkin, Slipper gourd, squash)	Kakoda/ kaakri/ pahadi karela/ kheerkanda	*Brassica* sp, *Cucurbita maxima, Cucumis sativus, Cyclanthera pedata, Sechium edule*	Cucurbitaceae	Mono-cropping, Multiple-cropping	Entomophily
30.		Chili pepper/ Capsicum**	Mirch/ Shimla mirch	*Capsicum annuum, C. frutescens*	Solanaceae	Mono-cropping, Multiple-cropping	Entomophily

31.		Onion**	Pyaz	*Allium cepa*	Amaryllidaceae	Mono-cropping, Multiple-cropping	Entomophily
32.		Garlic**	Lehsun	*Allium sativum*	Amaryllidaceae	Mono-cropping, Multiple-cropping	Entomophily
33.		Ginger**	Adarak	*Zingiber officinale*	Zingiberaceaae	Mono-cropping	Entomophily
34.		Safflower**	Pahadi kesar	*Carthamus tinctorius*	Asteraceae	Mono-cropping, Multiple-cropping	Entomophily
35.		Coriander**	Dhania	Coriandrum sativum	Apiaceae	Multiple-cropping	Entomophily
36.		Cardamom**	Elaichi	*Elettaria cardamomum*	Zingiberaceaae	Mono-cropping	Entomophily
37.		Turmeric**	Haldi	*Curcuma domestica*	Zingiberaceaae	Mono-cropping	Entomophily
38.		Radish**	Muli	*Raphanus sativus*	Brassicaceae	Multiple-cropping	Entomophily
39.		Mint**	Pudina	*Mentha viridis*	Lamiaceae	Mono-cropping	Entomophily
40.		Beans**	Sem	*Dolichus lablab*	Fabaceae	Multiple-cropping	Entomophily
41.		Brinjal**	Baingan	*Solanum melangena*	Solanaceae	Multiple-cropping	Entomophily
42.		Fenugreek**	Methi	*Trigonella foenumgraecum*	Fabaceae	Multiple-cropping	Entomophily

Table 4.2: Crops grown in Navdanya organic farms (Doon valley) with their number of native seed varieties

S.No	**Crop**	**Scientific name**	**Family**	**Varieties (as on 2019)**
01.	Paddy	*Oryza sativa*	Poaceae	740
02.	Basmati	*Oryza sp.*	Poaceae	41
03.	Wheat	*Triticum aestivum*	Poaceae	240
04.	Barley	*Hordeum vulgare*	Poaceae	27
05.	Oats	*Avena sativa*	Poaceae	20
06.	Finger millet	*Eleusine coracana*	Poaceae	30
07.	Barnyard millet	*Echinochloa frumentacea*	Poaceae	3
08.	Foxtail millet	*Setaria italica*	Poaceae	21
09.	Pearl millet	*Pennisetum glaucum*	Poaceae	14
10.	Maize	*Zea mays*	Poaceae	21
11.	Lentils	Lentils, Peas, Chickpea, Soybeans	Fabaceae	97

12.	Vegetables	Pumpkin, Tomato, Brinjal, Lady's finger, Carrot	Apiaceae, Cucurbitaceae, Malvaceae, Solanaceae	159
13.	Oil seeds	Castor, Flaxseed, Sesame	Euphorbiaceae, Pedaliaceae, Linaceae	24
14.	Mustard	*Brassica campestris*	Brassicaceae	24
15.	Cereal grain (Rye)	*Secale cereal*	Poaceae	18
16.	Green manures	Alfalfa, Clover, Fenugreek	Fabaceae	134
17.	Kidney beans (Rajma)	*Phaseolus vulgaris*	Fabaceae	175
18.	Aromatics	Oregano, Citronella, Chamomile, Peppermint	Lamiaceae, Asteraceae	58
19.	Medicinal	Leek, Stevia, Tinospora, Terminalia, Centella	Apiaceae, Amaryllidaceae, Asteraceae	47
TOTAL				**1,940**

4.5. Socio-economic Aspects

Three gram panchayats of Ukhimath block of Rudraprayag district, having a total population of 1340 individuals and 266 households scattered in seven villages, were chosen. Of those 395 respondents, particularly women farmers, from 224 households were randomly selected for primary data generation. In Huddu GP, 77 out of 85 households, 67 out of 96 Ushara GP households, and 80 out of 85 households in Barangali GP were taken into account. A total of 87 sampling sites have been considered for the collection of pollinators, of which 37 from Huddu GP, 34 from Ushara GP, and 16 from Barangali GP from Ukhimath block in Rudraprayag district of Uttarakhand state.

Village: Social segregation was prominent and clearly distinguishable. The villages lying in the upper regions were more economically stable than those lying below the roads, lower regions.

Farming System:

- Mono-cropping as well as multiple-cropping systems (saviour from hunger in the worst scenario of crop failure)
- Prevalence of kitchen gardens (each household has small or big kitchen gardens where spices or seasonal vegetables were grown)
- Subsistence-oriented (paddy and wheat are the major food crops)
- Traditional farming (without the use of tools and farm machinery)

Division of Labour: Women played a substantial role, from household chores to farming activities.

Landholdings (1 Nali=200 m² and 50 Nali=1 ha) *and Secondary Livelihood options:* Farmlands, were generally scattered and terraced fields. Cow dung, urine from livestock, and ashes from burnt fuel wood are often used as manure. A total of 115 (n) farmers were interviewed. Of these, only 36 (31.3%) supported the indigenous farming system and wished to continue it in the future. Interestingly, out of these 36 respondents, 69.4% were generally above the poverty line (APL) card holders and belonged to the general social group category. The desire to continue farming stemmed from the social prestige associated with traditionally practising agriculture as a household activity, which fits their identity as an agrarian family and also contributes to household food security. At least 79 (68.6% of respondents opposed the indigenous farming system and wanted it to be phased out in the foreseeable future. Mountain agriculture was considered more of a part-time than a full-time occupation. The main reasons behind this were: high risk of crop failure due to erratic rainfall, insect-pest infestation, crop raiding by wild animals (monkeys, langurs, porcupines, barking deers, and wild boars), poor income, migration, and labour scarcity. During the surveys studied and collated, confirmed that an average occupancy of 13 Nali of landholdings. 68% of respondents were dependent on land for subsistence farming, while 30% of respondents worked as seasonal labourers (MGNREGA), 25% as shop owners, and 21% as pony keepers or doli bearers (chardham yatras) on a temporary basis. Though the number of people switching to MGNREGA has increased dramatically in recent years.

Apart from their primary occupation, i.e., agriculture, rural folks are actively involved in the following livelihood options in order to get extra income. People who are unable to migrate due to a lack of resources engage in a variety of secondary activities, such as;

- Weaving Basketry (Kanda, Hathkandi- *Dendrocalamus* spp.)
- Sericulture: Oak Tasar and Mulberry silkworm rearing (*Quercus* spp.) and spinning silk thread from silkworm cocoons
- Apiculture (*Apis cerana indica*) and honey selling
- Juice Extraction (*Rhododendron* spp., *Citrus sinensis*)
- Spices and Food Grains (cereals, pseudo-cereals)
- Dairy and Poultry (milk, ghee, eggs, meat)
- Sheep Rearing (wool, meat)
- Traditional broom making
- Tailoring and knitting (NMHS-provided training centre)
- Farm produce sold under the tag of organic products (pseudo-cereals, pulses, garlic)

Family Ownership, Average Income, and Seed or Chemical Usage: At least 154 households had working farm tools (hand hoe, sickle, iron/wooden plough, axe, spade, neck yoke, harrow, etc.). Besides, 63 of them had their own poly houses. Average members was 5 with an average annual income was one lakh. The seasonal loss of the farm yield was 1,500-3,500 INR. Around 123 households were into using treated seeds while 141 advocated the use of native seeds. Use of decomposed cow dung and burnt ashes in fields as manure to enhance their productivity. 119 families used chemical pesticides and fertilizers to get rid of insect pests or to get matured crops on time and enhance their productivity, which has a negative impact on pollinators.

Status of bee hives, bee colony and bee foraging resource:

- At least 95.08% of households were into traditional mud wall hives and bee keeping prior to 2017 and has seen a downfall by ten percent (84.37%) in 2020
- Average number of wall hives per house: 3-5 (2020) and >7 (prior to 2017)
- Number of traditional mud wall hives and colonies was decreasing in tandem with the increasing number of modern cemented houses
- Floral diversity ensured the availability of pollen-nectar (Amaryllidaceae, Apiaceae, Asteraceae, Brassicaceae, Cucurbitaceae, Rosaceae)

Status of Beekeepers:

- At least 79.41% of respondents: Ancestral knowledge and rest came from KVIC agencies or NGOs
- 15% of the total families engaged in beekeeping
- Only 7.95% of respondents: beekeeping as full-time job, rest as part-time
- 68.10% of respondents: pass on the indigenous knowledge of beekeeping to the next generation
- Male members: management and upkeep of wall hives and bee boxes, honey extraction.
- Older respondents-better knowledge and expertise
- Mandakini valley: the traditional wall hive-wall cavity left during house/cowshed construction, 150cm above ground level (>150 in cemented households)
- Entrance hole from outside (2 cm dia), plastered and covered with a wooden block from inside (oaks, chir pines, or deodar woods)
- *Apis cerana* naturally descends in the cavity, forming a series of parallel combs
- The wall hive is opened twice only to extract the honey (Verma and Attri., 2006)
- Probabilities of low or no bee forage during the off season or instances of weather adversities
- Beekeepers manage bee colonies and sustain the bee population by feeding sugar or jaggery solutions

The declining trend of beekeeping due to increased migration and house conversion (Tiwari et al., 2013) was verified. There are chances of disturbed mountain agro-ecosystems, if the issue is not addressed seriously. In comparison to 45 cm wide mud and stone dwellings, cemented houses with a 25 cm wall width are insufficient to host conventional wall hives (lack of insulation). Abandoned or dilapidated houses and cattle sheds could be renovated to epitomize valuable nesting sites for managed bees, *Apis cerana* (Singh et al., 2013). Traditional beekeeping practices in the mountains must be preserved in order to support the bee population and preserve the cultural heritage of the beekeeper communities. Furthermore, scientific investigations are needed to harness the full potential of beekeeping in the valley.

Table 4.3: Socio-economic baseline survey {1 Nali- 200 m², 50 Nali- 1 ha}

Category	**Household details**
Village (household) sampled	07 (187)
Number of people in household (average)	5 (3 to 11)
Average landholdings per household	13 Nali (3-26 Nali)
Possession of small farm tools and equipment	154
Ownership of poly houses	63
Livestock ownership (average/household)	5 (1 to 14)
Percent of household in traditional beekeeping (prior to 2017)	84.37% (95.08%)
Number of wall hives (average/household)	7 (3-5)
Ancestral knowledge of Beekeeping respondents	79.41%
Knowledge garnered from KVIC agencies or NGOs.	20.59%
Percentage of respondents, beekeeping as full-time job	7.95%
Percentage of respondents, beekeeping as part-time job	92.05%
Pass on the indigenous knowledge of beekeeping to the next generation	68.10%
Donot want to pass on the indigenous knowledge of beekeeping to the next generation	31.90%
Annual Income (average/household)	1,00,000 (₹ 30,000 to 4,00,000)
Seasonal loss of yield due to crop raiding/household	₹ 1,500-3,500
Use of treated seeds for cultivation	123
Use of native seeds for cultivation	141
Use of manure (cow dung, burnt ashes of fuelwood)	141
Use of chemicals fertilizers	119

Table 4.4: Preferences of farmers regarding their desire to continue with agriculture as a livelihood option or not as per their socio-economic status.

Category	Social Class	Desired (Reasons)	% (n1=36)	Not desired (Reasons)	% (n2=79)
Social Group	Scheduled Caste	- Food security	11 (3.96%)	- Low income - Other job options (MGNREGA, Anganwadi) - Lack of resources - Erratic rainfall - Crop raiding by wildlife	49 (62.02%)
	General	- Food security - Traditional occupation - Cannot leave the land fallow - Necessary tools & money	25 (69.4%)	- Erratic weather conditions (rain, snow, hailstone) - Crop raiding by wildlife - Labour unavailability	30 (37.9%)
Economic Status	Below Poverty Line (BPL)	- Food security	14 (38%)	- Migration - Erratic weather conditions (rain, snow, hailstone) - Crop raiding by wildlife - Lack of resources	25 (31.64%)
	Above Poverty Line (APL)	- Traditional occupation - Cannot leave the land fallow - Necessary tools & money	22 (61.1%)	- Migration - Erratic weather conditions (rain, snow, hailstone) - Crop raiding by wildlife	54 (68.35%)

n= Number of respondents interviewed
n1= Number of respondents desired to continue indigenous farming system
n2= Number of respondents desired to discontinue indigenous farming system

4.6. Conclusion

The road map for the overall development of the agriculture sector in the state is being achieved by the Uttarakhand Agriculture Policy 2011, though a new draft for the state agriculture policy 2018 has already been proposed. The current policy looks into the conversion of agricultural land for non-cultivable purposes, prioritizing soil and water conservation, one-time free soil testing for all farmers, promotion of farm mechanization, and the development of marketing infrastructure in the state. The principal objective of the state agriculture department is to have long-term food and nutrient security. It is also trying to recognize Uttarakhand as a seed state and an "*organic state,*" besides ensuring the economic security of the farming communities. For this, the state government intends to provide agriculture-related subsidies and crop insurance, increase HYVs crop area coverage, promote IPM, organic farming, mixed-cropping and intercropping, farmer-oriented training programs, and the organization of Krishi mahotsava, promotion of post-harvest management technology, etc. To expand organic farming, the state government plans to implement a number of ground-breaking initiatives, such as the use of bio-fertilizers, green manures, and vermicomposting. According to the state government, the total area certified for organic farming is currently at 23%, but will increase to 31% by the end of 2021. This is an important step because Uttarakhand currently accounts for 40% of the country's total organic farming, and it is also the first state in the country to pass an organic farming law.

Cross-pollination is required for most agricultural crops, which rely on insects for pollination and fertilization. Farmers are often unaware that the reason for their immature fruit formation and low seed production is the decline in pollinators (Partap and Partap, 2001). Therefore, it is necessary to make the public aware of the importance of pollinators and the process of pollination. A few research projects embracing pollination have been accomplished in the past with the collaboration of certain apiculturists and crop specialists. As per the recent trend in IHR, a sustained proportional drop in apple productivity is highlighted (Indian Horticulture Database, 2014). Inadequate pollination is also contributing to the productivity decline (Delaplane and Mayer, 2000; Sharma et al., 2009). There have been few systematic investigations into the orchards of IHR, particularly in the Kumaun Himalaya, to demonstrate links between pollinators and crop yield. However, a few studies from Himachal Pradesh demonstrate that insect pollinators influence fruit quality and quantity production in apples and other crops (Kumar, 1997; Mattu et al., 2012).

PLATE 15- Mono-cropping practiced in Non-Organic Farms

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1. *Echinochloa esculenta* in Millets group 2. *Cajanus cajan* in Lentil group 3. *Amaranthus caudatus* in Pseudocereals group 4. Cash crop of *Solanum tuberosum* 5. *Elettaria cardamomum* in Spices group 6. *Hordeum vulgare* in cereals group

PLATE 16- Multiple-cropping practiced in Organic Farms

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6

1. Mixed cropping 2. Practice of Agroforestry 3. Cash Crops 4. Twelve crops in a patch of land (Barahnaja) 5. Intercropping 6. Paired row cropping

PLATE 17- Secondary Livelihood Options in Mandakini Valley

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8

1. Basket Weaving (Kanda) 2. Spinning silk thread from Silkworm Cocoons 3. Tailoing and Knitting (Provision of Training centre under NMHS) 4. Traditional Broom making 5. Dairy and Cattle rearing 6. Apiculture (Tradional Mud-walled Hive) 7. Organic products (Pseudo-cereals, Garlic, Pulses) 8. Sericulture (*Loepa katinka* & *Bombyx mori*)

Chapter 5: Impact of Different Farming System on Richness of Pollinators

5.1. Overview

Terrace farming is the lifeline of the indigenous people of the Garhwal Himalaya. Traditional agricultural systems are used by several ethnic groups around the world. This mode of mountain agriculture is designed in such a way that it suits the microclimate of that particular region (Martin and Sauerborn, 2013; Thrall et al., 2010). The crop growers also devised a variety of indigenous ways of maximizing the use of available resources (Singh and Rana, 2019). Field preparation, seed sowing, and weed eradication procedures, crop selection based on environmental suitability, pest control, harvesting methods, and seed storage are some of these practices. Indigenous people typically produce a variety of crops in an intermixed or in crop rotation manner in order to maintain soil health and crop productivity.

Horticultural crops, spices and herbs, ethnomedicines, tea gardens, orchard culture, nursery operations, and reforestation are inextricably part of the Garhwal Himalaya farming system. In every way, these activities exhibit the diverse nature of rural livelihood options. Here, farm-related activities are primarily done in a traditional way. Cropping seasons, cropping patterns, land use patterns, crop output and productivity, and ecological zones and sub-zones vary according to the climate, ranging from low-lying river valleys and foothill plains like *Tarai*, *Bhabar*, *Doon*, and *Duar* to highly elevated, snow-covered areas. The land in the Garhwal Himalaya is characterised by undulating hills, terraced fields, and erosion-prone areas. The crop yields are significantly low due to the non-application of chemical fertilizers and the lack of adoption of advanced agricultural tools and machinery. Countless highland mountain rivers have deposited huge amounts of silt in the plains and foothills of the lower Himalayas. The region is known for its fertile alluvial plains and high productivity. People of the state have developed different forms of farming practices such as the Sari system (please refer to chapter 4). Barahnaja, IPM practices, cow dung and dried-green leaves as compost, mulching, field preparation for various crops, and rouging and weeding methods (Kumari et al., 2009; Maikhuri et al., 1997).

Even across short distances, mountain farming systems demonstrate various degrees of variation. The Himalayan Mountains have microclimatic diversity due to height, slope orientation, temperature, humidity, rainfall, water supplies, and distance from the snowline (Singh et al., 2014). Thus, according to the specific location, mountain farming can be classified into 11 situations (Singh, 1998b), viz., i) valleys - irrigated, ii) valleys - unirrigated, iii) lower altitude – north aspect, iv) lower altitude – south aspect, v) mid-altitude – north aspect, vi) mid-altitude – south aspect, vii) high altitude – north aspect, viii) high altitude – south aspect, ix) very high altitude – north aspect, x) very high altitude – south aspect, and xi) alpine meadows.

According to the Indian Network for Climate Change Assessment (INCCA 2010), the northwest Himalayas have five major farming systems: (i) cereal-based production systems (paddy, maize, millets, wheat); (ii) horticulture or agrihorti-based production systems; (iii) vegetables, floriculture, and mushroom-based production systems; (iv) livestock-based production systems; and (v) agrihorti-silvipastorial-based production systems. Wheat is the predominant crop in the western Himalayan region, but rice, maize, millets, barley, buckwheat, pulses, and oil seeds are wildely cultivated (Partap, 2011).

Indigenous farming systems have evolved to match average climatic patterns, resulting in the development of distinct crop calendars known as Fasal Chakra (crop cycles). Other factors that influence the crop calendar include labour availability, competing input demands, the availability of desirable crops or genotypes, and a lack of market. According to Singh et al. (1997), crop selection was influenced by nutritional requirements, ecological gradients, and socio-economic conditions in the area. Rotation patterns vary according to livestock fodder needs and seed availability. Crop rotation inputs based on scientific assessments of soil nutrient dynamics may aid in system advancement. The cropping calendar in villages of Mandakini valley in Rudraprayag district of Garhwal Himalaya is presented in Table 5.1.

Table 5.1: Annual crop calendar of major food grains, farming operations at villages of Garhwal Himalaya.

Cereals, Pseudo-cereals, Crops, Oilseeds												
Months	***Maize***	***Soybean***	***Paddy***	***Foxtail millet***	***Barnyard millet***	***Finger millet***	***Cowpea***	***Horse gram***	***Black gram***	***Wheat***	***Mustard***	***Lentils***
April–May	SW		SW									
May–June	WD		WD-1st	SW	SW	SW						
June–July		SW	WD-2nd					SW				
July–Aug		WD		TP	TP	TP	SW	WD				
Aug–Sept	HV		HV	WD	WD	WD	WD		BD		SW	
Sept–Oct		HV										
Oct–Nov				HV	HV		HV			LP	HV	SW
Nov–Dec						HV	HV	HV	HV	SW		
Dec–Jan Jan–Feb	LP											
Feb–Mar	LP											HV
Mar–April	SW									HV		

Note: BD = Broadcasting; HV = Harvesting; LP = Land preparation; SW = Sowing; TP = Transplanting; WD = Weeding

5.2. Methodology

A replicated trial was carried out to determine pollinator foraging preferences in different farming systems having crops belonging to diverse families. Seven sampling plots (5m x 5m dimension) in each transect were studied in each type of farming system (for details, please refer to chapter 2). The diversity and foraging behaviour of insect visitors in various farming systems were visually recorded at different times of the day, namely at 10.00, 12.00, and 15.00 hours, with observations taken every alternate day beginning with the first day of flowering. The observations were recorded from the bloom of every treatment replicated three times. Simultaneously, weather parameters were also recorded. The collected insects were killed, preserved, and identified by comparing them with the reference collection maintained at the laboratory.

5.3. Results and Discussions

In order to achieve my third objective, I performed an ANOVA (Stahle and Wold, 1989) followed by a Tukey's pairwise test (Tukey, 1953; Smith, 1971) for different insect orders and crop families under the farming systems. ANOVA (Stahle and Wold, 1989) is used for separating observed variance data into different components using a statistical approach. A one-way ANOVA is used for data sets with three or more groups. Tukey's pairwise comparison statistical test (Tukey, 1953; Smith, 1971) is a one-step multiple comparison procedure that is frequently used in conjunction with ANOVA (for details please refer to chapter 2).

Objective 3: Comparative study of different farming systems adopted in different study sites and its impact on richness of pollinators

Hypothesis: There will be significant difference of species richness of pollinators between different farming systems

Statistical Method: I performed ANOVA followed by Tuky's pair wise test.

Results: As per ANOVA, the significant difference present between species richness of pollinators and different farming systems

Significant difference present between

Amaryllidaceae and Apiaceae

Amaryllidaceae and Araceae

Amaryllidaceae and Lamiaceae

Amaryllidaceae and Pedaliaceae

Significant difference present between

Hymenoptera and Coleoptera

Lepidoptera and Coleoptera

Lepidoptera and Diptera

The insect pollinator diversity of the Garhwal Himalaya as reflected through investigation showed that the order lepidoptera was the most active group of pollinators during the day followed by the hymenoptera, diptera, and coleoptera, which includes 177 species belonging to 119 genera in 32 families and 53 sub-families. The crop families that were the most preferred forage by the insect pollinators were Amaryllidaceae, Asteraceae, Rosaceae, Rutaceae, Solanaceae, Polygonaceae, Brassicaceae, Cucurbitaceae, and Fabaceae. The least preferred families were Apiaceae, Araceae, Lamiaceae, and Pedaliaceae. The families such as Amaranthaceae, Meliaceae, Moraceae, Myrtaceae, and Zingiberaceae were the moderately preferred ones.

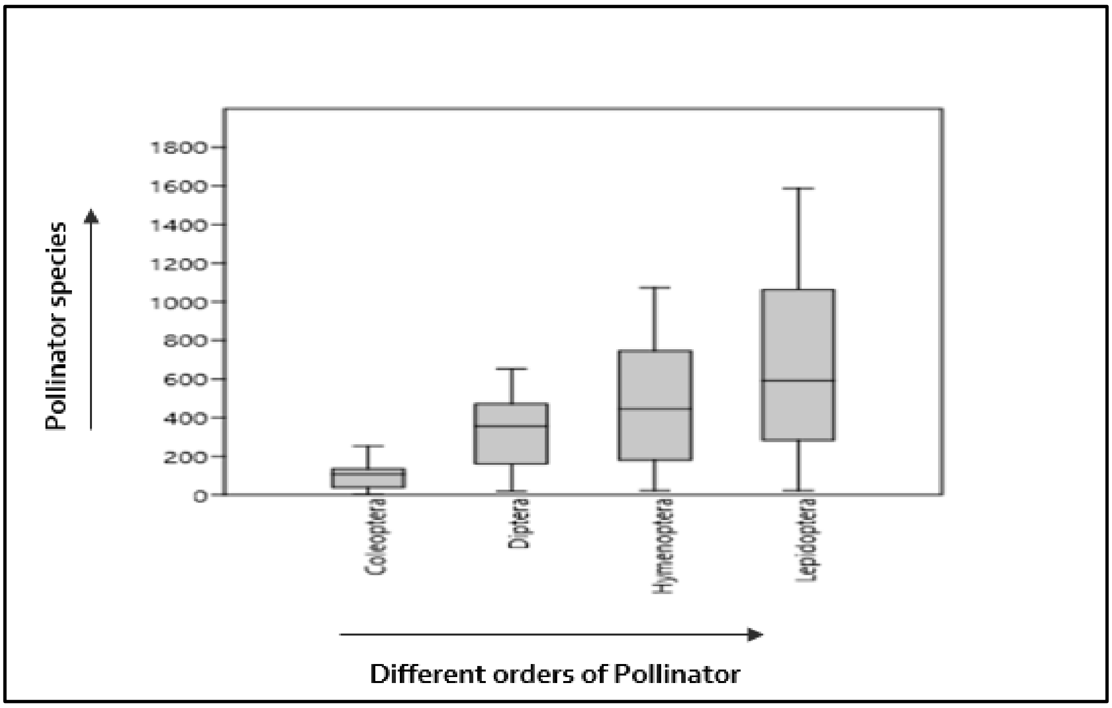

Fig 5.1: Box plot depicts the range of visiting agricultural crops by different orders of pollinators

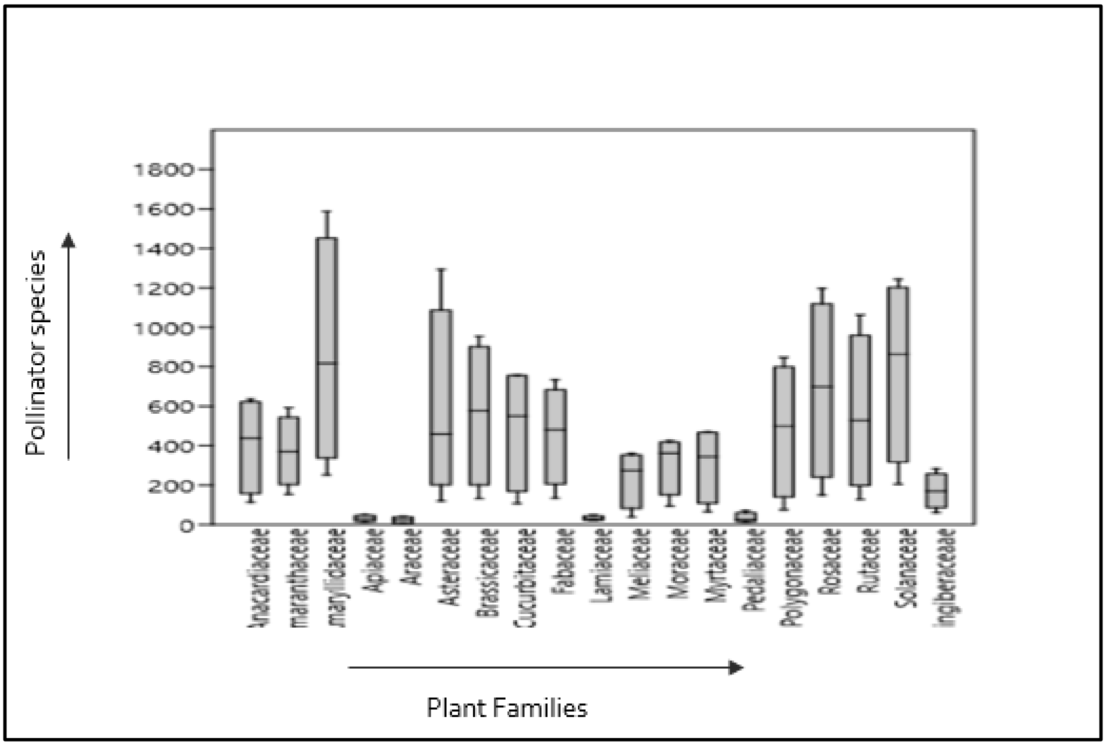

Fig 5.2: Box plot depicts the pollinator species visiting different plant families

5.4. Status of Pollinators and Pollinator-dependent Crops and Wild Plants

Diversity and abundance of the bee fauna are vital for healthy agro-ecosystems. As pollinators of crops and wild flowers, bumblebees serve a crucial role in agricultural and natural ecosystems. These commercially vital insects pollinate plants that produce a large portion of our food supply. Bumblebees are the primary pollinators when honey bee pollination is hampered by cold weather (Stelzer et al., 2010; Raina et al., 2019). Bee pollinators prefer crop species; *Allium cepa, Allium sativum* (Amaryllidaceae), *Coriandrum sativum* (Apiaceae), *Lactuca sativa, Carthamus tinctorius* (Asteraceae), *Citrus aurantifolia, Citrus limon, Citrus sinensis* (Rutaceae), *Brassica alba, Brassica napus, Brassica nigra, Brassica botrytis, Brassica oleracea, Brassica rapa* (Brassicaceae), *Cucumis sativus, Cucurbita maxima, Lagenaria siceraria, Luffa aegyptiaca, Momordica charantia, Sechium edule* (Cucurbitaceae), *Dolichus lablab, Pisum sativum, Cajanus cajan, Phaseolus mungo, Vigna angularis, Vigna mungo, Vigna radiata, Vigna sinensis, Vigna umbellate, Phaseolus radiates, Phaseolus vulgaris, Glycine max, Glycine soja, Trigonella* sp., *Cicer arietinum, Lens esculenta, Macrotyloma uniflorum* (Fabaceae), *Mentha viridis* (Lamiaceae), *Linum usitatissimum* (Linaceae), *Sesamum indicum* (Pedaliaceae), *Fragaria* spp., *Malus* spp., *Prunus* spp., *Pyrus* spp., *Rubus* spp. (Rosaceae), *Capsicum annum, Capsicum frutescens, Solanum lycopersicum, Solanum melangena, Solanum tuberosum* (Solanaceae), *Curcuma longa, Elettaria cardamomum, Amomum subulatum* (Zingiberaceaae) cover crops such as, *Tagetes patula*, *Cynarascolymus* (Asteraceae), *Trifolium alba* (Fabaceae), *Fagopyrum esculentum* (Polygonaceae). The above mentioned crops are mainly visited by bumble bees (*Bombus haemorrhoidalis, Bombus tunicatus)* (Raina et al., 2019) and honey bee species (*Apis cerana indica*, *A.dorsata,* and *A. laboriosa*).

Bumble bees are key pollinators, particularly in alpine areas and during the early flowering stage (Kevan and Baker, 1983; Yu et al., 2012). They can certainly be used for pollination services in greenhouses as they are highly efficient pollinators and are easy to handle. Their (*Bombus* sp.) pollination efficiency outperforms that of other pollinator species because of their unusual "*buzz pollination*" behaviour (Buchmann, 1985). *Apis laboriosa* is the world's largest honey bee species, has a limited range, and exhibits unique nesting behaviours. It is found mostly in the mountainous terrain of Nepal, Bhutan, India, and China-Yunnan province (Batra, 1995; Ahmad and Roy, 2000). Earlier, *Apis laboriosa* was regarded as a subspecies of *Apis dorsata*. It is polylectic and visits a diverse range of flora for foraging.

Honey bees are the most efficient and primary pollinators of both cultivated and wild plants. According to Ali et al. (2011), the most efficient pollinators of canola (*Brassica napus*) are *Apis dorsata*, *Apis florea*, and *Halictus* sp. Stingless bees, according to Heard (1994) and Abrol (2010), are frequent visitors to many tropical plants and are likely better pollinators than honeybees. Slaa et al. (2006) previously reported on the possibility of stingless bees as pollinators of greenhouse crops. In Australia, Bell et al. (2006) used *Amegilla holmesi* as an effective alternative to mechanical pollination for pollinating greenhouse tomatoes. Carpenter bees (*Xylocopa pubescens* and *Xylocopa fenestrate)* are the principal pollinators of *Calotropis procera hamiltonii* (Asclepidiaceae), while honeybees, *Apis florea*, are the minor pollinators, according to Ali and Ali (1989). Garcia-Robledo et al. (2004) reported beetle pollination in *Xanthosoma daguense* (Araceae). Jacobs et al. (2010) suggest that *Vespula* sp. are possibly the most successful pollinators of *Hedera helix* (Araliaceae).

Clement et al. (2007) reported fly pollination in the leek, *Allium ampeloprasum* (Amaryllidaceae), claiming that the fly species, *Calliphora vicina*, was a more efficient and cost-effective pollinator in field cages than the honeybee, *Apis mellifera.* According to Kevan and Baker (1983) and Proctor et al. (1996), inherent phenological and morphological constraints, such as size, body shape, flight ability, tongue length, and sensory system, flower visitor behaviour on various plant species is influenced by inherent phenological and morphological constraints. According to Goulson (1999), insect pollinator foraging behaviour is flexible and complex, allowing foragers to adjust to the pattern of rewards they encounter. According to Michener (2007), foragers such as Xylocopa sp., Bombus sp., and Apis mellifera are "*pollen thieves or nectar robbers*" in some blooms, but they are key pollinators in many other plants. He also highlighted that bees that comb pollen from the majority of their body and appendages for transfer in the scopa are less likely to cross-pollinate. From the beginning of foraging to the end, insect pollinators exhibit a wide spectrum of foraging behaviour, their seasonality and flower phenology are intertwined, and their pattern of flight, their foraging strategy, their durational stay on the flowers and plants, their blossom steadfastness etc. attributes to the degree of pollination and reproductive success of the plant.

5.5. Conclusion

Indigenous farming practices create a diverse mosaic of crop and non-crop habitats in the landscape (Altieri, Merrick and Anderson, 1987; Reichardt et al., 1994). This has an impact on abundance, species richness, and community structure (Connor, Courtney, and Yoder, 2000; Debinski and Holt, 2000), as well as on the provision of key ecological/ecosystem services (Naeem et al., 1995; Tewksbury et al., 2002). Ecosystem services refers to a wide range of circumstances and processes found in natural ecosystems, as well as the species that make up such ecosystems that contribute to the survival and fulfillment of human life (Daily et al., 1997). Predation of insect pests (Moguel and Toledo, 1999; Klein, Steffan-Dewenter and Tscharntke, 2002b) and pollination of wild and cultivated plants are only a few examples (Rathcke and Jules, 1993; Daily et al., 1997; Klein, Steffan-Dewenter and Tscharntke, 2003b). Plant–pollinator interactions may be disrupted due to habitat fragmentation and degradation (Rathcke and Jules, 1993; Renner, 1998; Cane, 2001; Donaldson et al., 2002; Steffan-Dewenter et al., 2002). Traditional farming methods are repositories of numerous crops and cultivars, the majority of which are still unknown to mainstream civilizations, and are better fitted to environmental and socioeconomic conditions than modern agricultural systems (Altieri 1995; Ramakrishnan and Saxena 1996). Intercropping and mixed cropping are the most widespread of these, having been used by farmers in Asia's drylands for generations (Stroud et al, 2000).

Chapter 6: Key Findings & Recommendations

6.1. Overview

In the Himalayas, pollinators are often considered the lifeline of a subsistence form of mountain agriculture. Prior to this study, however, there was little knowledge of pollinator diversity in indigenous farming systems in the Garhwal Himalayas. Despite surveys and research on farming systems in areas such as Tehri, the Pindar basin, and the Garhwal Himalaya (Kumar and Tripathi, 1989; Sati and Rawat, 1993; Sati, 2005), none on primary insect pollinators has been conducted. This is despite the fact that large-scale studies on lepidopterans have been conducted in the Kedarnath Wildlife Sanctuary (Singh, 2007, 2009; Sharma, 2013; Singh and Sondhi, 2016), Nanda Devi National Park (Uniyal, 2004), and the Gangotri landscape (Uniyal et al., 2013). Ecological, environmental, and biodiversity indicator species have long been utilized with invertebrates (Stork and Eggleton, 1992; Brown, 1997; McGeoch, 1998), butterflies and moths (Rainio and Niemelä, 2003), and carabid beetles (Rainio and Niemelä, 2003).

Abrol's (2009) study in India demonstrated the diversity of stingless bee pollinators in the Indian subcontinent. Various studies on carpenter bee pollinators (Shivanna, 2009), butterfly pollinators (Pajni and Kaur, 1986), and fly pollinators (Jonathan and Raju, 2009) were carried out. A population study of insect pollinators in India has yet to be conducted. Like in most countries, pollination-based studies in India primarily revolve around pollination ecology and the propagative success of significant vegetation species. Solomon Raju and Rao (2002) studied *Acacia sinuata*, with saponin-rich pods in high market demand, an important non-timber forest shrub, for pollination ecology and fruiting. According to Neli et al. (2011), identified *Pithitis binghami* and *Apis cerana indica* as potential pollinators, with *Apis dorsata* as the most effective pollinator of *Acacia concinna.* According to Shivanna, *Adhatoda vasica,* another medicinal plant, is pollinated by *Xylocopa* sp. (2009). However, it has been reported that it has a poor reproductive success rate in terms of fruit set due to a lack of compatible pollen. Singhal et al. (2011) investigated the pollination biology of *Aegle marmelos* (Rutaceae) and discovered that the *Apis dorsata* is the plant's primary and legitimate pollinator. Bhatnagar (1986) described insect pollination adaptation in some asclepiads, claiming that carpenter bees, polistine wasps, and butterflies were adapted for pollination of *Calotropis* sp., polistine wasps, and butterflies to *Asclepias* *curassivica*, and so on. Sihag and Wadhwa (2011) investigated another medicinal plant, *Rauvolfla serpentina* (Apocynaceae), and concluded that the plant has a psychophilous pollination mode.

Different functions delivered by Mother Nature that enhance and sustain the overall wellbeing of humans are considered ecosystem services (Daily, 1997). Mobile organisms foraging within or between habitats generate certain ecosystem services, such as fertilization and pollination, insect pest control, and dissemination of seed, on a local scale (Gilbert, 1980; Lundberg and Moberg, 2003; Sekercioglu, 2006). Both wild species of invertebrates, birds, and mammals (mainly bees, but also numerous moths, butterflies, beetles, dipteran flies, and wasps), as well as commercially managed bee species (mostly *Apis mellifera*) perform pollination services (Kremen, 2007). The marginal rise in the yield of subsistence or market-based crops, fibre, timber, forage, and NTFPs (e.g., firewood, medicinal goods, and wild fruits) as a result of animal pollination is the direct value (regulating) of ecosystem services to mankind. The indirect value (supporting) is the marginal increase in wild plant reproduction that helps to provide other ecosystem functions due to animal pollination (Kremen, 2007).

6.2. Species richness of Pollinators

The present study, conducted at the Navdanya Agrobiodiversity Conservation & Ecological Farm and Mandakini valley of the Garhwal Himalaya, has made a significant contribution to our understanding of the distributions of insect pollinators in these landscapes. Both areas have a high diversity of primary insect pollinators (Hymenoptera, Lepidoptera, Diptera, and Coleoptera). During the study period of four years (2017-2020), 177 species, 119 genera, 32 families, and 53 sub-families from four orders were sampled. Due to the huge diversity of insect pollinators in the region, conservation efforts should be ensured not only for large vertebrates (which receive a lot of attention) but also for lower invertebrates. There has been no previous research in this area on pollinators associated with the indigenous farming systems, hence the study provides new distribution records for all the insect pollinators found.

Insect pollinators recorded from the belonged to four orders: Lepidoptera (family Hesperiidae, Lycaenidae, Nymphalidae, Papilionidae, Pieridae, Riodinidae, and Sphingidae), Hymenoptera (family Andrenidae, Apidae, Chrysididae, Colletidae, Crabronidae, Halictidae, Ichneumonidae, Leucospidae, Megachilidae, Scoliidae, Sphecidae, Vespidae), Diptera (family Asilidae, Bibionidae, Bombyliidae, Calliphoridae, Muscidae, Scathophagidae, Syrphidae, Tabanidae, and Tachinidae) and, Coleoptera (family Buprestidae, Coccinellidae, Meloidae, and Scarabaeidae). Order Lepidoptera has the highest abundance (72 species, 52 genera, 16 sub-families, and 7 families), followed by Hymenoptera (65 species, 36 genera, 22 sub-families, and 12 families), then Diptera (28 species, 20 genera, 12 sub-families, and 9 families). The lowest abundance was recorded for Coleoptera with only 12 species belonging to 11 genera, representing 5 sub-families of 4 families. Bees, being one of the largest groups of pollinators, can either be social or solitary (Berenbaum, 2007). Honey bees are recognized best for their honey, royal jelly, propolis, wax, and other products. Furthermore, they are the most effective pollinators for the majority of crops for agriculture and horticulture (Jay, 1986; Verma and Pratap, 1993; Kumar et al., 1994; Tiwari et al., 2013). They also visit a wide range of floral diversity to collect nectar and pollen from blooms for food, which is referred to as "*bee foraging*" or "*bee pasturage*" (Singh, 1982).

6.3. Impact of cropping system on pollinators

The investigation found that there was a significant difference present in the mean number of species richness of pollinators between mono-cropping and multiple-cropping of organic agro-ecosystems ($t=10.345$, $p < 0.05$) and non-organic agro-ecosystems ($t=5.715$, $p < 0.05$). The box plot signifies the higher species richness of primary pollinators in the multiple-cropping of organic agro-ecosystems than those of non-organic agro-ecosystems. Likewise, the box plot signifies the higher species richness of primary pollinators in the mono-cropping of organic agro-ecosystems than those of non-organic agro-ecosystems. Possible explanations include (i) the higher availability of foraging options in multiple-cropping agro-ecosystems, (ii) the generalist species can congregate around any crop plant regardless of floral habitat, and (iii) the specialist species prefer specific plants for their pollen preferences.

The Mandakini valley lies in the Western Himalayan Region of the agro-climatic zone. Here, mountain agriculture involves the indigenous methods of propagating food grains as well as cash crops. Cereals, pseudo-cereals and cash crops such as *Elettaria cardamomum, Citrus reticulata, Zingiber officinale* and *Solanum tuberosum* are extensively cultivated here. Agricultural intensification on a local to landscape scale is often associated with a decrease in wild pollinator abundance, diversity, and services to crops (Kremen and Chaplin-Kramer, 2007). Among two types of cropping systems in the Mandakini valley, butterfly abundance was highest. Pollinators are responsible for 35% of global crop production (Klein et al., 2007). Human activities have altered the landscape by fragmenting, degrading, and destroying natural habitats while also creating new anthropogenic habitats. Greater floral diversity (Fenster et al., 2004) generates a broader range of foraging niches for different pollinating visitors.

6.4. Impact of farming system on pollinators

The core sectors of agriculture are comprised of crops, livestock, and forestry. Diversified farming systems influence agrobiodiversity, pollinators, and pollination. Certain wasps and flies, other than bees, buzz from blossom to flower in search of nectar, becoming key pollinators. Flowers rely heavily on insects to disseminate their pollen far and wide. Agriculture is the primary source of income, followed by the livestock sector. The replacement of food grain crops by non-food grain crops has resulted in continual diversification. Other than basic food crops, local fruits, vegetables, spices, tea, and medicinal plants have mainly replaced coarse cereals in farmers' quest for a higher income. Reinvesting in sustainable agriculture is critical for achieving the right to food for all, rural economic growth with economically self-sufficient farmers, healthy environments, climate change adaptation, and biodiversity conservation.

This study discovered that farming systems with various combinations of crop preferences, as well as the size and location of cultivable farmlands, determine the diversity of species. Both the diversity of pollinators and the composition of crops in different farming systems were different. Crop patches in mono-cropping systems, in particular, had a different pollinator assemblage than crop patches in multiple-cropping systems. The insect pollinator diversity of the Garhwal Himalaya as reflected through investigation showed that the order lepidoptera was the most active group of pollinators during the day, followed by the hymenoptera, diptera, and coleoptera, which includes

177 species belonging to 119 genera in 32 families and 53 sub-families. The crop families that were the most preferred forage by the insect pollinators were Amaryllidaceae, Asteraceae, Rosaceae, Rutaceae, Solanaceae, Polygonaceae, Brassicaceae, Cucurbitaceae, and Fabaceae. The least preferred families were Apiaceae, Araceae, Lamiaceae, and Pedaliaceae. The families such as Amaranthaceae, Meliaceae, Moraceae, Myrtaceae, and Zingiberaceae were the moderately preferred ones.

6.5. Management actions and key recommendations

Pollination by animals is an important regulating ecosystem service in nature. Pollinators, both wild and managed, play an important part in crop pollination worldwide. However, their relative contributions vary by crop and locale. Knowledge of pollinators and pollination ecology (Heinrich and Raven, 1972) at grass root levels is crucial for their better conservation and management plans that ensure the sustainable use of biodiversity at par. From data collated over the last decade, insights into declining bee populations have emerged both in Europe and the US. The discovery led to Americans' becoming more conscious of *Apis mellifera*, a threatened species in the country, in the same light as other significant fauna, such as dolphins and panda bears (Bhuyan, 2019). Crop output and/or quality are affected by the abundance and diversity of pollinators. According to the IUCN Red List assessments, 16.5% of vertebrate pollinators are endangered worldwide (up to 30% for islands). Insect pollinators on the global Red List have not yet been assessed. However, regional and national analyses show that a couple of butterflies and bees are in grave danger. 9% of bee and butterfly species in Europe are endangered, while 37% of bees and 31% of butterflies' populations are falling. When national Red List evaluations are available, they frequently reveal that more than 40% of bee species are endangered. The red list includes thorough details on the conservation of each listed species, as native bees are in decline.

The Bumblebee Specialist Group was established by the IUCN in 2011 to assess the threat level of all bumblebee species globally using the criteria of its Red List. However, the conservation debate continues to focus mainly on big cats, elephants, and rhinos, particularly in India, and pollinators appear to be absent from these conversations. Since 2018, the United Nations has recognized their efforts by instituting *"World Bee Day"* on May 20th. The FAO urged the respective countries to increase their efforts to safeguard bees, which are critical allies in the fight against hunger. Pollinator abundance, variety, and health, as well as pollination services, are endangered by direct forces that pose threats to communities and ecosystems. Land use change, intensive agricultural practices, pesticide use, pollution, invasive alien species, diseases, and climate change are some of the threats. For the first time, the European Red List of Bees (Nieto et al., 2014) provides accurate information on the state of all European bees (nearly 2,000 species). According to the study, agricultural intensification (e.g., use of chemical pesticides or fertilizers), urbanization, increased instances of fire, and climate change have all contributed to the extinction of bees in Europe (9%).

In summary, my doctoral thesis generates inventorial knowledge on insect pollinators in different farming systems and a variety of habitats in the Garhwal Himalayas. Mountain agriculture, in coming years, is vulnerable due to the advent of chemical pesticides, encroachment, non-regulation of tourism in the region, habitat loss and land fragmentation, and extreme climatic conditions in the Garhwal Himalaya. Though this doctoral study did not engage in any population estimation, collected data shows there are a minimum of 177 crucial insect pollinator species from 32 families in this landscape. The key management actions and future recommendations that can be undertaken based on this study are described below:

- The findings of this doctoral work have identified a number of genera from the families Hesperiidae, Lycaenidae, Nymphalidae, and Pieridae (order Lepidoptera) that are already enlisted under Schedule I (Part-IV, I: Butterflies & Moths), Schedule-II (Part-II), and Schedule-IV) of the Wild Life (Protection) Act, 1972. This valley supports a considerable number of primary insect pollinators from the orders Diptera, Hymenoptera, and Coleoptera, which should be undoubtedly taken into consideration from a conservation point of view as under different schedules of the Wild Life (Protection) Act, 1972 based on other extended research studies.
- Recognition of Indian butterflies and bees as threatened species under IUCN's Red List or Red Data Book.

- Our surveys and data collection highlight the importance of the cropping systems prevailing in the region. Even the conversion of agricultural land to non-agricultural purposes such as animal rearing and husbandry, the construction of homestays, shops, and cemented houses, has caused continuous land fragmentation and habitat destruction of these tiny pollinator communities. Preliminary observations from primary and secondary data suggest that the overall cropping area has been reduced for a variety of reasons.
- Future studies in the Western Himalayas should focus on bridging the research gaps such as generation of distribution maps of primary pollinators, more taxonomically based studies, isolation and speciation based research at the molecular level, and genetic profiling of bumble bees. Also, how do the phenomena of climate change and seasonal variation in crop resources, landscape features (wild strips, vegetation cover), environmental covariates (snowfall and precipitation) and anthropogenic covariates (human disturbance regimes) affect the whole existence of primary pollinators in this landscape?
- The migration patterns of bumble bees (*Bombus* sp.) or managed bees (*Apis mellifera*, *Apis cerana indica*) need to be explored. Such fine-scale data could help in identifying and preserving the pollinators' corridors and ensure their conservation during unfavourable weather conditions. The unmasking of the habitat suitability index of bees and butterflies can also be achieved through remote sensing and geo-informatics. Habitat models and species distribution based on LiDAR-driven structural variables can provide a better representation of the habitat. Habitat classifications based on land cover types, habitat suitability indices, and seasonality have made major contributions to animal migration studies and species distribution models.
- Promote integrated pest management (IPM) and design incentives or similar programs to enable farmers to gain from ecosystem services rather than agrochemicals.
- The acknowledgement and acceptance of pollination biology as an essential element in agricultural extension services.
- Endorse and support organic farming by sensitizing farmers to reduce their use of chemical fertilizers and pesticides. It is critical to launch a public awareness

campaign against chemicals that harm bees and other pollinators. The National Bee Board, NABARD, and state agriculture departments must incorporate this into their programs.

- Pollinator-friendly activities such as organic farming or diversified farming systems, awareness generation programs, citizen science tools, and the establishment of a pollinator conservation resource centre for attracting native bees and butterflies, where one can quickly locate regional plant lists, habitat conservation guides, and other relevant resources.
- Maintaining community seed banks and conservation of gene pools at the village or gram panchayat level is important for maintaining a healthy mountain biodiversity.
- Finally, crop raiding wildlife necessitates ongoing attention and collaboration efforts that are organized and action-oriented.

6.6. Conservation Implications

The findings of this study emphasize the need for organic agriculture adoption and promotion to conserve insect pollinator diversity in mountain agriculture, where inorganic agriculture is prevalent. Although our findings suggest that both types of farming practices (organic as well as non-organic) may support similar levels of insect pollinator diversity as in the Garhwal Himalayas and Navdanya Agrobiodiversity Conservation & Ecological farms, at least for hymenoptera and coleoptera species, this does not mean that multiple-cropping systems are unimportant for conserving their diversity.

Furthermore, stakeholders (small-scale farmers, commercial farmers, horticulturists, apiculturists, and apiarists) must be familiar with pollination phenomena and pay close attention to the structural complexity inextricably linked to the mountain agroecosystem. Therefore, this doctoral work brings into focus the general assessment of pollinators in indigenous farming systems in specific regions of the Garhwal Himalayas. The implications of this work are useful for scholars, scientists, and R & D agents because they pave the way for further investigation and monitoring of pollinators in mountain agroecosystems. Thus, the ecology-based knowledge is critical for the protection of insect pollinators and could help policymakers' draught management plans for fragile mountain agroecosystems.

Risks associated with pollinator decline can be mitigated by moving toward more sustainable agriculture and reversing the simplification of agricultural landscapes. The following three complementary techniques help keep pollinator communities healthy and agriculture productive: (a) ecological intensification, i.e., improving agricultural production and livelihoods while reducing environmental damage by controlling nature's ecological functions; (b) reinforcing diversified farming systems favoring heterogeneity in landscapes (including kitchen gardens, homesteads, agroforestry, mixed cropping, and livestock rearing) to foster pollinators and pollination through science-based or indigenous knowledge (e.g., Barahnaaja); and (c) investing in ecological infrastructure makes it possible to protect, restore, and connect natural and semi-natural habitat patches across agricultural landscapes. These techniques can help pollinators while also mitigating the effects of land use change, land management intensity, pesticide use, and climate change. Indigenous knowledge-based practices can help with the abundance and diversity of pollinators and may turn out to be a source of solutions to current challenges. Pesticides pose a threat to pollinators due to a combination of toxicity and exposure level. Under controlled experimental conditions, insecticides have been found to harm pollinators in a variety of ways, both lethal and non-lethal. Pollinator exposure to pesticides can be reduced by limiting pesticide use, pursuing alternative pest control methods, and implementing a variety of particular application procedures, such as pesticide drift reduction technology. Pesticide use can be reduced by encouraging IPM, which is supported by farmer education, organic farming, and policies that reduce its overall use (IPBES, 2016).

Lastly, I would like to infer that Zero Hunger under SDG-2015 can solely be achieved through resilient agricultural practices, native seed conservation, and protection of pollinator communities. Insect pollinators are popularly branded as hard-working, detail-oriented, and tenaciously determined allies of flowers and nectar fabricators who benefit the environment while also enriching human existence. These pollinators are also influential partners in achieving the SDGs by promoting biodiversity (Goal 15), fighting hunger (Goal 2), and providing decent jobs (Goal 8) in agriculture and allied sectors, therefore, advancing Goal 1, no poverty (UNDP, 2021).

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APPENDIX-1

Appendix 1: *Village wise population and number of households in the Rudraprayag district as per census 2011*

<table>
<tr><th>Name of the Gram Panchayat</th><th>Name of Village with geographical attributes (Elevation/Lat/Long)</th><th>Area of village (in ha)</th><th>Total House holds</th><th>House hold sampled</th><th>Total Population</th><th>Respondents Interviewed</th></tr>
<tr><td rowspan="2">Huddu GP
(77 house holds out of 85)</td><td>Huddu (1769mts)
30°30’24.3” N
79°09’01.6” E</td><td rowspan="2">89.19</td><td>68</td><td>61</td><td rowspan="2">361</td><td>89</td></tr>
<tr><td>Karnadhar 1743mts)
30°30’26.0” N
79°08’54.2” E</td><td>17</td><td>16</td><td>49</td></tr>
<tr><td rowspan="2">Ushara GP
(67 house holds out of 96)</td><td>Taala (2029mts)
30°30’45.6” N
79°09’50.8” E</td><td rowspan="2">159.98</td><td>28</td><td>21</td><td rowspan="2">544</td><td>73</td></tr>
<tr><td>Ushara (1817mts)
30°30’25.6” N
79°09’42.7” E</td><td>68</td><td>46</td><td>40</td></tr>
<tr><td rowspan="3">Barangali GP
(80 house holds out of 85)</td><td>Semar (1848mts)
30°29’58.0” N
79°08’34.1” E</td><td>34.90</td><td>10</td><td>8</td><td>34</td><td>26</td></tr>
<tr><td>Kanda (1893mts)
30°29’54.9” N
79°08’40.0” E</td><td>58.99</td><td>35</td><td>32</td><td>195</td><td>61</td></tr>
<tr><td>Barangali (1708mts)
30°29’58.3” N
79°08’21.9” E</td><td>98</td><td>40</td><td>40</td><td>206</td><td>7</td></tr>
<tr><td colspan="2">Total</td><td>439.06</td><td>266</td><td>224</td><td>1340</td><td>395</td></tr>
</table>

Appendix-2

Appendix 2: *Sampling sites of Garhwal Himalaya with their geographical coordinates*

Sampling Sites	Latitude	Longitude	Elevation (in mts)
Taala	30°30'33.0" N	79°09'42.7" E	1876
Ushada	30°30'11.7" N	79°09'20.3" E	1943
Hudu	30°30'24.3" N	79°09'01.6" E	1779
Karnadhar	30°30'26.0" N	79°08'54.2" E	1743
Semaar	30°29'58.0" N	79°08'34.1" E	1848
Kanda	30°29'54.9" N	79°08'40.0" E	1893
Barangali	30°29'58.3" N	79°08'21.9" E	1708
Guwar	30°29'34.8" N	79°08'22.8" E	1748
Bhankund	30°29'31.3" N	79°08'37.1" E	1897
Langashali	30°29'49.9" N	79°08'39.7" E	1922
Daira	30°30'23.1" N	79°08'35.6" E	1646
Bantoli	30°29'56.0" N	79°08'45.7" E	1921
Upper Bantoli	30°36'27.2" N	79°11'22.8" E	1787
Bantoli river stream	30°29'57.0" N	79°08'47.2" E	1915
Sunset point Hudu	30°30'20.0" N	79°08'51.0" E	1826
Bantoli lost	30°29'43.1" N	79°09'02.3" E	2107
New Base camp	30°30'17.0" N	79°09'01.9" E	1826
Pangaran	30°30'08.6" N	79°09'11.5" E	1882
Dhondhuru	30°30'09.5" N	79°09'20.7" E	1976
Ushada dhaab	30°30'25.6" N	79°09'22.7" E	1817
Taala bottom	30°30'28.9" N	79°09'46.3" E	1829
Taala upper end	30°30'45.6" N	79°09'50.8" E	2029
Taala mid	30°30'31.6" N	79°09'48.1" E	1866
Baratal	30°30'09.2" N	79°08'57.3" E	1846
Bumble bee loc	30°30'16.7" N	79°08'52.4" E	1816
High rock	30°30'12.0" N	79°08'54.6" E	1834
Fodder colllection	30°29'51.9" N	79°09'04.4" E	2013
Leaf insect loc	30°30'22.4" N	79°09'05.5" E	1818

Sampling Sites	Latitude	Longitude	Elevation (in mts)
Loc 1	30°30'03.7" N	79°08'45.3" E	1862
Loc 2	30°30'07.2" N	79°08'44.6" E	1847
Loc 3	30°30'23.0" N	79°08'40.7" E	1654
Loc 4	30°30'09.7" N	79°08'57.3" E	1850
Loc 5	30°30'03.2" N	79°09'01.9" E	1894
Loc 6	30°30'17.0" N	79°09'02.0" E	1826
Loc 7	30°30'05.1" N	79°09'05.3" E	1892
Loc 8	30°30'22.3" N	79°09'01.4" E	1783
Loc 9	30°30'23.3" N	79°08'35.7" E	1646
Loc 10	30°30'24.6" N	79°09'02.2" E	1779
Loc 11	30°30'08.4" N	79°09'08.7" E	1878
Loc 12	30°30'08.7" N	79°09'09.9" E	1878
Loc 13	30°30'08.9" N	79°09'09.7" E	1873
Loc 14	30°30'08.2" N	79°09'10.2" E	1879
Loc 15	30°30'08.1" N	79°09'11.3" E	1879
Loc 16	30°30'23.7" N	79°08'35.9" E	1648
Loc 17	30°30'08.2" N	79°09'10.3" E	1880
Loc 18	30°30'08.0" N	79°09'10.5" E	1883
Loc 19	30°30'07.8" N	79°09'10.9" E	1883
Loc 20	30°30'07.8" N	79°09'11.0" E	1883
Loc 21	30°30'08.1" N	79°09'11.2" E	1881
Loc 22	30°30'07.3" N	79°09'12.1" E	1897
Loc 23	30°30'24.8" N	79°08'36.3" E	1652
Loc 24	30°30'54.6" N	79°09'15.6" E	2020
Loc 25	30°30'06.2" N	79°09'13.6" E	1895
Loc 26	30°30'23.8" N	79°09'10.7" E	1911
Loc 27	30°30'10.7" N	79°09'17.8" E	1910
Loc 28	30°30'24.5" N	79°08'40.3" E	1653
Loc 29	30°30'11.4" N	79°09'21.5" E	1939
Loc 30	30°30'32.9" N	79°09'42.7" E	1877
Loc 31	30°30'08.8" N	79°09'02.5" E	1844
Loc 32	30°30'21.6" N	79°09'00.5" E	1777

Sampling Sites	Latitude	Longitude	Elevation (in mts)
Loc 33	30°30'21.4" N	79°09'00.6" E	1777
Loc 34	30°30'21.4" N	79°09'00.6" E	1778
Loc 35	30°30'21.3" N	79°09'00.8" E	1778
Loc 36	30°30'44.1" N	79°09'50.0" E	2028
Loc 37	30°30'37.3" N	79°09'46.0" E	1937
Loc 38	30°30'40.7" N	79°09'42.0" E	1956
Loc 39	30°30'31.4" N	79°09'44.6" E	2013
Loc 40	30°30'51.3" N	79°09'17.0" E	2020
Loc 41	30°30'26.9" N	79°09'54.8" E	1744
Loc 42	30°30'24.7" N	79°09'52.7" E	1741
Loc 43	30°29'51.1" N	79°08'11.9" E	1742
Loc 44	30°29'49.4" N	79°08'37.6" E	1921
Loc 45	30°30'07.2" N	79°08'44.6" E	1846
Loc 46	30°30'07.2" N	79°08'40.3" E	1846
Loc 47	30°31'23.0" N	79°08'40.7" E	1654
Loc 48	30°30'20.9" N	79°09'01.8" E	1795
Loc 49	30°30'20.9" N	79°09'01.9" E	1795
Loc 50	30°30'22.6" N	79°09'01.6" E	1784
Loc 51	30°30'22.6" N	79°09'01.9" E	1784
Loc 52	30°30'21.7" N	79°09'02.4" E	1784
Loc 53	30°30'20.8" N	79°09'02.1" E	1798
Loc 54	30°30'21.2" N	79°09'03.2" E	1799
Loc 55	30°30'23.0" N	79°09'07.2" E	1800
Loc 56	30°30'21.7" N	79°09'03.5" E	1800
Loc 57	30°30'22.9" N	79°09'01.8" E	1785
Loc 58	30°30'23.3" N	79°09'02.4" E	1785
Loc 59	30°30'23.5" N	79°09'03.7" E	1785

Appendix-3

Appendix 3: *Crops in Navdanya farm with their number of native seed varieties*

S.No	Crop	Scientific name	Family	Varieties (as on 2019)
01.	Paddy	*Oryza sativa*	Poaceae	740
02.	Basmati	*Oryza sp.*	Poaceae	41
03.	Wheat	*Triticum aestivum*	Poaceae	240
04.	Barley	*Hordeum vulgare*	Poaceae	27
05.	Oats	*Avena sativa*	Poaceae	20
06.	Finger millet (Mandwa)	*Eleusine coracana*	Poaceae	30
07.	Barnyard millet (Jhangora)	*Echinochloa frumentacea*	Poaceae	3
08.	Foxtail millet (Kauni)	*Setaria italica*	Poaceae	21
09.	Pearl millet (Bajra)	*Pennisetum glaucum*	Poaceae	14
10.	Maize	*Zea mays*	Poaceae	21
11.	Pulses/Legume	Beans, Lentils, Peas, Chickpea, Soybeans	Fabaceae	97
12.	Vegetables	Pumpkin, Tomato, Brinjal, Lady's finger, Carrot	Apiaceae, Malvaceae, Cucurbitaceae, Solanaceae	159
13.	Oil seeds	Castor, Flaxseed, Sesame, Peanut, Rapeseed	Euphorbiaceae, Fabaceae, Linaceae, Pedaliaceae	24
14.	Mustard	*Brassica campestris*	Brassicaceae	24
15.	Cereal grain (Rye)	*Secale cereal*	Poaceae	18
16.	Green manures	Alfalfa, Buckwheat, Cowpea, Clover, Fenugreek	Fabaceae	134
17.	Kidney beans (Rajma)	*Phaseolus vulgaris*	Fabaceae	175
18.	Aromatics	Oregano, Citronella, Chamomile, Peppermint	Lamiaceae, Asteraceae	58
19.	Medicinal	Leek, Stevia, Tinospora, Terminalia, Centella	Apiaceae, Asteraceae, Amaryllidaceae	47
TOTAL				**1,940**

Appendix-4

Appendix 4 and 5: *Result of first and second Objective*

		Organic	**Lower**	**Upper**	**Non-organic**	**Lower**	**Upper**
	Taxa_S	162	162	162	146	146	146
	Individuals	18351	18351	18351	11521	11521	11521
	Dominance_D	0.006408	0.006426	0.006501	0.007085	0.007124	0.007222
	Simpson_1-D	0.9936	0.9935	0.9936	0.9929	0.9928	0.9929
	Shannon_H	5.069	5.061	5.067	4.966	4.956	4.963
	Evenness_e^H/S	0.9813	0.9741	0.9798	0.9824	0.9725	0.9797
	Brillouin	5.04	5.033	5.039	4.927	4.917	4.924
	Menhinick	1.196	1.196	1.196	1.36	1.36	1.36
	Margalef	16.4	16.4	16.4	15.5	15.5	15.5
	Equitability_J	0.9963	0.9948	0.996	0.9964	0.9944	0.9959
	Fisher_alpha	24.47	24.47	24.47	23.57	23.57	23.57
	Berger-Parker	0.01095	0.009754	0.01248	0.009635	0.009895	0.01189
	Chao-1	162	162	162	146	146	146
One-tailed	The t-value is 15.85268. The p-value is < .00001. The result is significant at p < .05.						
Two-tailed	The t-value is 15.85268. The p-value is < .00001. The result is significant at p < .05.						

APPENDIX-5

	Mono-cropping	Lower	Upper	**Multiple-cropping**	Lower	Upper			**Mono-cropping**	**Multiple-cropping**			**Mono-cropping**	**Multiple-cropping**
Taxa_S	200	200	200	200	200	200		N	200	200		N	200	200
Individuals	17275	17275	17275	20067	20067	20067		Min	3	5		Shapiro-Wilk W	0.9554	0.9521
Dominance_D	0.006962	0.006928	0.007112	0.006828	0.006799	0.006956		Max	245	267		p(normal)	6.44E-06	2.99E-06
Simpson_1-D	0.993	0.9929	0.9931	0.9932	0.993	0.9932		Sum	17275	20067		Anderson-Darling A	1.989	3.003
Shannon_H	5.095	5.08	5.097	5.103	5.09	5.105		Mean	86.375	100.335		p(normal)	4.39E-05	1.45E-07
Evenness_e^H/S	0.8157	0.8043	0.8178	0.8223	0.812	0.8245		Std. error	3.835738	4.300831		p(Monte Carlo)	0.0003	0.0001
Brillouin	5.06	5.046	5.063	5.072	5.06	5.075		Variance	2942.577	3699.43		Jarque-Bera JB	11.4	9.485
Menhinick	1.522	1.522	1.522	1.412	1.412	1.412		Stand. dev	54.24553	60.82294		p(normal)	0.003346	0.008715
Margalef	20.4	20.4	20.4	20.09	20.09	20.09		Median	84	95.5		p(Monte Carlo)	0.01	0.0178
Equitability_J	0.9615	0.9589	0.962	0.9631	0.9607	0.9636		25 prcntil	37	43.25				
Fisher_alpha	31.74	31.74	31.74	30.87	30.87	30.87		75 prcntil	123	149.75				
Berger-Parker	0.01418	0.01331	0.01609	0.01331	0.01216	0.0149		Skewness	0.574443	0.325597				
Chao-1	200	200	200	200	200	200		Kurtosis	-0.2364	-0.83985				
								Geom. mean	66.62687	78.08521				
								Coeff. var	62.80235	60.61986				
			organic agro-ecosystem (t=10.345, $p < 0.05$)											
			non-organic agro-ecosystem (t=5.715, $p < 0.05$)											
			overall agro-ecosystem (t=8.558, $p < 0.05$)											