Species Diversity and Molecular Study of Bees (*Bombus* and *Xylocopa*) in Dehradun District, Uttarakhand, India

Thesis submitted for the award of the degree of

Doctor of Philosophy

in

WILDLIFE SCIENCE

By

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to

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DECLARATION

I, hereby, declare that the work conducted under this thesis titled " **Species Diversity and Molecular Study of Bees (*Bombus* and *Xylocopa*) in Dehradun District, Uttarakhand, India**." is a record of original and independent research work done by me and subsequently submitted for the award of the degree of **Doctor of Philosophy in Wildlife Science** to the **Saurashtra University, Rajkot (Gujarat)**. This research work has been carried out under the guidance and supervision of Dr. V.P.Uniyal and Dr. Sandeep Gupta of Wildlife Institute of India, Dehradun and Dr. Gaurav Sharma of Zoological Survey of India, Dehradun. The work has not formed the basis for the award of any other degree, diploma or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge.

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CERTIFICATE

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Ms. Abha Purohit has researched on this thesis for more than six terms under our supervision and guidance. The work presented in this thesis has not been submitted for any other degree. It meets all of the specifications stated forth in the ordinances of Saurashtra University in Rajkot, Gujarat, and the Wildlife Institute of India.

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I certify that the research work was appreciated by all who were present, and the comments made by the faculty and researchers have been appropriately included in the thesis.

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CERTIFICATE OF PLAGIARISM CHECK

It is certified that the PhD thesis titled "**Species Diversity and Molecular Study of Bees (*Bombus* and *Xylocopa*) in Dehradun District, Uttarakhand, India.**" submitted by **Ms. Abha Purohit** has been examined by Library and Documentation Centre of Wildlife Institute of India for plagiarism check as per UGC (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulations. The following inferences are drawn from this check:

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Summary

1. Introduction

Pollinators are fundamental to the functioning of terrestrial ecosystems, as they facilitate the reproduction of a vast majority of flowering plants and thereby sustain biodiversity and ecological stability. Globally, an estimated 87.5% of flowering plants depend onanimal pollinators for successful reproduction (Ollerton *et.al*. 2011). In addition to their ecological role, pollinators, particularly bees, are indispensable for global agriculture. Approximately 75% of the world’s leading food crops rely on pollination to enhance both yield and quality (Klein *et.al*. 2007). Agricultural commodities such as fruits, vegetables, nuts, oilseeds, and spices are especially dependent on bee-mediated pollination. Beyond agricultural productivity, pollinators provide critical services that directly influence human nutrition. By increasing the diversity, availability, and quality of nutrient-rich foods, they indirectly contribute to balanced diets enriched with vitamins, antioxidants, and essential micronutrients (Eilers *et.al.*2011). Thus, pollinators not only underpin biodiversity but also strengthen food security and human well-being, highlighting their ecological, agricultural, and nutritional significance.

2. Research objectives

The study aims to conduct a systematic survey of *Bombus* (bumblebees) and *Xylocopa* (carpenter bees) in the Dehradun district, focusing on their taxonomy, ecology, and seasonal distribution in different habitat zones. It also seeks for identification and characterization of their habitats, with emphasis on the availability of food plants that sustain high species diversity. Molecular tools, including DNA barcoding, was applied for accurate identification of collected specimens. Additionally, the research evaluated the impact of anthropogenic pressures and other environmental threats on the survival and diversity of these pollinator groups in the study area.

3. Study area

The study was conducted in Dehradun district, Uttarakhand**,** located between 29˚55'–30˚30' N latitude and 77˚33'–78˚20' E longitude. Geographically, it is bounded by the Himalayas to the north, the Shivaliks to the south, the Ganges to the east, and the Yamuna to the west, with neighboring districts including Uttarkashi, Tehri, Pauri, Sirmour (Himachal Pradesh), Haridwar, and Saharanpur (U.P.). The district features diverse physical geography ranging from mountains to plains. The valley is shaped by perennial and seasonal torrents (Rao) descending from the Himalayas, which frequently alter their course during monsoon runoff. This dynamic process has formed a broad expanse of gravel, scree fans, and stepped terraces at varying elevations along eroding riverbeds (Walton, 1911). The valley has a subtropical to temperate climate (Mukesh *et.al*. 2011). Elevations range from 500 to 2,500 m a.s.l. the study area was divided into four habitat zones: agaroecosystem, riverine forest, urban area and mixed forest area.

4. Methodology

The study was conducted between January 2021 to December 2022 in various habitat zones of Dehradun district between an altitudinal gradient of 500 m - 2500 m amsl. Various field surveys were carried out for bumblebee and carpenter bee diversity and distribution study and their preferred habitat zones as well as foraging plants were also recorded. Various identification keys were used for collected specimen identification. Further identification was confirmed by DNA barcoding and sequences were submitted in NCBI database. Various anthropogenic threats were also assessed for bees' decline in the study area.

5. Taxonomical, ecological and seasonal analysis of genus *Bombus* and *Xylocopa* in Dehradun district

Various morphological keys were used for the identification of collected samples and 8 species, 4 of *Bombus* and 4 of *Xylocopa* were identified based on these keys. Meteorological parameters like temperature, rainfall and humidity had moderate effect on bee abundance during different seasons of the study period. Seasonal analysis concludes that both bumblebees and carpenter bees have highest distribution during the monsoon season and that may be because of availabilty of preferred foraging plants during that season. Also with high humidity levels, nectar and pollen production increases providing bees with more food and nectar. Also, bees' body remains hydrated and they do not have to face heat stress during humid conditions of the monsoon season and they can forage easily during that season.

6. Suitable habitat identification and assessment of preferred foraging plants supporting high bee diversity

Different habitat zones were studied for bee diversity and distribution and it is inferred that Agaroecosystem has highest diversity and richness for both bumblebees and carpenter bees.

Agaroecosystem has both cultivated and wild plants availability for foraging. In total 22 preferred plant families are recorded for bumblebees which includes Acanthaceae, Berberidaceae, Lamiaceae, Ranunculaceae and Rosaceae as the most preferred foraging families as 3 out of 4 bumblebee species prefer these for their foraging. Cucurbitaceae is also seen as one of the most favorite foraging plant family.

In case of carpenter bees 16 preferred foraging plant families are recorded. Lythraceae and cucurbitaceae are recorded as the most preferred foraging plant families and the most preferred and visited plants are *Calotropis gigantean* and *Calotropis procera.*

7. DNA barcoding study of the collected specimens

Total 75 samples of bumblebees and carpenter bees are processed for sequencing. In total 43 sequences are generated for bumblebee and carpenter bees. 50 bumblebee samples were processed for DNA sequencing and 30 sequences are generated for 3 bumblebee species. 25 carpenter bee's samples were processed for DNA sequencing and 13 sequences are generated for 4 carpenter bee species. All the obtained sequences of bumblebee and carpenter bee species were submitted to NCBI GenBank nucleotide sequence database and accession numbers are extracted. Phylogenetic trees are also constructed for *Bombus* and *Xylocopa* genus.

8. Assessment of various anthropogenic factors and their impact on bumblebee and carpenter bee population

As Dehradun has undergone rapid urbanization in the last 2 decades, its environment and wildlife also has faced major consequences. The diversity and richness of bee populations in Dehradun are increasingly threatened by both natural and anthropogenic factors**.** Rapid urban expansion, habitat loss, and environmental changes have significantly altered ecosystems, reducing the availability of suitable habitats for bees. Bee populations in Dehradun are declining due to a combination of habitat loss, invasive species, pesticide use, climate change, pathogens, forest fires, and pollution. These threats collectively reduce floral resources, nesting opportunities, and overall bee health, posing serious risks to their diversity and sustainability.

Chapter 1.
Introduction

Earth consists of many ecosystems and is home to an estimated 8.1 million species of plants and animals. Biodiversity is a variety of life forms in an ecosystem and is a key indicator of a healthy ecosystem. Thriving biodiversity is necessary for healthy ecosystems without which we would not have a secure and healthy food supply, clean water, essential medicines and a habitable climate.

Pollinators and the process of pollination play a crucial role in maintaining the functioning of nearly all terrestrial ecosystems, including those dominated by agriculture, as they ensure continuous productivity through plant reproduction. The interaction between flowering plants and their pollinators holds both ecological significance and economic value. Approximately 88% of angiosperms rely on animals for pollination services (Ollerton *et.al.* 2011). Insects, being the most diverse group in the animal kingdom, comprise over one million described species and account for more than half of all known living organisms. They inhabit nearly every part of the world, excluding the deep oceanic zones and polar regions, adapting to diverse ecological niches through their distinct biological and behavioral traits. Moreover, insects serve as vital indicators for assessing, managing, and monitoring biodiversity within natural ecosystems.

Insects are not only the most effective pollinators of plants but also play a vital role in maintaining plant diversity in natural ecosystems and enhancing the productivity of various agricultural and horticultural products, including crops, vegetables, and fruits. Recent studies have shown that a decline in insect populations has a greater negative impact on crop yield than reductions in other agricultural inputs, such as fertilizers or irrigation (Fijen *et.al*. 2020). The health of an ecosystem is often reflected in the diversity and community structure of its insect populations (Fagundes *et.al*. 2011).

Among the various groups of insects, Hymenoptera **r**epresents the second-largest and one of the most active groups of pollinators, encompassing both bees and wasps. The term *Hymenoptera* is derived from the Greek words *"Hymen"* (membrane) and *"Pteron"* (wing), referring to their characteristic membranous wings. Members of this order possess two pairs of wings — forewings and hindwings — which are linked by tiny hooks known as *hamuli*. The ovipositor in many species has evolved into a stinger, used for defense through toxin injection, while in some cases, it is adapted to immobilize prey (Hoell *et. al.*, 1998).

Globally, approximately 150,000 species of Hymenoptera have been identified, with 12,605 species recorded from India and around 3,054 species found in the Indian Himalayas. Worldwide, about 20,000 bee species have been documented (Michener, 2007), of which 5,700 species belong to the diverse and widely distributed family Apidae, which includes honeybees, bumblebees, and carpenter bees. Within this family, three major subfamilies — Apinae, Xylocopinae, and Nomadinae — are represented by around 15 genera in the Indian Himalayan region, including the genera *Bombus* and *Xylocopa*. In total, 337 bee species have been reported from the Himalayan region, of which 122 species belong to the Apidae family (Chandra *et.al.* 2018).

Bees (Hymenoptera: Apoidea) are an ideal taxon and the most important providers of biotic pollination services in the world. Conservation of many ecosystems and habitats thus depend upon preservation of bee population. Bees and wasps play an important role in pollination of plant species, they are pollinators of both natural vegetation and crops and these plant species fulfill the requirement of humans as well as their livelihood. If bees disappear from the earth, there will be limited reproduction of major elements of the flora. Bees (honeybees) are also source of other economically important material (Kevan, 1999).

Since ancient times people have been fascinated with bees and their study. Anyone studying their behavior would find them attractive, partly because they work in warm sunny places, during pleasant times and seasons. The sight and odor of the fieldwork ambience plays major role for the wellbeing of the researcher (Michener, 2000).

Bees occur in a variety of shape and sizes and displays an array of life histories. According to Danforth *et.al*. (2006) bees are considered as the symbol for social behavior evolution. India is a land of honeybees. The term ‘honeybees’ includes bees that store liquid honey and make waxen combs that people can harvest. Some of these bees have been domesticated for their honey and wax production. All the bees other than honeybees are pollen bees, because they are significant and valued for their pollination services. They are also known as “wild bees”, “non-apis bees” and “native bees”. They make only a little honey which fulfill their requirement but can’t be consumed by humans.

The greatest diversity of bees is found in tropical and subtropical areas (Michener, 2000). Due to their great diversity and high habitats requirements the bees considered as the major pollinators and bioindicators (Tscharntke *et.al*. 1998; Steffan-Dewenter *et.al*. 2002; Dauber *et.al*. 2003). According to Food and Agriculture Organization reports of U. N., more than 100 agricultural crops are pollinated by bees which provide 90% of global food (Pannure, 2016).

Bees are considered the most significant pollinators, as they are among the most frequent arthropod visitors to flowers (Neff and Simpson, 1993; Winfree *et.al.*2011). Being obligate florivores, both their larvae and adults rely on floral resources for nourishment. In contrast, among other arthropod taxa that act as pollinators, only certain species within each group visit flowers, and floral feeding is typically limited to the adult stage (Michener, 2007).

The Himalayas, known for their unique topography and diverse ecosystems, are home to a wide variety of flora and fauna, including a rich diversity of bee species. The altitudinal gradient and climatic variation in this region create a multitude of ecological niches that support different species of bees, making it an ideal location for studying species diversity and ecosystem interactions.

There are 12,605 species of Hymenoptera in India out of which around 4,872 are found in Indian Himalayas of which 337 are bee species. Bumblebee fauna consists of approximately 250 known species (Williams, 1994) and out of which 62 species of bumblebees have been reported from Indian Himalayan region (Williams, 2022). In the Himalayan regions bumblebee general distribution has been started from 400 m to 5600 m (Williams *et.al.* 2010). They are most abundantly distributed in the mountains to the east of Tibet and in the mountains of central Asia (Williams, 1994). The Himalayas, the longest mountain range in the world is home to high bumblebee diversity due to its variety of suitable habitats.

1.1 Bumblebee

Bumblebee species richness reaches its peak in Asia, particularly in the Himalaya and Hengduan Mountains along the southern and eastern margins of the Qinghai–Tibetan Plateau. One major reason for this high diversity is that bumblebees are believed to have originated in this region around 35 million years ago (Williams, 1985; Kawakita *et.al*. 2004; Hines, 2008; Williams *et.al*. 2017b). This long evolutionary history has allowed them ample time to diversify and establish numerous species here. Within the Himalaya, bumblebees are typically found in areas that offer suitable food plants and favorable climatic conditions (Williams *et.al.*2007).

Recent classification places all of the known bumblebee species in a single genus Bombus. Majority of these bee species are known as true bumblebees and have a social worker caste which is mostly sterile as they cannot mate but can lay unfertilized eggs that develop into males. Some bumblebees are also known as cuckoo bumblebees and earlier they were placed in a separate genus but now they are included in genus Bombus under the subgenus name of *Psithyrus*. They are also monophyletic (Plowright and Stephen 1973; Pekkarian *et.al.* 1979; Ito 1985; Pamilo *et.al.* 1987; Williams, 1985, 1994; Cameron *et.al.* 2007).

Bumblebees are eusocial insects with distinct division of labour and have annual life cycles. The queens produce an entire colony after going through a number of physiological and developmental changes and progress through mating, diapauses and oviposition (Wang *et.al.* 2019). The body of bumblebee is large and furry than honeybee and hence it makes them more ideal for large load of pollen collection and transfer (Willmer *et.al.* 1994). Bumblebees are natural pollinators and are especially important for many wildflowers and crops, making their conservation crucial for ecosystem health and agricultural productivity. They are also used commercially as pollinators in greenhouse and other enclosed growing settings. They are more efficient than honeybees in such environments and are generally very docile and do not swarm as do honeybees. They can actively forage during rainy and cloudy weather conditions whereas the foraging activity of other species in these circumstances halts (Delaplane and Mayer, 2000; Richards and Kevan, 2002). Body size influences bumblebee ability to hover between floral resources patches and to effectively collect pollen and nectar from flower.

Bumblebees have different tongue (proboscis) length and their flower preference for foraging is mainly governed by this (Heinrich, 1979). Long tongued bees tend to visit deep tubular flowers and short tongued bees tend to visit shallow open flowers or sometimes they also rob flowers of their nectar and are known as nectar robbers. Bee species with long tongues tend to have larger bodies (Carieveau *et.al*. 2016, Arbetman *et.al*.2017). They may extract resources from flowers that are not available to other bees (Harder, 1986, Peat *et.al*. 2005a). In other words larger bodied species may be able to exploit a disproportionate share of high quality resources under rich resource condition, but under poor resource condition smaller species may be advantaged by their lower metabolic costs (Pyke, 1978). Some species of short tongued bees extend the basal segments of their mouthparts including the prementum during feeding, in contrast to long tongued bees like bombus which keep their prementum static and thus use it very little during feeding, instead extending their glossae (Harder, 1982).

Bumblebees are not specialist forager but are generalist forager. As their colonies last longer than the flowering period of most flowers they must shift their food preference according to availability and suitability of food plants (Heinrich, 1979). Efficient foraging is very crucial for social insects like bumblebees as they have to, maintain their colonies for non foragers like larvae and nursing individuals too (Heinrich, 2004).

However in high altitude regions where certain plant species dominate or are able to thrive, bumblebees also depend on that plant only for their food (Williams, 1991). Sometimes high reward flowers like legumes, Rhododendron, Aconitum etc. attract bumblebees from a long distance and they even cross elevational zones for that (Williams, 2022).

Bees choose their flowers on the basis of inflorescence, their color, their position on plant, their fragrance and sucrose concentration. Vibrant colors and fragrance of flowers have an alluring effect on bees and they in return get rewarded with pollen and nectar for their pollination services. Pollens are rich source of protein and lipids while nectar is a rich source of energy in the form of carbohydrates (Kacchawa *et.al*. 2020).

Foraging activity is affected by several environmental factors like temperature, humidity, light intensity and wind speed (Cooper *et.al.* 1985). Pollination efficiency is directly proportional to the temperature and inversely proportional to wind speed. Foraging activity could be diminished with extreme high and low environmental temperature. Light intensity independently can not affect the foraging behavior of bees but it can affect with the combination of temperature. Foraging activity is enhanced several times if the nest is supplemented with brood hormones. Large sized and odoriferous flowers efficiently attract bees, so should be planted more near the agriculture field for yielding more crop (Pankiw *et.al.* 1998).

Social insects share the unique ability to communicate about food sources, allowing colonies to efficiently coordinate and adjust their foraging behavior based on resource availability and demand (Seeley *et.al.,* 1991; Seeley and

Tovey, 1994). Communication occurs either at the foraging site or within the nest, where foragers can interact with other colony members. Bumblebees, for instance, use odor markings to identify food sources (Cameron, 1981; Stout *et. al.*, 1998), though they do not leave scent trails unless moving on foot (Chittka *et. al.*, 1999). Thus, they rely on pheromonal cues in the field to assess the quality of food sources. Inside the nest, bumblebees can also gather information about food availability and floral scents (Dornhaus and Chittka, 1999).

Certain agricultural crops-such as tomatoes, peppers, cucumbers, blueberries, cane berries, strawberries, squash, and melons-are more effectively pollinated by bumblebees than by any other insect pollinator (Anonymous, 2019). Several bumblebee species are commercially bred and utilized by farmers worldwide to enhance the pollination of major crops (Pratap and Pratap, 1997, 2000). In Norwegian orchards, honeybee activity is limited by low temperatures, and pollination is therefore predominantly carried out by bumblebees (Faegri and Van der Pijl, 1979).

Using their long tongues, bumblebees extract pollen from tomato flowers by grasping and vibrating them-a process known as sonication or buzz pollination, through which pollen is released via apical pores (Buchman, 1983). Unlike honeybees, which are unable to perform buzz pollination, bumblebees are far more efficient pollinators. Approximately 9% of the world's flowering plants rely on buzz pollination. Globally, around 95% of commercially reared bumblebee colonies are employed for pollinating greenhouse-grown tomatoes and sweet peppers (Ercan and Onus, 2003; Velthius and Van Doorn, 2006).

Bumblebees are also effective pollinators of red clover (*Trifolium pratense*) and cranberries (*Vaccinium macrocarpon*). Being polylectic, they can forage on a wide range of floral species and are better adapted to human-dominated habitats compared to oligolectic bee species that specialize in fewer plant types (Westrich, 1996). Additionally, bumblebees are capable of foraging across mountainous regions and pollinating both wild and cultivated plants.

They recognize flowers using cues such as floral temperature (Harrap *et.al*., 2017) and electric fields (Clarke *et.al*. 2013). Studies have shown that bumblebees prefer symmetrical over asymmetrical flowers (Møller, 1995; Møller and Sørci, 1998), with a stronger preference for bilaterally symmetrical flowers compared to radially symmetrical ones (West and Laverty, 1998). Furthermore, research indicates that bumblebees are highly effective and efficient pollinators of crops such as apple, cucumber, and watermelon (Stanghellini *et.al.*, 1997, 1998; Thomson and Goodell, 2001)

In insects, body temperature plays a crucial role in survival and reproduction. Larger-bodied insects have a lower surface-to-volume ratio, which minimizes heat exchange with the environment and leads to slower rates of heating and cooling (Pereboom and Biesmeijer, 2003; Willmer and Unwin, 1981). Moreover, because body size is positively correlated with thoracic muscle mass-the primary tissue responsible for heat generation (Heath and Heath, 1982)-larger insects likely possess a greater capacity for endothermic heat production. Elevated metabolic rates observed in larger insects further support this assumption (Niven and Scharlemann, 2005). Consequently, due to these physiological mechanisms of endothermic thermoregulation, larger insects generally maintain higher body temperatures than smaller ones (Heinrich, 1993; Stone, 1993; Willmer, 1988; Willmer and Unwin, 1981)

Bumblebees are not used to temperatures above 30°C (Plowright and Jay, 1966 a, b). Moreover, as a result of climate change, the distribution of bumblebees has changed and biodiversity has decreased (Martins *et.al*. 2015 a, b; Sirois-Delisle and Kerr, 2018 a,b). With rising temperatures, the flight ability of bumblebees has also decreased (Kenna *et.al*. 2021a, b). With elevated temperatures bumblebees reduce their wing beating frequency and flight path distance resulting in lower pollen collection and hence lower pollination (Kuo *et.al.* 2023).

Plants respond to rising temperatures by changing their flower, nectar, and pollen production, or by adjusting the availability of floral resources and the reproductive performance of pollinating insects. Likewise, pollinators may react to warming through shifts in foraging behavior, body size, or lifespan, which in turn can influence pollen transfer patterns and the pollination success of flowering plants..

Temperature also dictated the timing of anthesis, with flowers opening 2-3 hours earlier on warmer mornings (Murcia, 1990). Climate change is making flowers bloom half a day earlier each year, which means that plants are now blooming a month earlier than 45 years ago. Plants blooming earlier ultimately mean that they do not get pollinated and bees are left without food. This is leading to bee decline in several parts of the world.

Many insect pollinators have shown global population declines, likely resulting from multiple interacting factors (Potts *et.al*. 2010), accompanied by parallel reductions in insect-pollinated plant species (Biesmeijer *et.al*. 2006). Therefore, understanding the physiological impacts of climate warming on pollinators, their floral resources, and the mutualistic relationships between them is a critical conservation priority for the coming decades.

This is particularly important for high-elevation bumblebees, as mountain ecosystems are expected to undergo the most severe climatic shifts (Nogués-Bravo *et.al.* 2007), and bumblebees serve as key pollinators in these regions (Bergman *et.al*. 1996; Bingham and Orthner, 1998). Furthermore, with rising temperatures, bumblebees from lower elevations are shifting to higher altitudes in search of suitable foraging habitats, thereby increasing competition with native high-altitude bee species.

1.2 Carpenter bees

Xylocopa species belong to the order Hymenoptera**,** superfamily Apoidea, family Apidae**,** and subfamily Xylocopinae**.** Commonly known as carpenter bees, they derive their name from their unique nesting habit of boring holes into wood. These bees have a cosmopolitan distribution (Hurd *et.al*. 1963; Thakur, 2012) and are primarily solitary, occurring mostly in tropical and subtropicalregions**.** The genus comprises about 750 speciesgrouped into 31 subgenera (Michener, 2007), with approximately 45 species recorded in India**.**

The name "carpenter bee" reflects their nesting behavior, as nearly all species excavate tunnels in hard plant materials such as dead wood or bamboo. A related tribe**,** Ceratini, commonly called small carpenter bees, exhibits similar behavior, constructing nests in dead wood but is distinguished by its smaller body size (Dar *et.al*. 2016).

Xylocopa species have an extended activity period and visit a wide range of plant species, making them polylectic**.** Some species serve as key pollinators and are therefore utilized in horticultural pollination (Gerling *et.al*. 1989). Crops such as passion fruit, squash, tomato, Brazil nut**,** and eggplantare pollinated by specific *Xylocopa* species, which are commercially managed for this purpose in various countries (Keasar, 2010; Giannini *et.al.* 2015).

Xylocopa species are found worldwide, which is significant because native populations can often be utilized for pollination across broad regions, minimizing the need to introduce non-native pollinators (Keasar, 2010). The choice of nesting site and substrate strongly influences their distribution and genetic structure (Bernardino *et.al.*, 2008; Prager *et.al*., 2011).

These bees are typically black**,** metallic bluish**,** greenish-black, or purplish-blue in color, with some males exhibiting yellowish markingson the face. Large carpenter bees are often mistaken for bumblebees; however, they can be distinguished by their shiny black abdomens, in contrast to the densely pubescent and differently colored abdomensof bumblebees (Michener, 2007). The abdomen of *Xylocopa* species may display metallic or iridescent hues-such as blue, black, bronze, purple, green, or buff-depending on the species (Beyond Pesticides/NCAMP, 2016).

Females of most species are prominent, generally black or blue, often with lighter-colored hair patches. Males may resemble females or be covered entirely with light brown, green, or yellowish-green pubescence (Malyshev, 1931). All *Xylocopa* species are believed to be polylectic**,** visiting a wide variety of floral species-particularlylarge, showy flowers rich in pollen and nectar (Hurd, 1956).

Flower color as well as flower odour play a major role for foraging preference of bees. In general bees get attracted to yellow and white flowers followed by blue or purple flowers. Xylocopa bees prefer mostly yellow flowers like of family cucurbitaceae followed by purple white, creamy white and bluish white flowers like *Calotropis* sp., *Mansoa alliacea* etc. Xylocopa sp. prefers large sized flowers if available and rewarding by exhibiting floral fidelity. Floral symmetry and shape also have significance for foraging preference. They prefer non tubular or flowers with easy access to nectar and pollen source. If they visit long tubular flowers they tend to rob the nectar by biting holes at the corolla base. They also prefer zygomorphic or flowers with bilateral symmetry so as to avoid the wastage of pollen and nectar rewards (Aluri *et.al.* 2006)

Different carpenter bees species collect different types of pollen. Bee larvae feed on the pollen which is the sole nutrition source for it and is main ingredient of the stored food by the mother bee. It is also observed that same kind of carpenter bee collect different kinds of pollen in different distribution areas (Chunling *et.al*. 2020).

Carpenter bees have short mouthparts and are important pollinators on shallow flowers. They are considered obligate pollinators. Some flowers like the Maypop *(Passiflora incarnata)* and Orphium (Johnson, 1962) are not pollinated by other insects, except carpenter bees. Also, they are important pollinators of flowers with various forms of lids, e.g. Salvia species, Fabaceae, and Rosacea (apple, peach, plum, cherry, apricot, almond).Carpenter bees have short labia, therefore bees cannot reach nectar without piercing the long-tubed flowers; they miss contact with the anthers and perform no pollination. Therefore, they are considered to "rob" the nectar by slitting the sides of flowers with deep corollae. Carpenter bees are excellent pollinators of vine crops such as passion fruit (*Passiflora edulis* Sims), giant granadilla (*P. quadrangularis* L.), kiwi fruit

(*Actinida deliciosa*).

1.3 Molecular studies of bees

Although pollinators such as bees are well recognized for their vital ecosystem services, their true diversity remains largely unexplored by the scientific community. In India, species identification has traditionally relied on morphological taxonomy (Saini *et.al*. 2018); however, the genetic characterization of bee species from the Indian Himalayan Region (IHR) has not yet been undertaken. Furthermore, the presence of cryptic diversity often complicates accurate species differentiation, leading to taxonomic confusion among biologists (Hines and Williams, 2012; Vamosi *et.al.* 2017). Beyond species identification, molecular tools provide a dependable means to assess genetic distances and elucidate relationships among target species (Will and Rubinoff, 2004; Kekkonen and Hebert, 2014).

Taxonomic classification of bumblebees based solely on morphological traits is often difficult because of extensive color polymorphism within species (Huang *et.al*. 2015b; Ding *et.al*, 2019) and the occurrence of cryptic species (Williams *et.al*. 2020, 2022a). Although bumblebees exhibit comparatively uniform morphological features relative to other bee groups, their coloration patterns vary widely both within and between species (Williams *et.al.* 2020, 2022a). These color variations, however, can be deceptive due to convergent evolution-where unrelated species from the same region develop similar color patterns. Consequently, traditional morphology-based approaches are often unreliable for accurate species identification in bumblebees (Vogt, 1909, 1911; Reinig, 1939; Plowright and Owen, 1980; Williams, 2007)

Molecular methods have made species identification and the determination of phylogenetic relationship among focal taxa much easier compared with analysis based on morphological characters alone. In particular, DNA sequencing data, mainly cytochrome c oxidase subunit1 (CO1) gene sequences have accumulated for bumblebee species, revealing phylogenetic relationships among species, boundaries among closely related species and morphological variation within species (Murray *et.al*. 2008;Williams *et.al.* 2013, Williams *et.al*. 2012b, Huang *et.al.* 2015). In carpenter bees phylogenetic studies can be done by using mtDNA markers cytochrome- c oxidase subunit 1 (CO1) and cytochrome b genes (Leys *et.al*.2001).

1.4 Climate change impacts

Effect of climate warming on insect pollinators is difficult to study as very few long term monitoring datasets are available which could link pollinator ecology to climate change (Bartomeus *et.al.* 2011; Burkle *et.al.* 2013; Kudo and Ida, 2013; Ogilvie *et.al*. 2017). The mountains being an important part of the ecosystem serve as an ecosystem service provider to a wide range of flora and fauna of their surrounding areas, but land use land cover modifications and global warming leading to climate change is highly affecting the biodiversity of these ecologically functional areas (Das *et.al*. 2023). The Himalayan mountain range , one of the most significant biodiversity hotspot, have a complex topographical and climatic diversity and is home to a diversified endemic and exotic plant species whose distribution pattern depends on species distribution pattern of wild pollinators (Wambulwa *et.al*. 2021).

In recent times several Himalayan species especially pollinating insects face extinction due to climate change which may have irreversible effect on the ecosystem and biodiversity of this region. Insects show changes in their behavior, physiology and phonological coexistence with host plants because of climate change (Singh *et.al*. 2024).

Decline in pollinator population can lead to simultaneous decline of the plants they pollinate (Beismeijer *et.al*. 2006). Globally the main causes of decline are attributed to habitat loss and fragmentation, agro-chemicals, pesticides, pathogens, industrialization, introduction of alien species and interaction between all these (Potts *et.al.* 2010; Kondo *et.al*. 2009; Williams and Osborne, 2009; Morales *et.al.* 2013; Martins *et.al.* 2015).

While staple crops like rice, wheat, and maize are wind-pollinated, many insect-pollinated crops such as pumpkin (*Cucurbita maxima* and *Cucurbita argyrosperma*), okra (*Abelmoschus esculentus*), potato (*Solanum tuberosum*), peppers (*Capsicum annuum),* cucumber (*Cucumis sativus*), cowpea (*Vigna unguiculata*), and to some extent common bean (*Phaseolus vulgaris* are also essential in diets around the world. These crops provide crucial macro- and micronutrients. A decline in insect-pollinated crops could negatively affect global food security by impacting food availability,

nutrition, and stability. In essence, pollinators play a vital role not only in biodiversity but also in maintaining food systems that support human health and nutrition. (Eilers *et.al*. 2011). Furthermore, insect pollination is crucial for many domestic and wild fruit trees, cash crops such as cotton (*Gossypium hirsutum*) and other food plants, making them even more important for sustaining food and medicines for most rural communities that depend on them. As such, the conservation of pollinators requires urgent attention by policy makers, conservationists, and farmers alike. Despite increased research and advocacy for pollinator conservation, much of the public remains unaware of the diversity and importance of bee pollinators, which impacts their conservation actions. There is a clear link between public knowledge and conservation efforts, underscoring the need for education to drive action. This insight should guide the design and implementation of outreach and extension programs to raise awareness and promote effective conservation practices (Wilson *et.al*. 2017).

Chapter 2.

Review of literature

2.1. International Scenario

2.1.1. Taxonomy and Classification of Bees

The foundational work on the taxonomy and classification of hymenopteran insects begins with Smith (1852), who identified and described several new species from North China, laying the groundwork for future research in the region's hymenopteran fauna. Later, Starr (1992) provided a detailed account of bumblebee species in Taiwan, adding to the growing understanding of regional bee biodiversity. Williams has been a prominent figure in bumblebee taxonomy, offering a global checklist of bumblebee species (1998), followed by specific regional accounts such as Sichuan province of China (2009) and the Himalayan bumblebee species (2022). These comprehensive studies are critical for understanding species diversity, taxonomy, distribution, and ecology globally.

Han *et.al.* (2018) further advanced species identification using DNA barcoding, analyzing mitochondrial DNA to reveal genetic variations among South Korean bumblebees, showing how molecular tools complement traditional taxonomic methods. Similarly, Leys *et.al*. (2001) employed molecular techniques to reassess evolutionary relationships within the genus *Xylocopa*, uncovering how ecological factors and continental drift shaped the diversification of carpenter bees.

2.1.2. Morphology and Functional Ecology

Morphological studies have also played a key role in understanding bee biology. Meddler (1962) utilized morphometrics to measure physical traits of bumblebees, examining their size, shape, and anatomical features. Harder (1985) connected morphology with ecological function, showing how body size and tongue length influence flower choice during foraging. Macfarlane *et.al*. (1985) extended this understanding to agricultural contexts, demonstrating that bumblebees, with their long tongues, are more effective than honeybees at pollinating red clover, a deep-flowered crop. These insights tie into broader discussions about pollination efficiency and plant-bee co-evolution.

2.1.3. Behavioral Ecology and Foraging Patterns

The behavioral ecology of bees has been another major research focus. Alford (1969) examined the hibernation patterns of bumblebee queens in Southern England, offering insights into their survival strategies and lifecycle dynamics. Dramstad and Fry (1994) explored how bumblebee distribution depends on the availability of floral resources, emphasizing plant-bee relationships. Walther and Frankl (2003) investigated the foraging behavior of bumblebees in agricultural landscapes, finding that bees require diverse and accessible habitats to thrive. Liang *et.al*. (2022) investigates the molecular mechanisms underlying the adaptation of bumblebees to high-altitude environments. The study conducted on two species of bumblebees of Qinghai-Tibet Plateau i.e. *B. kashmirensis* and *B. waltoni*indicates that these bumblebees tend to up-regulate energy metabolism-related genes when facing extremely high-altitude environments. Miller-Struttmann *et.al*. (2015) revealed that two alpine bumblebee species *B. balteatus* and *B. sylvicola* have experienced a significant reduction in tongue length over the past 40 years and this reduction correlates with a decline in the abundance of deep-flowered plants, likely due to warmer summer temperatures and drier soils.

Luow and Nicolson (1983) studied the carpenter bee *Xylocopa capitata*, showing how thermal conditions and nutritional needs impact their foraging and reproductive success. Similarly, Durant *et.al.* (2015) investigated the molecular mechanisms behind overwintering in *Ceratina calcarata*, a bee species exhibiting both solitary and social behaviors, providing a unique perspective on the genetic regulation of overwintering and sociality.

Velthuis *et.al.* (1984) compared the foraging and cell-provisioning behaviors of two Israeli large carpenter bee species, *Xylocopa pubescens* and *Xylocopa sulcatipes*. Both species primarily foraged in the early morning; however, *X. sulcatipes* continued its activity later into the day. While *X. pubescens* collected pollen and nectar simultaneously, *X. sulcatipes* often made separate trips for each resource. In *X. pubescens*, nectar and pollen were mixed after every foraging trip, whereas *X. sulcatipes* mixed them only after nectar collection. This difference led to greater variation in the amount of bee bread produced, ultimately resulting in size differences among the adult bees.

2.1.4. Pollinators in Agriculture and Crop Productivity

The relationship between pollinators and agricultural productivity is a recurring theme. Free and Williams (1976) demonstrated that insufficient pollination by bees limits the productivity of field beans (*Vicia faba*), while Heard (1999) emphasized the importance of stingless bees (*Meliponini*) in subtropical and tropical agriculture. Goulson (2003) highlighted the role of wild bees, especially bumblebees, in crop pollination and underscored the need for habitat restoration and sustainable farming to support these pollinators.

Velthius and Van Doorn (2006) reviewed the domestication of bumblebees for crop pollination, especially in greenhouses, while Griffiths and Roberts (1996) discussed the advantages of using *Bombus terrestris* in controlled environments for economic and yield benefits. Roulston and Julier (2009) analyzed how farm management practices affect wild bee populations and their role in pollinating pumpkin crops, recommending the conservation of natural habitats and nesting sites to enhance pollination services.

2.1.5. Pollinator Decline and Conservation

Pollinator decline and its ecological consequences have been extensively studied by various researchers around the globe. Buchmann and Nabham (1996), in *The Forgotten Pollinators,* warned of the cascade of linked extinctions driven by human activities such as pesticide use and habitat fragmentation. Kevan (1999) argued that pollinators serve as vital indicators of environmental health, and Kevan and Phillips (2001) linked pollinator declines to economic risks, urging policymakers to adopt conservation strategies. Weather highly influences bees' foraging rates (Vicens & Bosch, 2000), which affects the flight speed, flight duration, and foraging behavior (Wratt, 1968; Heinrich & Heinrich, 1983; Corbet *et.al*., 1993; Abou- Shaara, 2014). Changes in the phenology of plants, such as early budding, delayed flowering, and fruit and seed malformation, can adversely affect the pollination and productivity of the ecosystem (Thuiller *et.al*., 2008). Bumblebee population is sensitive to the timing of resource availability, it can be concluded that fluctuations in temperature and precipitation influences snowfall, snowmelt and precipitation regimes which in turn affect habitat conditions by influencing nectar availability for pollinators. (Singh *et.al*. 2024)

Potts *et.al*. (2010) provided a global analysis of pollinator declines and called for urgent, multilevel conservation efforts. Biesmeijer *et.al*. (2006) connected pollinator declines with reductions in insect-pollinated plants in Britain and the Netherlands, while Pinder *et.al.* (2017) assessed pollinator health in Ontario, highlighting the threats facing bees and suggesting strategies for their conservation. The UN designated 20th May World Bees Day to inform people of their significant roles in sustainable development and the threats they face.

2.1.6. Pollinators and Ecosystem Services

The ecological roles of pollinators extend beyond agriculture into broader ecosystem services. Kearns and Inouye (1997) and Allen-Wardell *et.al*. (1998) both emphasized the importance of pollinators for biodiversity and ecosystem health, stressing the need for greater conservation attention. Goulson (2003a) observed that wild plants rely heavily on bumblebee pollination, and Waser *et.al.* (1996) noted that many insect-pollinated plants use diverse groups of pollinators, with bumblebees serving as generalists.

Ashman *et.al.* (2004) examined pollen limitation in plants and the potential impact of environmental changes on reproductive success. Winter *et.al.* (2006) raised concerns about introducing non-native bumblebees for commercial pollination, advocating for the use of native species and stronger regulations to mitigate ecological risks. Wild bees were more efficient in buzz pollination than honey bees (Buchmann, 1983; Herren & Ochieng, 2008). Even in tomato (Solanaceous) cultivation, better performance as pollinators was observed in wild bees than honey bees (Garibaldi *et.al*., 2013) as sonicating bees could efficiently extract pollen from poricidal anthers (Greenleaf & Kremen, 2006) and increased yield of the crop (Cooley & Vallejo-Marin, 2021).

2.1.7. Advances in Genetics and Genomics

Finally, advances in genetic and genomic research are deepening our understanding of bee biology and conservation. Sadd *et.al.* (2015) performed a genomic analysis of *Bombus terrestris* and *Bombus impatiens*, two eusocial bumblebee species crucial for pollination but facing population declines. Their findings revealed that genes governing behavior, neurophysiology, and endocrinology are conserved across bees, including *Apis mellifera*, shedding light on bee evolution and resilience. Such genetic insights, combined with ecological and behavioral studies, provide a comprehensive understanding of bee species and the urgent need to protect these vital pollinators. Han *et.al.* (2014) studies *Bombus ignitus* in South Korea and concluded that the species maintains genetic homogeneity across regions, likely due to their strong flight capabilities and lack of significant physical barriers. Findings also support the potential use of this species in commercial pollination programs due to their robust genetic health.

2.1.8. Environmental threats

Climatic conditions generally control the distribution and density of species, including flowering plants and pollinators. Climate change led to the alteration in the blooming periods of the flowering plants. The abundance of bee population in the region also related to the floral resources, but triggered environmental changes lead to the decline in the bee density. Climate change significantly contributes to the declining bee population (Kerr *et.al*., 2015). The high temperature and drought conditions makes it difficult for the bees to survive in the stressful conditions. Different studies show bumble bees are resistant to a temperature above 30° C (Plowright & Jay, 1966); as a consequence of climate change, the diversity and distribution of bumble bees have reduced (Martins *et.al*., 2014; Sirois-Delisle and Kerr, 2018). Rainfall patterns change due to climate change, increasing water stress and limiting flowers. Due to climate change, the functional attributes of the bees (tongue length) and floral partners (tubes) are becoming mismatched and causing a significant threat to their mutualistic associations (Miller-Struttmann *et.al*.,2015). Pesticides, i.e., synthetic chemicals, are highly responsible for pollinator mortality (Kearns & Inouye, 1997).

2.2. National Scenario

2.2.1. Taxonomic Studies of Bees in India

The early groundwork for the taxonomy of Hymenoptera in the Indian subcontinent was laid by Bingham (1897) through his comprehensive work in the *Fauna of British India* series, covering bees and wasps across India, Sri Lanka, Myanmar, and nearby regions. Ma (1938) provided a detailed account of the genus *Xylocopa*, focusing on the morphological characteristics and distribution of carpenter bees. Batra (1977) advanced this work by developing identification keys for Indian bee genera, significantly aiding future taxonomic efforts. Gupta and Yanega (2003) refined the classification of *Xylocopa* and the tribe Xylocopini, while Saini *et.al*. (2015) created identification keys for Indian bumblebees. Regional surveys, such as Gupta (2013) in Uttarakhand and Thayyullathil *et.al*. (2017) in Dumna Nature Park, broadened the known diversity of *Xylocopa* species. Raina *et.al*. (2017) described new morphological variants of *Bombus trifasciatus* from the Indian Himalayas, while Chikkabuddi *et.al*. (2016) enriched the taxonomy of *Koptortosoma* in the Western Ghats. Collectively, these studies have substantially improved the understanding of bee diversity and distribution across India's varied landscapes. Taye *et.al* (2021) identified five bumblebee species in Northeast India, providing insights into their distribution and morphological variations.

2.2.2. Foraging Behavior and Pollination Ecology

Research on the ecological roles of bees in India has provided valuable insights into their foraging behavior and pollination ecology. Abrol (1988) observed foraging stratification in *Apis cerana* and bumblebees on loquat trees, suggesting niche differentiation among pollinators. Sihag (1990) reported that *Xylocopa fenestrata* foraged on 44 plant species in Haryana, emphasizing their ecological versatility. Aluri *et.al.* (2000) highlighted the essential role of carpenter bees in pollinating native plant species, while Udayakumar *et.al.* (2004) stressed the broader importance of bee pollinators in sustaining ecosystem health. Furthering this understanding, Raju and Rao (2006) examined nesting behavior and floral preferences of *X. latipes* and *X. pubescens*, providing essential data for conservation efforts. These studies collectively underscore the intricate relationships between bees and their floral resources, highlighting their critical roles in maintaining biodiversity. Study in Uttarakhand observed higher species richness of primary pollinators in organic farming than non-organic agriculture (Mehrwar, 2022). Organic farming, intercropping, and crop rotation practices, along with planting flowering strips and maintaining wild native flower vegetation, can enhance the foraging rate of bees. Solanaceous (eggplant, tomato) and Cucurbitaceous (ridge gourd) crops were effectively pollinated by buzz pollinators (Kumar & Rai, 2020). Eggplant flowers had abundant pollen, but the expulsion of pollen requires vibration by insects like "buzz pollination." Zafar (2013) documented the nesting behavior of *Xylocopa latipes* and *Xylocopa pubescens* in Visakhapatnam, India. The study reported that these species built their nests in dead wood or in dead branches of living plants, particularly *Syzygium cumini*, *Cassia siamea*, and *Bambusa vulgaris*. A study in the Garhwal region of India observed plants like *Ageratum conyzoides*and *Tagetes erecta* bloom throughout the year and became continuous food sources for bees and also the studied bee pollen samples have high soluble sugars, protein, amino acids and phenolic contents, making it a good source of nutrition, medicine and dietary supplement for both humans and bees (Gloch *et.al*., 2023). The study conducted by investigates the diversity and composition of non-Apis bee communities across natural habitats and agroecosystems in the Doon Valley. The research reveals that natural habitats serve as refuges for rare and specialist bee species. Polyculture farms, especially those near forests, support higher bee diversity compared to monoculture systems. Study shows that *B. haemorrhoidalis* forage mainly on Cucurbitaceae and solanaceae family in Doon Valley (Purohit.A., 2022).

2.2.3. Bumblebees in High-Altitude Agriculture

The role of bumblebees as pollinators in high-altitude farming systems has been a focus of several studies. Sinu and Shivanna (2007) demonstrated that bumblebees are essential for the pollination of large cardamom in the Himalayas. Deka *et.al*. (2011) and Sinu *et.al*. (2011) emphasized the importance of species like *Bombus breviceps* and *Bombus haemorrhoidalis* in this context. Chauhan *et.al*. (2011, 2013) contributed by developing rearing techniques and exploring the behavior of bumblebees under subtropical conditions. Raina *et.al*. (2019) analyzed foraging patterns of Himalayan bumblebees along altitudinal gradients, advocating for diverse floral resources to support their populations. More recently, Parrey*et.al*. (2023) and Sharma *et. al*. (2023) documented bumblebee diversity and ecological roles in high-altitude sanctuaries and the Western Himalayas, respectively. These studies highlight the indispensable role of bumblebees in supporting both natural ecosystems and agricultural productivity in mountainous regions. *B. haemorrhoodalis, B. rotundiceps* and *B. trifasciatus* are reported along river Ganga both in high mountainous and plain areas (Uniyal *et.al.,* 2022)

2.2.4. Morphological and Molecular Characterization

Understanding the morphological and genetic diversity of bees has been advanced through both traditional and molecular approaches. Verma *et.al*. (1994) observed that honeybee populations at higher altitudes with lower rainfall are larger and darker, likely adaptations to local climatic conditions.

A study by Rana *et.al*. (2024) reported the first occurrence of *Bombus hypnorum* in Himachal Pradesh, India, using DNA barcoding to confirm species identification. This finding contributes to the understanding of bumblebee distribution in the region. Yogi (2016) employed mitochondrial markers such as COI and Cyt b to characterize *Xylocopa* species in Uttarakhand, providing molecular evidence of species distinctions. Pakrashi *et.al*. (2020) utilized DNA barcoding to improve species identification in the Indian Himalayas highlighting the limitations of traditional morphological taxonomy due to polymorphisms and mimetic color patterns, while Lazar *et.al*. (2024) linked climatic variables to the availability of floral resources and the foraging behavior of bees. These studies illustrate how integrating morphological observations with molecular tools can enhance our understanding of bee diversity, adaptation, and ecological interactions.

2.2.5. Conservation of Bee Populations

Many researcheshave increasingly focused on the conservation of bees in India, recognizing their ecological and agricultural importance. The study done by Dang and Doi (2020) underscores the ecological importance of wasps and bees in urban green spaces and highlights the need for biodiversity conservation in rapidly urbanizing areas like Kota.The findings provide baseline data for future ecological and conservation research in the region. Under the 'Mission Bee' initiative, advanced training has been provided by the state govt. of Gujarat to over 11,300 farmers, and special seminars are being organized in districts where beekeeping activities are popular.

Murthy *et.al*. (2024) analyzed the threats faced by pollinator populations and proposed actionable conservation strategies to mitigate these risks. Farook *et.al*. (2022) highlighted the ecological significance of carpenter bees in Jammu, Kashmir, and Ladakh, emphasizing their roles in pollinating both wild flora and cultivated crops. These studies underscore the urgent need to protect pollinator habitats and maintain floral diversity to sustain healthy bee populations amid changing environmental conditions.

Chapter 3.
Study area and Research Objectives

3.1. Study area

The study has been conducted in Dehradun district of Uttarakhand state. It lies between 29˚55' and 30˚30' N latitude, and 77˚33' and 78˚20' E longitude. It is bordered by the Himalayan range to the North, the Shivaliks to the south, the Ganges to the east and the Yamuna river to the west. The district has varied physical geography from Himalayan mountains to plains. Dehradun district is bounded on the north and north-west by the district of Uttarkashi and in the east by Tehri and Pauri districts, in the west by Sirmour district of Himachal Pradesh and to the south by Haridwar and Uttar Pradesh's Saharanpur district. (Fig. 1)

According to Walton (1911), the soils of Dehradun can be broadly categorized into three types: loam, clay, and a lower-grade mixture of loam or clay with stones, all formed through the weathering of parent rock material. The valley's surface is continually reshaped by several perennial and many seasonal streams, locally known as "Rao," which descend from the surrounding Himalayan ranges. The area consists mainly of recent gravel deposits and consolidated scree fans originating from the nearby mountains. These torrents often alter their courses annually due to monsoon runoff from the Himalayas, resulting in the valley being divided into a series of stepped terraces at varying elevations along the eroded riverbeds (Walton, 1911).

3.1.1 Climate

The Dehradun Valley experiences a subtropical to temperate climate (Mukesh *et. al.*, 2011), with elevations ranging from 500 to 2,500 m above sea level. The average annual temperature varies from around 18°C in January to about 40°C in June, while mean annual rainfall ranges between 1,600 and 2,200 mm, depending on altitude. Slight variations in rainfall, high humidity, and warm temperatures support a rich and diverse tropical vegetation (Babu, 1977), dominated by *Sal* (*Shorea robusta*) forests (Gautam *et.al.,* 2014).

Dehradun district experiences three main seasons typical of the upper Indian plains-summer, monsoon, and winter. The monsoon sets in by July and continues until late September or early October. October and November are characterized by clear skies, wide temperature fluctuations, and heavy night dews. These conditions persist through most of December, though by late December and early January, temperatures drop significantly, often dipping below freezing. From December to February, cloudy conditions prevail, reducing nighttime heat loss and leading to intermittent rainfall, often followed by snowfall over the Mussoorie range above Dehradun. By March and April, temperatures rise rapidly, occasionally bringing thunderstorms, and continue to increase through May and June until the onset of the monsoon in July (Walton, 1911).

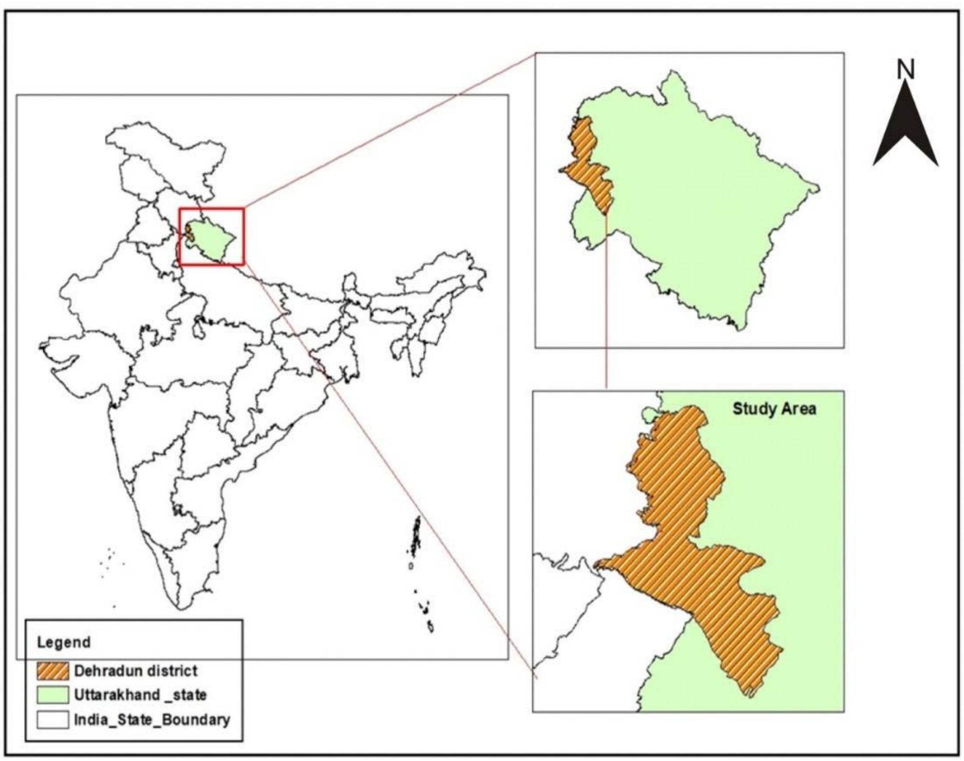


Fig.1. Map of Study Area

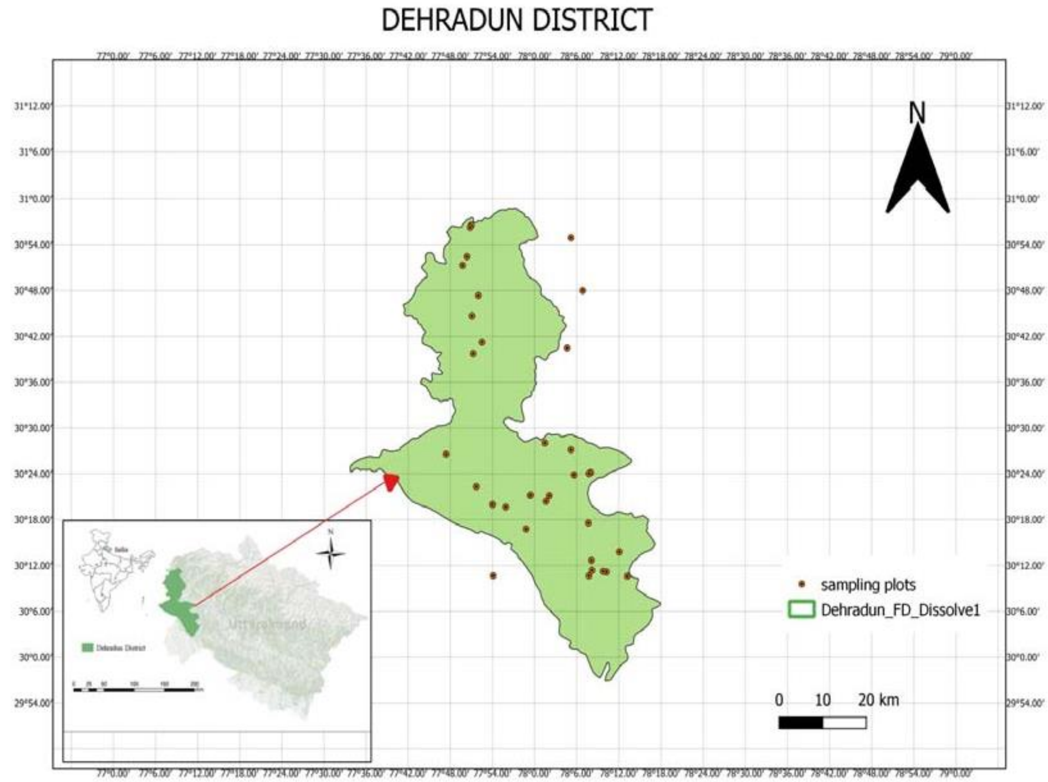


Fig. 2. Map of location points of study area.

3.1.2 Floral diversity

Champion and Seth (1968) have classified the Dehradun district into three subtypes base on Sal (*Shorea robusta*) forests; Moist Shivalik Sal forest, Moist Bhabar Doon Sal forest and Dry Shivalik Sal forest. Sal vegetation is dominant and its associates are *Mellotus phillippensis, Litsea glutinosa, Ardisia solanacea, Flaucortia indica, Diospyros malabarica* and *Petrospermum acerifolium.*

Sal forests- Sal forest is very common in the foothills of dehardun district and consists of the most commonly found tree species *Shoreo robusta*. Most of the forested area in the valley is Sal dominant. Sal trees are associated with other trees like *Anogeissus latifolia, Terminalia tometosa, Terminalia alata, Adina cordifolia, Lannea coromandalica, Garuga pinnata, Ougenia dalbergioides, Bridelia retusa, Buchanania latifolia, Lagerstroemia paviflora, Mallotus* *philippensis, Semecarpus anacardium, Careya arborea, Aegle marmelos, Ehretia laevis, Cassia fistula, Syzygium cumini, Holarrhena antidysenterica, Diospyros spp., Bauhinia variegate, Ardisia solanacea, Murraya koenigii, Colebrookea oppositifolia, Clerodendrum viscosum, Flemingia strobilifera etc.*

Mixed and Scrub Forests- These forests occur in the outer regions of the dense Sal forests continuously exposed to anthropogenic activities such as logging, fires, overgrazing, agricultural expansion, etc. Here, one can find Sal trees in more degraded conditions due to lopping. The various associated trees are more or less similar to those in dense Sal habitats, however, in degraded conditions. The shrubs consist of *Carissa opaca, Adhatoda zeylanica, Colebrookia oppositifolia, Leea crispa, Murraya koenigii, Calotropis procera, Clerodendrum viscosum, Woodfordia fruticosa, Nyctanthes arbor-tristis, Xeromphis spinosa, Zizyphus oenoplia* etc. *Lantana camara* is one species of shrub that has widely grown on the outer most boundaries and spread deep into the forests at many places especially in the South Western region of Dehradun. The commonly found climbers in the more mixed forests include the *Tinospora cordifolia, Ampelocissus latiflolia, Cissampelos pariera, Ventilago denticulata, and Ichnocarpus frutescens.*

Riverine forests- These habitats are physiographically dynamic due to the continuous supply of moisture to the extent of waterlogging along water torrents. Such habitats in the valley support vegetation that is of the evergreen type with the tolerance to high moisture. These trees comprise of *Syzygium cumini, Ficus racemosa, Trewia nudiflora, Pterospermum acerifolium, Albizia procera, Calamus tenuis, Phoebe lanceolata, Machilus gamblei, Salix tetrasperma, Diospyros exsculpta, Cudrania javanica, Toona ciliata, Ardisia solanacea, Bischofia javanica, Achronychiia pedunculata, Desmodium latifolium, Vetiveria zizanioides* and numerous species of ferns. *Eclipta alba, Mazus pumilus, Centella asiatica, Youngia japonica, Corchorus spp., Bupleurum hamiltonii, Lindenbergia spp., Rungia pectinata, and Hemigraphis hirta*. The vegetation along the streams are composed of *Trewia nudiflora,* *Dalbergia sissoo, Orthanthera viminea, Syzygium cumini, Xylosma longifolia, Opuntia spp., Adhatoda zeylanica, and Gonostegia pentandra.*

Plantations- These were managed for timber and consisted of trees such as *Tectona grandis*, Eucalyptus spp., and Pinus spp. Although, *Shorea robusta* is a dominant tree in Dehradun district under the forest management before the 1960s was managed for timber silviculturally. Patches of Sal forest are still evident across the district where the other associated trees were removed for monocultures of Sal for wood.

Agricultural Habitat- The next major land use to follow forest habitats is agriculture. The agricultural habitats comprise of traditional (polycultures and chemical free), conventional (monocultures with or without chemicals) and cash crop cultivation (Tea and Sugarcane). Sampling sites include traditional organic and polyculture farms such as local village kitchen gardens, and seasonal crops traditionally grown for domestic consumption. These consisted of radish, rapeseed, mustard, turnip, cabbage, fenugreek, linseed, broad bean, carrot, fennel, chamomile, mango, litchi, etc. While the conventional farms included crops such as wheat, sugarcane, tea and mustard grown for large-scale commercial purposes.

Upper hill forest- The upper hill forest of Chakrata, Benog and Mussoorie includes conifers like *Pinus roxburghii*, *Pinus wallichiana*, *Cedrus deodara* and other trees like *Prunus persica*, *Ficus palmeta*, *Juglans regina* , *Myrica esculanta*, *Quercus leucotrichophora* , *Grewia oppositifolia*, *Toona ciliate*, *Ilex dipyera* , *Aesculus Indica* , *Acer oblongum* , *Prunus armeniaca*, *Bauhinia vahlii* , *Punica granatum* , *Rhododendron arboretum*, and *Cinnamomum tamala*.

3.1.3 Faunal diversity

There are over 400 avian species found in Dehradun district. Besides mammals such as leopard *(Panthera pardus*), jungle cat (*Felis chaus*), Himalayan palm civet (*Paguma larvata*), small Indian civet (*Viverricula indica*), common mongoose (*Herpestes edwardsi*), yellow-throated marten (*Martes flavigula*), elephant (*Elephas maximus*) occurs in this landscape. A total 86 species of fishes belonging to 52 genera, 22 families and 8 orders have been recorded from the Dehradun district. (Uniyal, 2010). Dehradun represents 98% of the total amphibian diversity (20 species) of Uttarakhand (Bahuguna and Bhutia 2010).The district represents 60% of the total amphibian diversity (72 species) of Uttarakhand (Bahuguna 2010).The bird diversity of Dehradun district represents a total of 533 species belonging to 260 genera, 69 families and 17 orders. This constitutes 43% of the known bird diversity (1225 species) of the Indian subcontinent (Islam and Rahmani 2004) and 71% of the bird diversity (743 species) of Uttarakhand (Tak and Sati 2010).

12 study locations were selected and surveyed for diversity assessment of bees which were Bajawala, Sahastradhara, Tiuni, Jadi, Tea estate, Thano, Chandrabani, Jollygrant, Selaqui, Benog Wildlife Sanctuary, Koruwa and Mohund (Fig. 2).

Table 3.1. - Details of sampling locations

Location	Latitide	Longitude	Altitude(m amsl)
Bajawala	30.534181°N	77.9898117°E	560
Sahastradhara	30.4029021°N	78.1330826°E	900
Tiuni	30.9382977°N	77.8469744°E	935
Jadi	30.7448194°N	77.8512502°E	2257
Tea estate	30.3276038°N	77.9316054°E	500
Thano	30.2552154°N	78.1536931°E	580
Chandrabani	30.2807869°N	77.9806153°E	620
Jollygrant	30.1859713°N	78.1705159°E	550
Selaqui	30.3721125°N	77.8615995°E	682
Benog Wildlife Sanctuary	30.4759424°N	78.0240135°E	1720
Koruwa	30.6610696°N	77.8573942°E	1560
Mohund	30.1777112°N	77.9017492°E	600

3.2 Research Objectives

1. Systematic survey of genus *Bombus* and *Xylocopa* for taxonomical, ecological and seasonal sampling in Dehradun district.

2. Identification of habitats of genus *Bombus* and *Xylocopa* particularly the availability of food plants which support high level of diversity.

3. Molecular identification and DNA barcoding of the collected samples from the study area.

4. Impact of anthropogenic activities and various other threats to bumblebees and carpenter bees.

Plate no-1: Various habitat zones of the study area

Agroecosystem

Mixed forest

Plate no-2: Various habitat zones of the study area

Riverine area

Urban area

Chapter 4.

Materials and Methodology

4.1 Materials used

Systematic procedures and protocols are adopted to achieve the objectives set for the present study. The details of materials used and the methods adopted during the course of this study are presented in this chapter.

For insect collection: sweep net, killing jar (containing ethyl acetate), setting board, entomological pins, insect store box and absolute ethyl alcohol.

For taxonomic study: Bee specimens, microscope (40X magnification), taxonomic keys, ethanol, needle, forceps, brush, entomological pins and record book.

For molecular study: Reagents which were provided with the Qiagen kit as well as reagents used in phenol chloroform method for DNA extraction.

- 200 ml lysis buffer.
- 30ml of 150mM NaCl.
- 10ml of 50 mM Tris.
- 4ml 10mM EDTA (pH= 8.0).
- 20% Sodium Dodecycl Sulphate.
- Proteinase K (stock 25 mg/ml).
- Phenol.
- Chloroform.
- Isoamyl alcohol.
- 3M sodium Acetate.
- 60% Isopropyl alcohol.
- Ethanol.
- Tris EDTA Buffer.
- 10mM Tris HCl (pH= 7.5).
- 1mM EDTA (pH= 8.0)

4.2 Methodology

4.2.1 Sample Collection

To quantify the diversity and distribution of plant-pollinators, belt transects of 100 m x 5 m were laid within each patch according to the patch size. On each transect a quadrate of 5 m x 5 m was laid at every 10 m with its centre on the transect.

The insects were collected from the study areas using systematic net sweeps. They were collected in special transparent killing jars, so as to preserve the color of the pubescence, as the color of the pubescence in bumblebees holds great importance in the identification of species. The collected bee specimens were kept in glass jars filled with paper tissues to avoid bee damage, and some drops of ethyl acetate to kill the bees. After coming to the laboratory, the specimens were pinned with the help of entomological pins of different sizes, keeping in view the size of the specimens. After stretching, specimens were labeled with information such as location, altitude, date of collection, and collector's name. Stretched specimens were stored in boxes containing ethyl acetate-soaked cotton and naphthalene powder in the side grooves

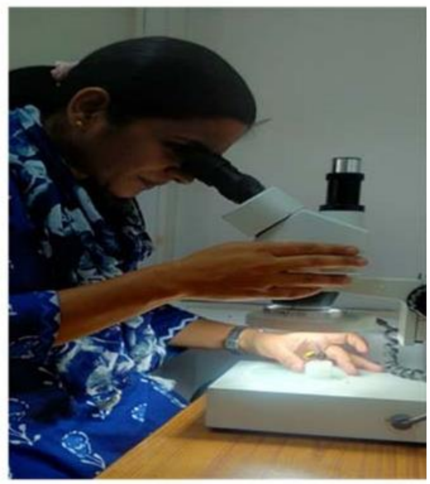
The collected samples were examined under a stereoscopic microscope in the laboratory and identified using published keys for adjoining areas, e.g., Nepal (William, 2010), India (Saini *et.al*., 2012) and Kashmir (William, 1991).

Plate No- 3: Methodology- Collection and analysis

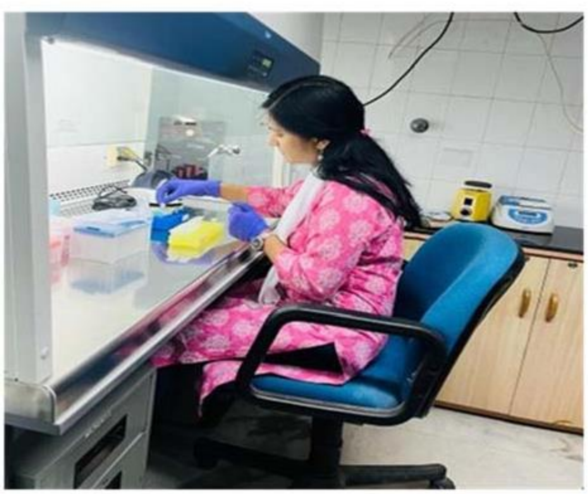
a. Sample collection with sweep net

b. Collection in insect jar

c. Preservation in insect box



d. Microscopic analysis



e. Molecular analysis

4.2.2 Molecular studies

i. DNA extraction using

a. Qiagen kit method

- Middle leg of specimens from both Bombus and Xylocopa species were crushed and stored in 1.5 eppendorf tube.
- 180µl buffer ATL was added followed by addition of 20µl of proteinase K .
- Samples were incubated for 3 hours at 56°C in water bath.
- Samples were centrifuged and 200µl of buffer AL was added and again incubated for 10 minutes at 70°C.
- 200µl ethanol was added and after pulse vortexing brief centrifugation was done.
- The contents were transferred in mini spin column and centrifuged.
- Then wash buffers AW1 and AW2 were added.
- After centrifugation buffer AE was added.
- Samples were allowed to run in agarose gel.

b. Phenol Chloroform method

- Middle leg of specimens from both Bombus and Xylocopa species (Tissue sample upto 80-100 µg) was taken for DNA extraction. It was chopped and crushed finely and kept in 2µl Eppendorf tubes.
- 300 µl lysis buffer, 30 µl 20% SDS and 15µl of proteinase K was added in each sample tube.
- They were kept at 56˚C in water bath for overnight.
- The equal volume of saturated phenol was added in all sample tubes. shake it properly for 10 minutes by hand and then centrifuge for 10 minutes at 10,000 rpm.

- 150 µl of chloroform: isoamylalcohol (24:1), 150 µl of phenol was added in supernatant and mixed for 10 minutes and then centrifuged for 10 minutes at 10˚C at 10,000 rpm.
- 300µl of chloroform: isoamylalcohol (24:1) was added and centrifuged at 10,000 rpm for 10 minutes.
- Supernatant was collected carefully without disturbing the pellet at the bottom of the tubes.
- First 0.6 volume of 60% isopropyl alcohol (or 2 volumes of ethanol) and then 0.1 volume of 3M sodium acetate was added in the collected supernatant and the mixture was mixed gently.
- The tubes were stored at room temperature for 1 hour for DNA precipitation.
- Samples were centrifuged for 10 minutes at 10,000 rpm.
- Supernatant was discarded and 500 µl of 80%ethanol was added and centrifuged for 10 minutes at 10,000 rpm.
- Again, supernatant was discarded and 500 µl of 100% ethanol was added and centrifuged for 10 minutes at 10,000 rpm.
- Dry the tubes at 56˚C for 2-3 minutes or till complete dryness.
- Add AE (elution buffer) accordingly.

Composition of lysis buffer (200 ml)

30 ml of 150 mM Nacl

10 ml of 50 mM tris

40 ml of 10 mM EDTA (ph 8.0)

Agarose gel electrophoresis is a standard method used to check the quality of DNA fragments. For resolving the DNA fragments on gel the DNA samples were loaded with dye in 5:1 ratio. The DNA was subjected to electrophoresis in 50X TE buffer at 120V for 25 minutes. Gel loading dye, electrophoresis buffer (50X TE) and ethidium bromide (1000 X) solutions were used for Agarose gel electrophoresis.

ii. **Polymerase Chain Reaction (PCR) amplification**

PCR is a powerful, extremely sensitive technique based on enzymatic amplification of DNA fragments that are flanked by oligo-nucleotide primers hybridizing to opposite strands of the target sequence. PCR tubes were labeled properly and individual specimen DNA was added in each PCR tube separately. A master mix of autoclaved milli-Q water, Taq buffer, dNTP, Taq polymerase, Bovine Serum Albumin (BSA), forward and reverse primers were prepared to reduce pipetting error. The master mix was then redistributed in each PCR tubes.

Table 4.1Details of primers used in the study

Gene	Primer	Sequence	Reference
COI	LCO 1490 (Forwad primer)	GGTCAACAAATCATAAAGATAT TGG	Folmer *et.al*. (1994)
	HCO 2198 (Reverse primer)	TAAACTTCAGGGTGACCAAAAA TCA	Folmer*et.al*. (1994)

Table 4.2 Thermal cycling conditions for PCR amplification

Cycle	Denaturation		Annealing		Polymerization	
First cycle	94˚C	5 minutes	-	-	-	-
35 cycles	94˚C	45 seconds	45˚C	1 minute	72˚C	1 minute
Last cycle	-	-	-	-	72˚C	10 minutes

iii. Sequencing

1. Exo sap preparation
    1. Exo
    2. Fast sap
    3. H_2O
2. 1 µl exo sap and 1 µl of amplified DNA samples in each well were added.
3. Centrifuge (short spin)
4. Short PCR is done at 37˚C for 20 min and 85˚C for 15 min.
5. Cycle sequencing is done with LCO 1490(forward primer).

Table 4.3 Cycle Sequencing

Cycle	Denaturation	Annealing	Polymerization
First cycle	96˚ 1 minute	- -	- -
28 cycles	96˚ 10 seconds	50˚C 10seconds	60˚C 4 minutes

6. Preparation of master mix
    1. Buffer
    2. Big dye
    3. Primer
    4. Milli Q
    5. PCR product

7. Clean up process
1. Centrifuged 4000 rpm for 25 min at 15 C̊.
2. 40 µl (24:1 alcohol: sodium acetate) was added in each wells of PCR plate.
3. Incubated at room temperature for 10 min.
4. Centrifuged at 4000 rpm for 30 min at 15 C̊ temperature.
5. Discarded carefully.
6. 100 µl of 80% ethanol was added in each well.

7. Again discard it.
8. Dry it for 10 min.
9. 9 µl Hidi was added in each well.
10. Centrifuged 4000 rpm for 1 min at 15 C̊.
11. Denatured at 95 C̊ for 5 min, one cycle.

Load in applied Biosystem 2300XL Genetic analyzer for sequencing.

Sequences were generated and submitted in NCBI gene databas

Chapter 5.

Results and Discussion

Systematic survey of genus *Bombus* and *Xylocopa* in Dehradun district has included extensive fieldwork, sample collection and molecular studies of collected specimens from different study points. These surveys were critical for diversity, distribution, habitat preferences assessment and also to assess various threats to their sustainability in the study area.

Objective 1. Systematic survey of genus *Bombus* and *Xylocopa* for taxonomical, ecological and seasonal sampling in Dehradun district.

Total 11 species are recorded from the study area. 4 of *Bombus* that are Bombus *haemorrhoidalis*, *Bombus trifasciatus*, *Bombus flavescens*, *Bombus rotundiceps* and 7 of *Xylocopa* genus that are *Xylocopa fenestrata, Xylocopa aestuans, Xylocop atenuiscapa*, *Xylocopa nasalis, Xylocopa sp.nov.1*, *Xylocopa sp.nov. 2* and *Xylocopa sp.nov.3.* 8 species are recorded from Dehradun region, except *B. trifasciatus*, *B. flavescens*, and *X. sp.nov.2*, 8 from Mussoorie region, except *X. nasalis, X. sp.nov.1* and *X.sp.nov.3,* 6 from Chakrata region, except *B. rotundiceps*, *X. tenuiscapa*, *X. nasalis, X. sp.nov.1* and *X. sp.nov. 3* and 8 from Tiuni region except *B. trifasciatus, B. flavescens and X. sp.nov.3*

Table 5.1 - Areas showing the presence of different species of *Bombus* and *Xylocopa*

Species	Dehradun	Mussoorie	Chakrata	Tiuni
Bombus haemorrhoidalis	✓	✓	✓	✓
Bombus trifasciatus		✓	✓	
Bombus flavescens		✓	✓	
Bombus rotundiceps	✓	✓		✓
Xylocopa fenestrata	✓	✓	✓	✓
Xylocopa aestuans	✓	✓	✓	✓
Xylocopa tenuiscapa	✓	✓		✓
Xylocopa nasalis	✓			✓
Xylocopa sp. nov.1	✓			✓
Xylocopa sp.nov. 2		✓	✓	
Xylocopa sp.nov. 3	✓			✓

Table 5.2 - Table showing Altitudinal distribution of recorded species

Species	**500-1000 m**	**1000-1500 m**	**1500-2000 m**	**2000-2500 m**
Bombus haemorrhoidalis	✓	✓	✓	✓
Bombus trifasciatus		✓	✓	✓
Bombus flavescens		✓	✓	✓
Bombus rotundiceps	✓	✓		
Xylocopa fenestrata	✓	✓	✓	✓
Xylocopa aestuans	✓	✓		
Xylocopa tenuiscapa	✓	✓		
Xylocopa nasalis	✓	✓		
Xylocopa sp. nov.1	✓	✓		

Xylocopa sp.nov. 2			✓	✓
Xylocopa sp.nov. 3	✓	✓		

B. haemorrhoidalis is the most predominant species among bumblebees from the study area and is recorded from all altitudinal gradients i.e. from 500-2500 m amsl. *B. trifasciatus*and *B. flavescens* are recorded from 1000-2500 m amsl, *B. rotundiceps, X. aestuans, X. tenuiscapa, X. nasalis, X. sp.nov.1 and X. sp. nov.3* are recorded from 500-1500 m amsl, *X. fenestrata* is the most predominant species among carpenter bees and like *B. haemorrhoidalis* recorded from all altitudinal gradients i.e. from 500-2500 m amsl and*X. sp. nov.2* is recorded from 1500-2500 m amsl.

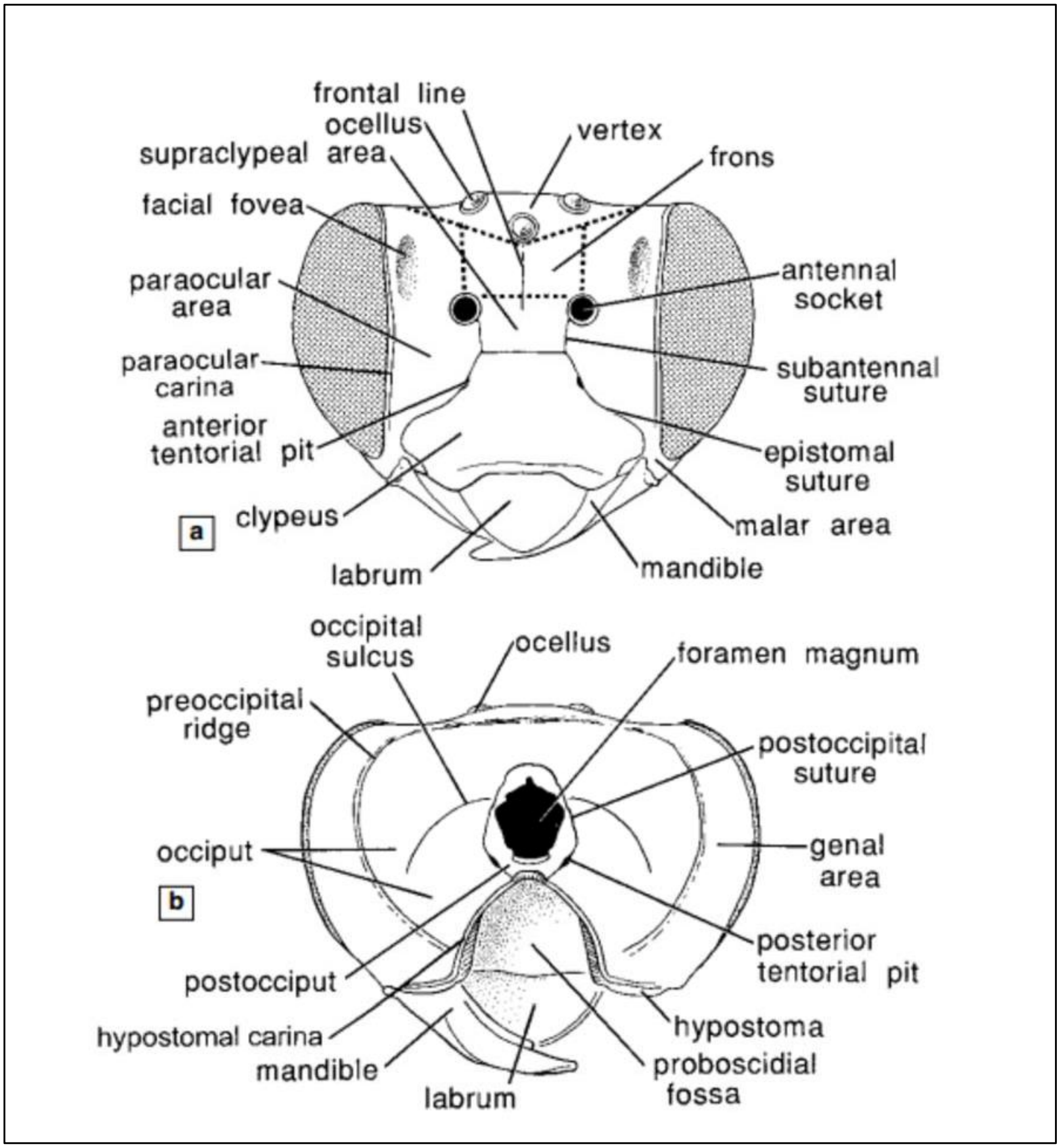


Fig. 5.1.1. Diagrams of a bee's head, showing major structures. a. Anterior view, b. Posterior view (Michener *et.al*., 1994).

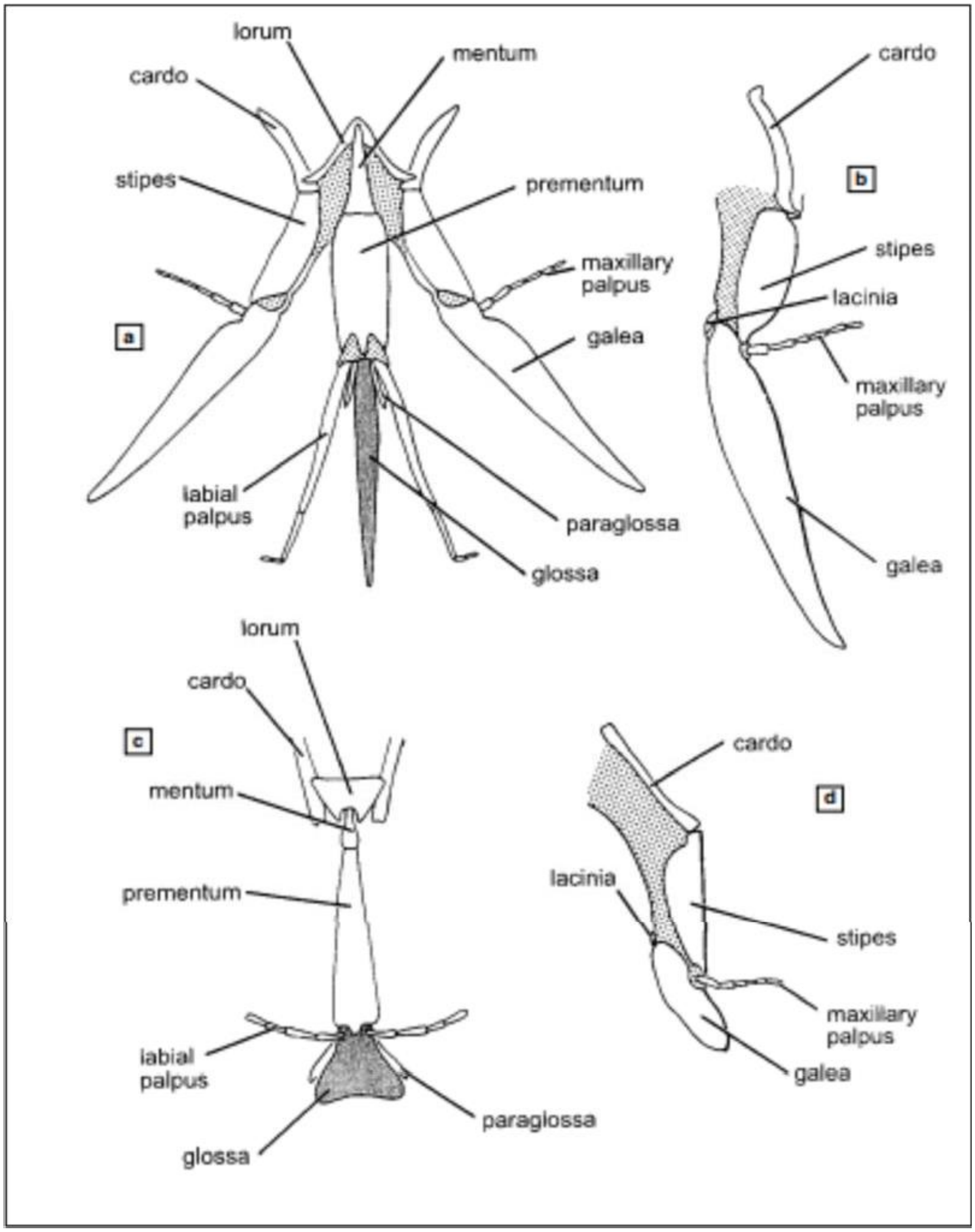


Fig. 5.1.2. Diagrams of proboscides of bees. a. Spread proboscis of a long-tongued bee, b. Maxilla of the same, c. Labium of short-tongued (here Colletid bee) showing portions of maxillary cardines at the base, d. Maxilla of the same (Michener *et.al*., 1994).

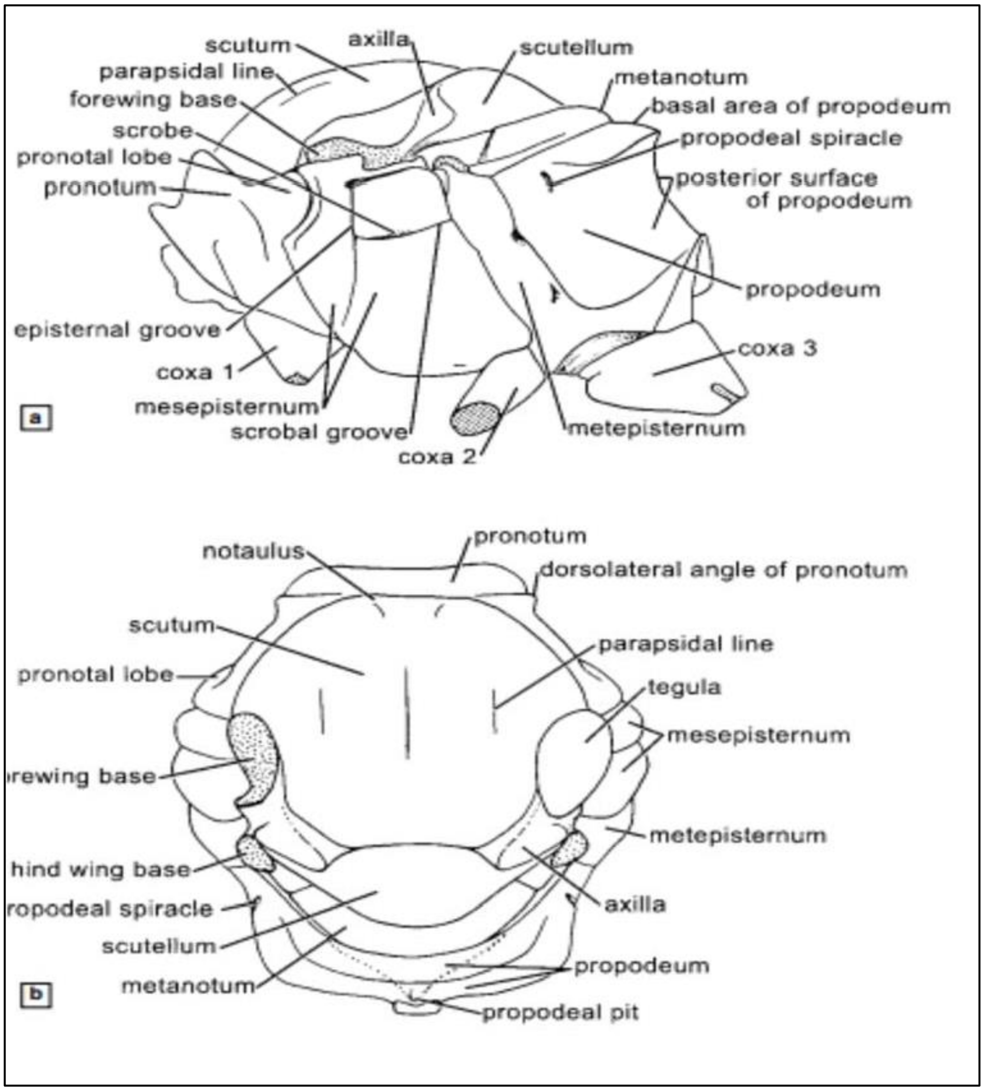


Fig. 5.1.3. Diagram of a bee's thorax, a. Lateral view, b. Dorsal view (Michener *et.al.*, 1994).

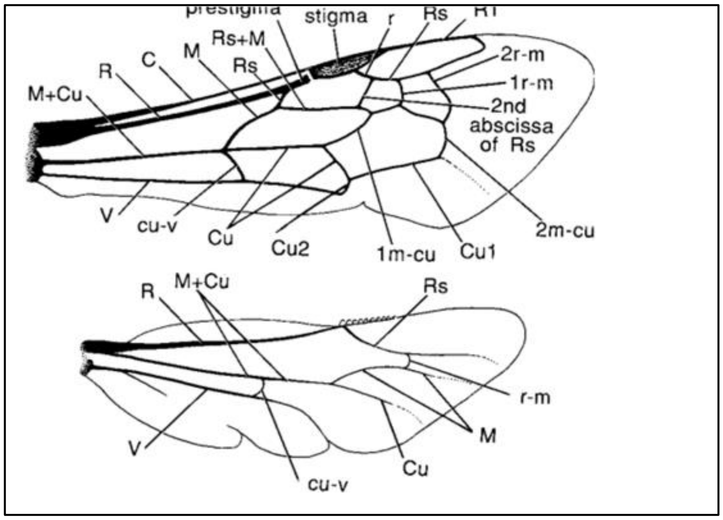


Fig.5.1.4 Diagram of the wings of a bee, showing the vein terminology (Michener *et.al.*, 1994).

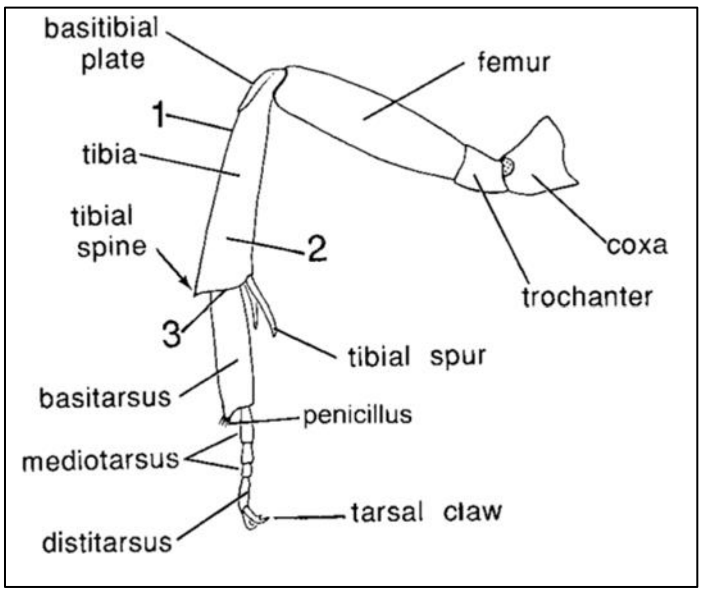


Fig. 5.1.5 Hind leg of a female bee, hairs omitted except those that from the penicillus. 1. indicates the posterior or upper margin of the tibia, 2. The outer surface 3. The distal margin (Michener *et.al.*, 1994).

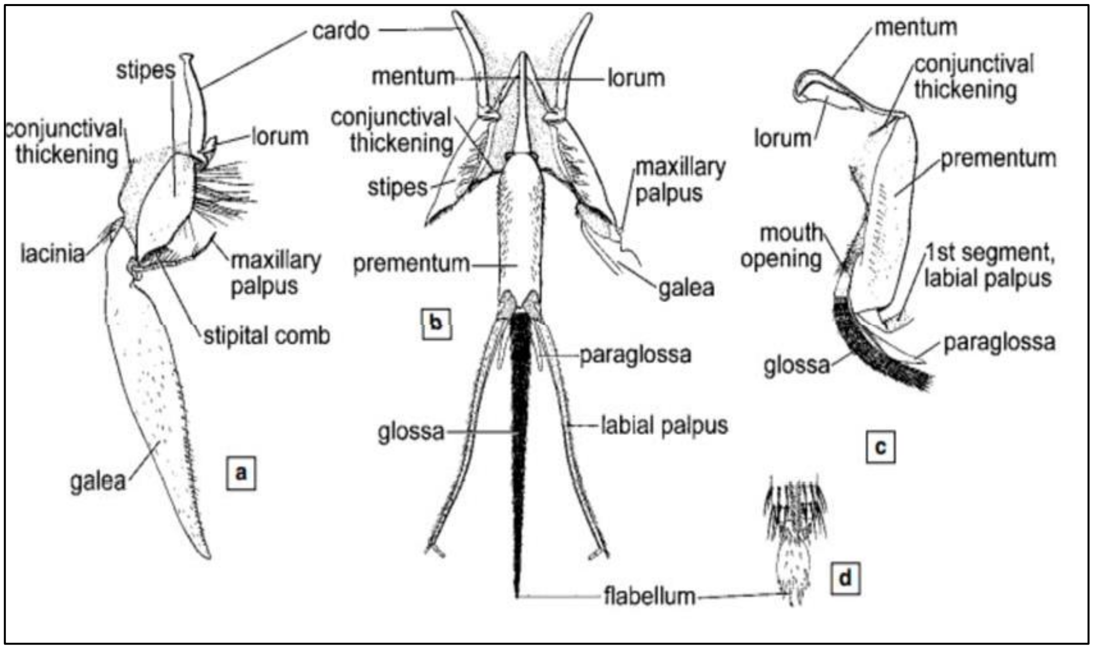


Fig. 5.1.6. Proboscis of an L-T bee (*Anthophora edwardsii*), a. Outer view of Maxilla, b. Posterior view of labium and basal parts of maxilla c. Lateral view of labium, the distal parts of the glossa and labial palpus omitted, d. Flabellum (Michener *et.al*., 1994).

5.1 Taxonomical analysis of recorded species.

5.1.1. Key features of genus *Bombus*

Classification

Kingdom - Animalia
Phylum - Arthropoda
Class - Insecta
Order - Hymenoptera
Family - Apidae
Subfamily - Apinae
Tribe - Bombini
Genus - *Bombus Latreille*, 1802

Distinguishing features of male and female bumblebee

Females- antenna with 12 segments (A1 scape, A2 pedicel, A3 -12 flagellomeres). The metasoma has 6 visible terga (T1-6), between the externally visible T6 and S6 is the sting.

Males- antenna with 13 segments (A1 scape, A2 pedicel, A3–13 flagellomeres). The metasoma has 7 visible terga (T1–7), and between the externally visible T7 and S6 is the genital capsule

FEMALES: key to SUBGENERA (these keys are revised and improved from the key by Williams in Williams *et.al*. 2008).

1. The hind tibia differs from the mid tibia in that it has a more broad and flat..... outer surface. The distal half lacks moderate to long hairs but is fringed with .. stout hairs that form a pollen basket (corbicula). The inner distal margin has a comb of stout spines (rastellum), and S6 lacks ventro-lateral keels .... and ridges… 2

2. (1) Hind tibia with the outer surface weakly sculptured, smooth and brightly... shining, and without long stout hairs in the middle of the proximal .... half beyond the proximal quarter; labrum with labral tubercles separated by a deep median longitudinal furrow, often for a quarter of the width of the labrum; mandible with the anterior keel reaching and continuous with the distal .... margin; The lateral ocellus of the hind basitarsus is typically narrow and . pointed, either longer than its breadth proximally where it joins the basitarsus. or shorter than its breadth, with a diameter equal to half or less than half of the distance separating it from the inner margin of the eye… 3

3. (2) Mandible distally rounded with two anterior teeth and often a posterior tooth; hind basitarsus with the longest outwardly upright hairs toward the

anterior margin of the outer surface, either as long as or generally shorter than the narrowest breadth of the basitarsus. 4

4. (3) The mid basitarsus has a distal posterior corner that extends to a ......sharp angle of 45° or less. This can be a narrow tooth or spine (less evident.... in smaller individuals) or a more rounded shape The cheek (oculo-malar area) has a diagonal band of small, widely spaced punctures, while the area between the lateral ocellus and the inner edge of the eye has an unpunctured shining section that occupies less than half of the distance between the two… 5

- The mid basitarsus has a broadly or narrowly rounded distal posterior corner with an angle of more than 45° and no narrow tooth or spine. If more narrowly acute, the area between the lateral ocellus and the inner margin of the eye with the unpunctured bright part occupying more than three quarters of the distance between the lateral ocellus and the eye, and the cheek (oculo-malar area) in the center with few or no punctures...7

5. (5) The middle region of the Clypeus is bulbous and has several big or medium punctures. The antennal segment A4 is shorter than broad …...***MEGABOMBUS***

7. (4) The ocello-ocular area has medium or tiny unpunctured and shining areas, with more than a quarter of the inner eye margin pierced. The unpunctured area anterior to the three ocelli extends for less than the breadth of an ocellus. 8

- The ocello-ocular area is large, with only the outer quarter along the inner eye margin punctured. The unpunctured area includes most of the area anterior to the three ocelli for more than the breadth of an ocellus, except for narrow bands of punctures between the median and lateral ocelli. .... **ORIENTALIBOMBUS**

8. (7) The mandible near its distal posterior corner has a less prominent posterior tooth notch. The clypeus in its central area is usually weakly swollen or nearly flat, with only shallow lateral depressions adjacent and parallel to the ventral labral margin. Large punctures are widely scattered among many smaller punctures. The hind basitarsus posterior margin curves strongly in its proximal half and nearly straight in its distal half. 9

9. (8) The hind basitarsus in its distal half has short slightly feathery hairs widely spread so that the surface is plainly visible and shining in between; the center portion of the clypeus has widely scattered large and small punctures that appear uneven and dull. area between the lateral ocellus and the inner margin of the eye, either with the band of punctures along the inner margin of the eye dorsally usually for most of its length with very few small punctures, mostly consisting of a few scattered large punctures separated by shining areas broader than the puncture widths, the large unpunctured and shining area adjacent to the ocellus usually large occupying nearly three quarters of the distance between the lateral ocellus and the inner margin of the eye, or if with many dense small punctures then these cover the entire area between the eye and the depression around the lateral ocellus. ....***PYROBOMBUS***

MALES : key to SUBGENERA

1. The hind tibia differs significantly from the mid tibia, with short hairs in the center and long hairs anteriorly and posteriorly. The head in dorsal view is unenlarged from anterior to posterior, with an anterior to posterior distance of 0.5× its breath. The volsella and gonostylus are usually strongly sclerotized and mid or dark brown, with the gonostylus lacking medium-length branched

hairs on the inner proximal process. Volsella is not always present. Penis-valve head can be straight, bent inward, or curved outward. 2

2. (1) Antenna medium to long, reaching back at least to the anterior margin of the tegula at the wing base; volsella has a process or hook on its inner margin; gonostylus has an inner proximal process. The penis-valve head can be straight, curled inwards, or curved outwards, with an expanded or unenlarged eye compared to a female bumblebee… 3
3. (2) Penis valve narrows dorso-ventrally, at least in its distal third, which is slightly ventrally curved; antenna either medium length or longer, going back to or beyond the tegula at the wing base. 4
4. (3) From the dorsal perspective, the penis-valve head is either almost straight or slightly curved outwards, with a small internally pointed tip. 5

- The penis-valve head is shaped like a sickle or spoon, with a noticeable broad hook pointed inwards distally from the dorsal view… 6

5. (4) Gonostylus has a unique inner proximal process separated from the distal lobe by a deep incision. ....***MEGABOMBUS***

- Gonostylus lacks a narrow inner proximal process, characterized by a wide, weak curve or swelling……………………………**ORIENTALIBOMBUS**

6. (4) Gonostylus usually a simple flat triangle, exceptionally reduced to a spine, but without a distinct inner proximal process; gonostylus in cross section with the inner distal margin in part with a narrow submarginal longitudinal groove… ....***PYROBOMBUS***

Diagnostic features of subgenera

1. *Megabombus*

Females- The hind tibia is more broad and almost flat than the midtibia, with the majority of the outer surface in the distal half lacking moderate to long hairs but fringes with stout hairs that form a pollen basket (corbicular), the inner distal margin with a comb of stout spines (restellum), and S6 lacking ventro-lateral keels or ridges.

Mandibles are extensively rounded distally, with two front teeth and often a posterior tooth, and the hind basitarsus has the longest outwardly upright hairs around the anterior margin of the outer surface, which are either as long as or shorter than the narrowest breadth of the basitarsus.

The area between the lateral ocellus and the inner margin of the eye with the unpunctured shining part occupying less than half of the distance between the lateral ocellus and the eye.

Cheek (oculo-malar area) in the centre smooth and shining at most with a very few very shallow punctures.

Clypeus central area bulbous with atleast a few large or medium punctures. Antennal segment A4 is shorter than broad.

Males- Hind tibia differing in form strongly from the mid tibia the outer surface flat with atmost only short hairs in the centre and long hairs and anterioirly and posteriorly, head in dorsal view unenlarged from anterior to posterior so that the anterior to posterior distance is 0.5x its breadth.

Antenna medium to long, reaching back atleast to the margin of the tegula at the wing base.

Eye either enlarged or unenlarged relative to the eye of the female bumblebee.

Antenna either of medium length or longer, reaching back either to or beyond the tegula at the wing base.

Penis valve narrow dorso-ventrally atleast on the distal third, which is slightly ventrally curved. Its head from the dorsal view distally either nearly straight or turned slightly outwards, atmost with only a tiny inwardly directed point.

Gonostylus with a distinct inner proximal process strongly separated from the distal lobe by a deep incision.

2. ***Orientalibombus***

Females- Hind tibia compared with the mid tibia with the outer surface more broad, almost flat, most of the outer surface in the distal half without moderate to long hairs, but fringed with stout hairs that form a pollen basket (corbicula) the inner distal margin with a comb of stout spines (rastellum). S6 without ventrolateral keels or ridges.

Hind tibia with the outer surface weakly sculpted, smooth and brightly shining and without long stout hairs in the middle of the proximal half beyond the approximal quarter.

Labrum with the labral tubercles separated by a deep median longitudinal furrow often for quarter of the breadth of the labrum.

Mandible with the anterior keel reaching and continuous with the distal margin. It is distally broadly rounded with two anterior teeth and often a posterior tooth.

Hind basitarsus with the proximal posteriorly directed process usually narrow and pointed, either longer than its breadth proximally where it joins the basitarsus or if it is shorter than broad then the lateral ocellus diameter is equal to half or less than half of the distance separating the lateral ocellus from the inner margin of the eye.

Hind basitarsus with the longest outwardly erect hairs near the anterior margin of the outer surface either as long as or usually shorter than the narrowest breadth of the basitarsus.

Mid basitarsus with the distant posterior corner broadly or narrowly rounded but either forming an angle of more than 45 degree and without a narrow tooth or spine or if more narrowly acute then the area between the lateral ocellus and the inner margin of the eye with the unpunctured shining part occupying more than three quarters of the distance between the lateral ocellus and the eye.

The cheek (oculo-malar area) in the center with few or no punctures. Ocello-oculo area with the unpunctured and shining area very large, only the outer quarter along the inner eye margin with punctures. The unpunctured area including most of the area anterior to the three ocelli for a distance of more than the breadth of an ocellus except for narrow bands of punctures between the median and lateral ocelli.

Males- Hind tibia differing in form strongly from the mid tibia. the outer surface flat with at most only short hairs in the center and long hairs anteriorly and posteriorly, head in dorsal view unenlarged from anterior to posterior so that the anterior to posterior distance is 0.5 x its breadth.

Penis valve head either straight or curved inwards or curved outwards, at most with only a tiny inwardly directed point.

Gonostylus without a narrow inner proximal process at most marked only with a broad weak curve or swelling.

Antenna medium to long, reaching back at least to the anterior margin of the tegula.

Eye either enlarged or unenlarged relative to the eye of a female bumblebee.

3. ***Pyrobombus***

Females-Hint tibia compared with the mid tibia with the outer surface more broad, almost flat, most of the outer surface in the distal half without moderate to long hairs, but fringed with stout hairs that form a pollen basket (curbicula) the inner distal margin with a comb of stout(rastellum). S6 withoutventro lateral keels or ridges. Hindtibia with the outer surface weakly sculpted, smooth and brightly shining and without long stout hairs in the middle of the proximal half beyond the proximal quarter. Hind basitarsus with the proximal posteriorly directed process usually narrow and pointed either longer than its breath proximally where it joins the basitarsus, or if it is shorter than broad then lateral ocellus diameter is equal to half or less than half of the distance separating the lateral ocellus from the inner margin of the eye.

Labrum with the labral tubercles separated by a deep median longitudinal furrow often for quarter of the breadth of the labrum.

Mandible with the anterior keel reaching and continuous with the distal margin. It is distally broadly rounded with two anterior teeth and often a posterior tooth.

The cheek (oculo-malar area) in the center with few or no punctures ocello ocular area with the unpunctured and shining area medium or small, more than the outer quarter along the inner eye margin with punctures.The unpunctured area anterior to the three ocelli extending for less than the breadth of an ocellus.

Mandible near its distal posterior corner with a notch that is less than half as deep as wide or often completely lacking so that it does not separate a weak posterior tooth.

Clypeus in its central area usually weekly swollen or nearly flat with only shallow lateral depressions adjacent and parallel to the ventral labral margin. Large punctures at most widely scattered among many more of the small punctures. Central area of clypeus with widely scattered large as well as small punctures appearing irregular and dull area between the lateral ocellus and the inner margin of the eye either with the band of punctures along the inner margin of the eye dorsally usually for most of its length with very few small punctures mostly consisting of a few scattered large punctures separated by shining areas broader than the punctures width. The large unpunctured and shining area adjacent to the ocellus usually large, occupying nearly three quarters of the distance between the lateral ocellus and the inner margin of the eye, or if with many dense small punctures then these cover the entire area between the eye and the depression around the lateral ocellus.

Mid basitarsus with the distal posterior corner broadly or narrowly rounded but either forming an angle of more than 45 degree and without a narrow tooth or spine or if more narrowly acute then the area between the lateral ocellus and the inner margin of the eye with the unpunctured shining part occupying more than three quarters of the distance between the lateral ocellus and the eye.

Hind basitarsus posterior margin curving much more strongly in its proximal half and nearly straight in its distal half.

Males-Hind tibia differing in form strongly from the mid tibia. The outer surface flat with at most only short hairs in the cenre and long hairs anteriorly and posteriorly, head in dorsal view unenlarged from anterior to posterior so that the anterior to posterior distance is 0.5x its breadth.

Penis valve head either straight or curved inwards or curved outwards.

Antenna medium to long reaching back at least to the anterior margin of the tegula at the wing base.

Eyes either enlarged or unenlarged relative to the eye of the female bumblebee.

Penis valve head from the dorsal view turned inwards distally as a distinct broad hook, either dorso-ventrally flattened in the shape of the sickle or as a spoon.

Gonostylus usually a simple flat triangle exceptionally reduced to a spine but without a distinct inner proximal process. In cross section with the inner distal margin in part with a narrow submarginal longitudinal groove.

Diagnostic features of recorded *Bombus* species

1. ***Bombus haemorrhoidalis*** **Smith*, 1852***

(Subgenera-*Orientalibombus*)

Females- large sized bee species, pubescence of head and thoracic dorsum entirely black, abdominal tergites 1-2 white, abdominal tergum 3 black in colour, tergites 4-5 brick red in colour. Workers with head, thorax and abdominal tergum 3 entirely black, abdominal tergites 1-2 are yellow and abdominal tergites 3-4 are brick red in colour (Plate no-4: a). Head covered with thick pubescence except the malar space clypeus. Thorax and abdomen uniformly covered with thick pubescence. Clypeus strongly protuberant with lateral and basal margin curved back to join gena and supraclypeal area respectively. Its central area is flattened with almost no large punctures.

The labrum has a basal transverse depression that extends apically as a deep furrow between prominent lateral tubercles, pushing the ridge between them to produce a lamella that overhangs the apical border; the lateral lamella is large, more than half the width of the labrum. Wings are heavily infuscated, with short and uniform pubescence. (Plate no-5:a).

Meso basitarsus is broadly rounded at distoposterior corner.

Meta basitarsus with dense pubescence on proximal margin continuing on to the outer surface of proximoposterior projection as just few sparse hairs. Length of projection longer than its breadth at its base, posterior margin of metabasitarsus convex with a distoposterior corner bluntly pointed and equal to distoanterior corner.

Outer surface of meta tibia smooth, shining, without any long stout hair.

Males have completely black pubescence on their heads and thoraxes, with abdominal tergites 1-2 being brilliant yellow and abdominal tergites 3-5 being brick red. Anterior edge of labrum is somewhat concave. Penis valve is dorsally, apically straight, bent outward, and flattened, with a sickle shape.

Gonostylus lacks an intrabasal process. Volsella with apical corner narrowly formed distal to inner hooks and curled inward, inner hooks near to corner and concealed from dorsal aspect by gonostylus, and a large section of volsella immediately proximal to inner hooks.

Material examined

Bajawala30.534181°N, 77.9898117°E, 4♂, 3♀. Sahastradhara 30.4029021°N, 78.1330826°E, 3♂, 1♀. Tiuni 30.9382977°N, 77.8469744°E, 3♂, 2♀. Jadi, 30.7448194°N, 77.8512502°E, 2♂, 3♀. Tea estate 30.3276038°N, 77.9316054°E, 3♂, 2♀. Thano 30.2552154°N, 78.1536931°E, 4♂, 3♀. Chandrabani 30.2807869°N, 77.9806153°E, 1♂, 2♀. Selaqui 30.3721125°N, 77.8615995°E, 1♂. Benog Wildlife Sanctuary 30.4759424°N, 78.0240135°E, 1♂, 1♀. Koruwa 30.6610696°N, 77.8573942°E, 1♀. Mohund 30.1777112°N, 77.9017492°E, 1♂.

2. ***Bombus flavescens*** Smith, 1852

(Subgenus- *Pyrobombus*)

Females- head thorax and abdomen covered with long bright pale yellow pubescence. Legs are bright reddish (Plate no-4: b). Labrum with basal transverse depression extending apically as a deep median furrow between pronounced lateral tubercles, which are bluntly raised, displacing ridge between them to form a lamella that extends apical margin. Clypeus stongly protuberant, with lateral and basal margins curved back to join gena and supraclypeal area respectively. Area lateral to lateral ocellus unpunctured for more the the diameter of ocellus. The lateral ocelli are below the POC (post ocular line). Wings hyaline, very slightly fuscescent, darkening towards the apex (Plate no-5: b).

The distoposterior corner of mesobasitarsus bluntly pointed, never produced as a spine. Outer (corbicular) surface of meta tibia smooth, shining, without any long stout hair arising from posterior surface below upper or proximal quarter. Apex of tergite VII trunctate with a very fine notch in centre, boss covering the apical half, surface sculptured, with a weak median groove.

Males- pubescence dull dirty yellow, very variable, from having the hair most often uniformly yellow on the head, thorax and metasomal terga 1-2, with tergum 3 black and terga 4-7 orange.

Anterior margin of labrum broadly notched with a trunctate base.

A very fine inconspicuous band of punctures along eye margincovering one fourth of the area between lateral ocellus and eye margin. The lateral ocelli are at the level of POC (post ocular line).

Penis valve almost straight when seen from the dorsal side, its pointed tips bent downward and slightly inward.

Gonostylus is triangular in outline with its inner angle bluntly pointed; outer lateral margin of apical 1/3 of spatha is free.

Material examined

Jadi 30.7448194°N, 77.8512502°E, 1♂, 1♀. Benog Wildlife Sanctuary 30.4759424°N, 78.0240135°E, 1♀.

3. ***Bombus trifasciatus*** **Smith, 1852**

(Subgenera- *Megabombus*)

Females- Queens have black pubescence on head and thorax, abdominal tergites 1-3 yellow and abdominal tergites 4-5 brick red in colour. Workers have black pubescence on head and thorax, abdominal tergites 1-2 yellow and abdominal tergites 3-5 brick red in colour (Plate no-4:c).

Head covered with thick pubescence except malar space. Dorsum of the head with punctures scattered almost throughout except in the ocellar depressions. Clypeus with many large punctures throughout. Labrum with basal transverse depression extending apically as a deep median furrow between pronounced lateral tubercles, which are bluntly raised, displacing ridge between them to form a lamella that overhangs apical margin.

Mandible apex broadly rounded, with a basal tooth, one pre basal tooth and often an apical tooth (Plate no-5: c).

Oculo-malar distances approximately 1.7 times the proximal breadth of the mandible.

Antennal segments 4 just shorter than broad, half of the length of segment 3.

Meso basitarsus with the distal posterior corner produced as a narrow sharp spine, the length of distoposterior corner little longer than the length of distoanterior corner. Meta basitarsus with dense pubescence of proximal margin continuing on to the surface of proximoposterior projection as just few sparse hairs, length of projection longer, near two times its breadth at its base ; distal half of its posterior margin concave with a distoposterior corners spinosely pointed and longer than distoanterior one.

Males- pubescence of head and abdominal tergum 3 black in colour, black thorax with lateral aspects white, abdominal tergites 2-3 yellow and abdominal tergites 4-5 brick red in colour.

Anterior margin of labrum with a slight median notch. Lateral tubercles interrupted in centre due to very fine groove which is intermingled with macropunctures.

Compound eyes unenlarged relative to that of female.

Antenna long, reaching posteriorly to the wing base; a band of micropunctures very close to eye margin covering a negligible area between lateral ocellus and eye margin.

Genitalia with the penis valve distally short, weakly flared and head toothed; gonostylus short and broad, nearly rectangular, with two recurved spine-like inner proximal processes.

Material examined

Benog Wildlife Sanctuary 30.4759424°N, 78.0240135°E, 2♂, 1♀, Jadi 30.7448194°N, 77.8512502°E, 1♂, 1♀, Koruwa 30.6610696°N, 77.8573942°E, 1♀

4. ***Bombus rotundiceps*** Friese, 1916

(Subgenus- *Pyrobombus*)

Females- First three tergites are black and dirty yellow and last three are brick red (Plate no-4: d). Head, thorax and abdomen are uniformly and densely covered with pubescence except malar space and clypeus. Labrum with basal transverse depression extending apically as a deep median furrow between pronounced lateral tubercles, which are slightly bluntly raised, displacing ridge between them to form a lamella that overhangs apical margin. Clypeus strongly protuberant, with lateral and basal margin curved back to join gena and supraclypeal area respectively (Plate no-5: d).

Mid basitarsus having the distal posterior corner broadly rounded by the ocello- oculo area having a broad band of punctures along the inner margin of the eye, and by the mandibles having just two anterior teeth and a broadly rounded distal margin.

Males- first two abdominal tergites are black, bright yellow and rest of tergites brick red.

Anterior margin of labrum shallowly notched.

Lateral tubercles not meeting in the centre. Central area depressed and profusely micropunctured.

Area anterior to lateral ocellus unpunctured equal to half the diameter of ocellus.

Penis valve head recurved part being more than 3X longer than broad.

Material examined

Bajawala 30.534181°N, 77.9898117°E, 2♂, 3♀. Sahastradhara 30.4029021°N, 78.1330826°E, 3♂. Tiuni 30.9382977°N, 77.8469744°E, 1♂, 2♀. Tea estate 30.3276038°N, 77.9316054°E, 3♂, 2♀. Thano 30.2552154°N, 78.1536931°E, 2♂, 3♀. Chandrabani 30.2807869°N, 77.9806153°E, 1♂. Selaqui 30.3721125°N, 77.8615995°E, 1♂. Benog Wildlife Sanctuary 30.4759424°N, 78.0240135°E, 1♂, 1♀. Koruwa 30.6610696°N, 77.8573942°E, 1♀.

Plate no - 4: Bumblebees- Dorsal and Ventral side

a. Bombus haemorrhoidalis

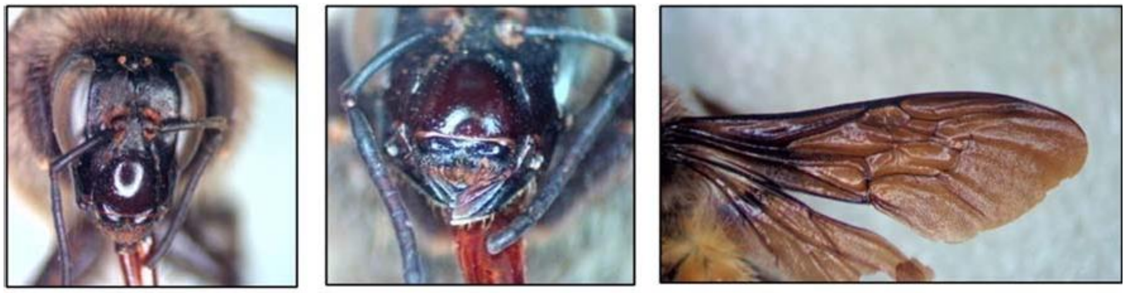
b. Bombus flavescens

c. Bombus trifasciatus

d. Bombus rotundiceps

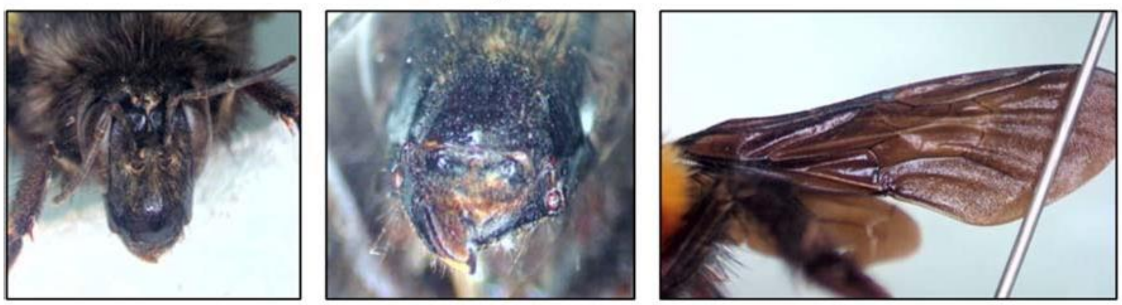
Plate no-5: Bumblebees - Head, mouth parts and wings

a. Bombus haemorrhoidalis

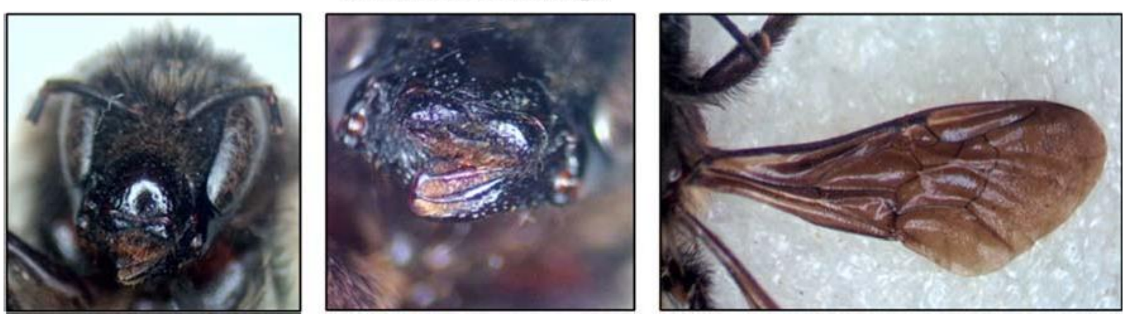


b. Bombus flavescens

c. Bombus trifasciatus



d. Bombus rotundiceps



5.2.Key features of genus *Xylocopa*

Classification

Kingdom - Animalia
Phylum - Arthropoda
Class - Insecta
Order - Hymenoptera
Family - Apidae
Subfamily - Xylocopinae
Tribe - Xylocopini
Genus - *Xylocopa Latreille*, 1802

Distinguishing features of carpenter bees.

Large and robust bees (13-30 mm); head transverse, subrotund; apex of mandibles with two or three teeth; first flagellar segment longer than the second and third taken together; stigma absent, prestigma very long; posterior tibiae and tarsi densely pubescent; arolia absent; abdomen fringed with long hairs on the sides of the segments.

Females- 6 visible tergites. Posterior metatarsi never flattened. Eyes are smaller as compared to males.

12 antennal segments. Mandibles are bi or tri dentate.

Males- 7 visible tergites. Sometimes basally swollen or flattened posterior metatarsi.

Eyes are large as compared to females. 13 antennal segments. Mandibles are bi dentate.

Females: Keys to SUBGENERA

1. Scutellum running gradually into postscutellum, only separated by a suture, posterior portion of scutellum never projecting over the postscutellum which is at almost the same level… 2
2. Epipygium medially furrowed 3
3. Upunctate crescent shaped markingslateral to median ocellus present; knee caps of posterior tibiae simple ....***BILUNA***
4. Ocelli of ordinary size, median ocellus rounded...5
5. Transverse ridges between lateral ocelli present..................***CTENOXYLOCOPA, SUBGENERA.NOV***
6. Mandibles tri-dentate…......................................***XYLOCOPA LATRIELLE, S.S***
7. Upper orbital distance less than the lower 8
8. Dorsum of thorax and of I abdominal tergite very sparsely pubescent; vein r-m complete… ....***PLATYNOPODA WESTWOOD***

Males: Keys to SUBGENERA

1. Scutellum and postscutellum sharply marked off from the succeeding segments by a distinct ridge of varying height..2
2. Knee caps on posterior tibiae absent.. 3
3. Face with unpunctured cresecent shaped marking lateral to median ocellus… ....***BILUNA***
4. Ocelli of ordinary size, median ocellus rounded..5
5. Transverse ridges lateral to median ocellus absent… 6
6. Knee caps of posterior tibiae bifurcate, spiracular tubercles on III abdominal tergite with teeth like projections .... ***CTENOXYLOCOPA***
7. Disc of mesonotum unpunctate… .... ***XYLOCOPA LATRIELLE, S.S***
8. Inner orbits converging at their upper extremities, dorsum of II-VI abdominal tergites very sparsel pubescent..9
9. Anterior metatarsi greatly dilated; vein r-m complete… .... ***PLATYNOPODA WESTWOOD***

Diagnostic features of subgenera

1. ***Biluna***

Body of large or medium size. Integument dominantly black. Sometimes with some greenish tints. ♂ with pale face markings. Pubescence dominantly black. ♂ with more or less pale hairs on basal portion of thorax and of abdomen. Inner orbits in ♂ weakly convergent both at upper and lower extremities. Median ocellus elliptical; lateral side with elevated, unpunctate, crescent- shaped markings. Lateral portion of front on the same level as the3 clypeus. Mandibles bidentate. Disc of mesonotum unpunctate. Propodeum in ♂ anteriorly strongly elevated. Vein R5 curved and perpendicular to vein *M* 1 +2 at their junction. Knee caps absent in ♂ and simple in ♀. Proximal end of posterior metatarsi of ♂ ventrally swollen and unpunctate. Inner and outer teeth of claws diverging. Submedian processes of epipygium ♀ long. Narrow, widely separated, not parallel. Hypopygium keeled in ♀ only.

2. ***Ctenoxylocopa***

Body of medium or small size. Integumentblack. Wings with more or less violaceous tints. Basally hyaline in ♂. Pubescence in black or whitish. Inner orbits of straight, parallelor weakly converging at their upper extremities. Frontal keel of ♀ extraordinary short. ♀ with transverse ridges lying between lateral ocelli. Base of ocellar triangle about one and one-third times as long as the lateral sides. Mandibles of ♂ bidentate and ♀ tridentate. Disc of mesonotum unpunctate. Vein R5 forming obtuse interior angles with vein M*1+2*. Knee caps very strong, apically bifurcate, that of ♀ with two rows of spine-like processes. Inner and outer teeth claws of ♂ almost parallel. Spiracular tubercles on III abdominal tergite of ♂ teeth-like and strongly projecting outwards. Submedian processes of epipygium of ♀ narrow, projecting outwards. Hypopygium of ♂ apically very broadly rounded and that of ♀ medially keeled.

3. Platynopoda

Body of large size. Integument black. Pubescence dominantly black, very sparse. Head of ♂ much narrower than thorax and usually with more or less pale markings. Inner orbits very strongly converging at their upper extremities. Frontal keel distinct but never very strong. Base of ocellar triangle about thrice in ♂ or two and a half times in ♀ as long as the lateral sides. Laberumof ♀ strongly tuberculated. Mandibles bidentate. Disc of mesonotum unpunctate. Scutellum anteriorly weakly curved and posteriorly sharply marked off and elevated. Veins*1'-m* and M*1+2* forming obtuse interior angles. Knee caps simple; major apical spur of posterior tibiae and anterior and posterior metatarsi greatly flattened. Antenna- cleaners with very short apical projection. Anterior margin of dorsum of I abdominal tergite sharply marked off; anterior surface of this tergite with a very deep and round depression. Submedian processes of epipygium of ♀ absent. Hypopygium sometimes keeled.

Diagnostic features of recorded*Xylocopa* species

***1. Xylocopa fenestrata*(Fabricius)**

(Subgenus- *Ctenoxylocopa*)

Female**-** Black shining body with black pubescence; sparse on head and thorax; ferruginous along the apex of anal abdominal segment; dense on the intermediate and posterior legs, otherwise sparse.

Head densely punctured; thorax and abdomen sparsely punctured; the disc of the mesonotum impunctated.

Diagnostic characters

Clypeus nearly flat, emarginate anteriorly; frontal carina having strong contrast between the basal and apical half; triangular area of propodeum large, extending slightly beyond mid-point to posterior end of latter segment; a row of tubercles along each margin of the basitibial plate (practically parallel) that ends with 2 apical projections; and a single spine on the outer apex of the hind tibia.

Male- Black body with black pubescence; (Plate no- 6:a), ferruginous along the apical 3 or 4 abdominal segments; dense on the face, sides of thorax and, on intermediate and posterior legs, otherwise sparse. Head densely punctured; thorax and abdomen sparsely punctured; the disc of the mesonotum impunctated (Plate no 7: a).

Diagnostic characters

Clypeus with purely black setae; (Plate no-8:a) wings with very clear hyaline areas at extreme bases; third abdominal segment with minute spiracular lateral impressions near its base covered with short brown pubescence; tergum 7 with apically acute postero-lateral lobes.

Material examined

Bajawala 30.534181°N, 77.9898117°E, 2♂, 3♀. Sahastradhara 30.4029021°N, 78.1330826°E, 3♂, 3♀. Tiuni 30.9382977°N, 77.8469744°E, 3♂, 1♀. Jadi, 30.7448194°N, 77.8512502°E, 2♂, 3♀. Tea estate 30.3276038°N, 77.9316054°E, 4♂, 2♀. Thano 30.2552154°N, 78.1536931°E, 4♂, 2♀. Chandrabani 30.2807869°N, 77.9806153°E, 4♂, 2♀. Jollygrant 30.1859713°N , 78.1705159°E, 3♂, 2♀. Selaqui 30.3721125°N, 77.8615995°E, 1♂. Benog Wildlife Sanctuary 30.4759424°N, 78.0240135°E, 1♂. Koruwa 30.6610696°N, 77.8573942°E, 1♂, 1♀. Mohund 30.1777112°N, 77.9017492°E, 1♂.

2. Xylocopa tenuiscapa

(*Subgenus- Platynopoda*)

Female- Black body with black pubescence; short and dense on the mesonotum anteriorly; long and tuft on the lateral margins of the abdominal segments; dense and stiff on the posterior tibiae. Head, thorax and abdomen sparsely punctured.

Diagnostic characters

Crater like supraocellar pits on face; front with two deep sulcations from the base of the antennae to the posterior ocelli thus formed a marked ridge; scape of the antennae widened towards apex; wings with vibrant blue, purple and coppery effulgence (Plate no-9:e).

Male- Black body with black pubescence; (Plate no-6: e), short and dense on the mesonotum anteriorly; long and tuft on the lateral margins of the abdominal segments; dense and stiff on the posterior tibiae. Head, thorax and abdomen sparsely punctured (Plate no-7:f)

Diagnostic characters

The clypeus with small yellowish mark on each sides apically; sulcations on the front smaller; scape of the antennae much widened towards the apex; the eyes very large, nearly meeting on the vertex; (Plate no-7:f), the fore tibiae twisted, tibiae and tarsi of forelegs flattened and yellow, and fringed with long, thick and curved yellowish hairs.

Material examined

Bajawala 30.534181°N, 77.9898117°E, 2♂, 1♀. Sahastradhara 30.4029021°N, 78.1330826°E, 1♂, 1♀. Tiuni 30.9382977°N, 77.8469744°E, 1♂, 1♀. Jadi, 30.7448194°N, 77.8512502°E, 1♂. Tea estate 30.3276038°N, 77.9316054°E, 4♂, 2♀. Thano 30.2552154°N, 78.1536931°E, 2♂, 2♀. Chandrabani 30.2807869°N, 77.9806153°E, 3♂, 2♀. Jollygrant 30.1859713°N , 78.1705159°E, 3♂, 2♀. Selaqui 30.3721125°N, 77.8615995°E, 1♂. Benog Wildlife Sanctuary 30.4759424°N, 78.0240135°E, 1♂. Koruwa 30.6610696°N, 77.8573942°E, 1♂, 1♀. Mohund 30.1777112°N, 77.9017492°E, 1♂.

3. Xylocopa aestuans

(Subgenus- *Koptortosoma*)

Female- Black body with black and yellow pubescence; face with largely white or palepubescence; the pubescence on head, sides of the thorax and abdomen black; the thorax above densely covered by yellow pubescence obscuring the underlying black integument (Plate no-6:b). Head, thorax and abdomen finely punctured; the disc of the mesonotum smooth and impunctate under the yellow pubescence.

Diagnostic characters

Clypeus flat; clypeus and front not carinate;(Plate no-7:c), postero-dorsal margin of scutellum projecting beyond the posterior margin of metanotum; wings dark fuscous with purple effulgence (Plate no-9:d).

Male- Black body with yellow pubescence; whole body covered with dense olive-yellowpubescence; posterior tarsi only with brown pubescence (Plate no-6:c). Head, thorax and abdomen finely punctured.

Diagnostic characters

First metasomal tergum with sub-horizontal dorsal surface, angulately and abruptlyseparated from the declivitous anterior surface; wings hyaline (Plate no-9:b).

Material examined

Bajawala 30.534181°N, 77.9898117°E, 2♂, 1♀. Sahastradhara 30.4029021°N, 78.1330826°E, 1♂, 3♀. Tiuni 30.9382977°N, 77.8469744°E, 2♂, 1♀. Jadi, 30.7448194°N, 77.8512502°E, 1♂. Tea estate 30.3276038°N, 77.9316054°E, 4♂, 2♀. Thano 30.2552154°N, 78.1536931°E, 2♂, 2♀. Chandrabani 30.2807869°N, 77.9806153°E, 3♂, 2♀. Jollygrant 30.1859713°N , 78.1705159°E, 3♂, 2♀. Selaqui 30.3721125°N, 77.8615995°E, 1♂, 2♀. Benog Wildlife Sanctuary 30.4759424°N, 78.0240135°E, 2♂. Koruwa 30.6610696°N, 77.8573942°E, 1♂, 1♀. Mohund 30.1777112°N, 77.9017492°E, 1♂.

4. Xylocopa nasalis

(Subgenus – *Biluna*)

Females- Body is large and robust. Pubescence dominantly black, fore femora with less pubescence, outer portion of hind tibia with thick band of stout setae. Face without pale markings.

Mandibles bidentate, outer tooth slightly longer than inner tooth, outer groove not prominent, base with triangular depression, median ocelli with crescent shaped unpuctate black band (Plate no-7:d). Face skightly depressed at the base of the antennae.

Metasomal segments are less punctuate, anterior margin of T1 rounded not sharply angled.

Wings are semi transparent with bluish or purplish sheen.

Males- Body is medium to large sized and robust. Pubescence dominantly black, fore femora with no pubescence (Plate no-6:d). Hairs on anterior part of thorax and plurites yellowish white.

Mandibles bidentate, outer teeth elongated and pointed than inner teeth, malar area unpunctate and globrous (Plate no-6:d). Labrum with distict median tubercle strongly elevates, small groove present on posterior part of median ocelli, face is sparsely punctured as compared to abdominal tergites.

Metasomal segments are sparsely and uniformly punctured.

Wings are transparent with greenish and bluish tint (Plate no- 9:c).

Material examined

Bajawala 30.534181°N, 77.9898117°E, 2♂, 1♀. Sahastradhara 30.4029021°N, 78.1330826°E, 1♂, 1♀. Tiuni 30.9382977°N, 77.8469744°E, 1♂, 1♀. Tea estate 30.3276038°N, 77.9316054°E, 1♂, 2♀. Thano 30.2552154°N, 78.1536931°E, 1♂, 1♀. Chandrabani 30.2807869°N, 77.9806153°E, 2♂, 2♀. Jollygrant 30.1859713°N , 78.1705159°E, 1♂, 1♀. Selaqui 30.3721125°N, 77.8615995°E, 1♂, 1♀.

5. Xylocopa sp. nov.1

Body is medium sized and robust. Pubescence dominantly black (Plate no-6:f), thorax is densely punctured and abdomen is sparsely punctured. Paraocular area, supraclypeal area, clypeus and area around median ocellus is pale yellow in colour. Mandibles are bidentate with outer teeth slightly elongated than inner teeth (Plate no-8:f).

Wings are semi-transparent with bluish tint (Plate no- 9:f).

Material examined

Bajawala 30.534181°N, 77.9898117°E, 1♂, 1♀. Sahastradhara 30.4029021°N, 78.1330826°E, 1♂, 1♀. Tiuni 30.9382977°N, 77.8469744°E, 1♂. Tea estate 30.3276038°N, 77.9316054°E, 1♂, 1♀. Thano 30.2552154°N, 78.1536931°E, 1♂, Chandrabani 30.2807869°N, 77.9806153°E, 2♂. Jollygrant 30.1859713°N , 78.1705159°E, 1♂, 1♀. Selaqui 30.3721125°N, 77.8615995°E, 1♀.

6. Xylocopa sp. nov. 2

Body is small to medium sized. Pubescence is dominantly black (Plate no- 6:g).
Head is densely punctured. Tergites are sparsely punctured.
Mandibles are bidentate (Plate no-8:g).
Wings are non transparent and dark cloured (Plate no- 9:g).

Material examined

Jadi, 30.7448194°N, 77.8512502°E, 1♂. Benog Wildlife Sanctuary 30.4759424°N, 78.0240135°E, 2♂. Koruwa 30.6610696°N, 77.8573942°E, 1♂, 1♀.

7. Xylocopa sp. nov. 3

Body is small sized. Pubescence is dominantly black. Head and tergites are densely punctured. Last two tergites are very small and almost flat (Plate no-6:h).
Wings have bluish to brownish tint (Plate no- 9:h).

Material examined

Bajawala 30.534181°N, 77.9898117°E, 1♂. Sahastradhara 30.4029021°N, 78.1330826°E, 1♂, 1♀. Tiuni 30.9382977°N, 77.8469744°E, 1♂. Tea estate 30.3276038°N, 77.9316054°E, 1♂. Thano 30.2552154°N, 78.1536931°E, 1♂, Chandrabani 30.2807869°N, 77.9806153°E, 2♂. Jollygrant 30.1859713°N , 78.1705159°E, 1♂, 1♀. Selaqui 30.3721125°N, 77.8615995°E, 1♀.

Plate no-6: Carpenter Bees

a. Xylocopa fenestrata

b. Xylocopa aestuans (female)

c. Xylocopa aestuans (male)

d. Xylocopa nasalis

e. Xylocopa tenuiscapa

f. Xylocopa sp.nov.1

g. Xylocopa sp.nov.2

h. Xylocopa sp.nov.3

Plate no-7: Carpenter bees-head parts

a. *Xylocopa fenestrata*

b. *Xylocopa aestuans* (male)

c. *Xylocopa aestuans* (female*)*

d. *Xylocopa nasalis*

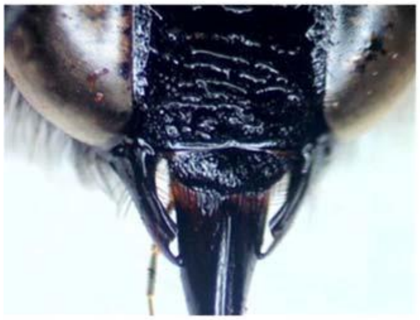
e. *Xylocopa sp.nov.1*

f. Xylocopa tenuiscapa

g. *Xylocopa sp. nov.2*

h. *Xylocopa sp.nov.3*

Plate no-8: Carpenter bees- mouth parts



a. *Xylocopa fenestrata*

b. *Xylocopa aestuans* (male)

c. *Xylocopa aestuans* (female)

d. *Xylocopa nasalis*

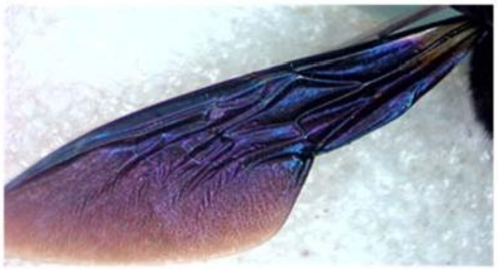
e. *Xylocopa tenuiscapa*

f. *Xylocopa sp.nov.1*

g. *Xylocopa sp. nov.2*

h. *Xylocopa sp.nov.3*

Plate no -9: Carpenter bee-Wings

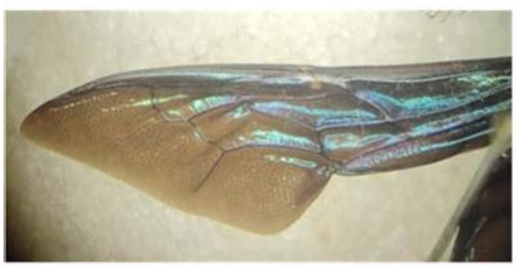


a. Xylocopa fenestrata

b. Xylocopa aestuans (male)

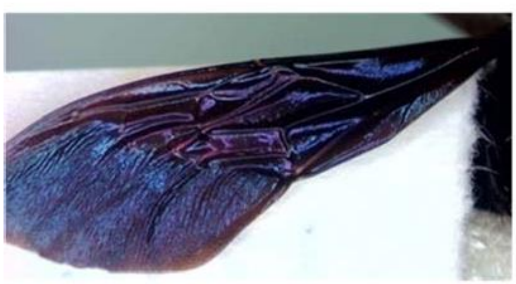
c. Xylocopa nasalis

d. Xylocopa aestuans (female)

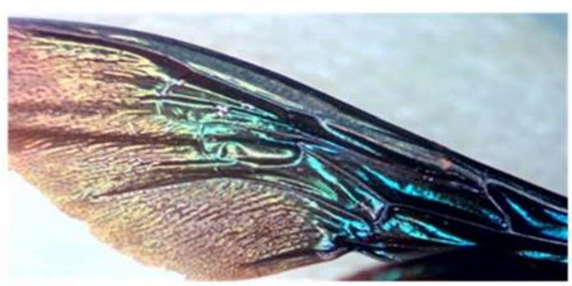


e,. Xylocopa tenuiscapa

f. Xylocopa sp.nov.1



g. Xylocopa sp. nov.2



h. Xylocopa sp.nov.3

5.2 Influence of different meteorological parameters on distribution and abundance of bees

Different ecological factors like temperature, humidity, rainfall, slope and elevation affects the distribution and abundance of species in a particular region. Insects are poikilothermic and are largely affected by various environmental factors specially temperature and humidity (Taylor, 1981; Pedigo, 1989).

The climate of Dehradun district is subtropical. The whole year is divided into three seasons, Pre - monsoon (February - May), Monsoon (June - September) and Post- monsoon (October- January). The two main environmental variables, temperature and humidity in many ways affect the distribution, mating behavior, developmental rate, body movement, digestion and respiration of insects (Beeson, 1941).

1. Monthly meteorological data of site 1- Bajawala in the year 2021-2022.

a. Pre-monsoon

The mean monthly temperature recorded at site 1 ranged between 12.28± 1.04 in February 2021 to 22.29± 0.72 in May 2021 and it ranged between 8.29± 1.31 in February 2022 to 24.52± 1.53 in May 2022.

The mean monthly humidity recorded between 42.06±2.52 in February 2021 to 47.25±1.89 in May 2021 and it is recorded between 66.24±2.13 in February 2022 to 41.1±2.29 in May 2022.

The mean rainfall recorded between 26.37±2.36 in February 2021 to 129.92±2.18 in May 2021 and it is recorded between 51.04± 16.91 in February 2022 to 70.17± 15.60 in May 2022.

b. Monsoon

The mean monthly temperature recorded at site 1 ranged between 24.93± 1.02 in June 2021 to 21.37± 0.87 in September 2021 and it ranged 26.39± 1.99 in June 2022 to 21.31± 0.29 in September 2022.

The mean monthly humidity recorded between 59.01±2.40 in June 2021 to 83.76±2.18 in September 2021 and it is recorded between 44.93±2.02 in June 2022 to 87.34±2.05 in September 2022.

The mean rainfall recorded between 127.09±1.98 in June 2021 to 261.25± 31.73 in September 2021 and it is recorded between 115.87± 25.59 in June 2022 to 370.92± 23.57 in September 2022.

c. Post-monsoon

The mean monthly temperature recorded at site 1 ranged between 17.82± 0.65 in October 2021 to 10.28± 0.69 in January 2021 and it ranged between 17.54± 1.02 in October 2022 to 7.18± 2.01 in January 2022.

The mean monthly humidity recorded between 70.29±1.95 in October 2021 to 41.1±1.99 in January 2021 and it is recorded between 75.29±1.91 in October 2022 to 71.1±2.18 in January 2022.

The mean rainfall recorded between 65.38± 12.69 in October 2021 to 21.09± 2.20 in January 2021 and it is recorded between 69.23±11.82 in October 2022 to 151.26± 3.28 in January 2022.

Table 5.2.1: Monthly meteorological data of site 1- Bajawala in the year 2021-2022

Season	Month	Temperature(°C)	Humidity (%)	Rainfall(mm)
Pre- monsoon	February (2021)	12.28± 1.04	42.06±2.52	26.37±2.36
	March	16.09± 0.82	36.09±1.84	10.55± 2.44
	April	20.83± 1.04	34.12±2.12	55.23±1.81
	May	22.29± 0.72	47.25±1.89	129.92±2.18
Monsoon	June	24.93± 1.02	59.01±2.40	127.09±1.98
	July	25.05± 1.01	77.91±1.95	449.73±30.19
	August	22.83± 1.05	85.31±1.89	266.25± 19.62
	September	21.37± 0.87	83.76±2.18	261.25± 31.73
Post- monsoon	October	17.82± 0.65	70.29±1.95	65.38± 12.69
	November	12.16± 0.60	52.37±2.37	0.29± 0.23
	December	9.38± 0.83	57.93±2.0	8.11± 2.41
	January	10.28± 0.69	41.1±1.99	21.09± 2.20
Pre- monsoon	February (2022)	8.29± 1.31	66.24±2.13	51.04± 16.91
	March	17.92± 0.78	51.21±2.41	0.54± 0.32
	April	23.29± 0.95	31.64±2.16	2.02± 2.51
	May	24.52± 1.53	41.1±2.29	70.17± 15.60
Monsoon	June	26.39± 1.99	44.93±2.02	115.87± 25.59
	July	23.83± 2.11	84.73±2.09	466.28± 43.17
	August	23.02± 1.02	87.43±2.34	269.74± 26.59
	September	21.31± 0.29	87.34±2.05	370.92± 23.57
Post- monsoon	October	17.54± 1.02	75.29±1.91	69.23±11.82
	November	12.8± 2.72	61.29±2.30	3.66± 2.19
	December	11.65± 1.96	54.29±2.33	0.84±1.02
	January	7.18± 2.01	71.1±2.18	151.26± 3.28

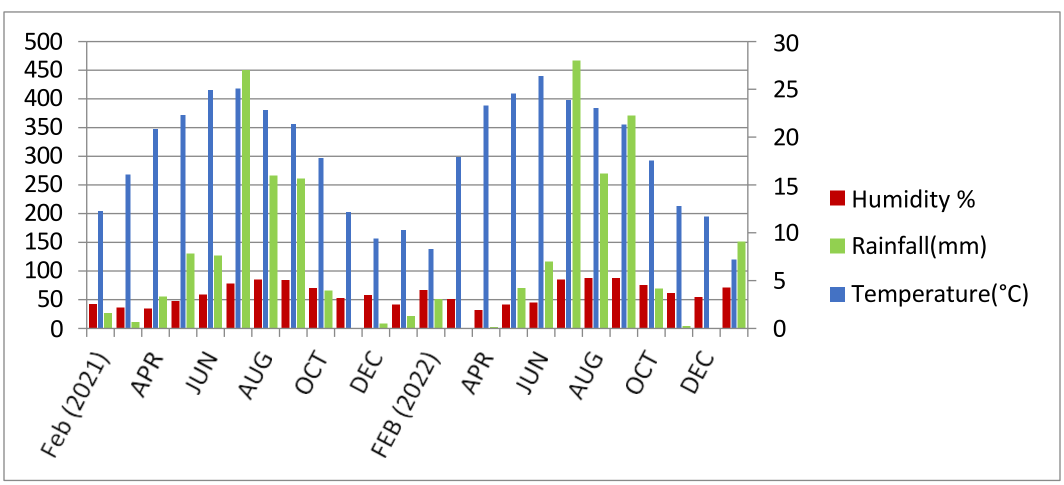


Fig. 5.2.1: Monthly meteorological data of site 1- Bajawala in the year 2021-2022

2. Monthly meteorological data of site 2- Sahastradhara in the year 2021-2022

a. Pre-monsoon

The mean monthly temperature recorded at site 2 ranged between 12.56±2.298 in February 2021 to 22.49±2.06 in May 2021 and it ranged between 8.62±1.94 in February 2022 to 24.7±1.86 in May 2022.

The mean monthly humidity recorded between 44.06±2.19 in February 2021 to 48.25±2.0 in May 2021 and it is recorded between 66.31±1.99 in February 2022 to 40.62±2.16 in May 2022.

The mean rainfall recorded between 26.23± 1.82 in February 2021 to 129.22± 9.23 in May 2021 and it is recorded between 51.09± 16.78 in February 2022 to 71.68± 15.60 in May 2022.

a. Monsoon

The mean monthly temperature recorded at site 2 ranged between 24.56±2.24 in June 2021 to 21.23±2.11 in September 2021 and it ranged 26.39± 1.99 in June 2022 to 21.31± 0.29 in September2022.

The mean monthly humidity recorded between 58.81±1.95 in June 2021 to 85.81±1.98 in September 2021 and it is recorded between 44.88±2.33 in June 2022 to 87.5±1.96 in September 2022.

The mean rainfall recorded between 129.96± 15.82 in June 2021 to 252.52± 31.73 in September 2021 and it is recorded between 118.91± 25.59 in June 2022 to 373.87± 23.57 in September 2022.

d. Post-monsoon

The mean monthly temperature recorded at site 2 ranged between 17.94±1.68 in October 2021 to 10.25±2.17 in January 2021 and it ranged between 17.22±1.99 in October 2022 to 7.28±1.66 in January 2022.

The mean monthly humidity recorded between 69.25±1.98 in October 2021 to 41.25±1.95 in January 2021 and it is recorded between 75.38±1.73 in October 2022 to 71.81±2.34 in January 2022.

The mean rainfall recorded between 68.05± 12.69 in October 2021 to 20.62± 2.20 in January 2021 and it is recorded between 69.23±11.29 in October 2022 to 144.94± 3.92 in January 2022.

Table 5.2.2: Monthly meteorological data of site 2- Sahastradhara in the year 2021-2022

Season	Month	Temperature(°C)	Humidity (%)	Rainfall(mm)
Pre- Monsoon	February (2021)	12.56±2.29	44.06±2.19	26.23± 1.82
	March	17.35±1.93	36.94±1.97	9.67± 2.24
	April	20.12±2.11	34.5±1.62	54.85± 5.33
	May	22.49±2.06	48.25±2.0	129.22± 9.23
Monsoon	June	24.56±2.24	58.81±1.95	129.96± 15.82
	July	24.05±2.24	77.69±1.67	449.76± 51.52
	August	22.47±2.06	86.31±1.95	261.64± 19.62
	September	21.23±2.11	85.81±1.98	252.52± 31.73
Post-Monsoon	October	17.94±1.68	69.25±1.98	68.05± 12.69
	November	13.06±2.07	52.25±2.00	0.31± 0.23
	December	9.03±2.13	58±1.95	7.18± 2.41
	January	10.25±2.17	41.25±1.95	20.62± 2.20
Pre- Monsoon	February (2022)	8.62±1.94	66.31±1.99	51.09± 16.78
	March	17.59±2.0	51±2.21	0.62± 0.32
	April	23.08±1.76	32.44±2.33	3.04± 2.51
	May	24.7±1.86	40.62±2.16	71.68± 15.60
Monsoon	June	26.6±1.91	44.88±2.33	118.91± 25.59
	July	23.44±2.01	84.69±2.01	447.98± 43.17
	August	22.832±2.11	87.31±1.99	271.47± 26.59
	September	21.3±1.88	87.5±1.96	373.87± 23.57
Post-Monsoon	October	17.22±1.99	75.38±1.73	69.23±11.29
	November	13.82±2.28	61.752.04	3.66± 1.92
	December	11.08±2.05	54.38±1.63	0.84±2.92
	January	7.28±1.66	71.81±2.34	144.94± 3.92

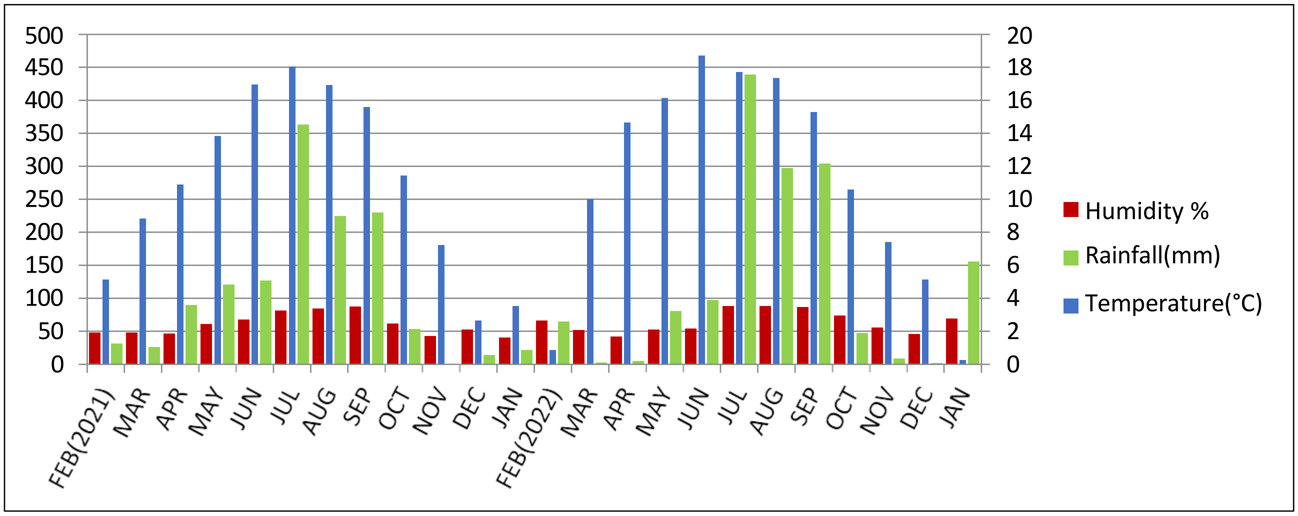


Fig. 5.2.2: Monthly meteorological data of site 2- Sahastradhara in the year 2021-2022

b. Monthly meteorological data of site 3 - Tiuni in the year 2021-2022.

a. Pre-monsoon

The mean monthly temperature recorded at site 3 ranged between 5.13±2.06 in February 2021 to 13.83±1.88 in May 2021 and it ranged between 0.85±1.04 in February 2022 to 16.14±1.70 in May 2022.

The mean monthly humidity recorded between 47.69±1.73 in February 2021 to 60.88±2.32 in May 2021 and it is recorded between 65.75±1.99 in February 2022 to 52.31±1.97 in May 2022.

The mean rainfall recorded between 31.64± 2.91 in February 2021 to 121.07±8.01 in May 2021 and it is recorded between 64.24± 2.93 in February 2022 to 80.93± 4.91 in May 2022.

b. Monsoon

The mean monthly temperature recorded at site 3 ranged between 16.96±2.17 in June 2021 to 15.58±2.05 in September 2021 and it ranged 18.71±2.29 in June 2022 to 15.3±1.99 in September2022.

The mean monthly humidity recorded between 67.38±2.01 in June 2021 to 87.12±1.95 in September 2021 and it is recorded between 53.69±2.05 in June 2022 to 86.88±1.53 in September 2022.

The mean rainfall recorded between 126.52± 12.29 in June 2021 to 229.7± 38.27 in September 2021 and it is recorded between 97.52± 10.28 in June 2022 to 304.03± 39.46 in September 2022.

c. Post-monsoon

The mean monthly temperature recorded at site 3 ranged between 11.44±1.95 in October 2021 to 3.51±1.73 in January 2021 and it ranged between 10.59±2.23 in October 2022 to 0.27±.20 in January 2022.

The mean monthly humidity recorded between 61.88±2.44 in October 2021 to 40.12±2.04 in January 2021 and it is recorded between 73.44±2.45 in October 2022 to 69.31±1.55 in January 2022.

The mean rainfall recorded between 53.5± 3.02 in October 2021 to 21.09± 0.29 in January 2021 and it is recorded between 47.11± 2.93 in October 2022 to 155.86± 3.16 in January 2022.

Table. 5.2.3: Monthly meteorological data of site 3- Tiuni in the year 2021-2022

Season	Month	Temperature(°C)	Humidity (%)	Rainfall(mm)
Pre-Monsoon	February (2021)	5.13±2.06	47.69±1.73	31.64± 2.91
	March	8.84±1.67	47.81±2.02	26.37± 1.02
	April	10.88±1.76	46.38±1.63	89.28±7.03
	May	13.83±1.88	60.88±2.32	121.07±8.01
Monsoon	June	16.96±2.17	67.38±2.01	126.52± 12.29
	July	18.05±2.31	81.31±2.0	362.73± 29.12
	August	16.92±2.03	84.19±1.57	224.73± 33.29
	September	15.58±2.05	87.12±1.95	229.7± 38.27
Post-Monsoon	October	11.44±1.95	61.88±2.44	53.5± 3.02
	November	7.21±2.05	42.5±2.03	0.51± 1.02
	December	2.66±1.68	52.5±1.99	14.16± 2.01
	January	3.51±1.73	40.12±2.04	21.09± 0.29
Pre-Monsoon	February (2022)	0.85±1.04	65.75±1.99	64.24± 2.93
	March	10.01±2.06	52±1.69	2.38± 1.02
	April	14.66±2.04	41.88±2.04	4.48± 1.29
	May	16.14±1.70	52.31±1.97	80.93± 4.91
Monsoon	June	18.71±2.29	53.69±2.05	97.52± 10.28
	July	17.71±1.88	88.06±1.61	438.61± 36.18
	August	17.33±1.86	88.06±1.61	297.17± 28.21
	September	15.3±1.99	86.88±1.53	304.03± 39.46
Post-Monsoon	October	10.59±2.23	73.44±2.45	47.11± 2.93
	November	7.4±1.95	55.31±2.45	8.82± 2.38
	December	5.12±2.06	45.44±2.41	2.11± 1.02
	January	0.27±.20	69.31±1.55	155.86± 3.16

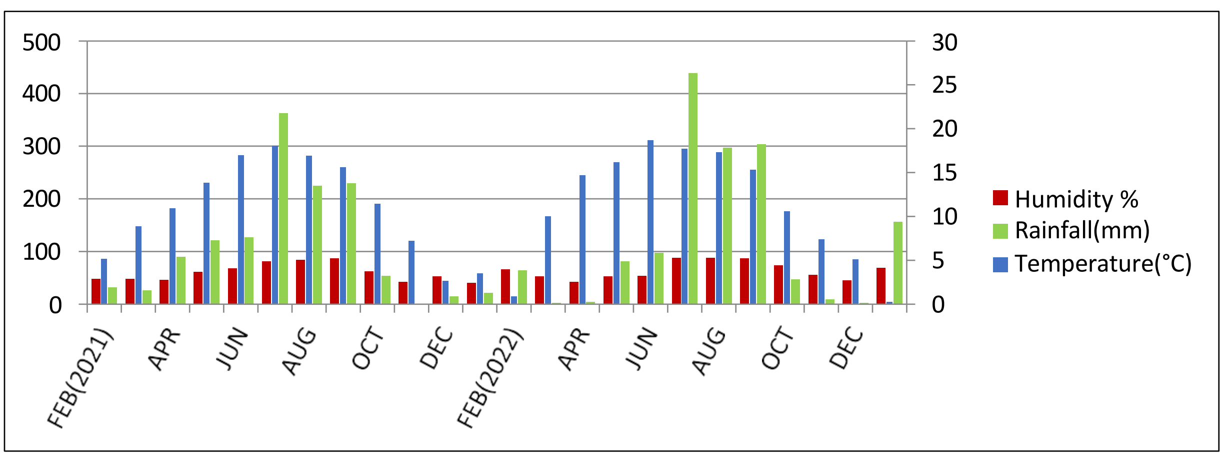


Fig. 5.2.3: Monthly meteorological data of site 3- Tiuni in the year 2021-2022

c. Monthly meteorological data of site 4 - Jadi in the year 2021-2022.

a. Pre-monsoon

The mean monthly temperature recorded at site 4 ranged between 12.56±1.69 in February 2021 to 22.491.87 in May 2021 and it ranged between 8.62±1.95 in February 2022 to 24.7±2.14 in May 2022.

The mean monthly humidity recorded between 44.06±1.66 in February 2021 to 48.25±2.05 in May 2021 and it is recorded between 66.31±2.35 in February 2022 to 40.62±2.31 in May 2022.

The mean rainfall recorded between 26.37± 2.98 in February 2021 to 129.92± 7.35 in May 2021 and it is recorded between 51.04± 3.92 in February 2022 to 70.17± 7.29 in May 2022.

b. Monsoon

The mean monthly temperature recorded at site 4 ranged between 24.56±2.10 in June 2021 to 21.23±1.74 in September 2021 and it ranged 26.6±1.90 in June 2022 to 21.3±2.04 in September2022.

The mean monthly humidity recorded between 58.81±2.05 in June 2021 to 85.81±2.02 in September 2021 and it is recorded between 44.88±2.36in June 2022 to 87.5±1.87 in September 2022.

The mean rainfall recorded between 127.09± 9.28 in June 2021 to 261.25± 11.54 in September 2021 and it is recorded between 115.87± 6.03 in June 2022 to 370.92± 9.12 in September 2022.

c. Post-monsoon

The mean monthly temperature recorded at site 4 ranged between 17.94±2.06 in October 2021 to 10.25±2.09 in January 2021 and it ranged between 17.22±1.87 in October 2022 to 7.28±1.83 in January 2022.

The mean monthly humidity recorded between 69.25±1.91 in October 2021 to 41.25±2.45 in January 2021 and it is recorded between 75.38±1.98 in October 2022 to 71.81±2.00 in January 2022.

The mean rainfall recorded between 65.38± 2.28 in October 2021 to 21.09± 2.02 in January 2021 and it is recorded between 69.23±2.01 in October 2022 to 151.26± 2.91 in January 2022.

Table 5.2.4: Monthly meteorological data of site 4- Jadi in the year 2021-2022

Season	Month	Temperature(°C)	Humidity (%)	Rainfall(mm)
Pre-Monsoon	February (2021)	12.56±1.69	44.06±1.66	26.37± 2.98
	March	17.35±1.59	36.94±1.99	10.55± 1.67
	April	20.12±2.01	34.5±2.01	55.23± 2.45
	May	22.491.87	48.25±2.05	129.92± 7.35
Monsoon	June	24.56±2.10	58.81±2.05	127.09± 9.28
	July	24.05±1.77	77.69±1.93	447.73± 30.17
	August	22.47±2.01	86.31±2.00	266.25± 19.28
	September	21.23±1.74	85.81±2.02	261.25± 11.54
Post-Monsoon	October	17.94±2.06	69.25±1.91	65.38± 2.28
	November	13.06±2.09	52.25±1.89	0.29±1.92
	December	9.03±2.12	58±2.00	8.11± 1.02
	January	10.25±2.09	41.25±2.45	21.09± 2.02
Pre-Monsoon	February (2022)	8.62±1.95	66.31±2.35	51.04± 3.92
	March	17.59±2.00	51±2.35	0.54± 2.01
	April	23.08±2.07	32.44±1.95	2.02± 2.26
	May	24.7±2.14	40.62±2.31	70.17± 7.29
Monsoon	June	26.6±1.90	44.88±2.36	115.87± 6.03
	July	23.44±1.69	84.69±2.13	466.28± 31.02
	August	22.83±2.25	87.31±1.86	269.74± 10.29
	September	21.3±2.04	87.5±1.87	370.92± 9.12
Post-Monsoon	October	17.22±1.87	75.38±1.98	69.23±2.01
	November	13.82±2.07	61.75±2.01	3.66± 1.62
	December	11.08±2.00	54.38±2.05	0.84± 1.01
	January	7.28±1.83	71.81±2.00	151.26± 2.91

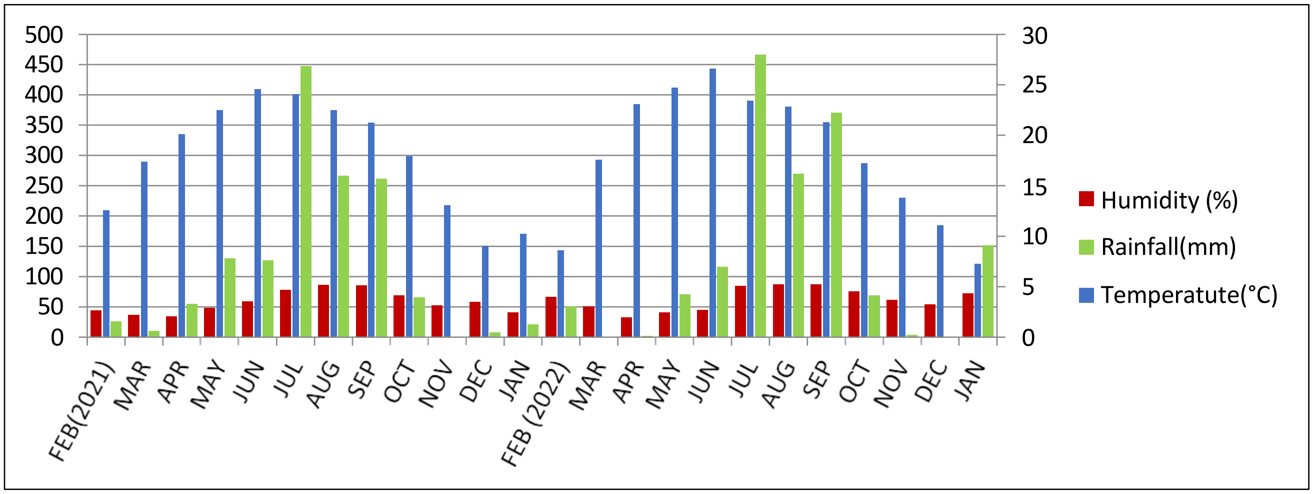


Fig. 5.2.4: Monthly meteorological data of site 4- Jadi in the year 2021-2022

d. Monthly meteorological data of site 5 -Tea estate in the year 2021-2022.

a. Pre-monsoon

The mean monthly temperature recorded at site 5 ranged between 12.28±2.00 in February 2021 to 22.2±2.32in May 2021 and it ranged between 8.29±1.68 in February 2022 to 24.52±2.04 in May 2022.

The mean monthly humidity recorded between 43.86±3.54 in February 2021 to 49.21±2.13 in May 2021 and it is recorded between 66.1±2.00 in February 2022 to 40.2±2.35 in May 2022.

The mean rainfall recorded between 26.37± 3.38 in February 2021 to 129.92± 7.48 in May 2021 and it is recorded between 51.04± 6.14 in February 2022 to 70.17± 6.93 in May 2022.

b. Monsoon

The mean monthly temperature recorded at site 5 ranged between 24.56±2.10 in June 2021 to 21.23±1.74 in September 2021 and it ranged 26.6±1.90 in June 2022 to 21.3±2.04 in September2022.

The mean monthly humidity recorded between 58.81±2.05 in June 2021 to 85.81±2.02 in September 2021 and it is recorded between 44.88±2.36in June 2022 to 87.5±1.87 in September 2022.

The mean rainfall recorded between 127.09± 9.28 in June 2021 to 261.25± 11.54 in September 2021 and it is recorded between 115.87± 6.03 in June 2022 to 370.92± 9.12 in September 2022.

c. Post-monsoon

The mean monthly temperature recorded at site 5 ranged between 17.03±2.03 in October 2021 to 10.53±1.55 in January 2021 and it ranged between 17.32±1.80 in October 2022 to 7.18±2.00 in January 2022.

The mean monthly humidity recorded between 69.02± 2.12 in October 2021 to 41.3±1.96 in January 2021 and it is recorded between 75.55±1.65 in October 2022 to 70.31±1.93 in January 2022.

The mean rainfall recorded between 65.38± 7.41 in October 2021 to 21.09± 3.00 in January 2021 and it is recorded between 69.23± 6.92 in October 2022 to 151.26± 3.02 in January 2022.

Table 5.2.5: Monthly meteorological data of site 5 -Tea estate in the year 2021-2022

Season	Month	Temperature(°C)	Humidity (%)	Rainfall(mm)
Pre-Monsoon	February (2021)	12.28±2.00	43.86±3.54	26.37± 3.38
	March	17.19±2.08	37.04±2.47	10.55± 2.05
	April	20.92±1.88	34.29±2.31	55.23± 3.11
	May	22.2±2.32	49.21±2.13	129.92± 7.48
Monsoon	June	24.56±2.27	58.29±2.07	127.09± 13.03
	July	24.83±2.28	77.48±2.15	443.73± 36.80
	August	22.93±1.92	86.93±2.05	266.25± 30.91
	September	21.48±1.86	84.21±2.17	261.25± 21.69
Post-Monsoon	October	17.03±2.03	69.02± 2.12	65.38± 7.41
	November	12.16±2.01	52.84±2.28	0.29± 0.07
	December	9.67±2.13	57.98±2.10	8.11± 1.74
	January	10.53±1.55	41.3±1.96	21.09± 3.00
Pre-Monsoon	February (2022)	8.29±1.68	66.1±2.00	51.04± 6.14
	March	17.64±2.19	51±29± .46	0.54± 0.19
	April	23.95±2.41	32.39±2.99	2.02± 2.13
	May	24.52±2.04	40.2±2.35	70.17± 6.93
Monsoon	June	26.2±2.45	43.29±2.04	115.87± 9.83
	July	23.29±2.01	84.21±2.06	466.28± 34.65
	August	22.79±2.01	87.29±1.68	269.74± 23.11
	September	21.83±2.00	87.1±1.66	370.92± 28.43

Post-Monsoon	October	17.32±1.80	75.55±1.65	69.23± 6.92
	November	13.09±2.45	61.23±1.89	3.66±3.02
	December	11.19±2.29	54.39±1.91	0.84± 1.41
	January	7.18±2.00	70.31±1.93	151.26± 3.02

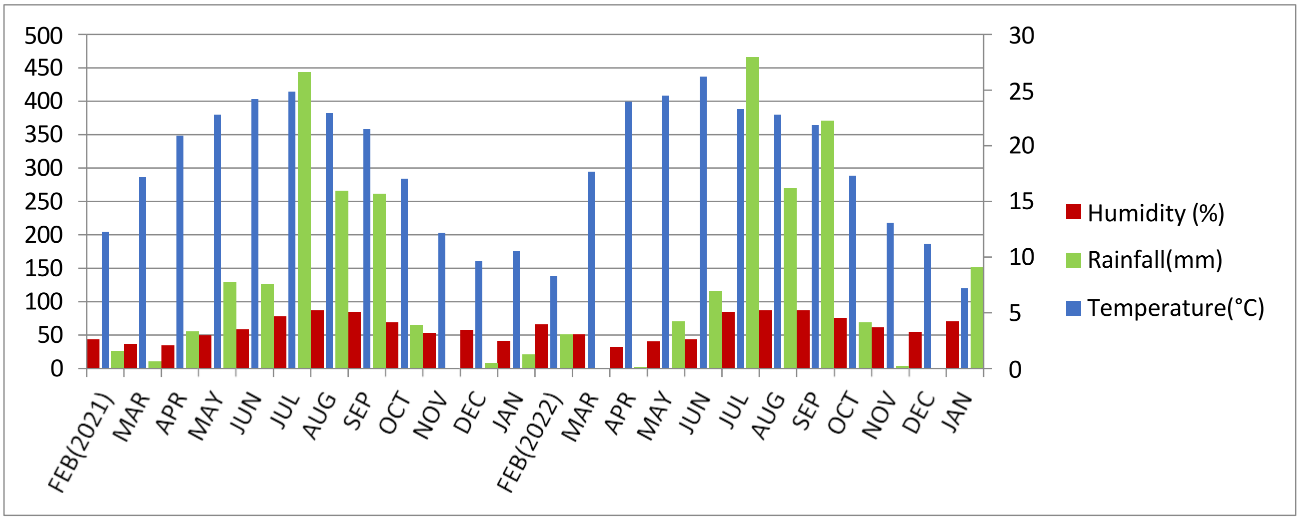


Fig. 5.2.5: Monthly meteorological data of site 5- Tea estate in the year 2021-2022

e. Monthly meteorological data of site 6 - Thano in the year 2021-2022.

a. Pre-monsoon

The mean monthly temperature recorded at site 6 ranged between 11.56±2.32 in February 2021 to 22.20±2.27 in May 2021 and it ranged between 8.29±1.81 in February 2022 to 23.90±1.55 in May 2022.

The mean monthly humidity recorded between 43.21±2.30 in February 2021 to 49.2±2.05 in May 2021 and it is recorded between 66.2±2.00 in February 2022 to 40.12±2.09 in May 2022.

The mean rainfall recorded between 27.32± 1.89 in February 2021 to 129.92± 4.09 in May 2021 and it is recorded between 51.04± 2.94 in February 2022 to 70.17± 2.38 in May 2022.

b. Monsoon

The mean monthly temperature recorded at site 6 ranged between 24.48±1.69 in June 2021 to 21.92±2.32 in September 2021 and it ranged 26.58±1.57 in June 2022 to 21.20±1.85 in September2022.

The mean monthly humidity recorded between 59.01±1.90 in June 2021 to 84.98±2.12 in September 2021 and it is recorded between 44.48±1.71 in June 2022 to 87.59±1.88 in September 2022.

The mean rainfall recorded between 127.06± 5.03 in June 2021 to 261.25± 18.39 in September 2021 and it is recorded between 115.87± 5.27 in June 2022 to 370.92± 5.26 in September 2022.

c. Post-monsoon

The mean monthly temperature recorded at site 6 ranged between 16.14±2.08 in October 2021 to 11.25±1.81 in January 2021 and it ranged between 16.12±1.81 in October 2022 to 8.28±1.69 in January 2022.

The mean monthly humidity recorded between 69.15±1.94 in October 2021 to 41.35±2.19 in January 2021 and it is recorded between 75.58±1.69 in October 2022 to 71.29±2.02 in January 2022.

The mean rainfall recorded between 65.38± 4.35 in October 2021 to 21.09± 4.92 in January 2021 and it is recorded between 70.23± 2.98in October 2022 to 151.26± 2.13 in January 2022.

Table 5.2.6: Monthly meteorological data of site 6- Thano in the year 2021-2022

Season	Month	Temperature (°C)	Humidity (%)	Rainfall(mm)
Pre-Monsoon	February (2021)	11.56±2.32	43.21±2.30	27.32± 1.89
	March	17.58±2.09	37.24±1.72	10.45±2.23
	April	20.65±1.87	34.34±2.14	54.23± 2.12
	May	22.20±2.27	49.2±2.05	129.92± 4.09
Monsoon	June	24.48±1.69	59.01±1.90	127.06± 5.03
	July	23.15±2.19	77.76±2.05	466.73± 30.29
	August	22.39±1.83	86.37±2.00	266.25± 25.02
	September	21.92±2.32	84.98±2.12	261.25± 18.39
Post-Monsoon	October	16.14±2.08	69.15±1.94	65.38± 4.35
	November	12.06±1.73	52.65±1.94	0.29±1.02
	December	10.03±2.12	58.02±1.95	8.11± 2.02
	January	11.25±1.81	41.35±2.19	21.09± 4.92
Pre-Monsoon	February (2022)	8.29±1.81	66.2±2.00	51.04± 2.94
	March	16.92±2.00	51.16±2.00	0.54± 1.98
	April	23.19±2.00	32.59±2.30	2.02± 2.46
	May	23.90±1.55	40.12±2.09	70.17± 2.38
Monsoon	June	26.58±1.57	44.48±1.71	115.87± 5.27
	July	22.14±2.01	84.87±1.91	472.21± 35.26
	August	22.52±1.71	86.31±1.99	269.74± 29.48
	September	21.20±1.85	87.59±1.88	370.92± 5.26
Post-Monsoon	October	16.12±1.81	75.58±1.69	70.23± 2.98
	November	13.32±1.99	61.47±2.01	3.46± 1.25
	December	12.08±1.87	54.3±2.00	0.84±1.03
	January	8.28±1.69	71.29±2.02	151.26± 2.13

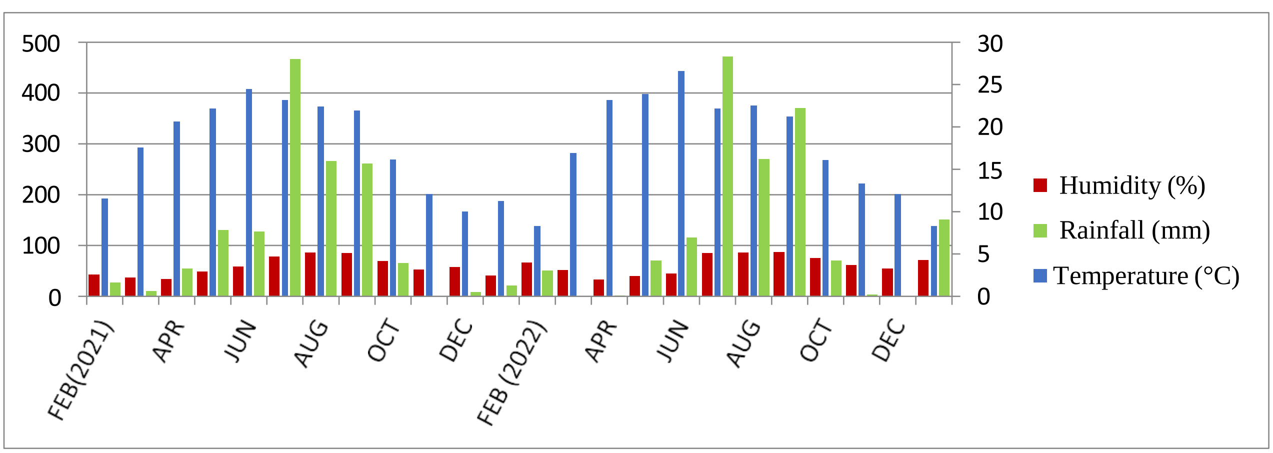


Fig. 5.2.6: Monthly meteorological data of site 6- Thano in the year 2021-2022

f. Monthly meteorological data of site 7 - Chandrabani in the year 2021-2022.

a. Pre-monsoon

The mean monthly temperature recorded at site 7 ranged between 12.56±1.99 in February 2021 to 22.49±1.89 in May 2021 and it ranged between 8.62±1.96 in February 2022 to 24.7±2.45 in May 2022.

The mean monthly humidity recorded between 44.06±1.56 in February 2021 to 48.25±2.22 in May 2021 and it is recorded between 66.31±2.18 in February 2022 to 40.62±1.96 in May 2022.

The mean rainfall recorded between 26.37± 2.01 in February 2021 to 129.92± 1.89 in May 2021 and it is recorded between 51.04± 3.16 in February 2022 to 70.17± 2.16 in May 2022.

b. Monsoon

The mean monthly temperature recorded at site 7 ranged between 24.56±2.22 in June 2021 to 21.23±1.86 in September 2021 and it ranged 26.6±1.68 in June 2022 to 21.3±2.32 in September2022.

The mean monthly humidity recorded between 58.81±1.92 in June 2021 to 85.81±1.73 in September 2021 and it is recorded between 44.88±1.67 in June 2022 to 87.5±2.39 in September 2022.

The mean rainfall recorded between 127.09± 6.09 in June 2021 to 261.25± 16.34 in September 2021 and it is recorded between 115.87± 3.68 in June 2022 to 370.92± 2.01 in September 2022.

c. Post-monsoon

The mean monthly temperature recorded at site 7 ranged between 17.94±2.10 in October 2021 to 10.25±1.99 in January 2021 and it ranged between 17.22±1.88 in October 2022 to 7.28±2.06 in January 2022.

The mean monthly humidity recorded between 69.25±2.04 in October 2021 to 41.25±2.33 in January 2021 and it is recorded between 75.38±2.03 in October 2022 to 71.81±2.28 in January 2022.

The mean rainfall recorded between 65.38± 2.24 in October 2021 to 21.09± 1.39 in January 2021 and it is recorded between 69.23± 1.81 in October 2022 to 151.26± 2.16 in January 2022.

Table 5.2.7: Monthly meteorological data of site 7- Chandrabani in the year 2021-2022

Season	Month	Temperature(°C)	Humidity (%)	Rainfall (mm)
Pre-Monsoon	February (2021)	12.56±1.99	44.06±1.56	26.37± 2.01
	March	17.35±2.01	36.94±1.95	10.55± 2.92
	April	20.12±2.33	34.5±2.05	55.23± 1.25
	May	22.49±1.89	48.25±2.22	129.92± 1.89
Monsoon	June	24.56±2.22	58.81±1.92	127.09± 6.09
	July	24.05±1.86	77.69±2.10	466.73± 31.90
	August	22.47±2.30	86.31±2.05	266.25± 27.45
	September	21.23±1.86	85.81±1.73	261.25± 16.34
Post-Monsoon	October	17.94±2.10	69.25±2.04	65.38± 2.24
	November	13.06±1.92	52.25±2.32	0.29± 1.89
	December	9.03±2.13	58±1.94	8.11± 2.47
	January	10.25±1.99	41.25±2.33	21.09± 1.39
Pre-Monsoon	February (2022)	8.62±1.96	66.31±2.18	51.04± 3.16
	March	17.59±1.95	51±2.00	0.54± 1.39
	April	23.08±2.40	32.44±2.31	2.02± 2.27
	May	24.7±2.45	40.62±1.96	70.17± 2.16
Monsoon	June	26.6±1.68	44.88±1.67	115.87± 3.68
	July	23.44±1.73	84.69±1.66	466.28± 34.15
	August	22.83±2.36	87.31±2.09	269.74± 25.98
	September	21.3±2.32	87.5±2.39	370.92± 2.01
Post-Monsoon	October	17.22±1.88	75.38±2.03	69.23± 1.81
	November	13.82±2.32	61.75±2.28	3.66± 1.23
	December	11.08±2.01	54.38±1.62	0.84± 1.25
	January	7.28±2.06	71.81±2.28	151.26± 2.16

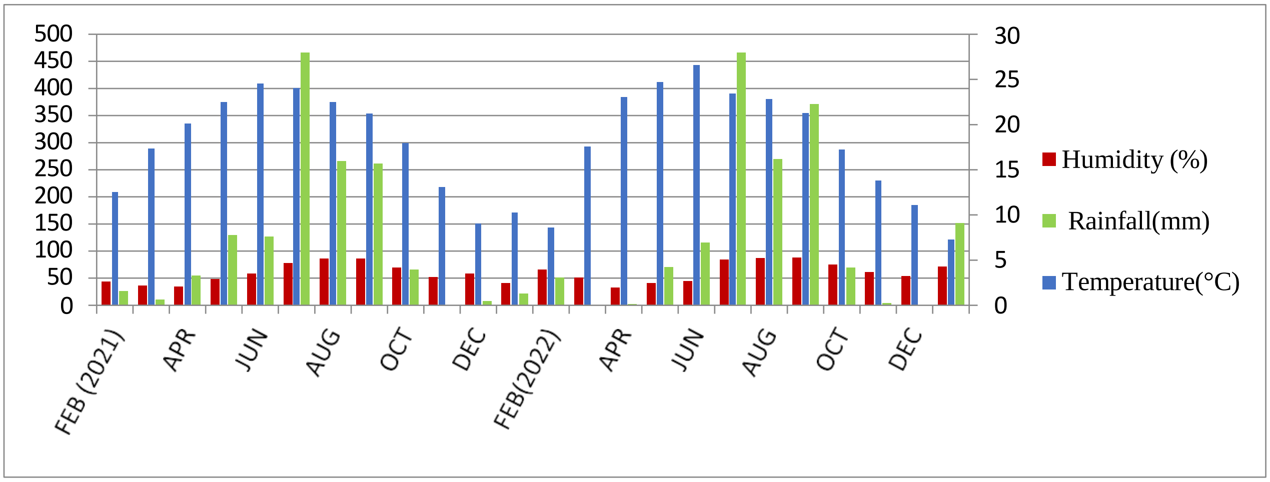


Fig. 5.2.7: Monthly meteorological data of site 7- Chandrabani in the year 2021-2022

g. Monthly meteorological data of site 8 - Jollygrant in the year 2021-2022.

a. Pre-monsoon

The mean monthly temperature recorded at site 8 ranged between 17.51±2.03 in February 2021 to 29.2±2.21 in May 2021 and it ranged between 13.3±1.97 in February 2022 to 31.5±2.13 in May 2022.

The mean monthly humidity recorded between 40.38±1.57 in February 2021 to 37.38±1.96 in May 2021 and it is recorded between 67.81±1.80 in February 2022 to 30.94±1.57 in May 2022.

The mean rainfall recorded between 21.09± 1 in February 2021 to 120.96± 1.14 in May 2021 and it is recorded between 39.94±1.13 in February 2022 to 60.06± 0.90 in May 2022.

b. Monsoon

The mean monthly temperature recorded at site 8 ranged between 30.6±1.86 in June 2021 to 25.83±2.28 in September 2021 and it ranged 32.73±2.26 in June 2022 to 25.96±1.89 in September2022.

The mean monthly humidity recorded between 49.56±1.94 in June 2021 to 82.56±1.57 in September 2021 and it is recorded between 37.12±2.36 in June 2022 to 83.5±1.97 in September 2022.

The mean rainfall recorded between 101.46± 1.03 in June 2021 to 258.15± 22.57 in September 2021 and it is recorded between 109.55± 0.88 in June 2022 to 352.43± 0.45 in September 2022.

c. Post-monsoon

The mean monthly temperature recorded at site 8 ranged between 22.53±1.98 in October 2021 to 13.85±1.95 in January 2021 and it ranged between 21.77±1.85 in October 2022 to 11.32±1.72 in January 2022.

The mean monthly humidity recorded between 72.44±1.61 in October 2021 to 44.81±2.17 in January 2021 and it is recorded between 76.94±1.99 in October 2022 to 76.06±2.13 in January 2022.

The mean rainfall recorded between 81.32± 3.65 in October 2021 to 31.64± 1.05 in January 2021 and it is recorded between 98.09±2.14 in October 2022 to 127.18± 0.95 in January 2022.

Table 5.2.8: Monthly meteorological data of site 8 - Jollygrant in the year 2021-2022

Season	Month	Temperature(°C)	Humidity (%)	Rainfall (mm)
Pre-monsoon	February(2021)	17.51±2.03	40.38±1.57	21.09± 1
	March	23.15±2.09	30.25±2.14	0
	April	27.23±1.66	23.752.03	27.79± 8.9
	May	29.2±2.21	37.38±1.96	120.96± 1.14
Monsoon	June	30.6±1.86	49.56±1.94	101.46± 1.03
	July	29.17±2.11	71.62±2.29	496.33± 63.56
	August	26.79±1.79	84.5±2.04	242.18± 40.01
	September	25.83±2.28	82.56±1.57	258.15± 22.57
Post-Monsoon	October	22.53±1.98	72.44±1.61	81.32± 3.65
	November	16.8±2.04	59.44±2.09	0.08± 0.04
	December	12.98±1.85	61.5±1.68	4.11± 0.40
	January	13.85±1.95	44.81±2.17	31.64± 1.05
Pre-monsoon	February(2022)	13.3±1.97	67.81±1.80	39.94±1.13
	March	22.81±2.03	46.62±2.11	0.05± 0.02
	April	29.63±1.99	23.69±1.63	0.87± 0.18
	May	31.5±2.13	30.94±1.57	60.06± 0.90
Monsoon	June	32.73±2.26	37.12±2.36	109.55± 0.88
	July	28.58±1.79	77.38±2.09	413.73± 0.62
	August	27.19±1.57	83.88±2.07	181.57± 0.92

	September	25.96±1.89	83.5±1.97	352.43± 0.45
Post-Monsoon	October	21.77±1.85	76.94±1.99	98.09±2.14
	November	17.72±2.25	68.88±2.09	1.28± 1.90
	December	14.26±1.80	62.81±2.08	0.4± 1.61
	January	11.32±1.72	76.06±2.13	127.18± 0.95

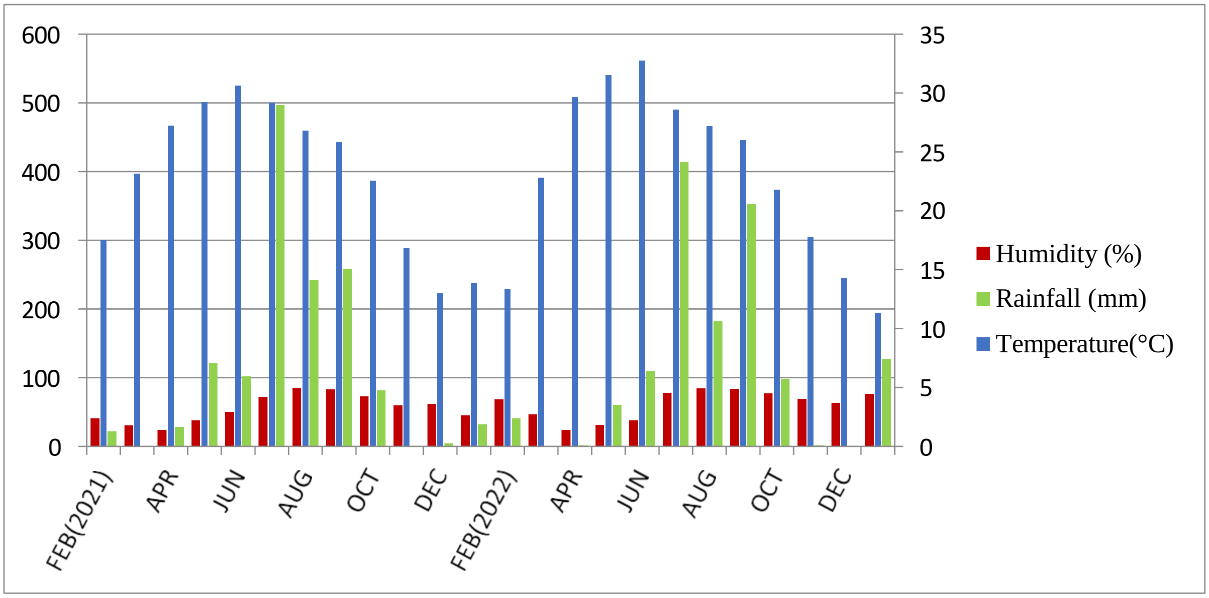


Fig. 5.2.8: Monthly meteorological data of site 8 - Jollygrant in the year 2021-2022

h. Monthly meteorological data of site 9 - Selaqui in the year 2021-2022.

d. Pre-monsoon

The mean monthly temperature recorded at site 9 ranged between 12.56±2.32 in February 2021 to 22.49±1.77 in May 2021 and it ranged between 8.62±2.01 in February 2022 to 24.7±2.04 in May 2022.

The mean monthly humidity recorded between 44.06±2.00 in February 2021 to 48.25±1.99 in May 2021 and it is recorded between 66.31±2.00 in February 2022 to 40.62±2.05 in May 2022.

The mean rainfall recorded between 26.37± 1.92 in February 2021 to 129.92± 3.02 in May 2021 and it is recorded between 51.04± 1.42 in February 2022 to 70.17±4.05 in May 2022.

e. Monsoon

The mean monthly temperature recorded at site 9 ranged between 24.56±2.32 in June 2021 to 21.23±2.29 in September 2021 and it ranged between 26.6±2.02 in June 2022 to 21.3±1.86 in September2022.

The mean monthly humidity recorded between 58.81±2.02 in June 2021 to 85.81±1.95 in September 2021 and it is recorded between 44.88±2.05 in June 2022 to 87.5±2.05 in September 2022.

The mean rainfall recorded between 127.09± 4.48 in June 2021 to 261.25± 7.35 in September 2021 and it is recorded between 115.87±6.93 in June 2022 to 370.92± 11.45 in September 2022.

f. Post-monsoon

The mean monthly temperature recorded at site 9 ranged between 17.94±2.02 in October 2021 to 10.25±1.96 in January 2021 and it ranged between 75.38±2.18 in October 2022 to 7.28±2.00 in January 2022.

The mean monthly humidity recorded between 69.25±2.00 in October 2021 to 41.25±2.33 in January 2021 and it is recorded between 76.94±1.99 in October 2022 to 71.81±2.02 in January 2022.

The mean rainfall recorded between 65.38± 2.19 in October 2021 to 21.09± 4.28 in January 2021 and it is recorded between 69.23± 2.76 in October 2022 to 151.26± 1.59 in January 2022.

Table 5.2.9: Monthly meteorological data of site 9 – Selaqui in the year 2021-2022

Season	Month	Temperature(°C)	Humidity (%)	Rainfall(mm)
Pre-Monsoon	February(2021)	12.56±2.32	44.06±2.00	26.37± 1.92
	March	17.35±2.00	36.94±2.07	10.55± 1.05
	April	20.12±2.33	34.5±2.01	55.23± 2.93
	May	22.49±1.77	48.25±1.99	129.92± 3.02
Monsoon	June	24.56±2.32	58.81±2.02	127.09± 4.48
	July	24.05±2.19	77.69±2.15	466.73± 22.39
	August	22.47±1.96	86.31±1.99	266.25± 19.24
	September	21.23±2.29	85.81±1.95	261.25± 7.35
Post-Monsoon	October	17.94±2.02	69.25±2.00	65.38± 2.19
	November	13.06±2.11	52.25±2.05	0.29±1.23

	December	9.03±1.58	58±2.00	8.11± 1.27
	January	10.25±1.96	41.25±2.33	21.09± 4.28
Pre-Monsoon	February(2022)	8.62±2.01	66.31±2.00	51.04± 1.42
	March	17.59±2.01	51±1.95	0.54±1.37
	April	23.08±2.46	32.44±2.05	2.02±3.29
	May	24.7±2.04	40.62±2.05	70.17±4.05
Monsoon	June	26.6±2.02	44.88±2.05	115.87±6.93
	July	23.44±2.01	84.69±2.12	466.28±25.58
	August	22.83±1.62	87.31±2.10	269.74± 21.57
	September	21.3±1.86	87.5±2.05	370.92± 11.45
Post-Monsoon	October	17.22±2.13	75.38±2.18	69.23± 2.76
	November	13.82±2.06	61.75±2.01	3.66± 1.47
	December	11.08±1.87	54.38±1.56	0.84± 1.36
	January	7.28±2.00	71.81±2.02	151.26± 1.59

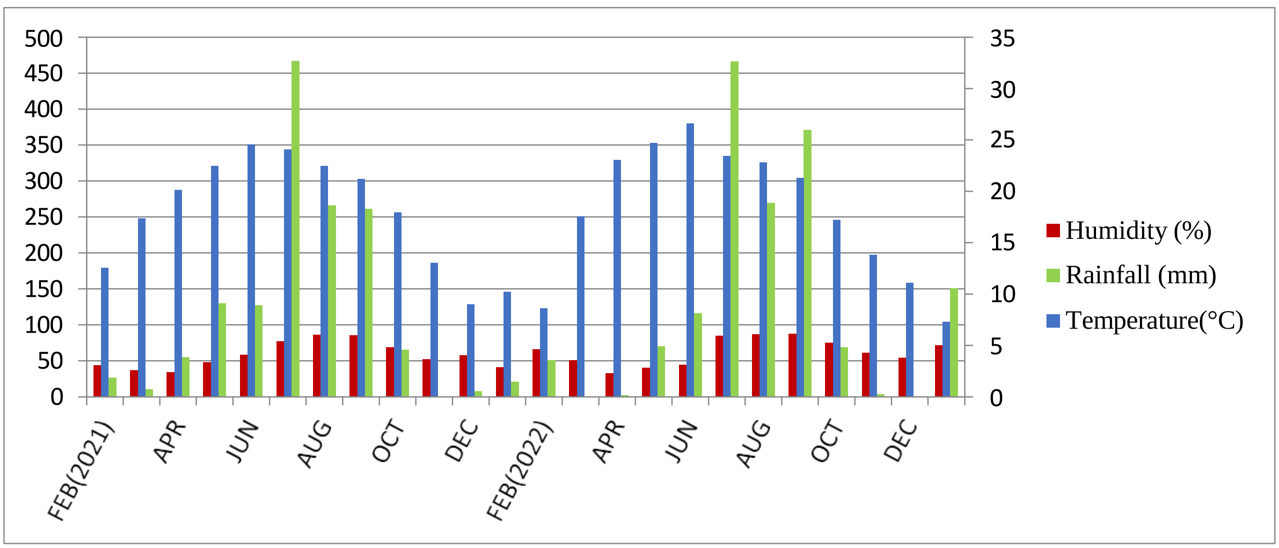


Fig. 5.2.9: Monthly meteorological data of site 9 – Selaqui in the year 2021-2022

i. Monthly meteorological data of site 10- Benog wildlife Sanctuary in the year 2021-2022.

a. Pre-monsoon

The mean monthly temperature recorded at site 10 ranged between 12.56±2.28 in February 2021 to 22.49±2.32 in May 2021 and it ranged between 8.62±2.15 in February 2022 to 24.7±2.03 in May 2022.

The mean monthly humidity recorded between 44.06±2.00 in February 2021 to 48.25±1.98 in May 2021 and it is recorded between 66.31± 1.73 in February 2022 to 40.62± 1.72 in May 2022.

The mean rainfall recorded between 26.37± 1.29 in February 2021 to 129.92± 5.28 in May 2021 and it is recorded between 51.04± 2.47 in February 2022 to 70.17± 2.26 in May 2022.

b. Monsoon

The mean monthly temperature recorded at site 10 ranged between 24.56±2.37 in June 2021 to 21.23±2.32 in September 2021 and it ranged 26.6±2.45 in June 2022 to 21.3±1.86 in September2022.

The mean monthly humidity recorded between 58.81±2.07 in June 2021 to 85.81± 2.05 in September 2021 and it is recorded between 44.88±1.76 in June 2022 to 87.5±1.56 in September 2022.

The mean rainfall recorded between 127.09 ± 7.45 in June 2021 to 261.25± 15.35 in September 2021 and it is recorded between 115.87± 9.37 in June 2022 to 370.92± 13.02 in September 2022.

c. Post-monsoon

The mean monthly temperature recorded at site 10 ranged between 17.94±2.08 in October 2021 to 10.25±2.00 in January 2021 and it ranged between 17.22±2.13 in October 2022 to 7.28±2.08 in January 2022.

The mean monthly humidity recorded between 69.25±2.14 in October 2021 to 41.25±2.31 in January 2021 and it is recorded between 75.38±2.36 in October 2022 to 71.81±2.02 in January 2022.

The mean rainfall recorded between 65.38± 2.14 in October 2021 to 21.09± 2.89 in January 2021 and it is recorded between 69.23± 1.23 in October 2022 to 151.26± 4.26 in January 2022.

Table 5.2.10: Monthly meteorological data of site 10 – Benog Wildlife Sanctuary in the year 2021-2022

Season	Month	Temperature(°C)	Humidity (%)	Rainfall (mm)
Pre-Monsoon	February(2021)	12.56±2.28	44.06±2.00	26.37± 1.29
	March	17.35±1.73	36.94±2.46	10.55± 2.93
	April	20.12±2.05	34.5±2.01	55.23± 2.37
	May	22.49±2.32	48.25±1.98	129.92± 5.28
Monsoon	June	24.56±2.37	58.81±2.07	127.09± 7.25
	July	24.05±2.38	77.69±2.16	466.73± 32.93
	August	22.47±2.37	86.31±2.00	266.25± 21.89
	September	21.23±2.32	85.81±2.05	261.25± 15.35
Post-Monsoon	October	17.94±2.08	69.25±2.14	65.38± 2.14
	November	13.06±2.00	52.25±2.28	0.29± 1.24
	December	9.03±2.46	58±2.03	8.11± 1.47
	January	10.25±2.00	41.25±2.31	21.09± 2.89
Pre-Monsoon	February(2022)	8.62±2.15	66.31±1.73	51.04± 2.47
	March	17.59±2.00	51±2.05	0.54± 1.26
	April	23.08±2.03	32.44±1.64	2.02± 4.14
	May	24.7±2.03	40.62±1.72	70.17± 2.26
Monsoon	June	26.6±2.45	44.88±1.76	115.87± 9.37
	July	23.44±2.01	84.69±1.68	466.28± 29.28
	August	22.83±2.00	87.31±1.74	269.74± 1.37
	September	21.3±1.86	87.5±1.56	370.92± 13.02
Post-Monsoon	October	17.22±2.13	75.38±2.36	69.23± 1.23
	November	13.82±1.80	61.75±1.92	3.66± 1.73
	December	11.08±2.00	54.38±2.19	0.84± 1.26
	January	7.28±2.08	71.81±2.02	151.26± 4.26

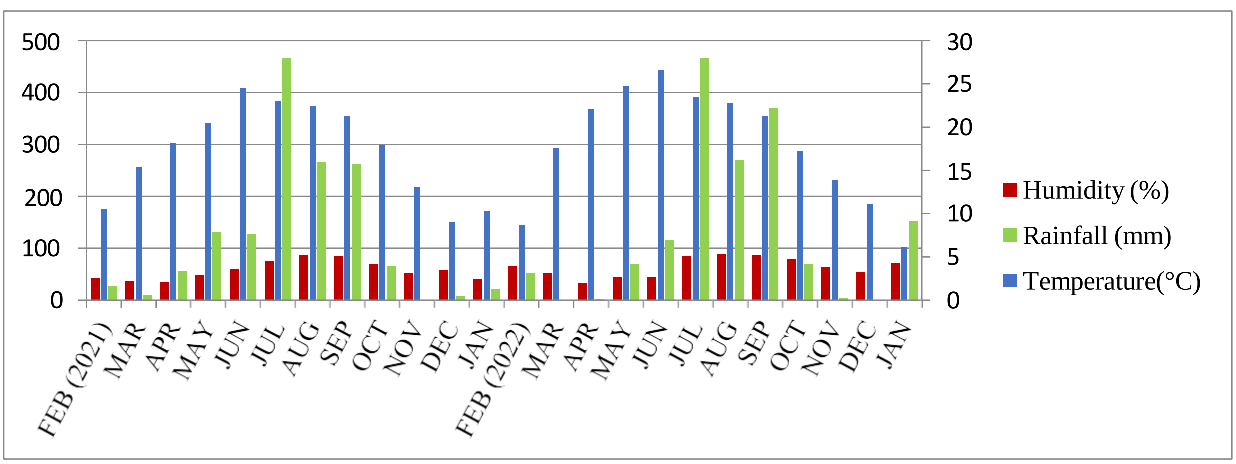


Fig. 5.2.10: Monthly meteorological data of site 10- Benog Wildlife Sanctuary in the year 2021-2022

j. Monthly meteorological data of site 11 - Koruwa in the year 2021-2022.

a. Pre-monsoon

The mean monthly temperature recorded at site 11 ranged between 12.56±2.00 in February 2021 to 22.49±2.00 in May 2021 and it ranged between 8.62±2.04 in February 2022 to 24.7±2.00 in May 2022.

The mean monthly humidity recorded between 44.06±2.13 in February 2021 to 48.25±2.39 in May 2021 and it is recorded between 66.31± 1.95 in February 2022 to 40.62± 2.32 in May 2022.

The mean rainfall recorded between 26.37± 1.29 in February 2021 to 129.92± 2.14 in May 2021 and it is recorded between 51.04± 2.82 in February 2022 to 70.17± 2.36 in May 2022.

b. Monsoon

The mean monthly temperature recorded at site 11 ranged between 24.56±1.98 in June 2021 to 21.23±2.34 in September 2021 and it ranged 26.6±1.61 in June 2022 to 21.3 ± 2.35 in September2022.

The mean monthly humidity recorded between 58.81±2.25 in June 2021 to 85.81± 2.07 in September 2021 and it is recorded between 44.88±1.69 in June 2022 to 87.5±1.87 in September 2022.

The mean rainfall recorded between 127.09 ± 4.98 in June 2021 to 261.25± 19.26 in September 2021 and it is recorded between 115.87± 8.18 in June 2022 to 370.92± 6.18 in September 2022.

c. Post-monsoon

The mean monthly temperature recorded at site 11 ranged between 17.94±2.03 in October 2021 to 10.25±2.28 in January 2021 and it ranged between 17.22±1.98 in October 2022 to 7.28±2.28 in January 2022.

The mean monthly humidity recorded between 69.25±2.00 in October 2021 to 41.25±1.69 in January 2021 and it is recorded between 75.38±2.00 in October 2022 to 71.81±2.19 in January 2022.

The mean rainfall recorded between 65.38± 2.87 in October 2021 to 21.09± 1.27 in January 2021 and it is recorded between 69.23± 1.25 in October 2022 to 151.26± 2.28 in January 2022.

Table 5.2.11: Monthly meteorological data of site 11 – Koruwa in the year 2021-2022

Season	Month	Temperature(°C)	Humidity (%)	Rainfall (mm)
Pre-Monsoon	February(2021)	12.56 ± 2.00	44.06±2.13	26.37± 1.29
	March	17.35±1.90	36.94±1.92	10.55± 2.36
	April	20.12±2.10	34.5±2.01	55.23± 2.87
	May	22.49±2.00	48.25±2.39	129.92± 2.14
Monsoon	June	24.56±1.98	58.81±2.25	127.09± 4.98
	July	24.05±1.97	77.69±1.96	466.73± 31.26
	August	22.47±2.32	86.31±2.00	266.25± 28.29
	September	21.23±2.34	85.81±2.07	261.25± 19.26
Post-Monsoon	October	17.94±2.03	69.25±2.00	65.38± 2.87
	November	13.06±2.13	52.25±2.00	0.29± 1.24
	December	9.03±2.30	58±1.76	8.11± 1.58
	January	10.25±2.28	41.25±1.69	21.09± 1.27
Pre-Monsoon	February(2022)	8.62±2.04	66.31±1.95	51.04± 2.82
	March	17.59±2.05	51±1.96	0.54± 1.38
	April	23.08±2.47	32.44±2.36	2.02± 1.26
	May	24.7±2.00	40.62±2.32	70.17± 2.36
Monsoon	June	26.6±1.61	44.88±1.69	115.87± 8.18
	July	23.44±1.99	84.69±2.16	466.28± 34.54
	August	22.83±1.92	87.31±2.00	269.74± 5.12
	September	21.3±2.35	87.5±1.87	370.92± 6.18
Post-Monsoon	October	17.22±1.98	75.38±2.00	69.23± 1.25
	November	13.82±2.03	61.75±2.32	3.66± 2.23
	December	11.08±2.00	54.38±2.14	0.84± 1.12
	January	7.28±2.28	71.81±2.19	151.26± 2.28

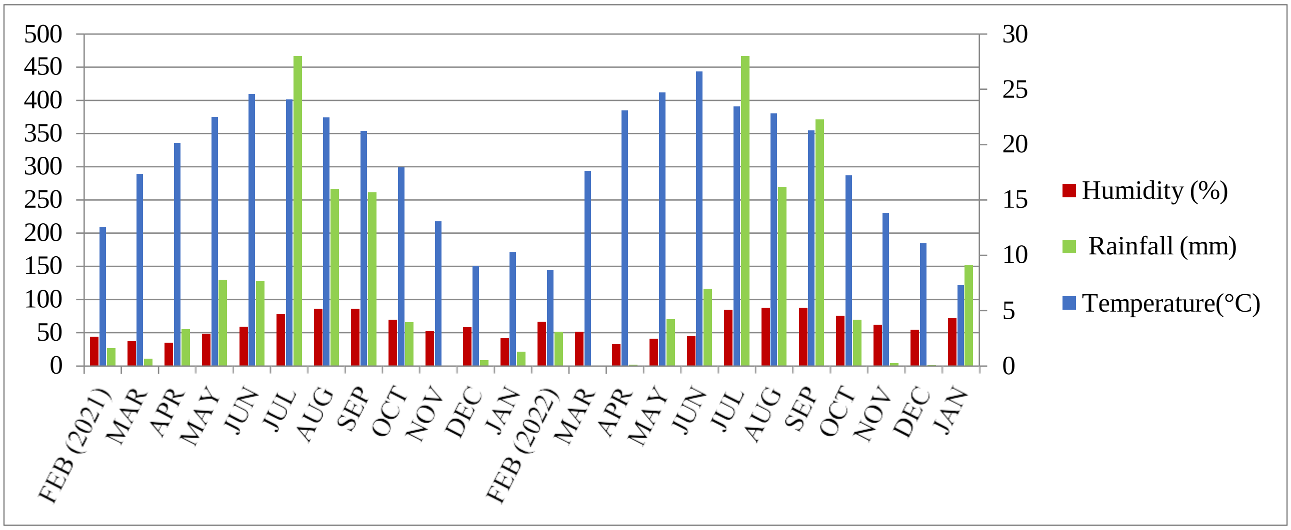


Fig. 5.2.11: Monthly meteorological data of site 11 – Koruwa in the year 2021-2022

k. Monthly meteorological data of site 12 - Mohand in the year 2021-2022.

a. Pre-monsoon

The mean monthly temperature recorded at site 12 ranged between 17.51±2.00 in February 2021 to 29.2±2.37 in May 2021 and it ranged between 13.3±2.07 in February 2022 to 31.5±2.32 in May 2022.

The mean monthly humidity recorded between 40.38±1.86 in February 2021 to 37.38±2.00 in May 2021 and it is recorded between 67.81±2.01 in February 2022 to 30.94±2.04 in May 2022.

The mean rainfall recorded between 21.09± 2.10 in February 2021 to 120.96± 1.27 in May 2021 and it is recorded between 39.94± 1.29 in February 2022 to 60.06± 2.18 in May 2022.

b. Monsoon

The mean monthly temperature recorded at site 12 ranged between 30.6±1.63 in June 2021 to 25.83±2.04 in September 2021 and it ranged 32.73±1.92 in June 2022 to 25.96±1.65 in September2022.

The mean monthly humidity recorded between 49.56±2.22 in June 2021 to 82.56±2.02 in September 2021 and it is recorded between 37.12±1.98 in June 2022 to 83.5±1.95 in September 2022.

The mean rainfall recorded between 101.46± 1.92 in June 2021 to 258.15± 2.38 in September 2021 and it is recorded between 109.55± 4.39 in June 2022 to 352.43± 8.28 in September 2022.

c. Post-monsoon

The mean monthly temperature recorded at site 12 ranged between 22.53±1.85 in October 2021 to 13.85±2.07 in January 2021 and it ranged between 21.77±1.89 in October 2022 to 11.32±1.88 in January 2022.

The mean monthly humidity recorded between 72.44±2.04 in October 2021 to 44.81±2.12 in January 2021 and it is recorded between 76.94±2.17 October 2022 to 76.06±1.69 in January 2022.

The mean rainfall recorded between 81.32± 2.03 in October 2021 to 31.64± 2.36 in January 2021 and it is recorded between 98.09± 2.38 in October 2022 to 127.18± 2.39 in January 2022.

Table 5.2.12: Monthly meteorological data of site 12 – Mohand in the year 2021-2022

Season	Month	Temperature(°C)	Humidity (%)	Rainfall (mm)
Pre-Monsoon	February(2021)	17.51±2.00	40.38±1.86	21.09± 2.10
	March	23.15±2.45	30.25±2.37	0
	April	27.23±1.62	23.75±1.94	27.79± 1.29
	May	29.2±2.37	37.38±2.00	120.96± 1.27
Monsoon	June	30.6±1.63	49.56±2.22	101.46± 1.92
	July	29.17±2.05	71.62±2.19	496.33± 29.38
	August	26.79±1.67	84.5±2.10	242.18± 21.92
	September	25.83±2.04	82.56±2.02	258.15± 2.38
Post-Monsoon	October	22.53±1.85	72.44±2.04	81.32± 2.03
	November	16.8±2.02	59.44±2.00	0.08± 1.12
	December	12.98±2.33	61.5±1.87	4.11± 1.17
	January	13.85±2.07	44.81±2.12	31.64± 2.36
Pre-Monsoon	February(2022)	13.3±2.07	67.81±2.01	39.94± 1.29
	March	22.81±2.80	46.62±1.96	0.05± 1.03
	April	29.632.15	23.69±1.87	0.87± 2.92
	May	31.5±2.32	30.94±2.04	60.06± 2.18
Monsoon	June	32.73±1.92	37.12±1.98	109.55± 4.39
	July	28.58±2.09	77.38±1.99	413.73± 26.29
	August	27.19±1.80	83.88±2.17	181.57± 13.83

	September	25.96±1.65	83.5±1.95	352.43± 8.28
Post-Monsoon	October	21.77±1.89	76.94±2.17	98.09± 2.38
	November	17.72±4.33	68.88±1.56	1.28± 1.29
	December	14.26±2.41	62.81±1.97	0.4± 1.02
	January	11.32±1.88	76.06±1.69	127.18± 2.39

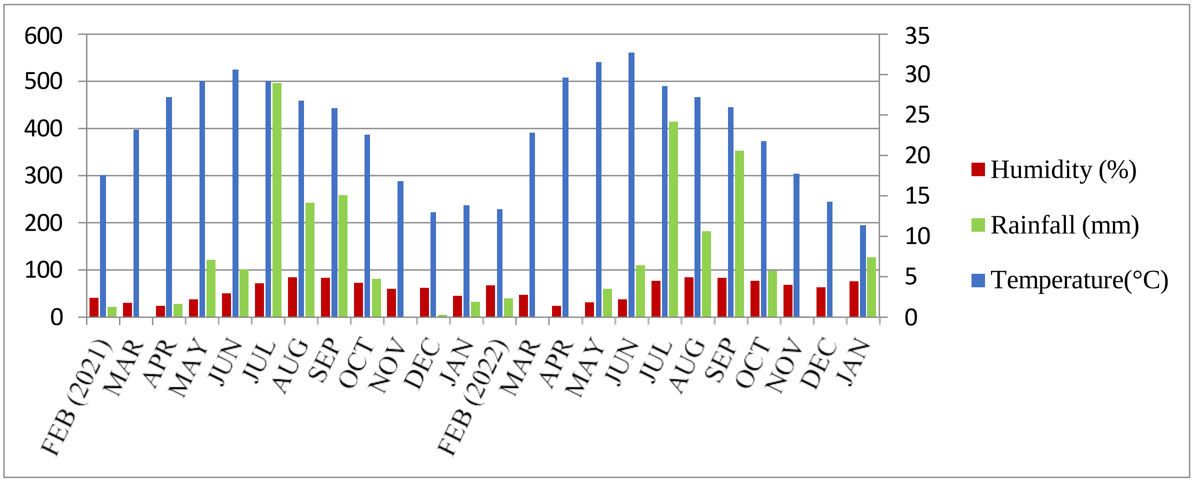


Fig. 5.2.12: Monthly meteorological data of site 12 – Mohand in the year 2021-2022

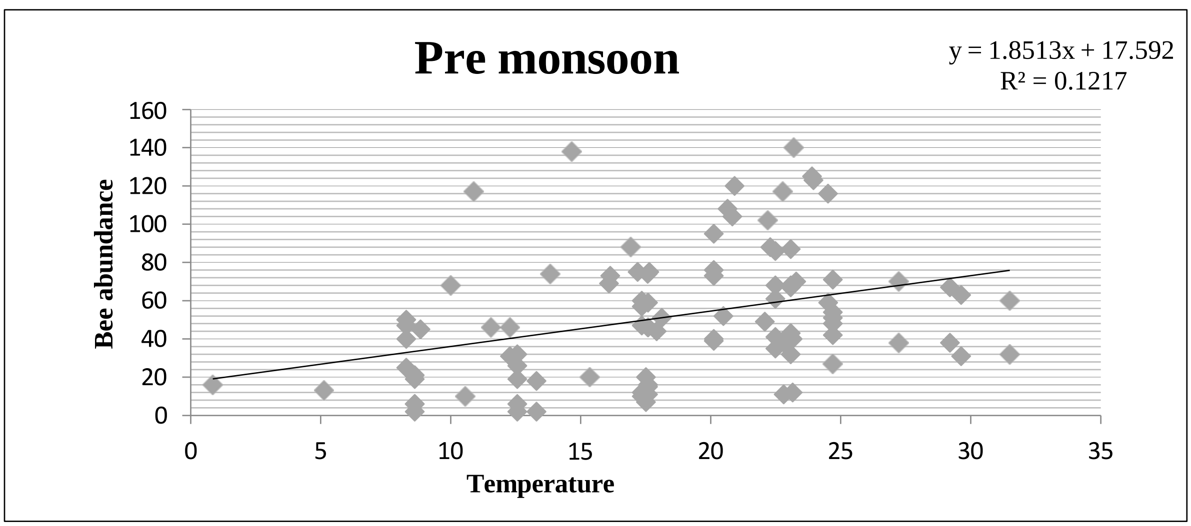


Fig. 5.2.13: Co- relationship between temperature and bee abundance during Pre monsoon 2021-2022

The relationship between temperature and bee abundance is positive linear with R^2 valueof 0.121. If value of one variable increases the value of other variable also tends to increase.

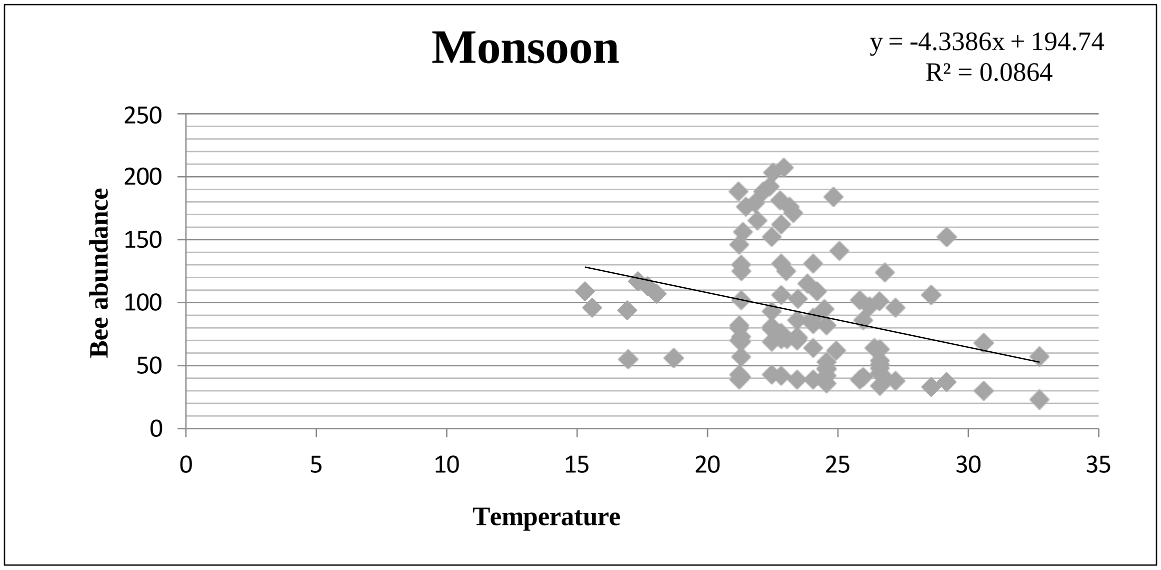


Fig. 5.2.14: Co-relationship between temperature and bee abundance during Monsoon 2021-2022

The relationship between temperature and bee abundance is negative linear with R^2 value of 0.086. If value of one variable increases the value of other variable tends to decrease.

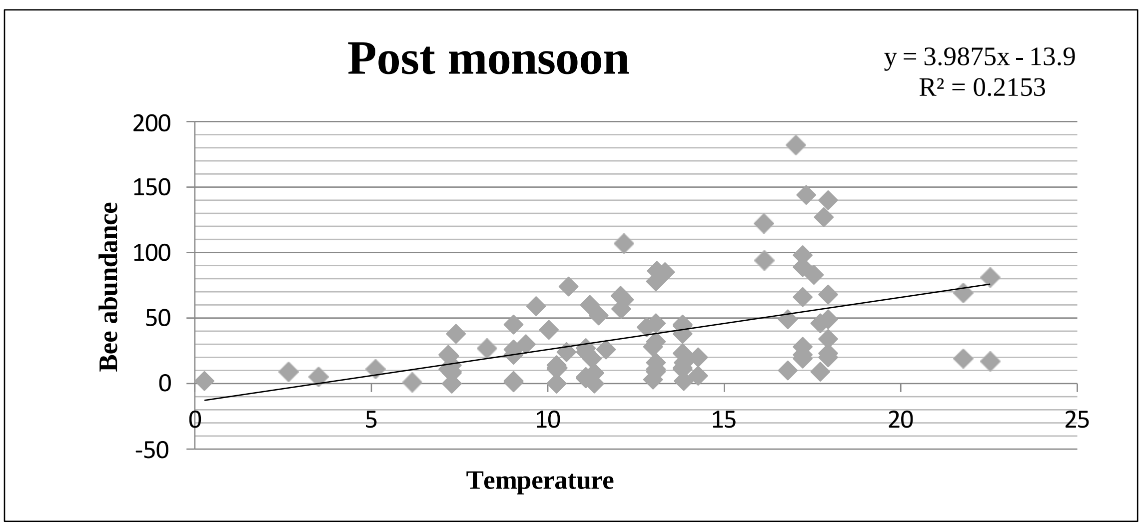


Fig. 5.2.15: Co-relationship between temperature and bee abundance during Post monsoon 2021-2022

The relationship between temperature and bee abundance is positive linear with R^2 value of 0.215. If value of one variable increases the value of other variable also tends to increase.

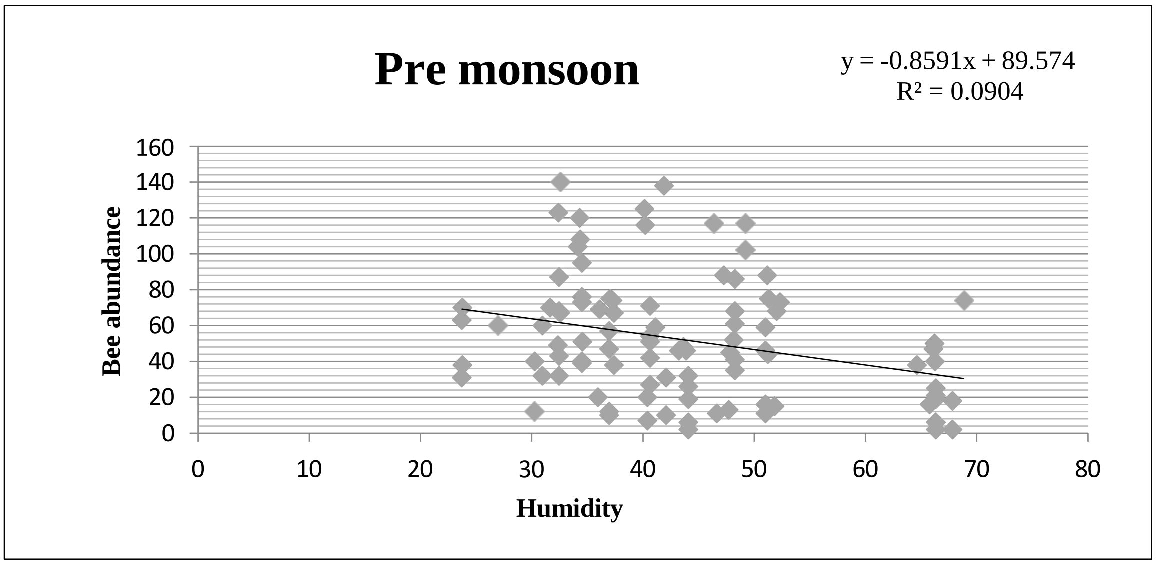


Fig. 5.2.16: Co-relationship between humidity and bee abundance during Pre monsoon 2021-2022

The relationship between humidity and bee abundance is negative linear with R^2 value of 0.090. If value of one variable increases the value of other variable tends to decrease.

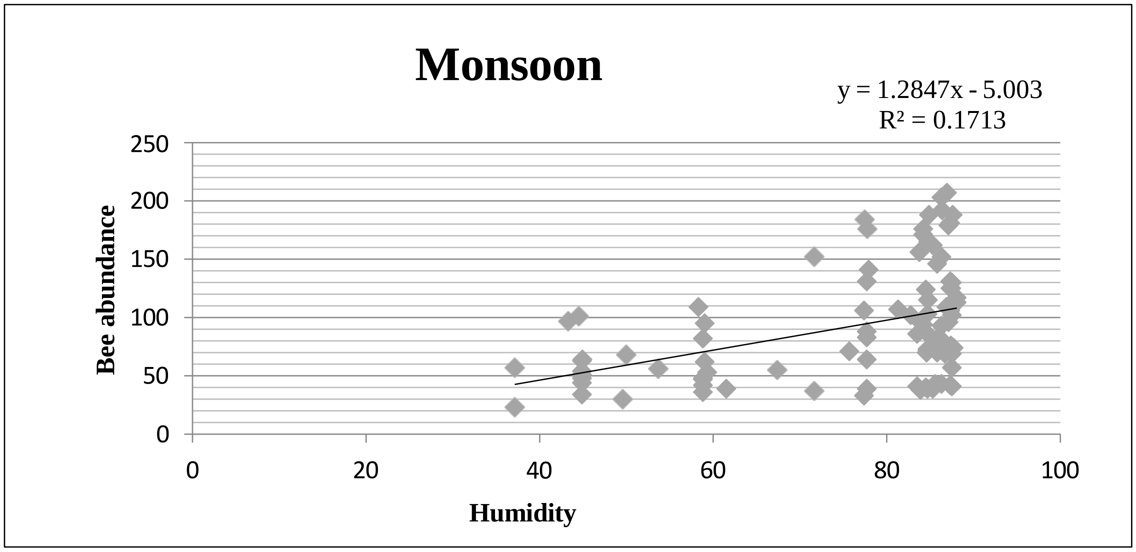


Fig. 5.2.17: Co-relationship between humidity and bee abundance during Monsoon 2021-2022

The relationship between humidity and bee abundance is positive linear with R^2 value of 0.171. If value of one variable increases the value of other variable also tends to increase.

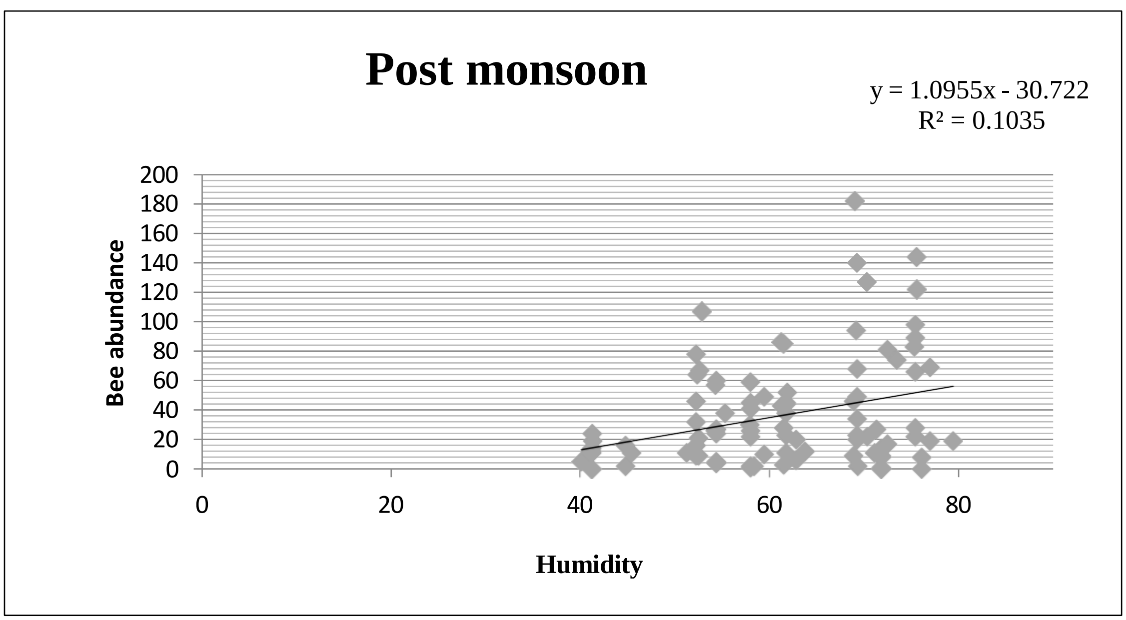


Fig. 5.2.18: Co-relationship between humidity and bee abundance during Post monsoon 2021-2022

The relationship between humidity and bee abundance is positive linear with R^2 value of 0.103. If value of one variable increases the value of other variable also tends to increase.

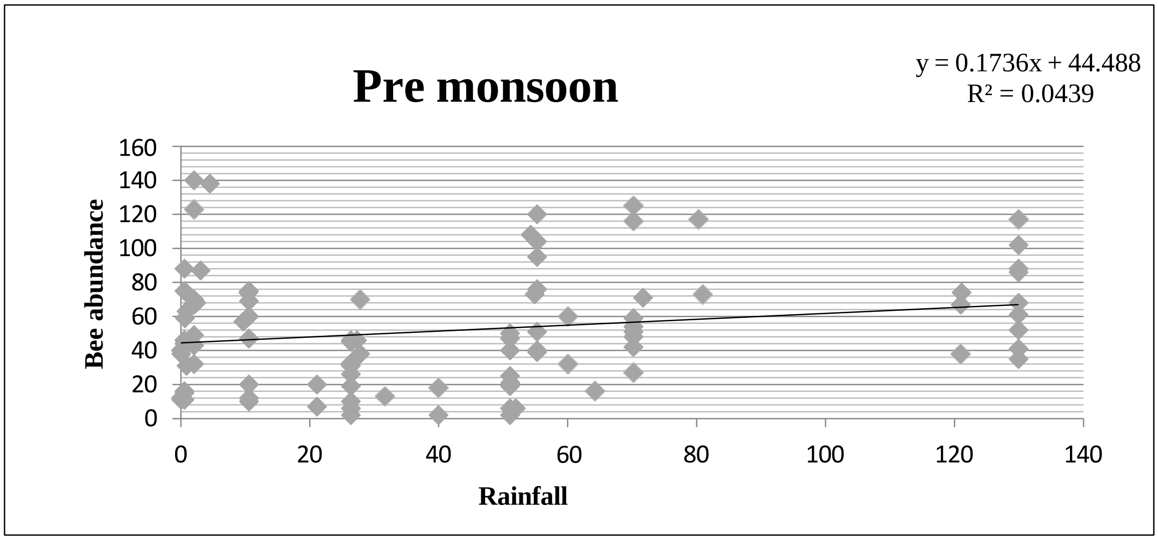


Fig. 5.2.19: Co-relationship between rainfall and bee abundance during Pre monsoon 2021-2022

The relationship between rainfall and bee abundance is positive linear with R^2 value of 0.043. If value of one variable increases the value of other variable also tends to increase.

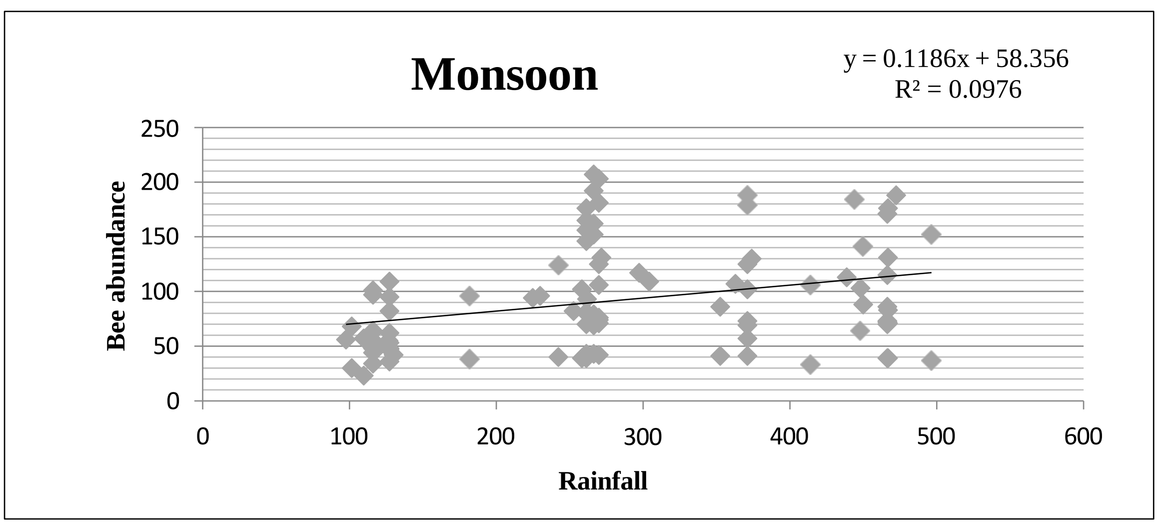


Fig. 5.2.20: Co-relationship between rainfall and bee abundance during Monsoon 2021-2022

The relationship between rainfall and bee abundance is positive linear with R^2 value of 0.097. If value of one variable increases the value of other variable also tends to increase.

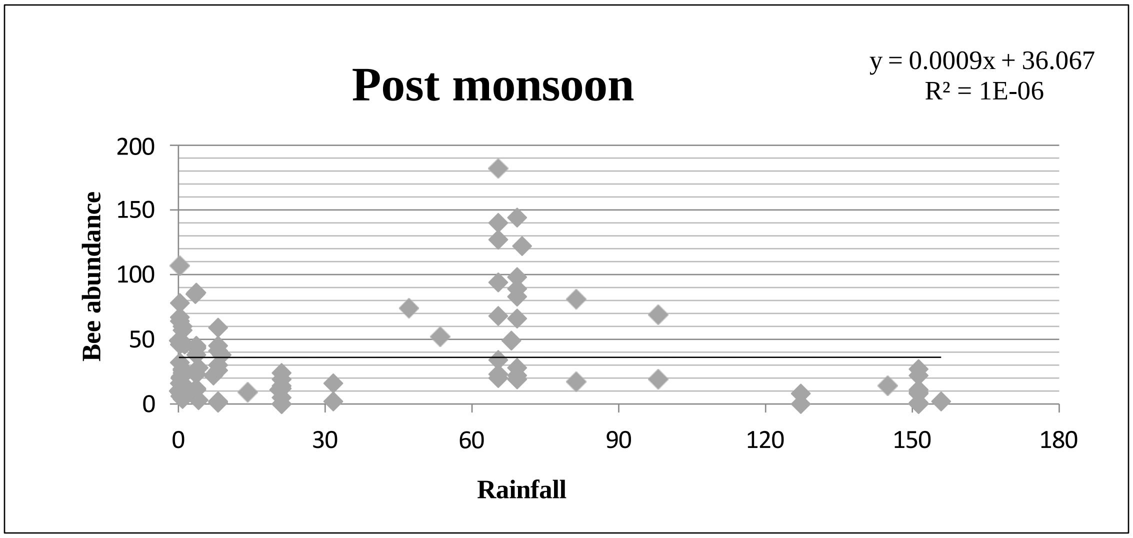


Fig. 5.2.21: Co-relationship between rainfall and bee abundance during Post monsoon 2021-2022

The relationship between rainfall and bee abundance is independent of each other with R^2 value of 0. The change in value of one variable does not have any effect on the other variable.

5.3 Seasonal distribution of *Bombus* and *Xylocopa*

1749 individuals of bumblebees were recorded during pre- monsoon, 2952 during monsoon and 967 during post monsoon season.

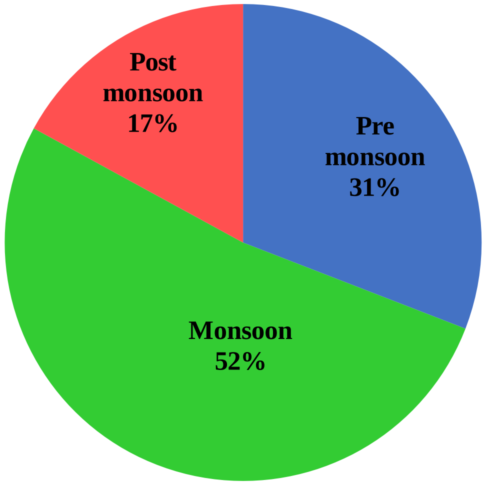


Fig. 5.3.1: Distributionof bumblebees during different seasons

3223 individuals of *Xylocopa* were recorded during pre monsoon, 5830 during monsoon and 2502 during post monsoon season

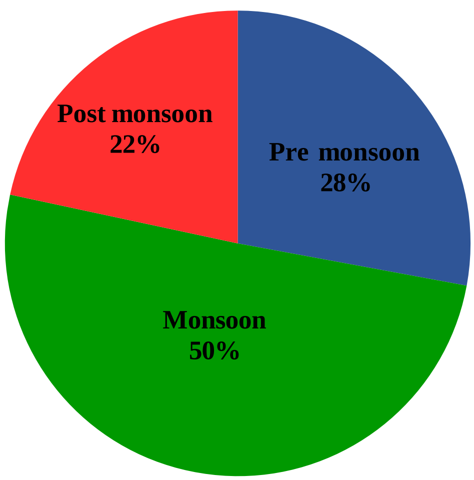


Fig. 5.3.2: Distribution of carpenter bees during different seasons

5.3.1 Seasonal occurrence of bees in different study sites

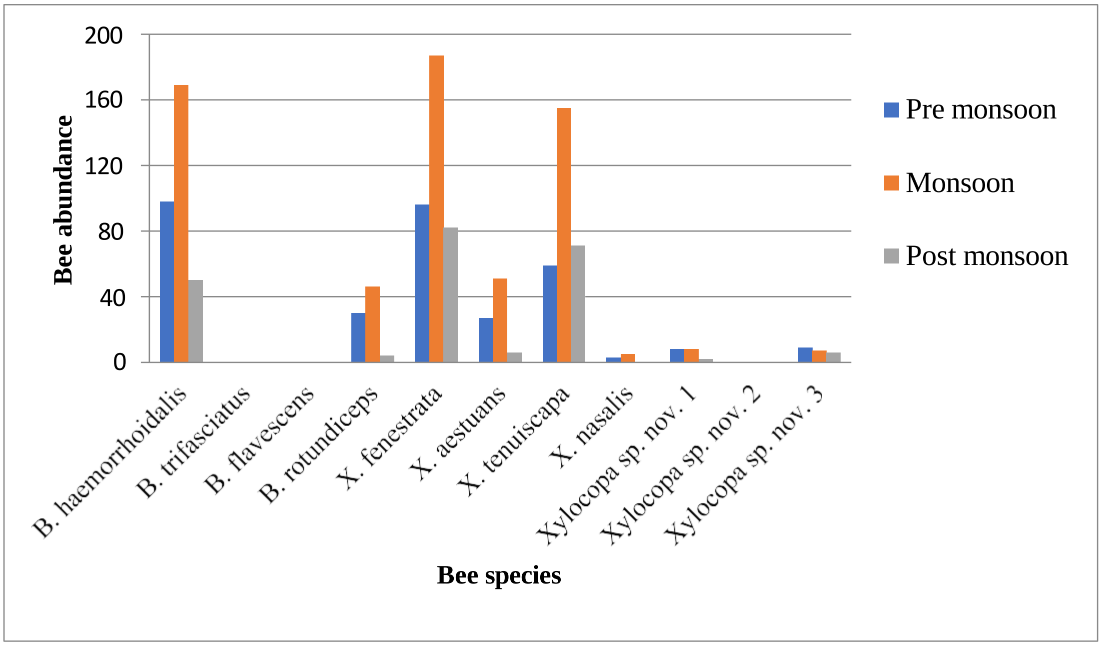


Fig. 5.3.3: Seasonal occurrence of bee species in Site 1- Bajawala in 2021

At site 1 during year 2021 *Bombus haemorrhoidalis* was recorded highest in monsoon season then in pre monsoon season and lowest in post monsoon season. *B. trifasciatus* and *B. flavescens* are not recorded from this site. *B. rotundiceps* is highest in monsoon, then in pre monsoon and lowest in post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon. *X. tenuiscapa* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. nasalis* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *Xylocopa sp.nov. 1* was recorded almost equally in both monsoon and pre monsoon season and absent in post monsoon. *Xylocopa sp.nov.2* was absent from this site. As of *Xylocopa sp.nov.3* it was recorded highest in monsoon, then in post monsoon and lowest in pre monsoon season.

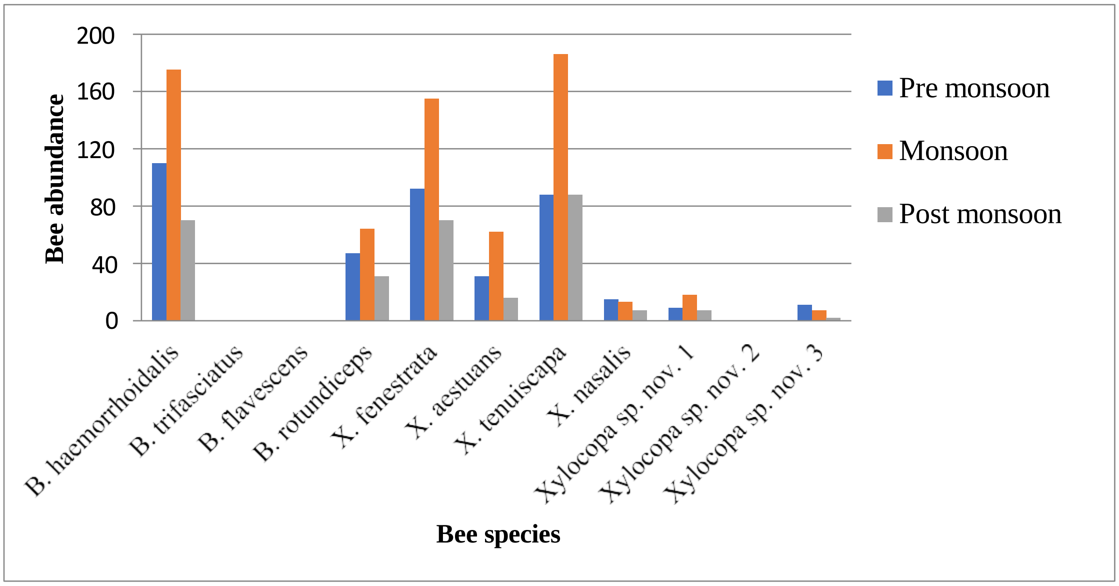


Fig. 5.3.4: Seasonal occurrence of bee species in Site 1- Bajawala in 2022

At site 1 during year 2022 *Bombus haemorrhoidalis* was recorded highest in monsoon season then in pre monsoon season and lowest in post monsoon season. *B. trifasciatus* and *B. flavescens* are not recorded from this site. *B. rotundiceps* is highest in monsoon, then in pre monsoon and lowest in post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in post monsoon and lowest in pre monsoon season. *X. aestuans* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon. *X. tenuiscapa* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. nasalis* was recorded highest in monsoon and none is recorded in pre monsoon and post monsoon season. *Xylocopa sp.nov.1* was recorded highest in monsoon then in pre monsoon season and lowest in post monsoon. *Xylocopa sp. nov.2* was absent from this site. As of *Xylocopa sp.nov. 3* it was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season.

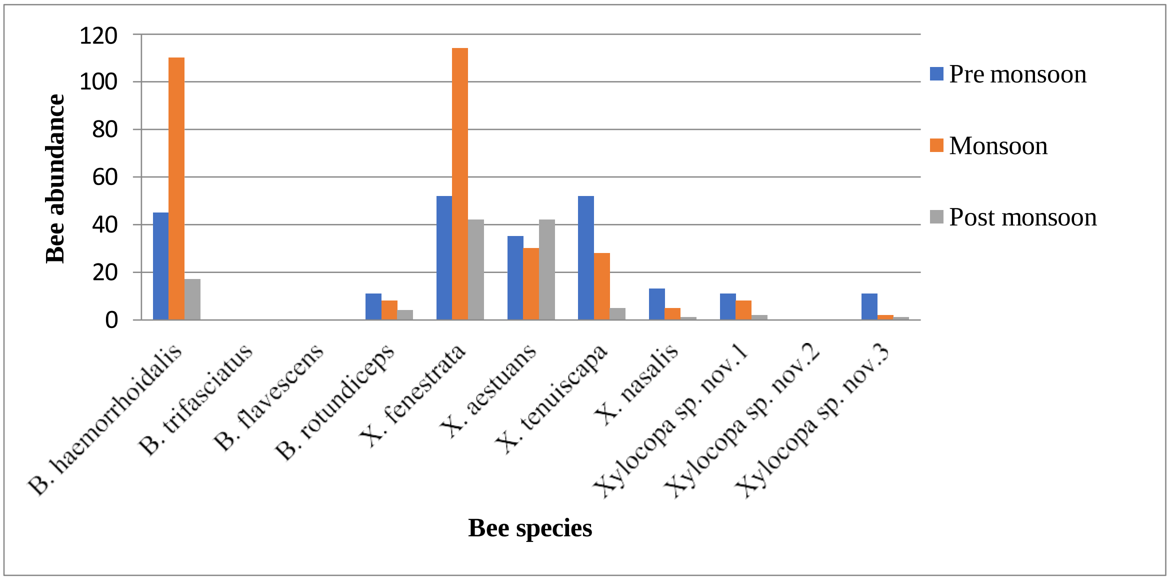


Fig. 5.3.5: Seasonal occurrence of bee species in Site 2- Sahastradhara in 2021

At site 2 during year 2021 *Bombus haemorrhoidalis* was recorded highest in monsoon season then in pre monsoon season and lowest in post monsoon season. *B. trifasciatus* and *B. flavescens* are not recorded from this site. *B. rotundiceps* is highest in pre monsoon, then in monsoon and lowest in post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in post monsoon, then in pre monsoon and lowest in monsoon. *X. tenuiscapa* was recorded highest in pre monsoon, then in monsoon and lowest in post monsoon season. *X. nasalis* was recorded highest in pre monsoon, then in monsoon season and lowest during post monsoon. *Xylocopa sp. nov.1* was recorded highest in pre monsoon and then in monsoon season and lowest in post monsoon. *Xylocopa sp. nov.2* was absent from this site. As of *Xylocopa sp. nov.3* it was recorded highest in pre monsoon then in monsoon and lowest in post monsoon season.

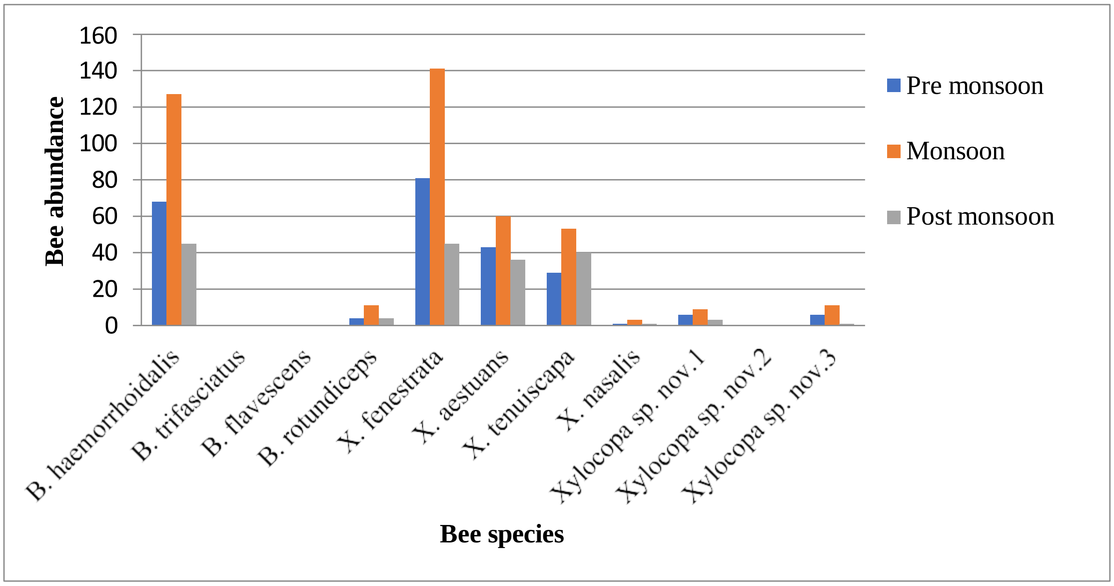


Fig. 5.3.6: Seasonal occurrence of bee species in Site 2- Sahastradhara in 2022

At site 2 during year 2022 *Bombus haemorrhoidalis* was recorded highest in monsoon season then in pre monsoon season and lowest in post monsoon season. *B. trifasciatus* and *B. flavescens* are not recorded from this site. *B. rotundiceps* is highest in monsoon, and almost equally in pre monsoon and post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon. *X. tenuiscapa* was recorded highest in monsoon, then in post monsoon and lowest in pre monsoon season. *X. nasalis* was recorded highest in monsoon and equally in pre and post monsoon season. *Xylocopa sp.nov.1* was recorded highest in monsoon and then in pre monsoon season and lowest in post monsoon. *Xylocopa sp.nov. 2* was absent from this site. As of *Xylocopa sp. nov.3* it was recorded highest in monsoon then in pre monsoon and lowest in post monsoon season.

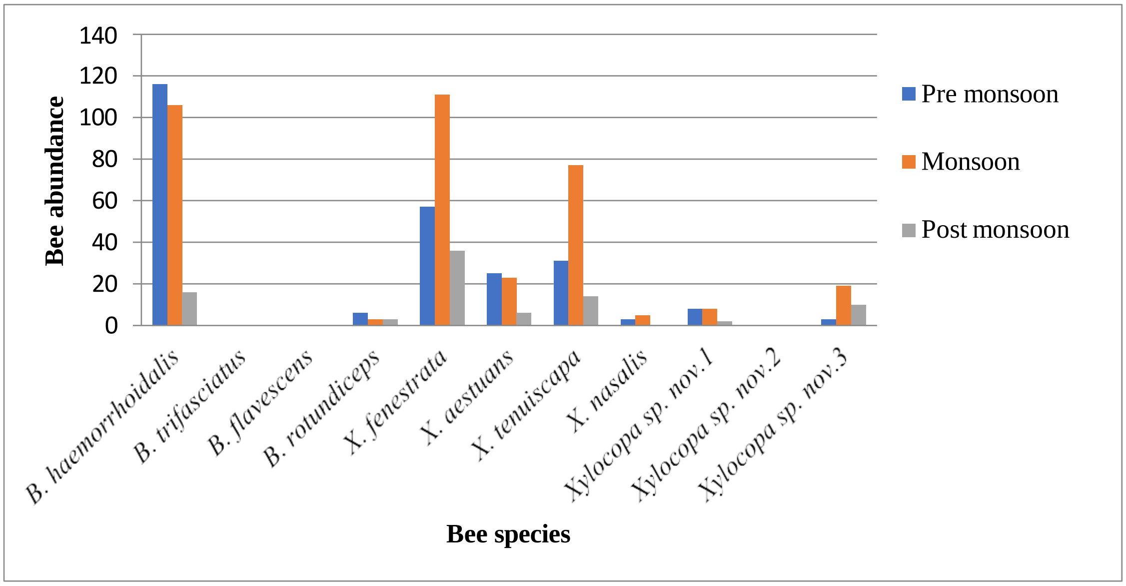


Fig. 5.3.7: Seasonal occurrence of bee species in Site 3- Tiuni in 2021

At site 3 during year 2021 *Bombus haemorrhoidalis* was recorded highest in pre monsoon season then in monsoon season and lowest in post monsoon season. *B. trifasciatus* and *B. flavescens* are not recorded from this site. *B. rotundiceps* is highest in pre monsoon, and almost equally in monsoon and post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in pre monsoon, then in monsoon and lowest in post monsoon. *X. tenuiscapa* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. nasalis* was recorded highest in monsoon, lowest in pre monsoon season and none in post monsoon season. *Xylocopa sp. nov.1* was recorded almost equal in monsoon and pre monsoon season and lowest in post monsoon. *Xylocopa sp. nov.2* was absent from this site. *Xylocopa sp.nov. 3* was recorded highest in monsoon then in post monsoon and lowest in pre monsoon season.

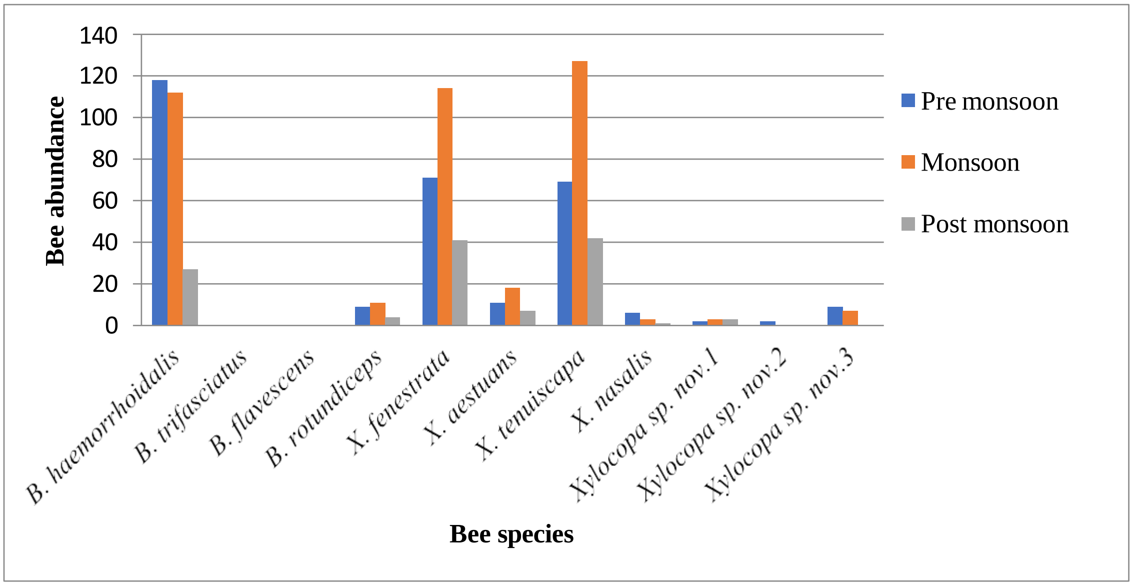


Fig. 5.3.8: Seasonal occurrence of bee species in Site 3- Tiuni in 2022

At site 3 during year 2022 Bombus *haemorrhoidalis* was recorded highest in pre monsoon season then in monsoon season and lowest in post monsoon season. *B. trifasciatus* and *B. flavescens* are not recorded from this site. *B. rotundiceps* is highest in monsoon, then in pre monsoon and lowest in post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon. *X. tenuiscapa* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. nasalis* was recorded highest in pre monsoon, then in monsoon season and lowest in post monsoon season. *Xylocopa sp. nov.1* was recorded almost equally in monsoon and post monsoon season and lowest in pre monsoon. *Xylocopa sp. nov.2* was recorded only during pre monsoon season. *Xylocopa sp. nov.3* was recorded highest in pre monsoon, lowest in monsoon season and none in post monsoon season.

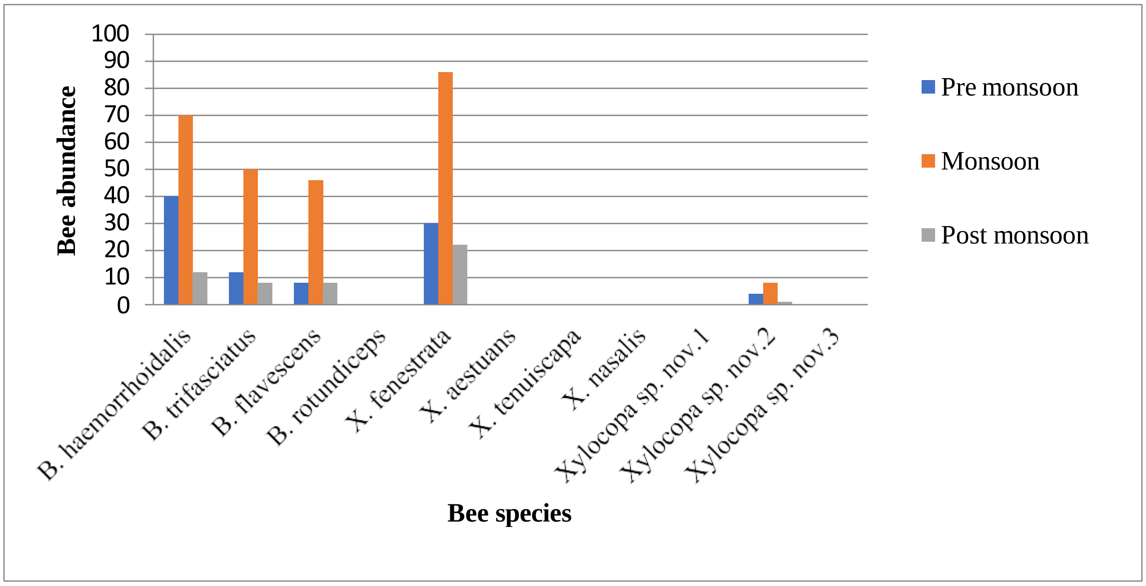


Fig. 5.3.9: Seasonal occurrence of bee species in Site 4- Jadi in 2021

At site 4 during year 2021 *Bombus haemorrhoidalis* was recorded highest in monsoon season then in pre monsoon season and lowest in post monsoon season. *B. trifasciatus*was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *B. flavescens* was recorded highest in monsoon and almost equal during pre and post monsoon season. *B. rotundiceps* was not recorded from this site. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans, X. tenuiscapa, X. nasalis* and *Xylocopa sp.nov.1* and *Xylocopa sp. nov.3* were not recorded from this site. *Xylocopa sp. nov.2* was recorded highest in monsoon, and lowest in post monsoon season.

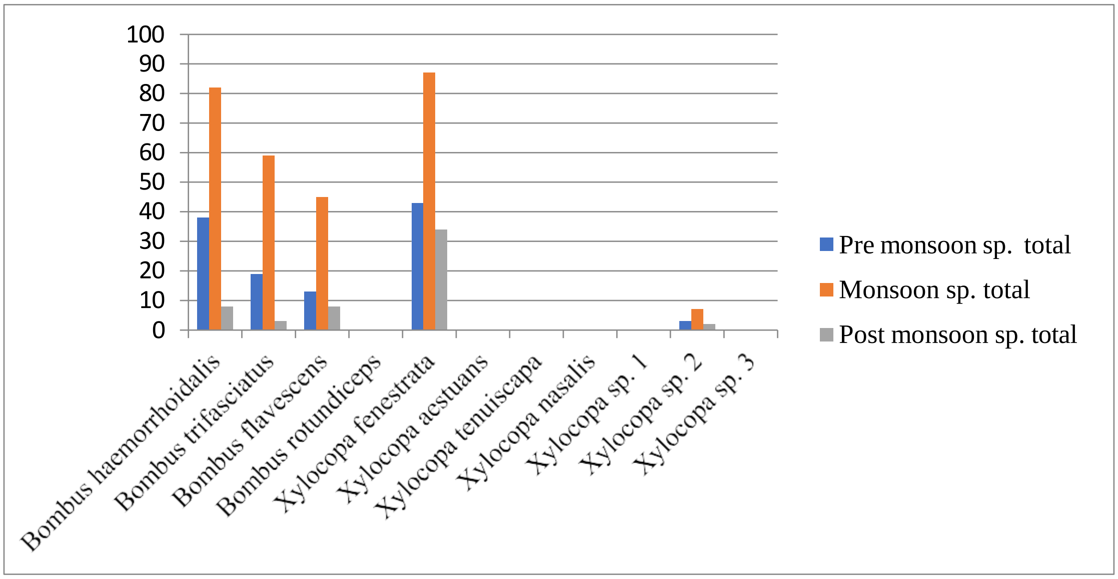


Fig. 5.3.10: Seasonal occurrence of bee species in Site 4- Jadi in 2022

At site 4 during year 2022 Bombus *haemorrhoidalis* was recorded highest in monsoon season then in pre monsoon season and lowest in post monsoon season. *B. trifasciatus* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *B. flavescens* was recorded highest in monsoon then in pre and lowest in post monsoon season. *B. rotundiceps* was not recorded from this site. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans*, *X. tenuiscapa*, *X. nasalis*, *Xylocopa sp.nov.1* and *Xylocopa sp.nov.3* were not recorded from this site. *Xylocopa sp.nov.2* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season.

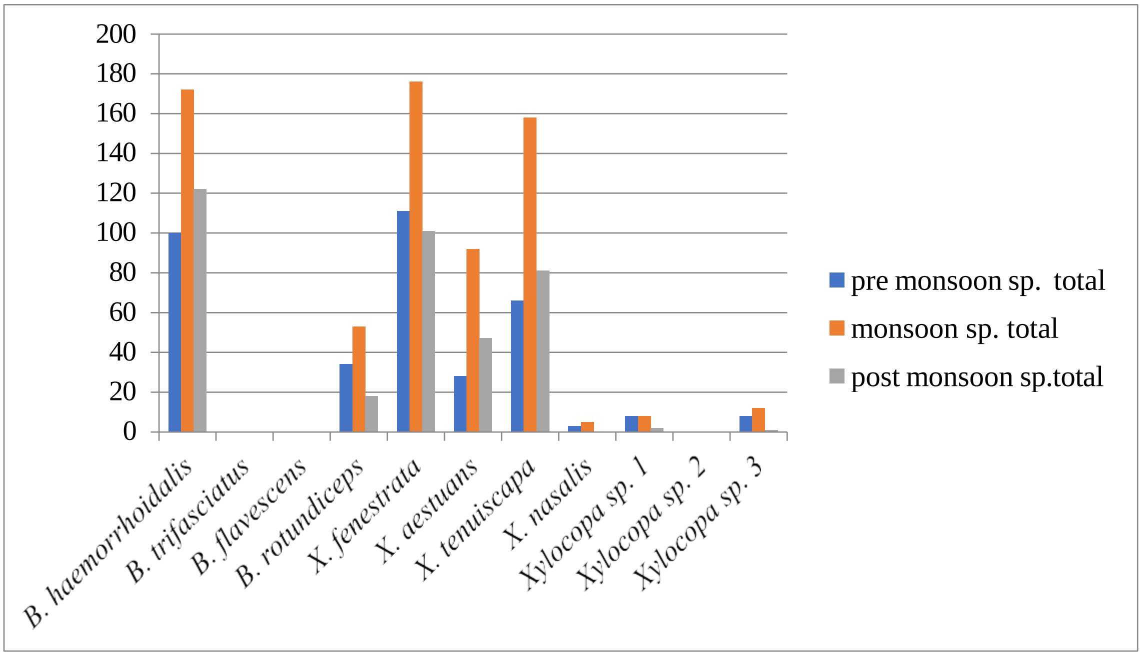


Fig. 5.3.11 : Seasonal occurrence of bee species in Site 5- Tea Estate in 2021

At site 5 during year 2021 *Bombus haemorrhoidalis* was recorded highest in monsoon season then in post monsoon season and lowest in pre monsoon season. *B. trifasciatus* and *B. flavescens* were not recorded from this site. *B. rotundiceps* is highest in monsoon, then in pre monsoon and lowest in post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon , then in post monsoon and lowest in pre monsoon. *X. tenuiscapa* was recorded highest in monsoon, then in post monsoon and lowest in pre monsoon season. *X. nasalis* was recorded highest in monsoon, and lowest in pre monsoon season. *Xylocopa sp.nov.1* was recorded almost equal in monsoon and pre monsoon season and lowest in post monsoon. *Xylocopa sp.nov. 2* was not recorded from this site. *Xylocopa sp. Nov.3* was recorded highest in monsoon, lowest in pre monsoon season and none in post monsoon season.

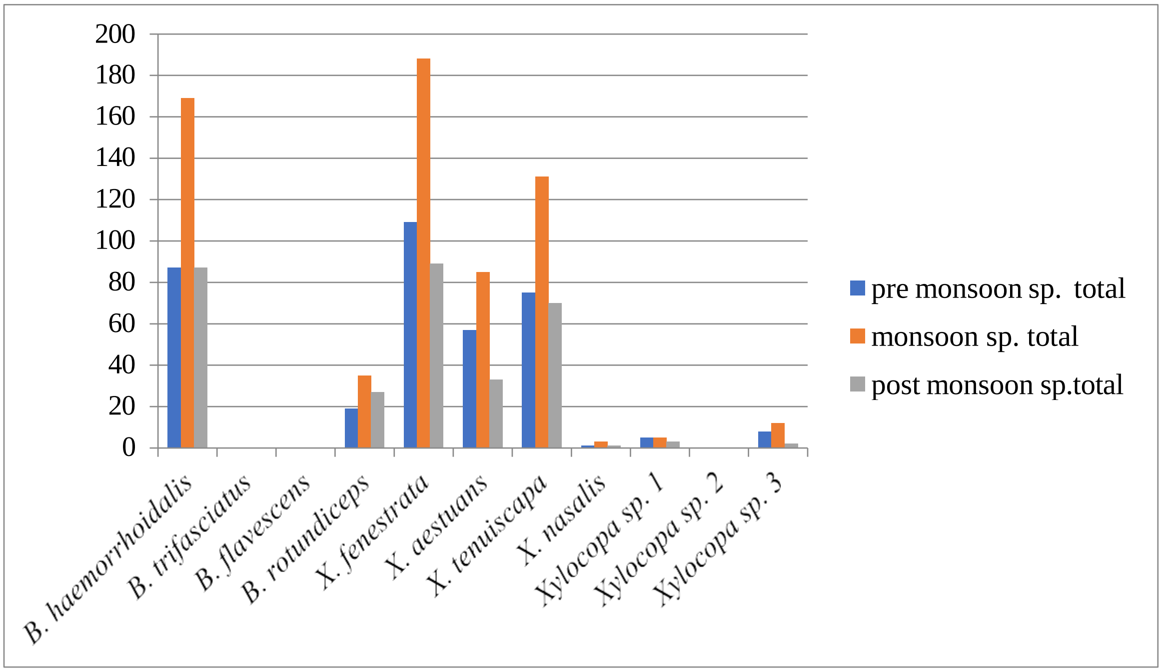


Fig. 5.3.12 : Seasonal occurrence of bee species in Site 5- Tea Estate in 2022

At site 5 during year 2022 *Bombus haemorrhoidalis* was recorded highest in monsoon season and almost equal in pre and post monsoon season. *B. trifasciatus* and *B. flavescens* were not recorded from this site. *B. rotundiceps* is highest in monsoon, then in post monsoon and lowest in pre monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon , then in pre monsoon and lowest in post monsoon. *X. tenuiscapa* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. nasalis* was recorded only during monsoon season. *Xylocopa sp.nov.1* was recorded almost equal in pre monsoon and monsoon season and lowest in post monsoon. *Xylocopa sp.nov.2* was not recorded from this site. *Xylocopa sp.nov.3* was recorded highest in monsoon, lowest in pre monsoon season and none in post monsoon season.

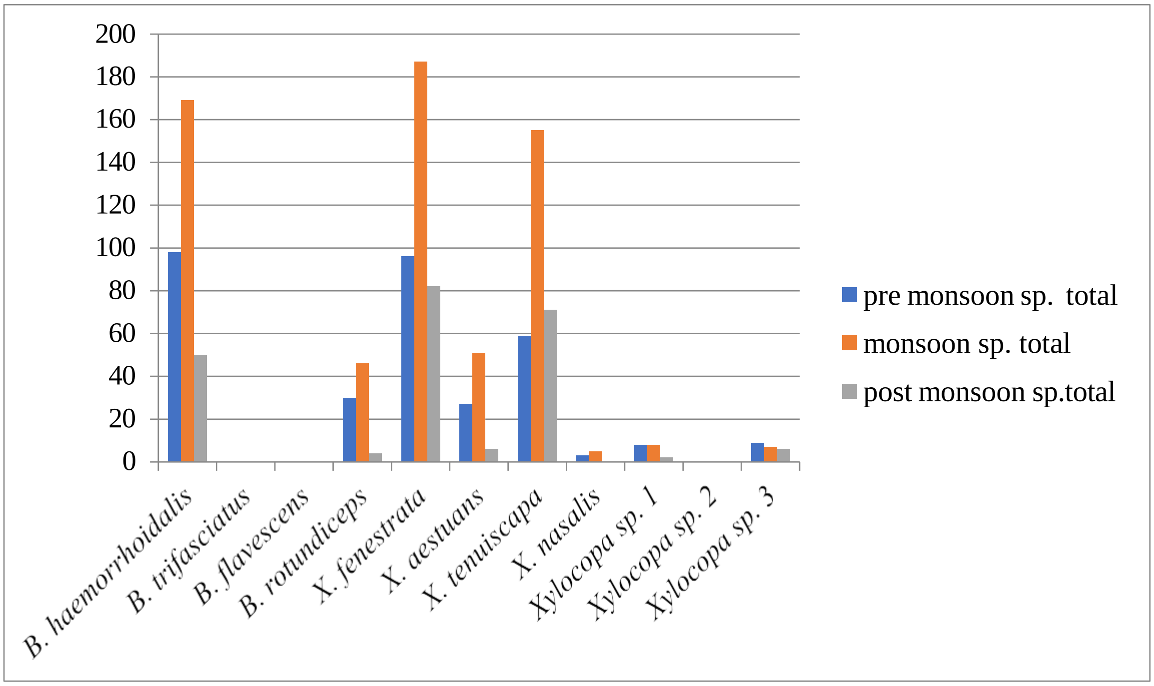


Fig. 5.3.13 : Seasonal occurrence of bee species in Site 6- Thano in 2021

At site 6 during year 2021 *Bombus haemorrhoidalis* was recorded highest in monsoon season then in pre monsoon and lowest in post monsoon season. *B. trifasciatus* and *B. flavescens* were not recorded from this site. *B. rotundiceps* is highest in monsoon, then in pre monsoon and lowest in post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon , then in pre monsoon and lowest in post monsoon. *X. tenuiscapa* was recorded highest in monsoon, then in post monsoon and lowest in pre monsoon season. *X. nasalis* was recorded highst in monsoon and lowest in pre monsoon season. *Xylocopa sp.nov.1* was recorded almost equal in pre monsoon and monsoon season and lowest in post monsoon. *Xylocopa sp.nov.2* was not recorded from this site. *Xylocopa sp.nov.3* was recorded highest in pre monsoon, then in monsoon season and lowest in post monsoon season.

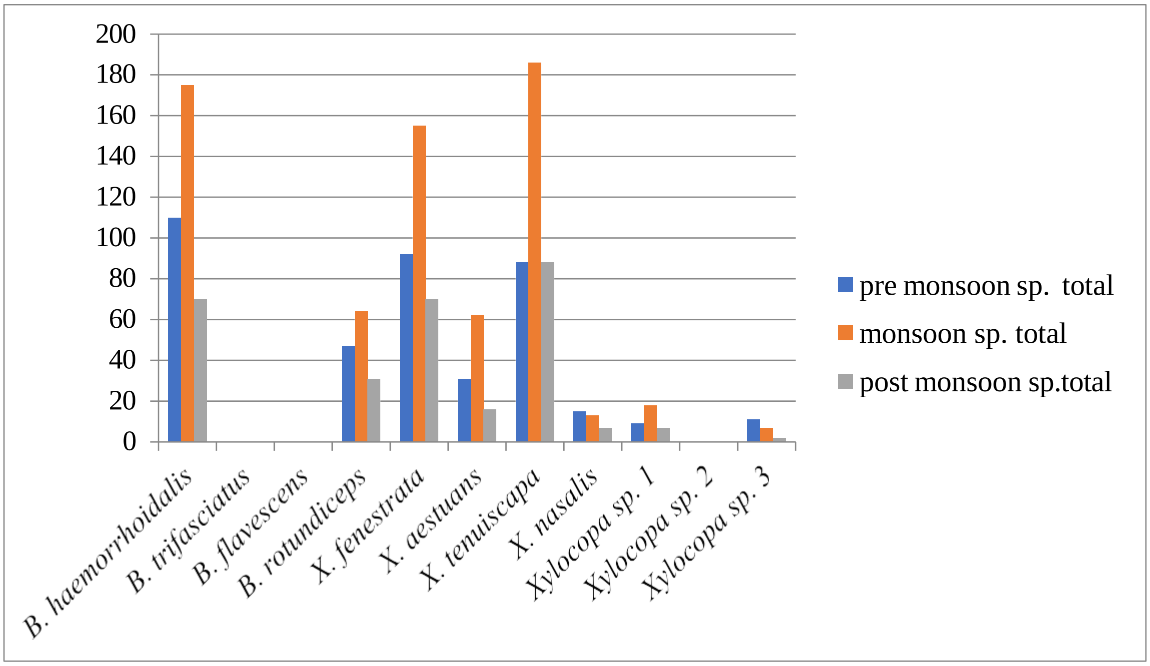


Fig. 5.3.14 : Seasonal occurrence of bee species in Site 6- Thano in 2022

At site 6 during year 2022 *Bombus haemorrhoidalis* was recorded highest in monsoon season and then in pre monsoon and lowest in post monsoon season. *B. trifasciatus* and *B. flavescens* were not recorded from this site. *B. rotundiceps* is highest in monsoon, then in pre monsoon and lowest in post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon , then in pre monsoon and lowest in post monsoon. *X. tenuiscapa* was recorded highest in monsoon, and almost equal in pre monsoon and post monsoon season. *X. nasalis* was recorded highest in pre monsoon ,then in monsoon and lowest in post monsoon season. *Xylocopa sp.nov.1* was recorded highest in monsoon then in pre monsoon season and lowest in post monsoon. *Xylocopa sp.nov.2* was not recorded from this site. *Xylocopa sp.nov.3* was recorded highest in pre monsoon, then in monsoon and lowest in post monsoon season.

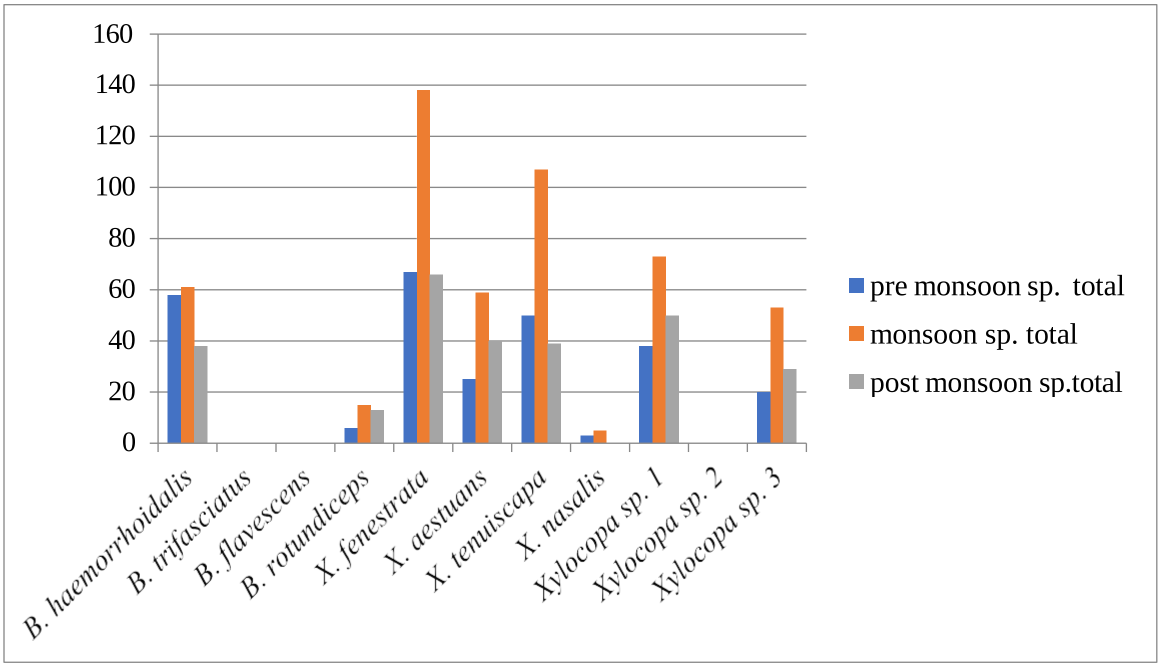


Figure 5.3.15 : Seasonal occurrence of bee species in Site 7- Chandrabani in 2021

At site 7 during year 2021 *Bombus haemorrhoidalis* was recorded highest in monsoon season and then in pre monsoon and lowest in post monsoon season. *B. trifasciatus* and *B. flavescens* were not recorded from this site. *B. rotundiceps* is highest in monsoon, then in post monsoon and lowest in pre monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon and equally in pre monsoon and post monsoon season. *X. aestuans* was recorded highest in monsoon , then in post monsoon and lowest in pre monsoon. *X. tenuiscapa* was recorded highest in monsoon, and almost then in pre monsoon and lowest in post monsoon season. *X. nasalis* was recorded highest in monsoon, lowest in pre monsoon and none in post monsoon season. *Xylocopa sp.nov.1* was recorded highest in monsoon then in post monsoon season and lowest in pre monsoon. *Xylocopa sp.nov.2* was not recorded from this site. *Xylocopa sp.nov.3* was recorded highest in monsoon, then in post monsoon and lowest in pre monsoon season.

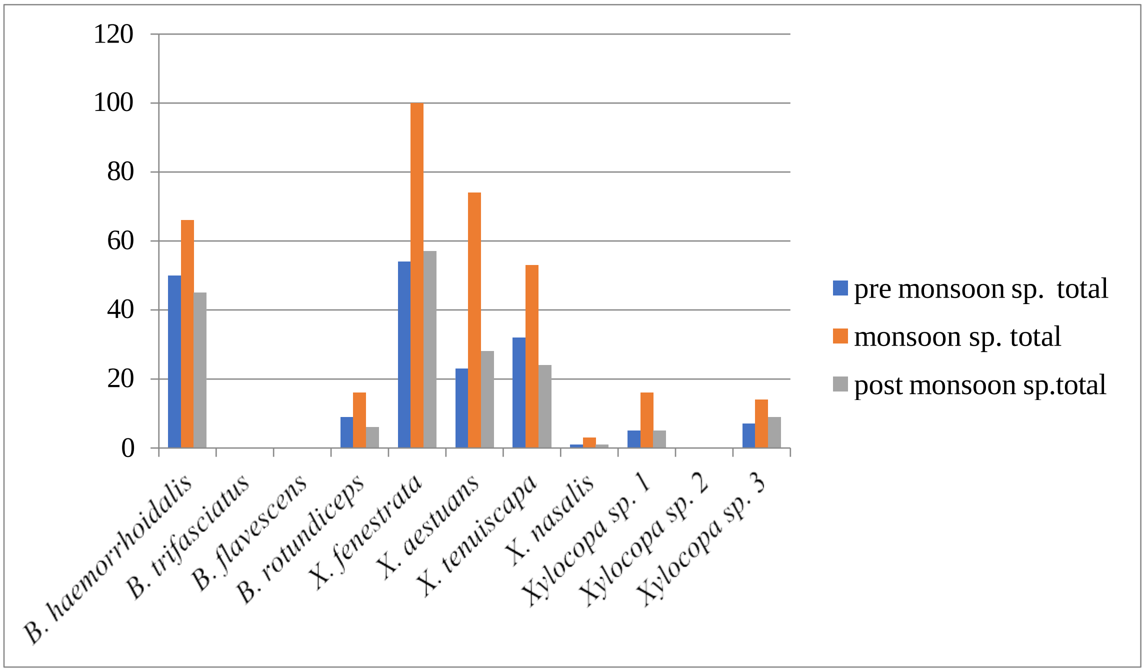


Fig. 5.3.16 : Seasonal occurrence of bee species in Site 7- Chandrabani in 2022

At site 7 during year 2022 *Bombus haemorrhoidalis* was recorded highest in monsoon season and then in pre monsoon and lowest in post monsoon season. *B. trifasciatus* and *B. flavescens* were not recorded from this site. *B. rotundiceps* is highest in monsoon, then in pre monsoon and lowest in post monsoon season. *Xylocpa fenestrata* was recorded highest in monsoon, then in post monsoon and lowest in pre monsoon season. *X. aestuans* was recorded highest in monsoon , then in post monsoon and lowest in pre monsoon. *X. tenuiscapa* was recorded highest in monsoon, and almost equal then in pre monsoon and lowest in post monsoon season. *X. nasalis* was recorded highest in monsoon, and almost equal in pre and post monsoon season. *Xylocopa sp.nov.1* was recorded highest in monsoon and almost equal in pre and post monsoon season. *Xylocopa sp.nov.2* was not recorded from this site. *Xylocopa sp.nov.3* was recorded highest in monsoon, then in post monsoon and lowest in pre monsoon season.

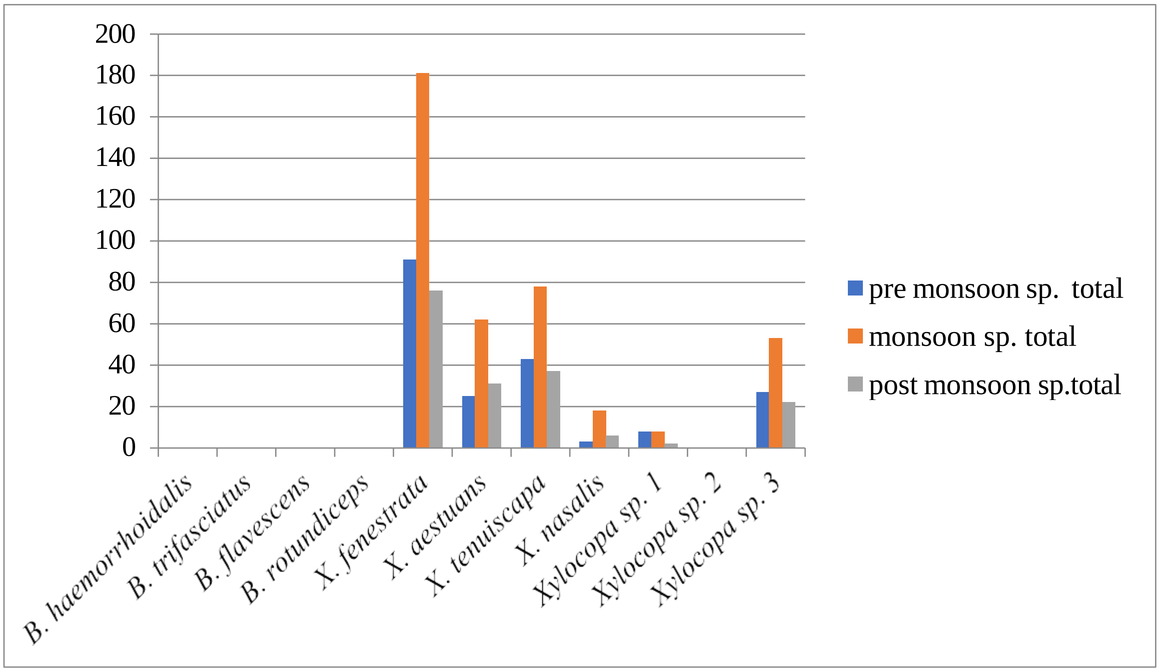


Fig. 5.3.17 : Seasonal occurrence of bee species in Site 8- Jollygrant in 2021

At site 8 during year 2021 no *Bombus* species were recorded from this site. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon, then in post monsoon and lowest in pre monsoon. *X. tenuiscapa* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. nasalis* was recorded highest in monsoon, then ib post monsson and lowest in pre monsoon season. *Xylocopa sp.nov.1* was recorded almost equal in monsoon and pre monsoon and lowest in post monsoon season. *Xylocopa sp.nov.2* was not recorded from this site. *Xylocopa sp.nov.3* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season.

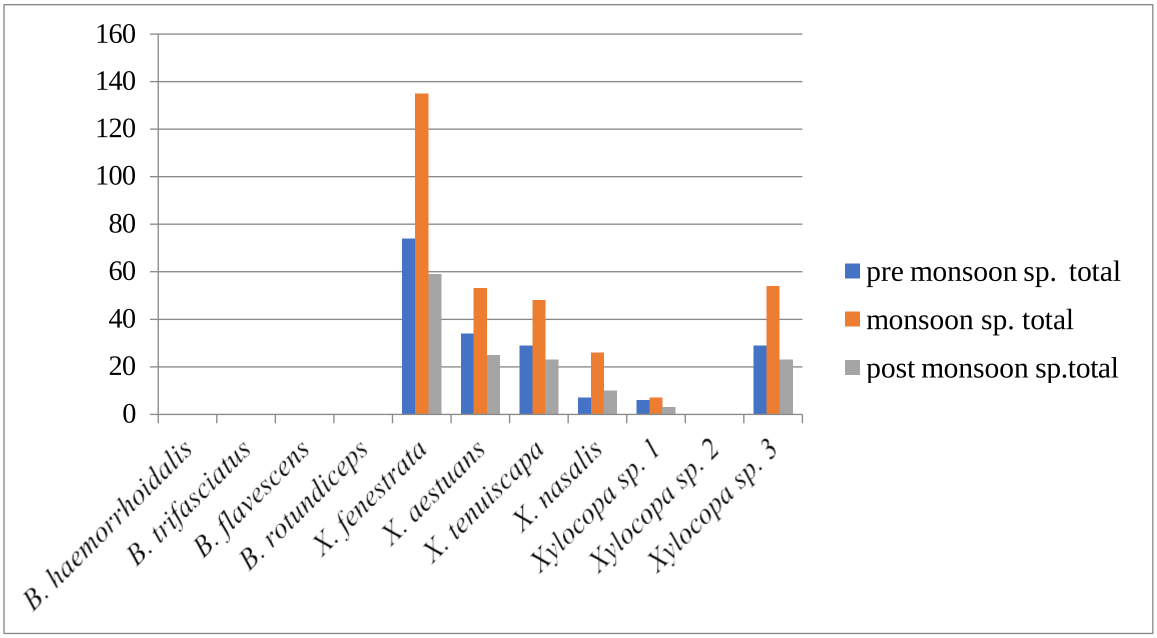


Fig.5.3.18 : Seasonal occurrence of bee species in Site 8- Jollygrant in 2022

At site 8 during year 2022 no *Bombus* species were recorded from this site. *Xylocpa. fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon , then in pre monsoon and lowest in post monsoon. *X. tenuiscapa* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. nasalis* was recorded highest in monsoon, then in post monsoon and lowest in pre monsoon season. *Xylocopa sp.nov.1* was recorded highest in monsoon, then in pre monsoon lowest in post monsoon season. *Xylocopa sp.nov.2* was not recorded from this site. *Xylocopa sp.nov.3* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season.

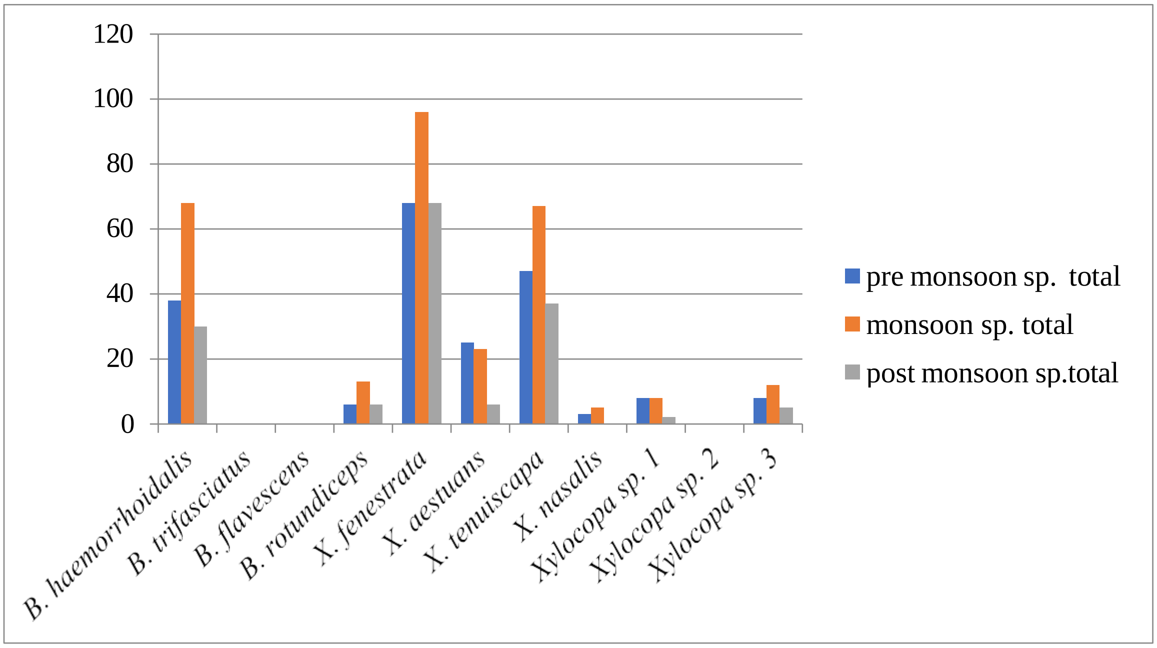


Fig. 5.3.19 : Seasonal occurrence of bee species in Site 9- Selaqui in 2021

At site 9 during year 2022 *Bombus haemorrhoidalis* was recorded highest in monsoon season and then in pre monsoon and lowest in post monsoon season. *B. trifasciatus* and *B. flavescens* were not recorded from this site. *B. rotundiceps* is highest in monsoon and almost equal in pre and post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, almost equal in pre and post monsoon season. *X. aestuans* was recorded highest in pre monsoon , then in monsoon and lowest in post monsoon. *X. tenuiscapa* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. nasalis* was recorded highest in monsoon, then in pre monsoon and none in post monsoon season. *Xylocopa sp.nov.1* was recorded almost equal in monsoonand pre monsoon season and lowest in post monsoon. *Xylocopa sp.nov.2* was not recorded from this site. *Xylocopa sp.nov.3* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season.

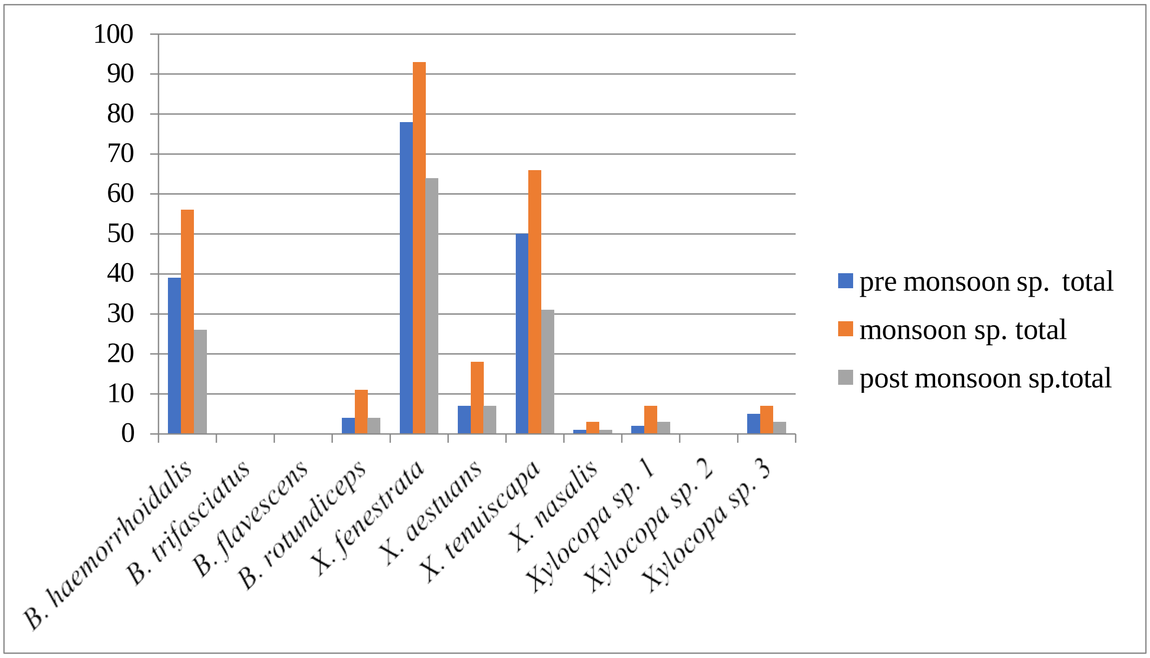


Fig. 5.3.20 : Seasonal occurrence of bee species in Site 9- Selaqui in 2022

At site 9 during year 2022 *Bombus haemorrhoidalis* was recorded highest in monsoon season and then in pre monsoon and lowest in post monsoon season. *B. trifasciatus* and *B. flavescens* were not recorded from this site. *B. rotundiceps* is highest in monsoon, and almost equal in pre monsoon and post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon ,and almost equal in pre monsoon and post monsoon. *X. tenuiscapa* was recorded highest in monsoon, and then in pre monsoon and lowest in post monsoon season. *X. nasalis* was recorded highest in monsoon, and almost equal in pre and post monsoon season. *Xylocopa sp.nov.1* was recorded highest in monsoon then in post monsoon season and lowest in pre monsoon. *Xylocopa sp.nov.2* was not recorded from this site. *Xylocopa sp.nov.3* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season.

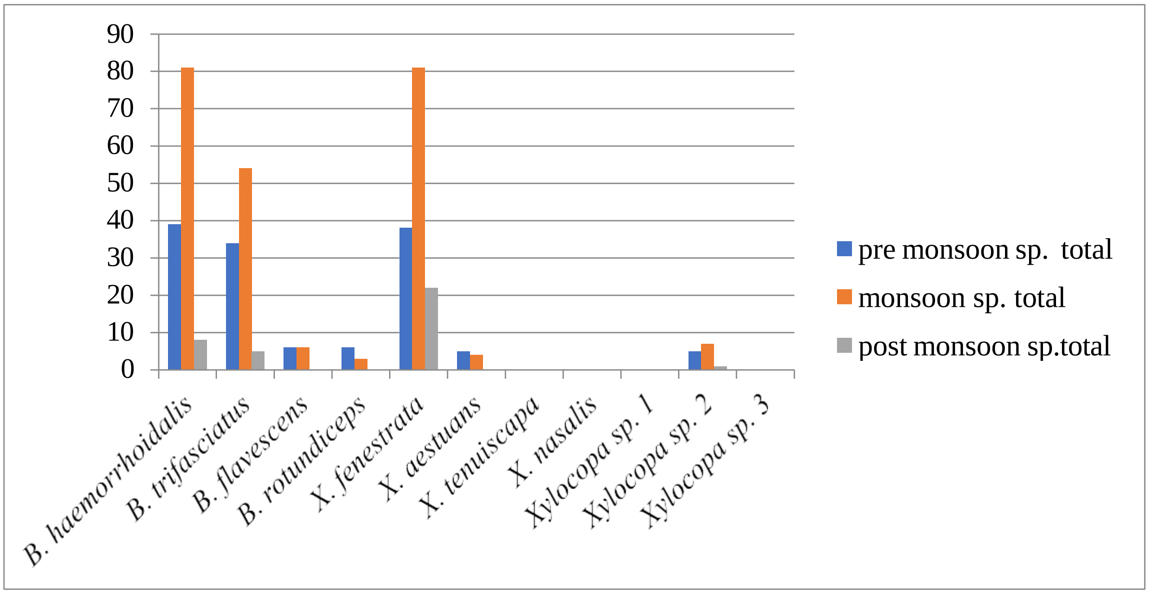


Fig. 5.3.21 : Seasonal occurrence of bee species in Site 10- Benog Wildlife Sanctuary in 2021

At site 10 during year 2021 *Bombus haemorrhoidalis* was recorded highest in monsoon season, then in pre monsoon and lowest in post monsoon season. *B. trifasciatus* was recorded highest in monsoon , then in pre monsoon and lowest in post monsoon season. *B. flavescens* was recorded almost equal during pre monsoon and monsoon season and none in post monsoon season. *B. rotundiceps* is highest in pre monsoon, lowest in monsoon and none in post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in pre monsoon, lowest in monsoon and none in post monsoon season. *X. tenuiscapa*, *X. nasalis*, *Xylocopa sp.nov.1* and *Xylocopa sp.nov.3* were not recorded from this site. *Xylocopa sp.nov.2* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season.

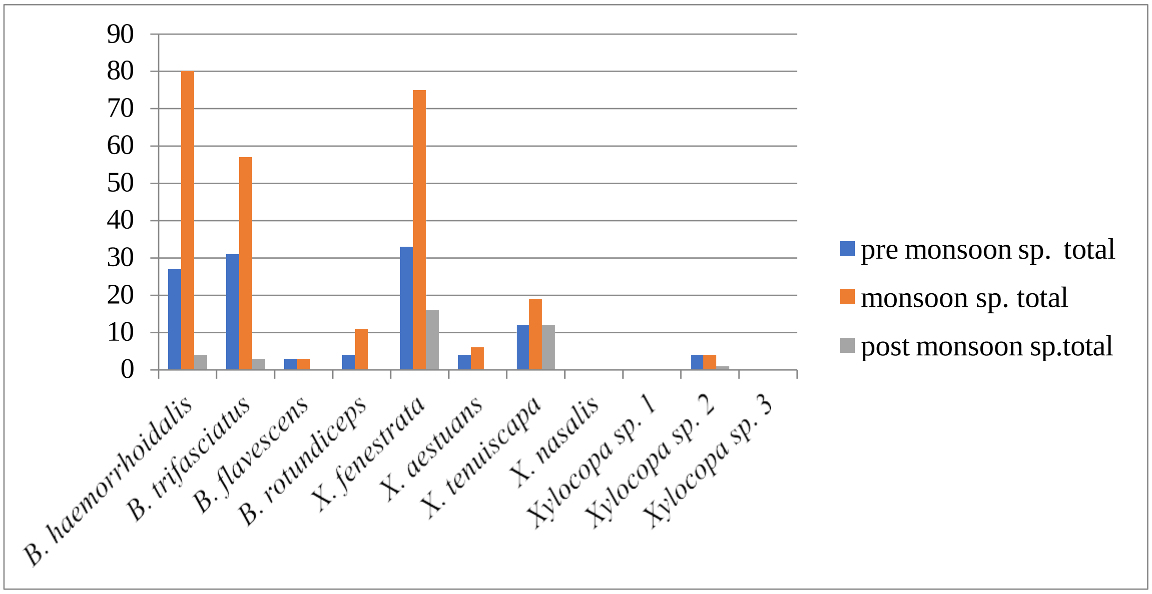


Fig. 5.3.22 : Seasonal occurrence of bee species in Site 10- Benog Wildlife Sanctuary in 2022

At site 10 during year 2022 *Bombus haemorrhoidalis* was recorded highest in monsoon season, then in pre monsoon and lowest in post monsoon season. *B. trifasciatus* was recorded highest in monsoon , then in pre monsoon and lowest in post monsoon season. *B. flavescens* was recorded almost equal during pre monsoon and monsoon season and none in post monsoon season. *B. rotundiceps* is highest in monsoon, then in pre monsoon and none in post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon, lowest in pre monsoon and none in post monsoon season. *X. tenuiscapa* was recorded highest in monsoon and almost equal in pre and post monsoon season. *X. nasalis*, *Xylocopa sp.nov.1* and *Xylocopa sp.nov.3* were not recorded from this site. *Xylocopa sp.nov.2* was recorded almost equal in monsoon and pre monsoon and lowest in post monsoon season.

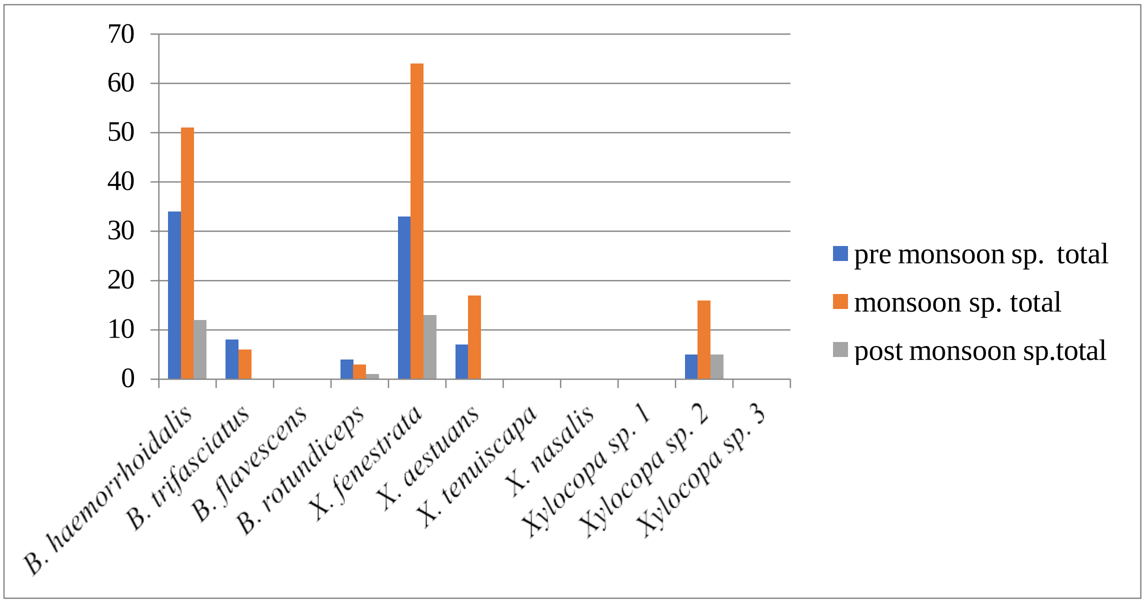


Fig. 5.3.23 : Seasonal occurrence of bee species in Site 11- Koruwa in 2021

At site 11 during year 2021 *Bombus haemorrhoidalis* was recorded highest in monsoon season, then in pre monsoon and lowest in post monsoon season. *B. trifasciatus* was recorded highest in pre monsoon, then in monsoon and none in post monsoon season. *B. flavescens* was not recorded from this site. *B. rotundiceps* is highest in pre monsoon, then in monsoon and lowest in post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon, lowest in pre monsoon and none in post monsoon season. *X. tenuiscapa*, *X. nasalis*, *Xylocopa sp.nov.1* and *Xylocopa sp.nov.3* were not recorded from this site. *Xylocopa sp.nov.2* was recorded almost equal in pre monsoon and post monsoon and highest in monsoon season.

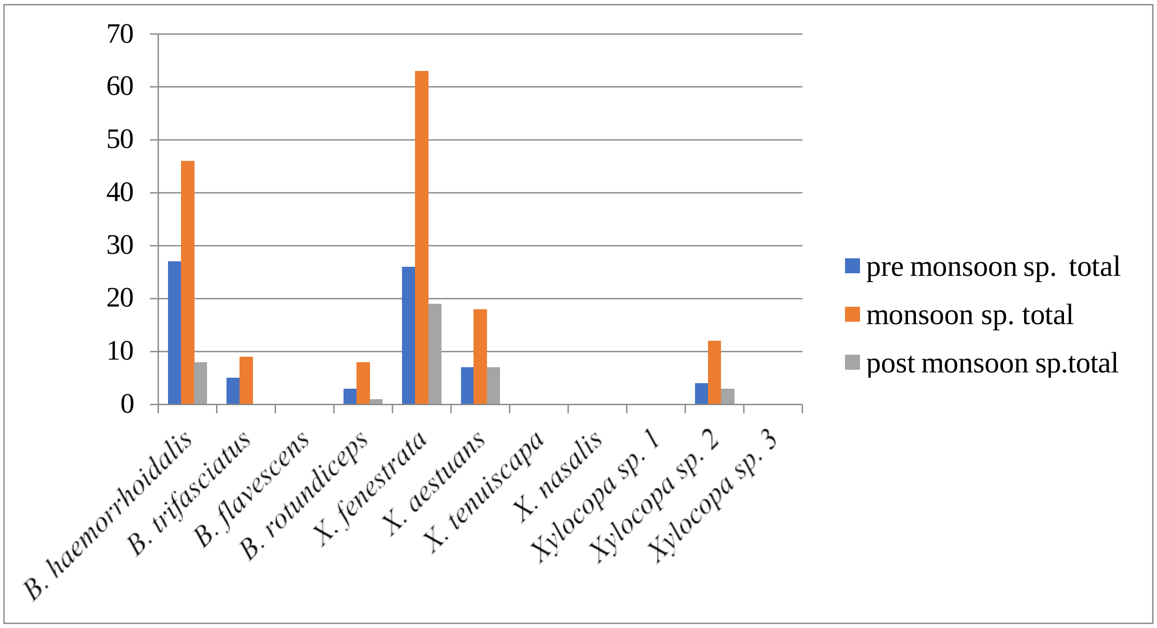


Fig. 5.3.24: Seasonal occurrence of bee species in Site 11- Koruwa in 2022

At site 11 during year 2022 *Bombus haemorrhoidalis* was recorded highest in monsoon season, then in pre monsoon and lowest in post monsoon season. *B. trifasciatus* was recorded highest in monsoon then in pre monsoon and none in post monsoon season. *B. flavescens* was not recorded from this site. *B. rotundiceps* is highest in monsoon, then in pre monsoon and lowest in post monsoon season. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon, and almost equal in pre and post monsoon season. *X. tenuiscapa*, *X. nasalis*, *Xylocopa sp.nov.1* and *Xylocopa sp.nov.3* were not recorded from this site. *Xylocopa sp.nov.2* was recorded highest in monsoon season then in pre monsoon and lowest in post monsoon season.

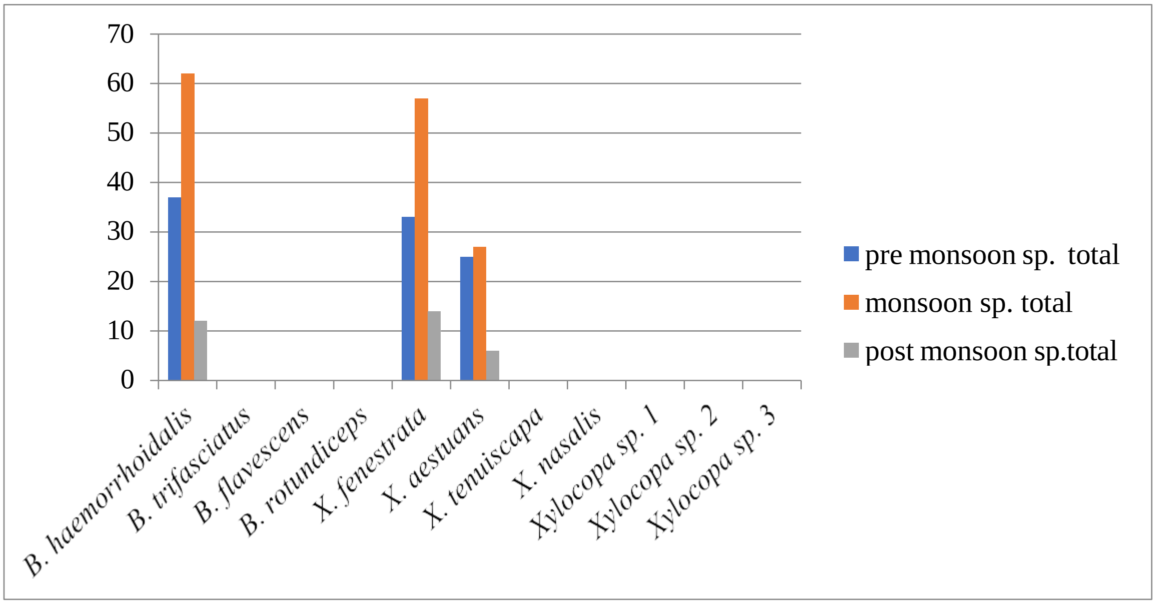


Fig. 5.3.25: Seasonal occurrence of bee species in Site 12- Mohand in 2021

At site 12 during year 2021 *Bombus haemorrhoidalis* was recorded highest in monsoon season, then in pre monsoon and lowest in post monsoon season. *B. trifasciatus,B. flavescens and B. rotundiceps*were not recorded from this site. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. tenuiscapa*, *X. nasalis*, *Xylocopa sp.nov.1*, *Xylocopa sp.nov.2* and *Xylocopa sp.nov.3* were not recorded from this site

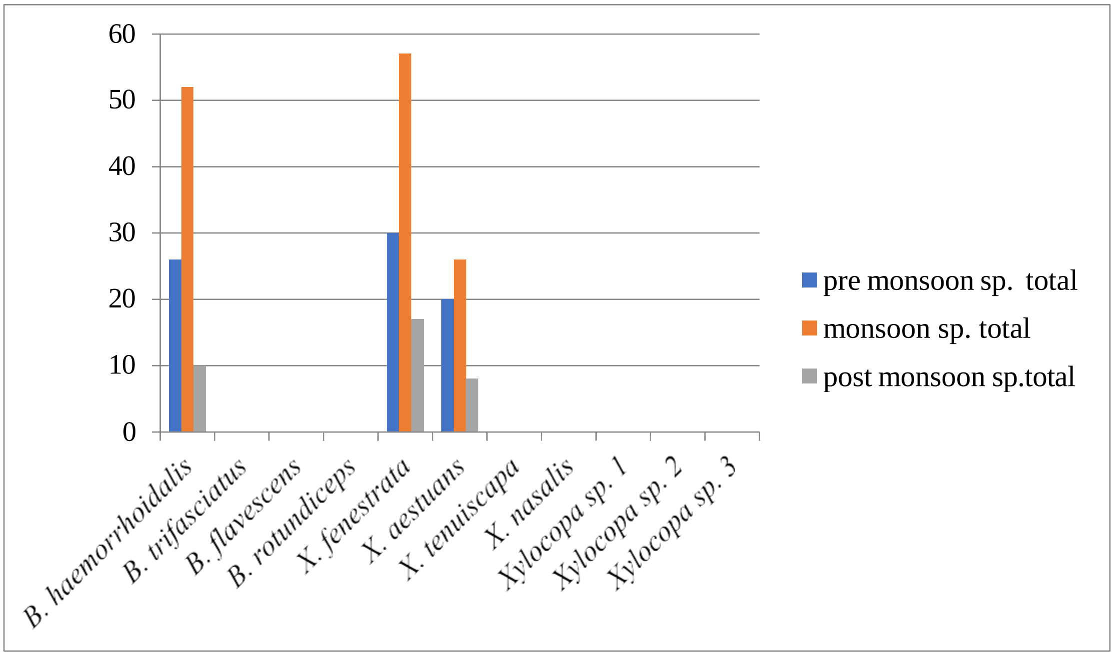


Fig. 5.3.26: Seasonal occurrence of bee species in Site 12- Mohand in 2022

At site 12 during year 2021 *Bombus haemorrhoidalis* was recorded highest in monsoon season, then in pre monsoon and lowest in post monsoon season. *B. trifasciatus, B. flavescens and B. rotundiceps* were not recorded from this site. *Xylocopa fenestrata* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. aestuans* was recorded highest in monsoon, then in pre monsoon and lowest in post monsoon season. *X. tenuiscapa*, *X. nasalis*, *Xylocopa sp.nov.1*, *Xylocopa sp.nov.2* and *Xylocopa sp.nov.3* were not recorded from this site.

5.4 Habitat wise seasonal distribution of species

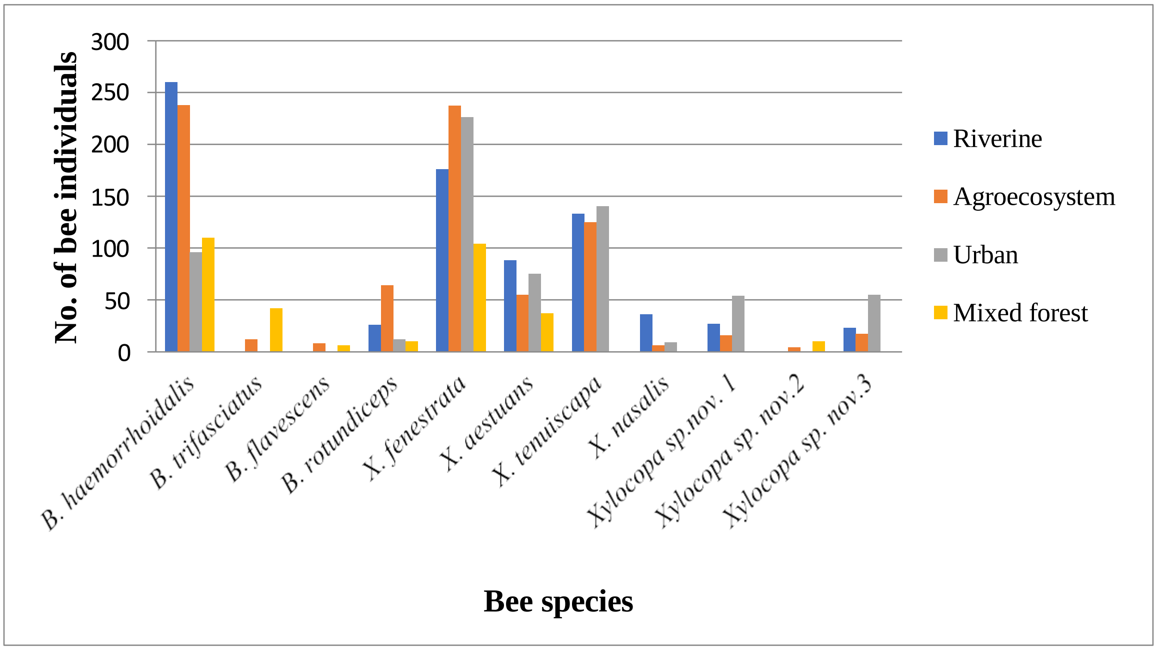


Fig. 5.4.1: Bee abundance during pre monsoon 2021

During Pre monsoon 2021, *Bombus haemorrhoidalis*no. was highest in riverine habitat, then in agroecosystem, then in mixed forest and lowest in urban habitat. *B. trifasciatus* was highest in mixed forest then in agroecosystem and absent from riverine and urban habitat. *B.flavescens*no. was slightly more in agroecosystem than in mixed forest and absent from riverine and urban habitat. *B. rotundiceps* no. was highest in agroecosytem then in riverine and urban habitat and lowest in mixed forest.

Xylocopa fenestrata no. was highest in agroecosystem then in urban and riverine habitat and lowest in mixed forest. *X. aestuans* was highest in riverine habitat then in urban and agroecosystem and lowest in mixed forest. *X. tenuiscapa* was highest in urban then in riverine and agroecosytem and absent from mixed forest. *X. nasalis* was highest in riverine habitat then in urban and agroecosystem and absent from mixed forest. *Xylocopa sp.nov.1* was highest in urban habitat then in riverine and agroecosystem and absent from mixed forest. *Xylocopa sp.nov.2* was highest in mixed forest then in agroecosystem and absent from riverine and urban habitat. *Xylocopa sp.nov.3* was highest in urban habitat then in riverine and agroecosystem and absent from mixed forest.

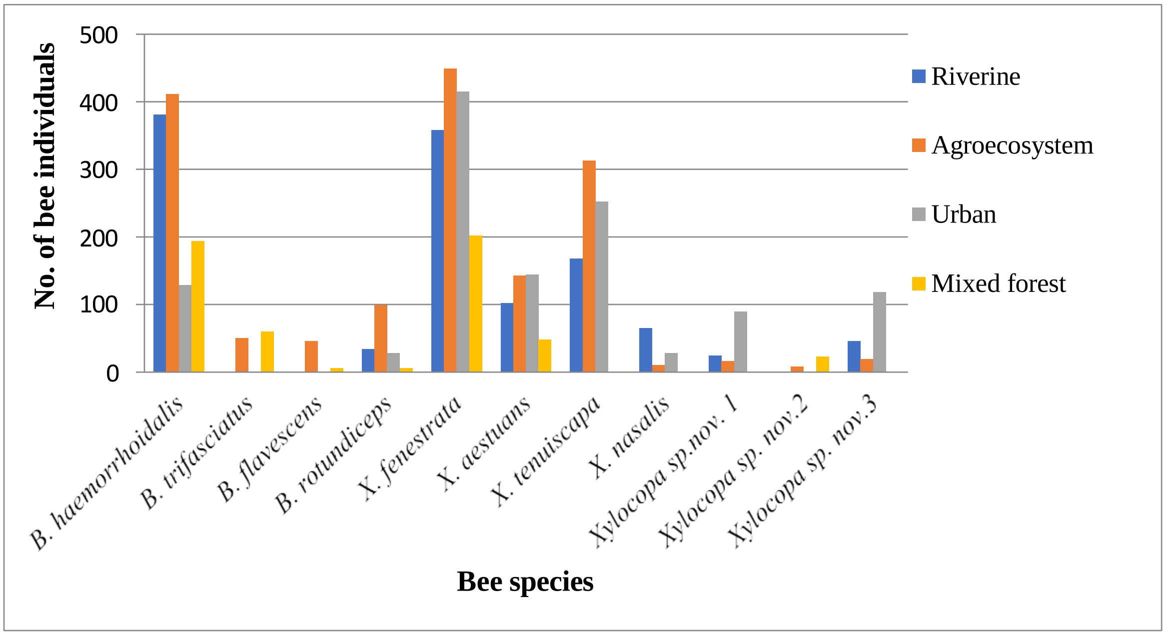


Fig. 5.4.2: Bee abundance during monsoon 2021

During Monsoon 2021, *Bombus haemorrhoidalis*no. was highest in agroecosystem, then in riverine habitat, then in mixed forest and lowest in urban habitat. *B. trifasciatus* was highest in mixed forest and then in agroecosystem and absent from riverine and urban habitat. *B. flavescens* no. was more in agroecosystem than in mixed forest and absent from riverine and urban habitat. *B. rotundiceps* no. was highest in agroecosytem then in riverine and urban habitat and lowest in mixed forest.

Xylocopa fenestrata no. was highest in agroecosystem then in urban and riverine habitat and lowest in mixed forest. *X. aestuans* was almost equal in agroecosystem and urban, then in riverine and lowest in mixed forest. *X. tenuiscapa* was highest in agroecosystem then in urban and riverine habitat and absent from mixed forest. *X. nasalis* was highest in riverine habitat then in urban and agroecosystem and absent from mixed forest. *Xylocopa sp. nov.1* was highest in urban habitat then in riverine and agroecosystem and absent from mixed forest. *Xylocopa sp. nov.2* was highest in mixed forest then in agroecosystem and absent from riverine and urban habitat. *Xylocopa sp.nov. 3* was highest in urban habitat then in riverine and agroecosystem and absent from mixed forest.

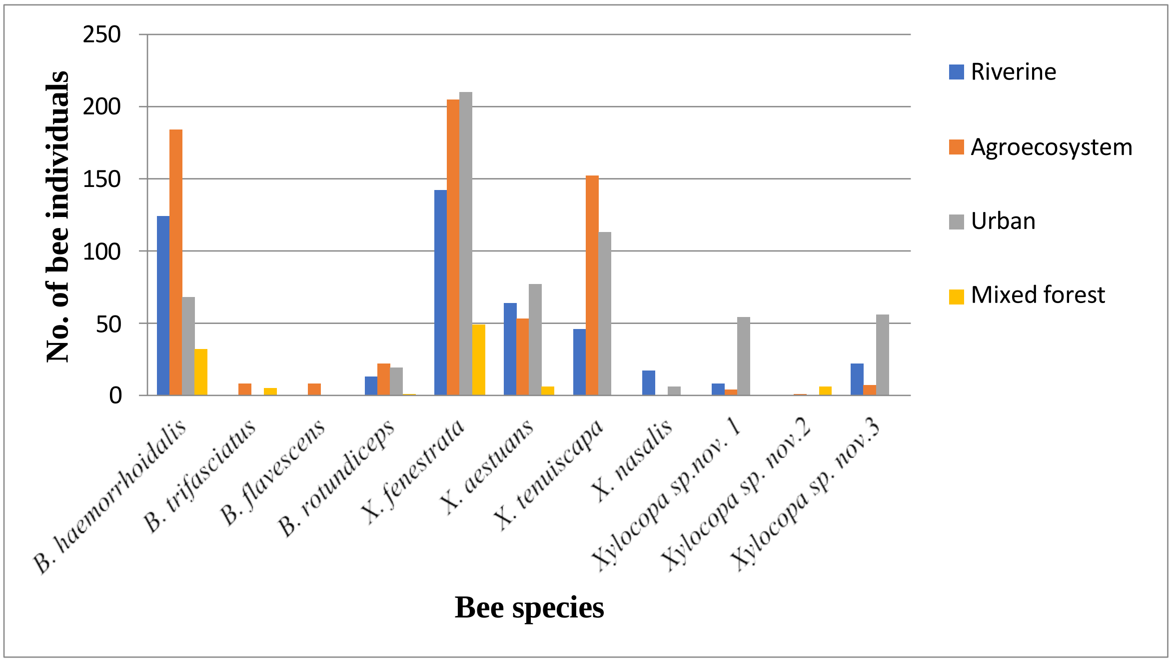


Fig. 5.4.3: Bee abundance during post Monsoon 2021

During Post Monsoon 2021, *Bombus haemorrhoidalis*no. was highest in agroecosystem, then in riverine and urban habitat and lowest in mixed forest. *B. trifasciatus* was highest in agroecosystem and lowest in mixed forest and absent from riverine and urban habitat. *B. flavescens* no. was recorded only from agroecosystem and absent from riverine, mixed forest and urban habitat. *B. rotundiceps* no. was highest in agroecosytem then in urban and riverine habitat and lowest in mixed forest.

Xylocopa fenestrata no. was highest in urban habitat then in agroecosystem and riverine habitat and lowest in mixed forest. *X. aestuans* was highest in urban then in riverine and agroecosystem and lowest in mixed forest. *X. tenuiscapa* was highest in agroecosystem then in urban and riverine habitat and absent from mixed forest. *X. nasalis* was highest in riverine habitat then in urban and absent from agroecosystem and mixed forest. *Xylocopa sp.nov. 1* was highest in urban habitat then in riverine and agroecosystem and absent from mixed forest. *Xylocopa sp. nov.2* was highest in mixed forest then in agroecosystem and absent from riverine and urban habitat. *Xylocopa sp.nov. 3* was highest in urban habitat then in riverine and agroecosystem and absent from mixed forest.

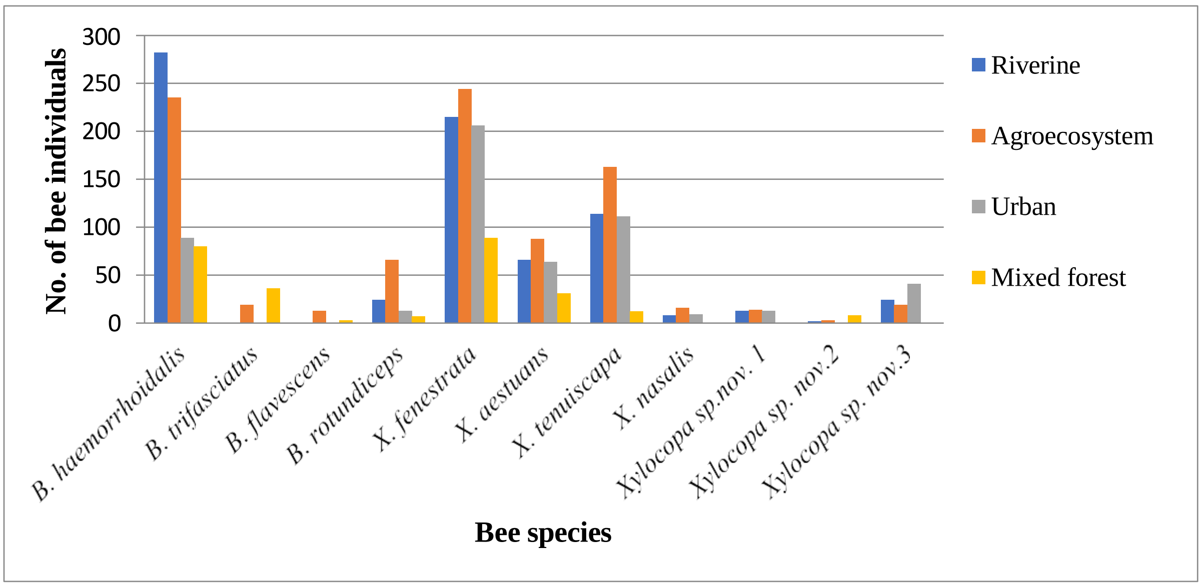


Fig. 5.4.4: Bee abundance during pre monsoon 2022

During Pre Monsoon 2022, *Bombus haemorrhoidalis*no. was recorded highest from riverine then in agrosystem and urban habitat and lowest in mixed forest. *B. trifasciatus* was highest in mixed forest then in agroecosystem and absent from riverine and urban habitat. *B. flavescens* no. was recorded from agroecosystem then in mixed forest and absent from riverine and urban habitat. *B. rotundiceps* no. was recorded highest from agroecosytem then in riverine and urban habitat and lowest in mixed forest.

Xylocopa fenestrata no. was highest in agroecosystem then in riverine and urban habitat and lowest in mixed forest. *X. aestuans* was highest in agroecosystem then in riverine and urban habitat and lowest in mixed forest. *X. tenuiscapa* was highest in agroecosystem then in urban and riverine habitat and lowest in mixed forest. *X. nasalis* was highest in agroecosystem then in urban and riverine habitat and absent from and mixed forest. *Xylocopa sp. nov.1* was slightly more in agroecosystem then in urban and riverine and absent from mixed forest. *Xylocopa sp.nov. 2* was highest in mixed forest then in agroecosystem and riverine and absent from urban habitat. *Xylocopa sp.nov. 3* was highest in urban habitat then in riverine and agroecosystem and absent from mixed forest.

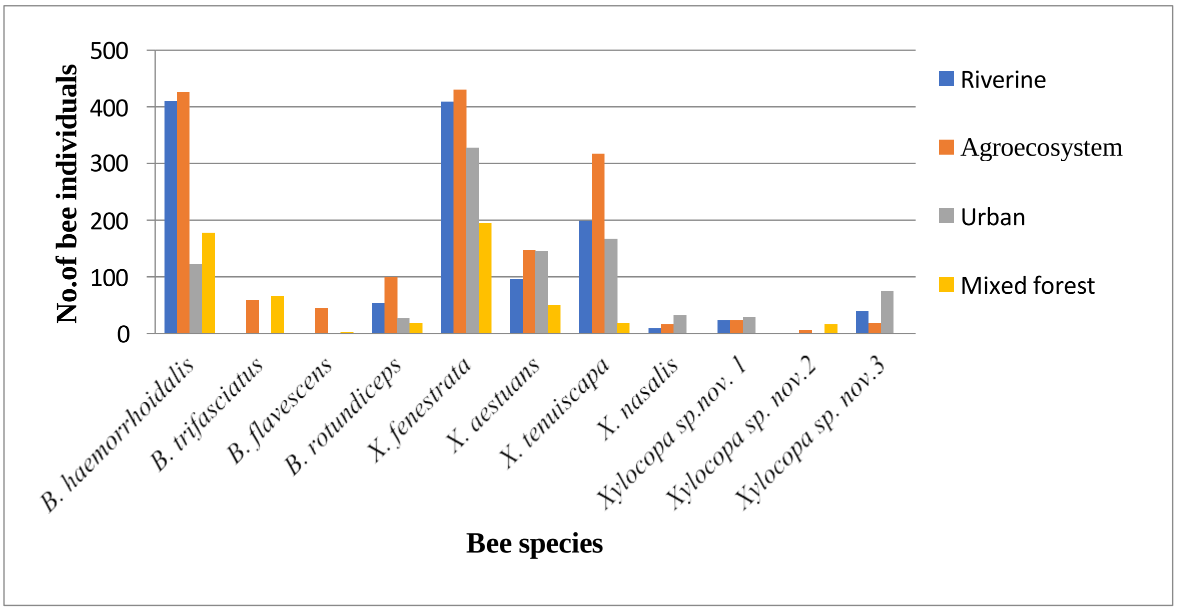


Fig. 5.4.5: Bee abundance during monsoon 2022

During Monsoon 2022, *Bombus haemorrhoidalis*no. was recorded highest from agroecosystem, then in riverine and mixed forest habitat and lowest in urban habitat. *B. trifasciatus* was highest in mixed forest and then in agroecosystem and absent from riverine and urban habitat. *B. flavescens* was recorded only from agroecosystem and absent from mixed forest, riverine and urban habitat. *B. rotundiceps* no. was highest in agroecosytem then in riverine and urban habitat and lowest in mixed forest.

Xylocopa fenestrata no. was highest in agroecosystem then in riverine habitat and urban habitat and lowest in mixed forest. *X. aestuans* was highest in agroecosystem then in urban and riverine and lowest in mixed forest. *X.*

tenuiscapa was highest in agroecosystem then in riverine and urban habitat and lowest in mixed forest. *X. nasalis* was recorded highest from urban habitat then in agroecosystem and riverine habitat and absent from mixed forest. *Xylocopa sp. nov. 1* was highest in urban habitat then in riverine and agroecosystem and absent from mixed forest. *Xylocopa sp. nov.2* was highest in mixed forest then in agroecosystem and absent from riverine and urban habitat. *Xylocopa sp. nov.3* was highest in urban habitat then in riverine and agroecosystem and absent from mixed forest.

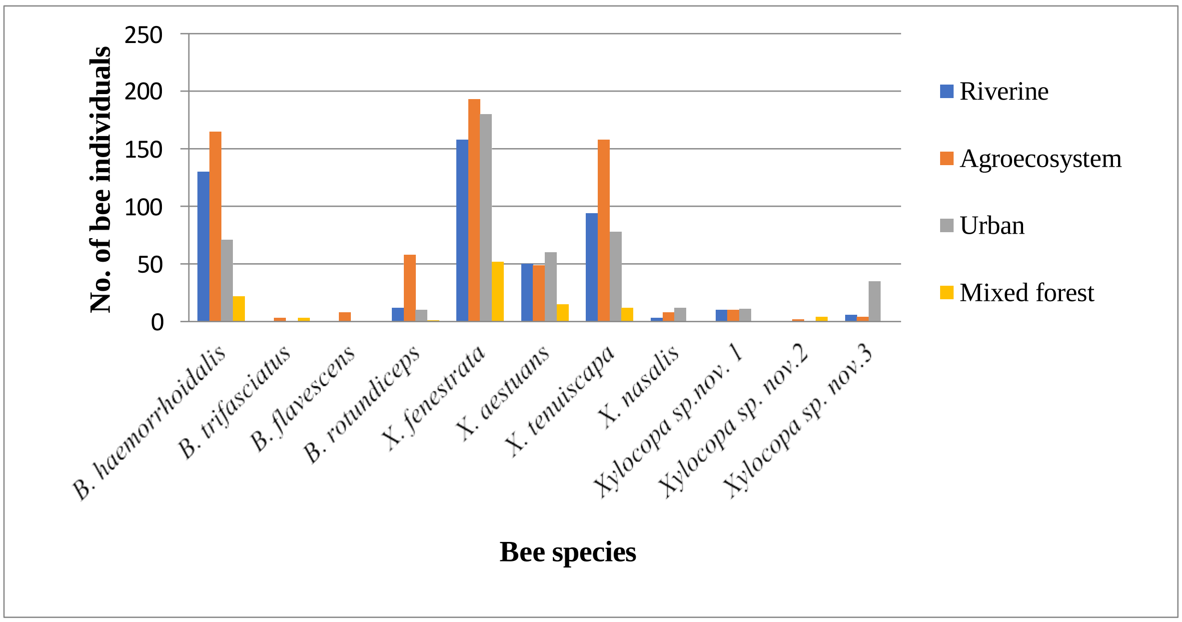


Fig.5.4.6: Bee abundance during post monsoon 2022

During Post Monsoon 2022, *Bombus haemorrhoidalis*no. was highest in agroecosystem, then in riverine and urban habitat and lowest in mixed forest. *B. trifasciatus* was recorded from agroecosystem and mixed forest and absent from riverine and urban habitat. *B. flavescens* no. was recorded only from agroecosystem and absent from riverine, mixed forest and urban habitat. *B. rotundiceps* no. was highest in agroecosytem then in urban and riverine habitat and absent from mixed forest.

Xylocopa fenestrata no. was highest in agroecosystem then in urban and riverine habitat and lowest in mixed forest. *X. aestuans* was highest in urban then in riverine habitat and agroecosystem and lowest in mixed forest. *X. tenuiscapa* was highest in agroecosystem then in riverine and urban habitat and lowest in mixed forest. *X. nasalis* was highest in urban habitat then in agroecosystem and riverine habitat and absent from mixed forest. *Xylocopa sp.nov. 1* was slightly higher in urban habitat then in riverine and agroecosystem and absent from mixed forest. *Xylocopa sp. nov. 2* was highest in mixed forest then in agroecosystem and absent from riverine and urban habitat. *Xylocopa sp. nov. 3* was highest in urban habitat then in riverine and agroecosystem and absent from mixed forest.

5.5. The Shannon index (H)

The value of Shannon index ranges from 0 to 5, where 5 represents infinite diversity and 0 represents no diversity, so the larger the value of H, the higher the diversity. The Shannon value varies from 1.009 to 1.877 in the study area which shows relatively low to moderate diversity of species.

Table. 5.5.1 The Shannon index (H) values in 2021-2022

	Pre monsoon 2021	Pre monsoon 2022	monsoon 2021	monsoon 2022	Post monsoon 2021	Post monsoon 2022
Site 1	1.739	1.476	1.775	1.475	1.619	1.376
Site 2	1.877	1.568	1.474	1.583	1.428	1.576
Site 3	1.49	1.528	1.581	1.467	1.606	1.463
Site 4	1.713	1.51	1.756	1.66	1.66	1.516
Site 5	1.664	1.637	1.67	1.612	1.503	1.594
Site 6	1.681	1.777	1.599	1.701	1.38	1.659
Site 7	1.821	1.688	1.846	1.756	1.865	1.68
Site 8	1.417	1.511	1.452	1.529	1.427	1.525
Site 9	1.698	1.425	1.681	1.609	1.443	1.459
Site 10	1.593	1.715	1.394	1.593	1.009	1.277
Site 11	1.443	1.44	1.405	1.49	1.137	1.282
Site 12	1.086	1.085	1.043	1.049	1.043	1.046

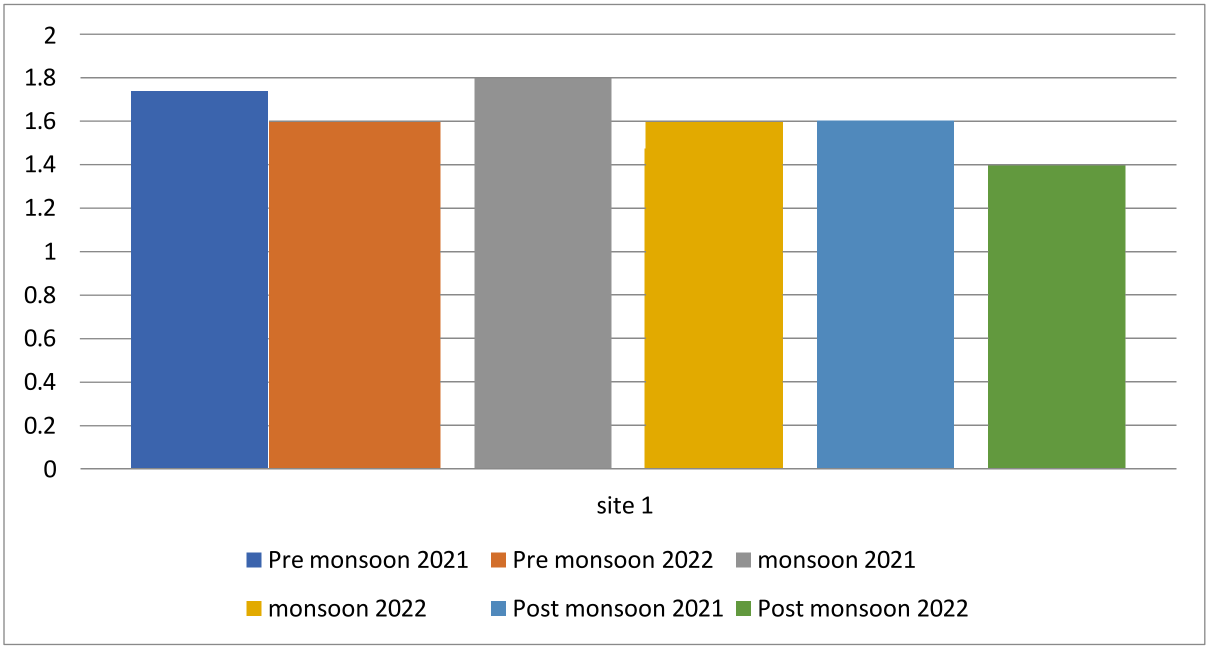


Fig. 5.5.1: The Shannon index of Site -1 Bajawala in 2021-22

At site- 1 the value of Shannon index varies from 1.376 to 1.775. The value fluctuates between 1.739 to 1.476 in pre monsoon period, between 1.775 to 1.475 in monsoon and between 1.619 to 1.376 in post monsoon period.

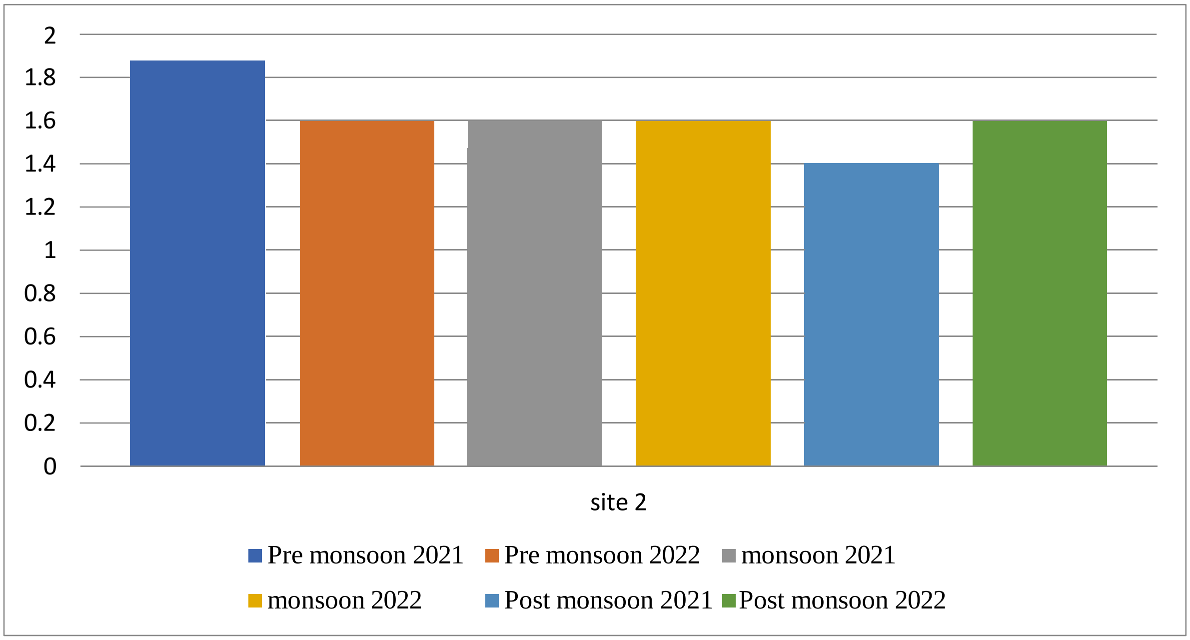


Fig. 5.5.2: The Shannon index of Site -2 Sahastradhara in 2021-22

At site - 2 the value of Shannon index varies from 1.428 to 1.877. The value fluctuates between 1.877 to 1.568 in pre monsoon period, between 1.474 to 1.583 in monsoon and between 1.428 to 1.576 in post monsoon period.

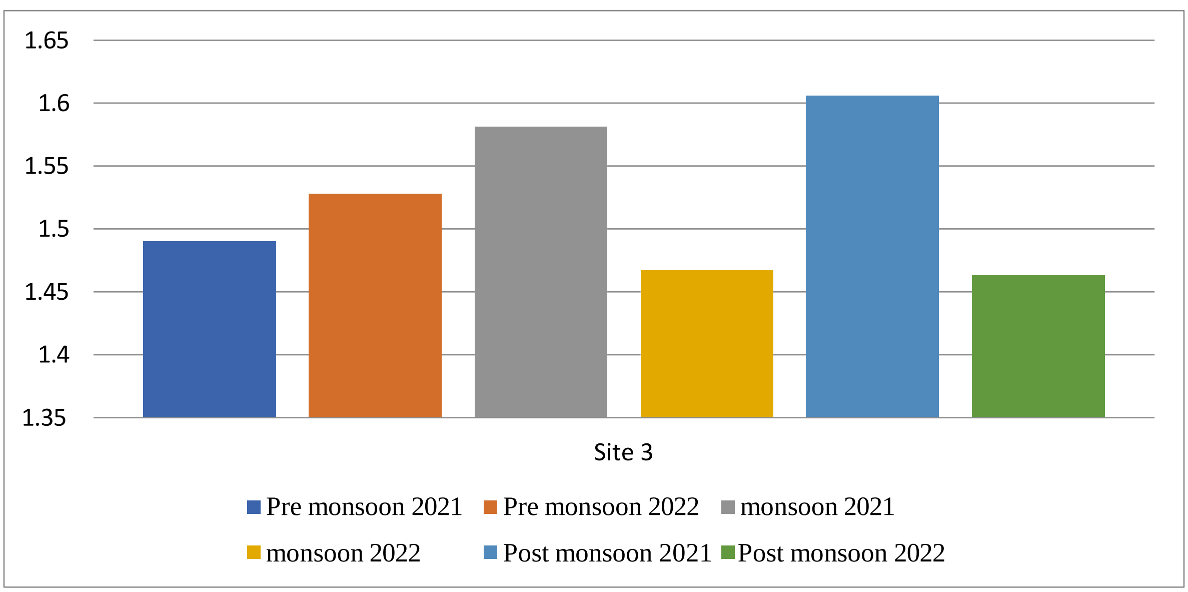


Fig. 5.5.3 : The Shannon index of Site -3 Tiuni in 2021-22

At site - 3 the value of Shannon index varies from 1.463 to 1.606. The value fluctuates between 1.49 to 1.528 in pre monsoon period, between 1.581 to 1.467 in monsoon and between 1.606 to 1.463 in post monsoon period.

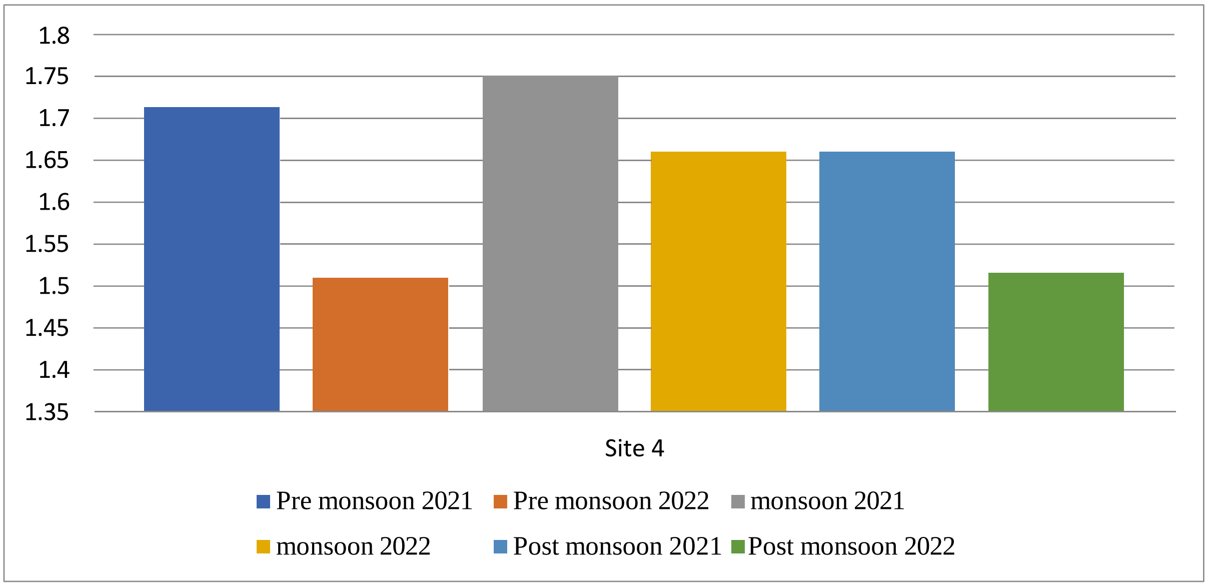


Fig. 5.5.4: The Shannon index of Site -4 Jadi in 2021-22

At site - 4 the value of Shannon index varies from 1.51 to 1.756. The value fluctuates between 1.713 to 1.51 in pre monsoon period, between 1.756 to 1.66 in monsoon and between 1.66 to 1.516 in post monsoon period.

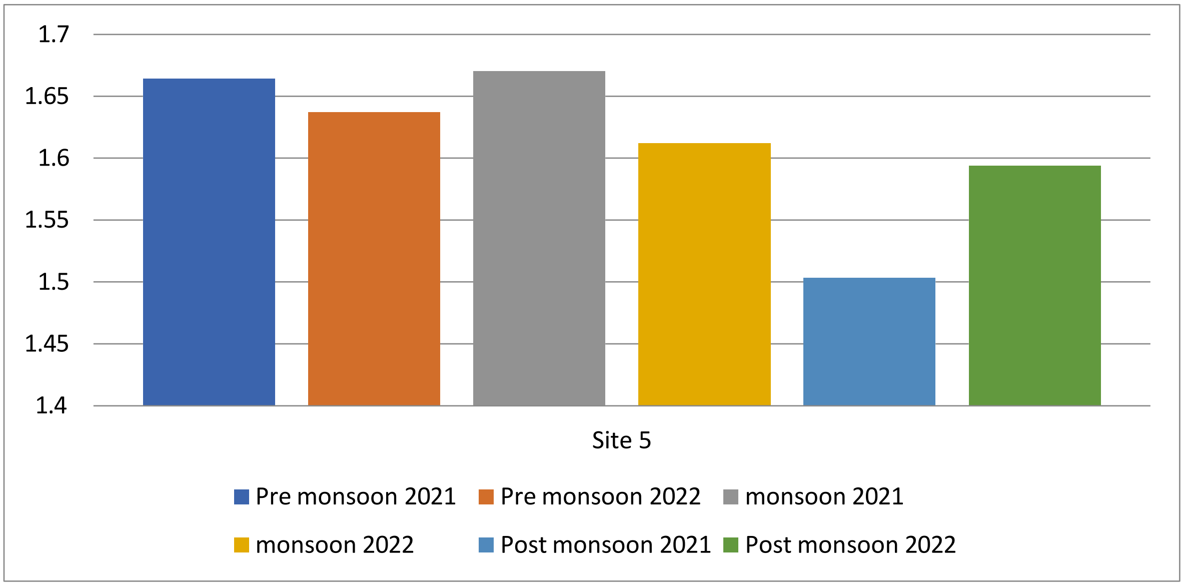


Fig. 5.5.5: The Shannon index of Site -5 Tea estate in 2021-22

At site - 5 the value of Shannon index varies from 1.503 to 1.67. The value fluctuates between 1.664 to 1.637 in pre monsoon period, between 1.67 to 1.612 in monsoon and between 1.503 to 1.594 in post monsoon period.

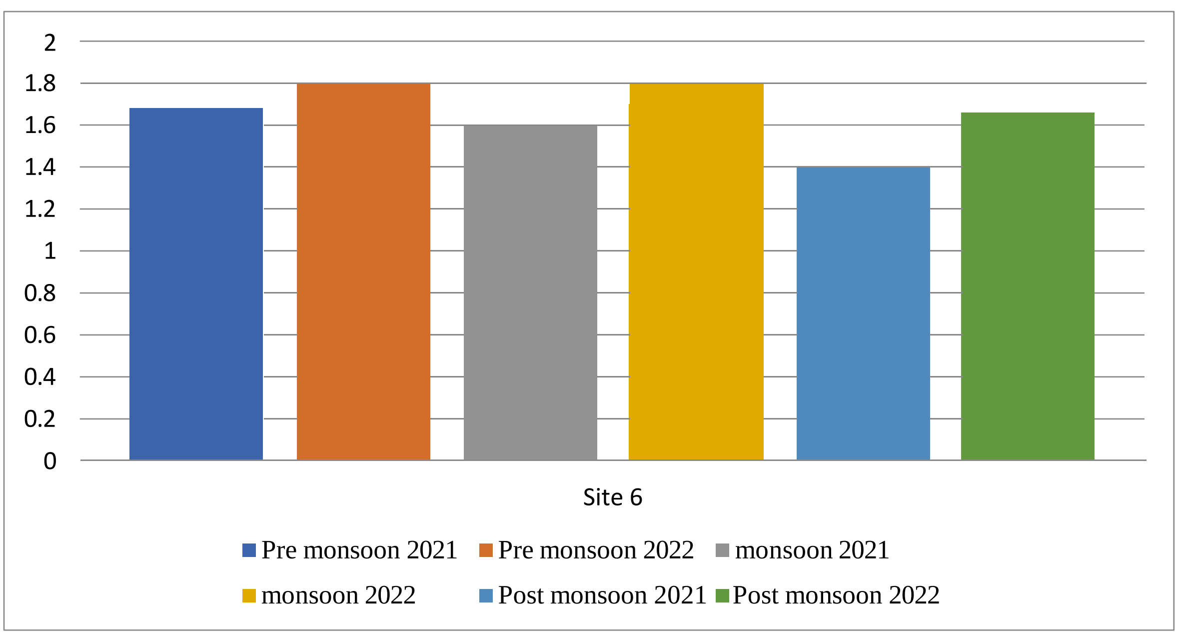


Fig. 5.5.6: The Shannon index of Site -6 Thano in 2021-22

At site - 6 the value of Shannon index varies from 1.38 to 1.777. The value fluctuates between 1.681 to 1.777 in pre monsoon period, between 1.599 to 1.701 in monsoon and between 1.38 to 1.659 in post monsoon period.

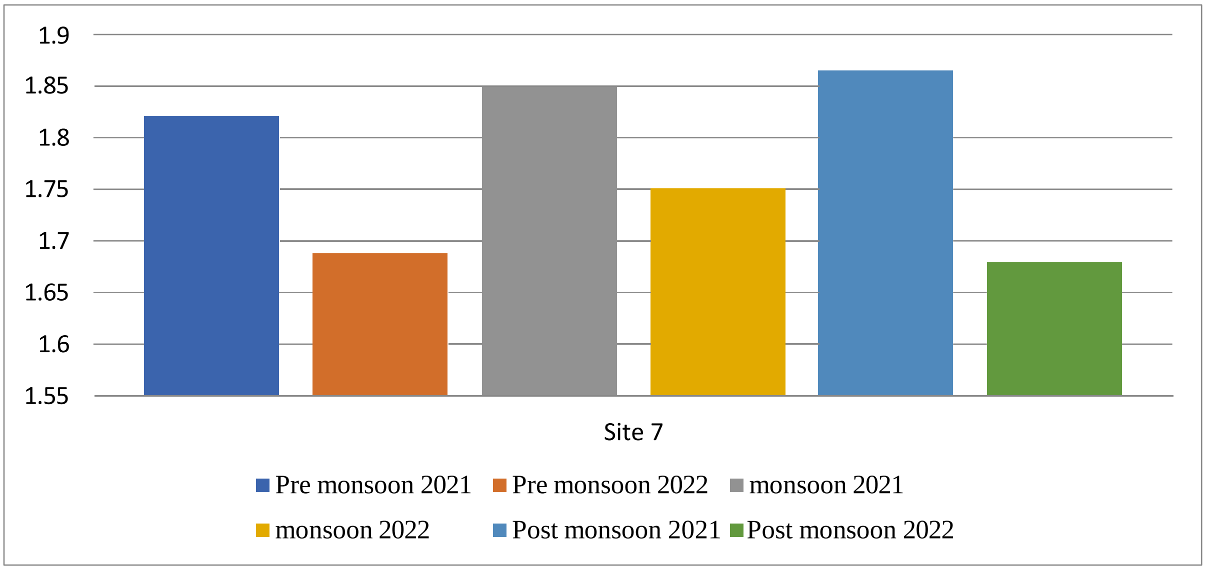


Fig. 5.5.7: The Shannon index of Site -7 Chandrabani in 2021-22

At site - 7 the value of Shannon index varies from 1.68 to 1.865. The value fluctuates between 1.821 to 1.688 in pre monsoon period, between 1.846 to 1.756 in monsoon and between 1.865 to 1.68 in post monsoon period.

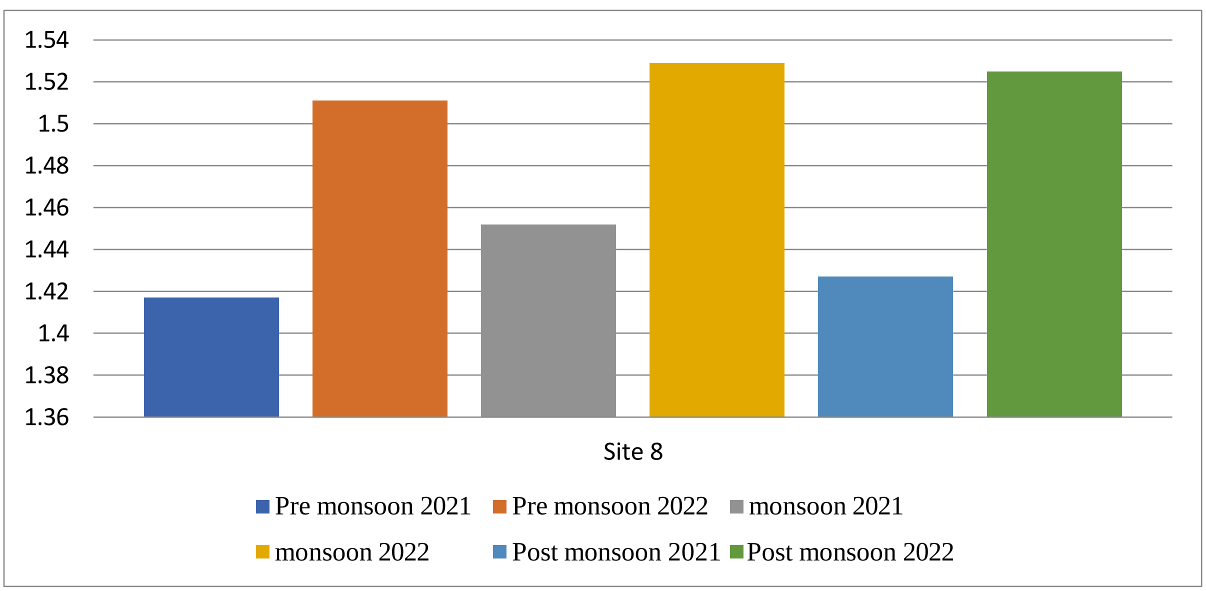


Fig. 5.5.8 : The Shannon index of Site -8 Jollygrant in 2021-22

At site – 8 the value of Shannon index varies from 1.417 to 1.529. The value fluctuates between 1.417 to 1.511 in pre monsoon period, between 1.452 to 1.529 in monsoon and between 1.427 to 1.525 in post monsoon period.

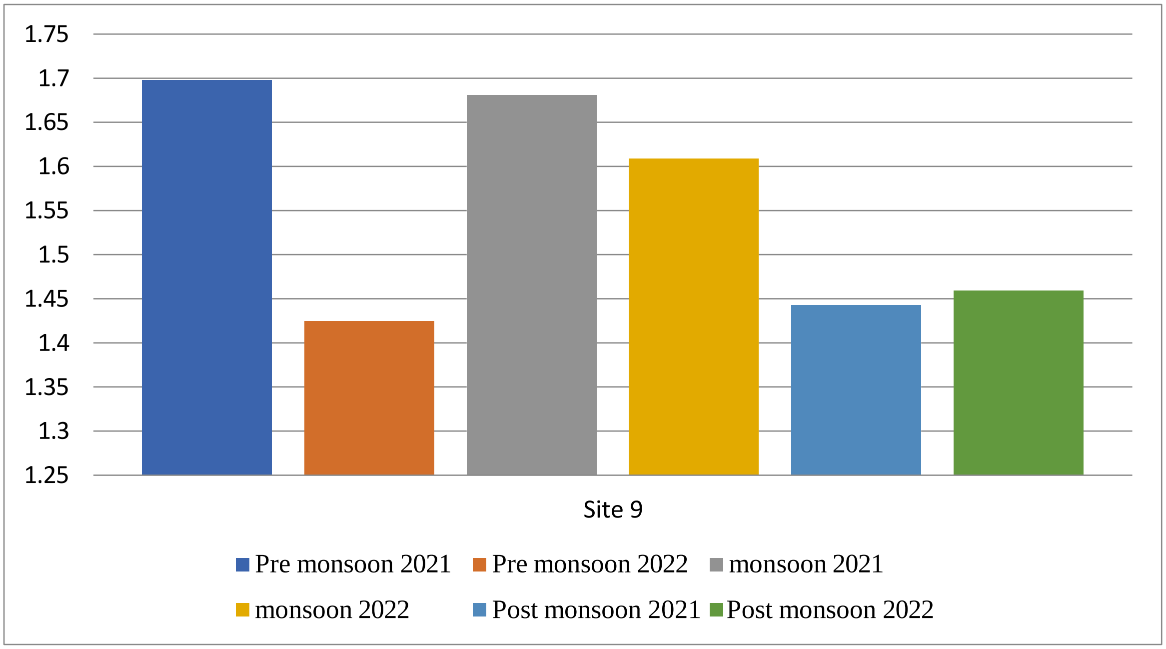


Fig. 5.5.9 : The Shannon index of Site -9 Selaqui in 2021-22

At site – 9 the value of Shannon index varies from 1.425 to 1.698. The value fluctuates between 1.698 to 1.425 in pre monsoon period, between 1.681 to 1.609 in monsoon and between 1.443 to 1.459 in post monsoon period.

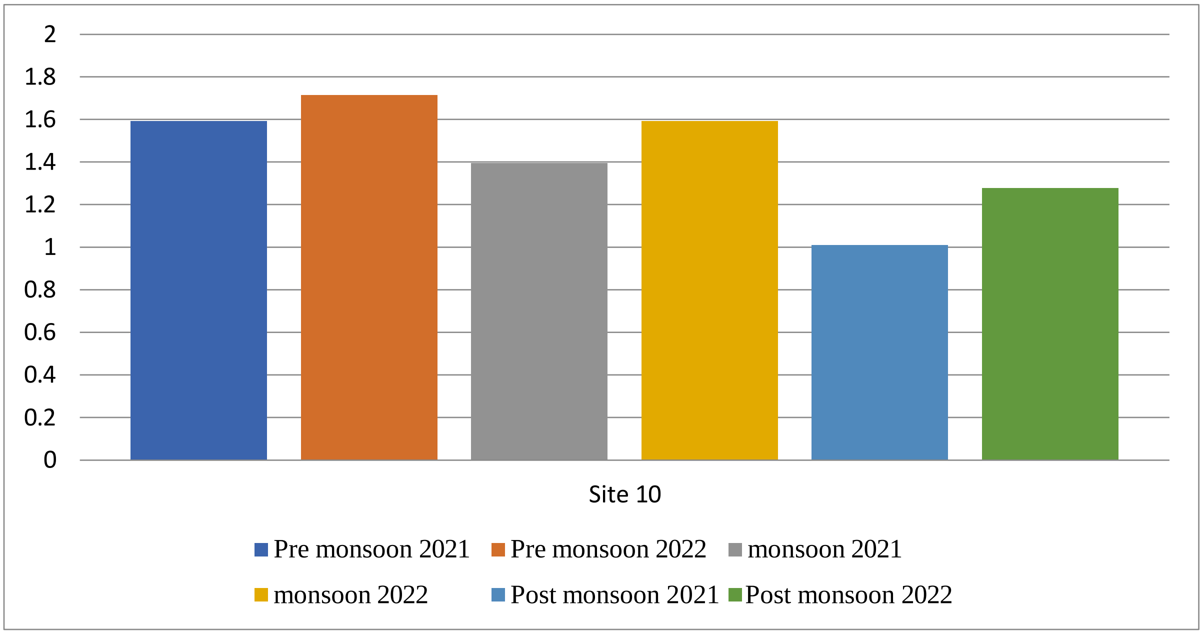


Fig. 5.5.10 : The Shannon index of Site 10 Benog Wildlife Sanctuary in 2021-22

At site – 10 the value of Shannon index varies from 1.009 to 1.593. The value fluctuates between 1.593 to 1.715 in pre monsoon period, between 1.394 to 1.593 in monsoon and between 1.009 to 1.277 in post monsoon period.

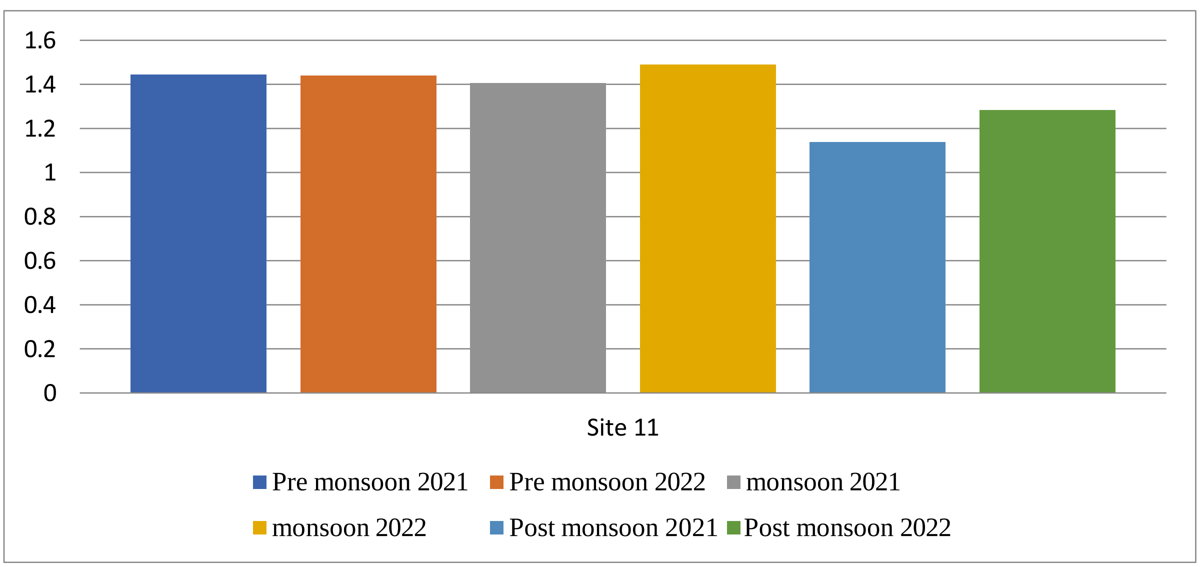


Fig. 5.5.11: The Shannon index of Site 11 Koruwa in 2021-22

At site – 11 the value of Shannon index varies from 1.137 to 1.490. The value fluctuates between 1.443 to 1.440 in pre monsoon period, between 1.405 to 1.490 in monsoon and between 1.137 to 1.282 in post monsoon period.

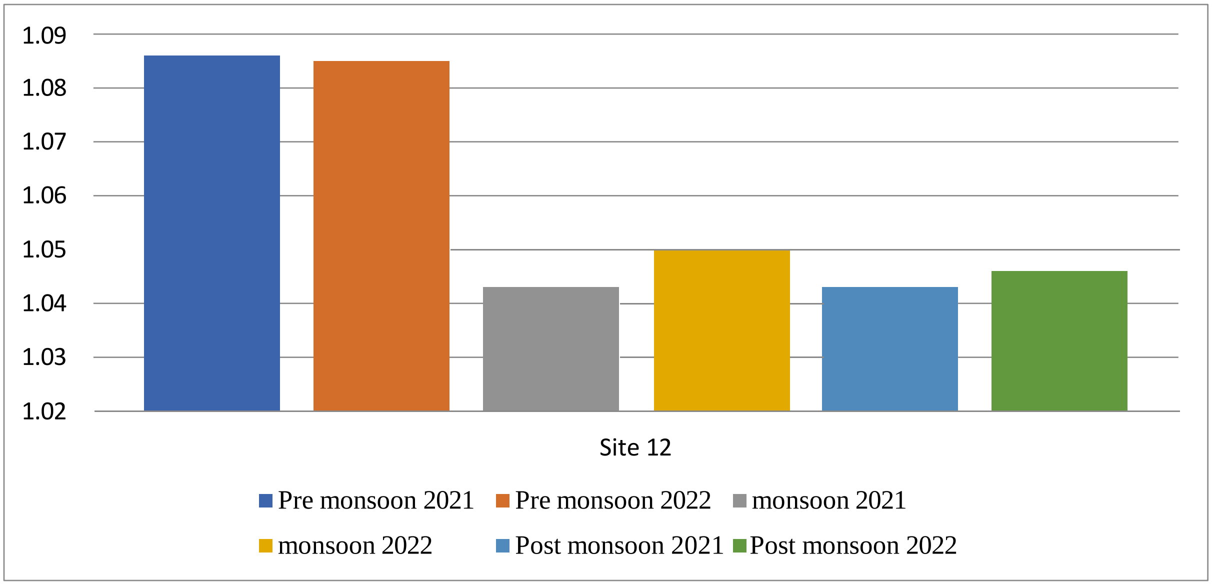


Fig. 5.5.12: The Shannon index of Site-12 Mohand in 2021-22

At site – 12 the value of Shannon index varies from 1.043 to 1.086. The value fluctuates between 1.086 to 1.085 in pre monsoon period, between 1.043 to 1.049 in monsoon and between 1.043 to 1.046 in post monsoon period.

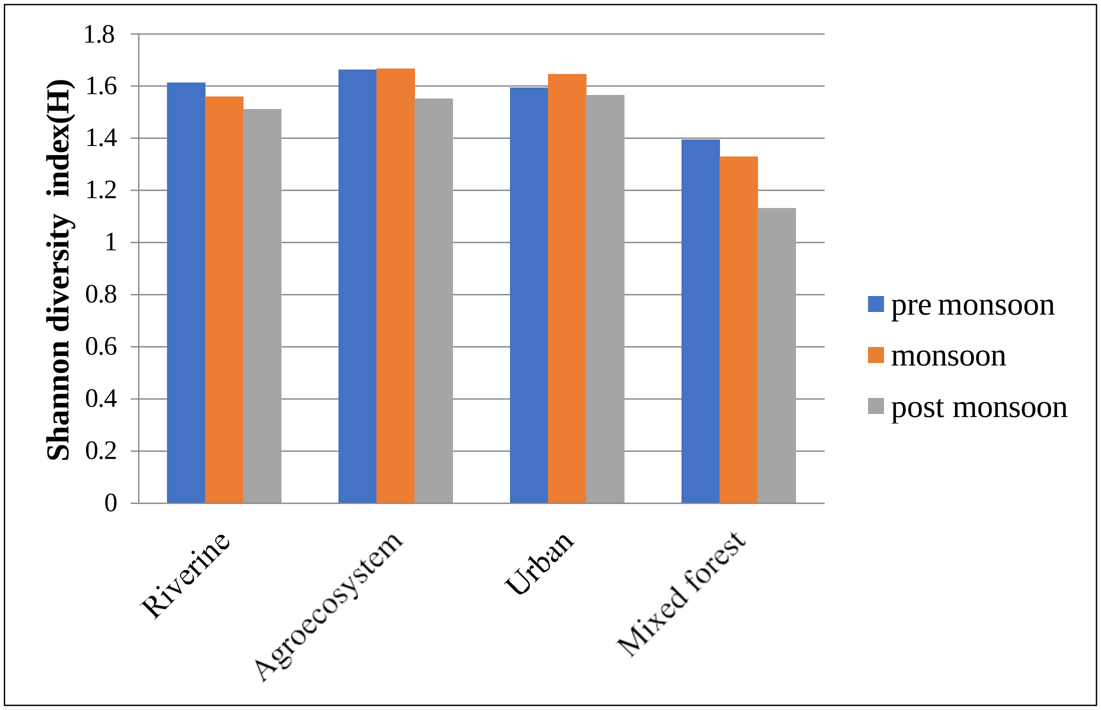


Fig. 5.5.13: Shannon diversity index (H) of bees in different habitats during different seasons in 2021-2022

During the study time (2021-2022), Shannon diversity index in riverine areas shows highest bee diversity (1.61) during pre monsoon season and least diversity (1.50) during post monsoon season. In agroecosystem highest bee diversity (1.65) is shown during both pre monsoon and monsoon season and low diversity (1.55) during post monsoon season. Urban areas shows maximum diversity (1.64) during monsoon season and least diversity (1.57) during post monsoon season whereas mixed forest shows highest diversity (1.40) during pre monsoon season and least diversity (1.13) during post monsoon season.

5.6. The Simpsons index (1-D)

The value of Simpson index ranges from 0-1, where 0 represents infinite diversity and 1 represents no diversity, so the larger the value of D, the lower the diversity. The Simpsons value varies from 0.5571 to 0.8356 in the study area which indicates that all the habitats support relatively moderate diversity of the species.

Table 5.6.1: The Simpson index value in 2021-22

Simpson_1-D	Pre monsoon 2021	pre monsoon 2022	monsoon 2021	monsoon 2022	Post monsoon 2021	Post monsoon 2022
Site 1	0.7856	0.6955	0.7954	0.6999	0.7462	0.6688
Site 2	0.8263	0.7535	0.7104	0.7518	0.7027	0.7723
Site3	0.7031	0.7273	0.7541	0.7297	0.7494	0.7281
Site4	0.7909	0.7435	0.8069	0.7833	0.7685	0.7003
Site 5	0.7756	0.7792	0.7877	0.7726	0.753	0.7717
Site 6	0.7788	0.8036	0.7657	0.7887	0.706	0.7772
Site 7	0.8195	0.7825	0.8235	0.8003	0.8356	0.7787
Site 8	0.7022	0.7379	0.7132	0.7414	0.715	0.7421
Site 9	0.7798	0.7052	0.7741	0.755	0.7051	0.6989
Site 10	0.7601	0.786	0.7101	0.7568	0.5571	0.6713
Site 11	0.7103	0.7099	0.7044	0.7248	0.6472	0.6648
Site 12	0.6584	0.6579	0.633	0.6363	0.6328	0.6302

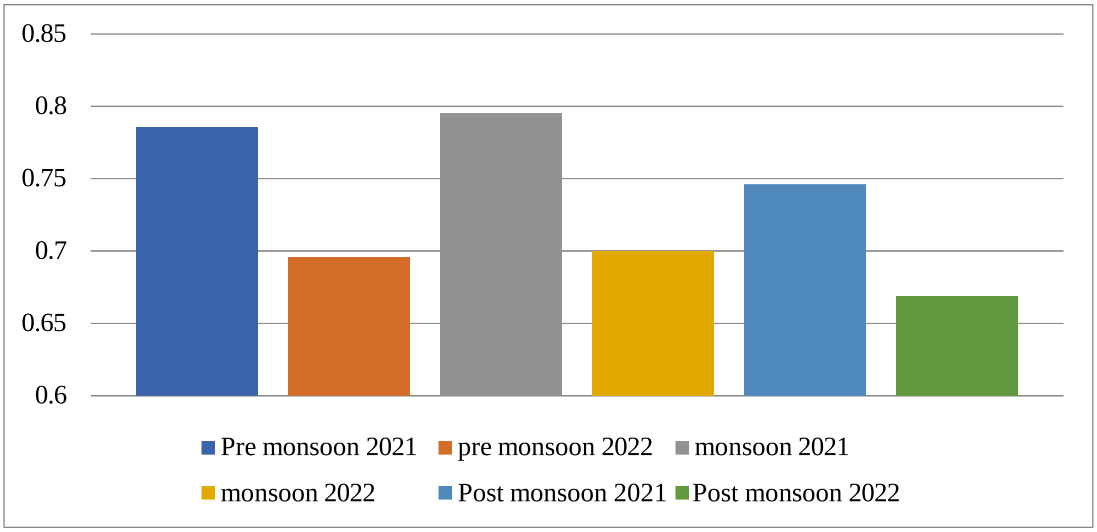


Fig. 5.6.1: The Simpson index of site 1- Bajawala in 2021-22

At the site- 1 the value of Simpson index varies from 0.6688 to 0.7954. The value fluctuates between 0.7856 to 0.6955 in the pre monsoon period, between 0.7954 to 0.6999 in the monsoon and between 0.7462 to 0.6688 in the post monsoon period.

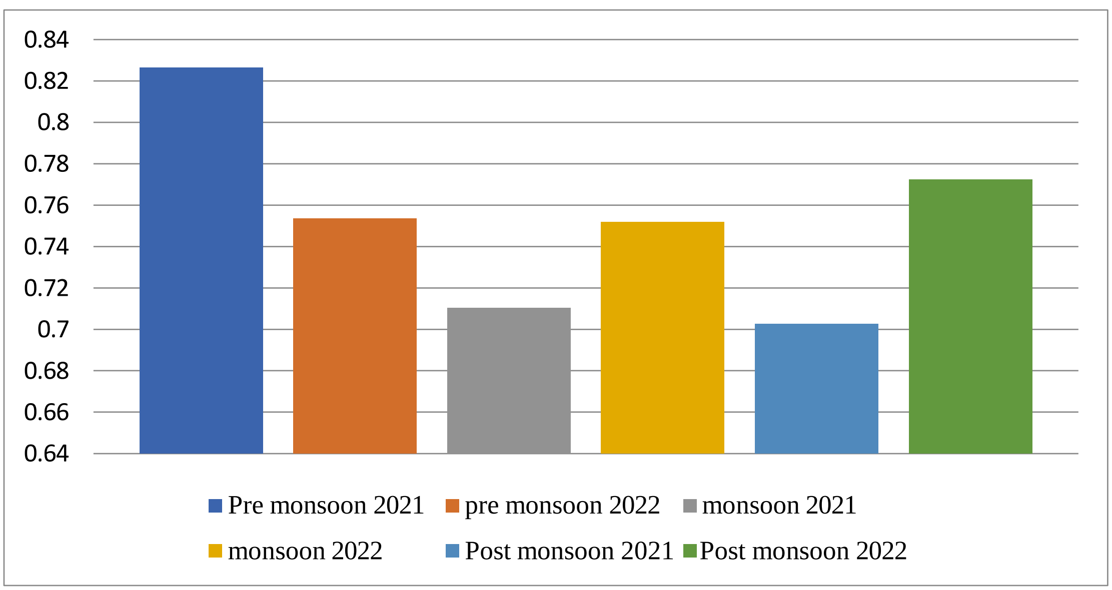


Fig. 5.6.2: The Simpson index of site 2- Sahasradhara in 2021-22

At the site- 2 the value of Simpson index varies from 0.7027 to 0.8263. The value fluctuates between 0.8263 to 0.7535 in the pre monsoon period, between 0.7104 to 0.7518 in the monsoon and between 0.7027 to 0.7723 in the post monsoon period.

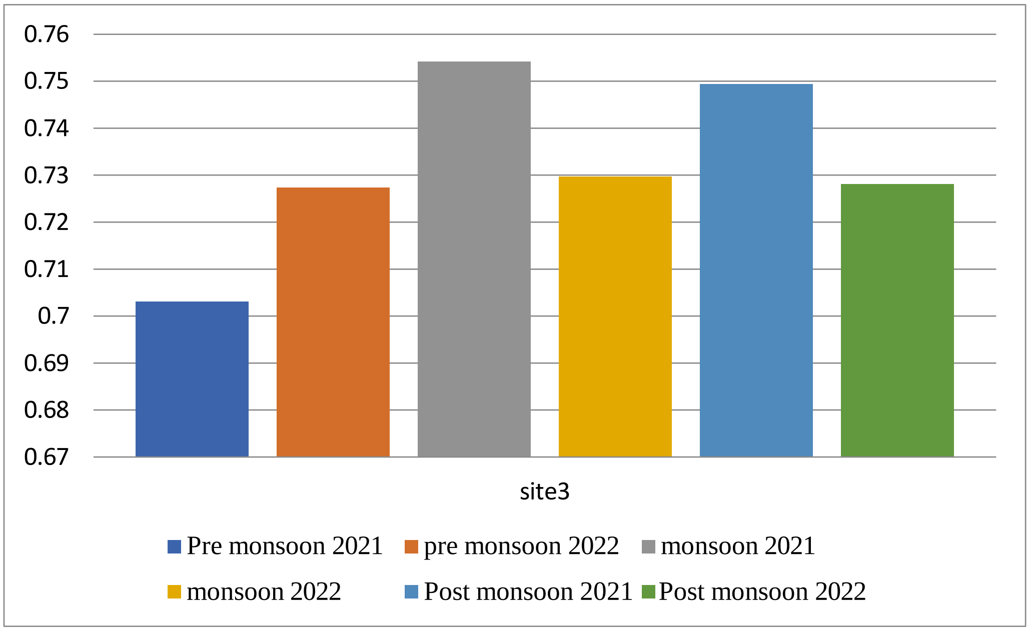


Fig. 5.6.3: The Simpson index of site 3- Tiuni in 2021-22

At the site- 3 the value of Simpson index varies from 0.7031 to 0.7541. The value fluctuates between 0.7031 to 0.7273 in the pre monsoon period, between 0.7541 to 0.7297 in the monsoon and between 0.7494 to 0.7281 in the post monsoon period.

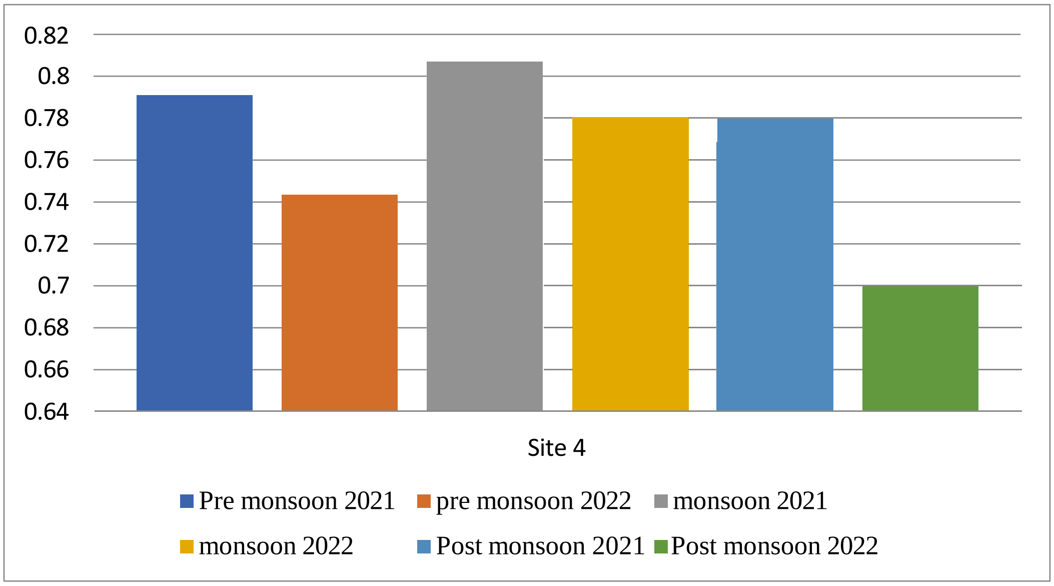


Fig. 5.6.4: The Simpson index of site 4- Jadi in 2021-22

At the site- 4 the value of Simpson index varies from 0.7003 to 0.8069 . The value fluctuates between 0.7909 to 0.7435 in the pre monsoon period, between 0.8069 to 0.7833 in the monsoon and between 0.7685 to 0.7003 in the post monsoon period.

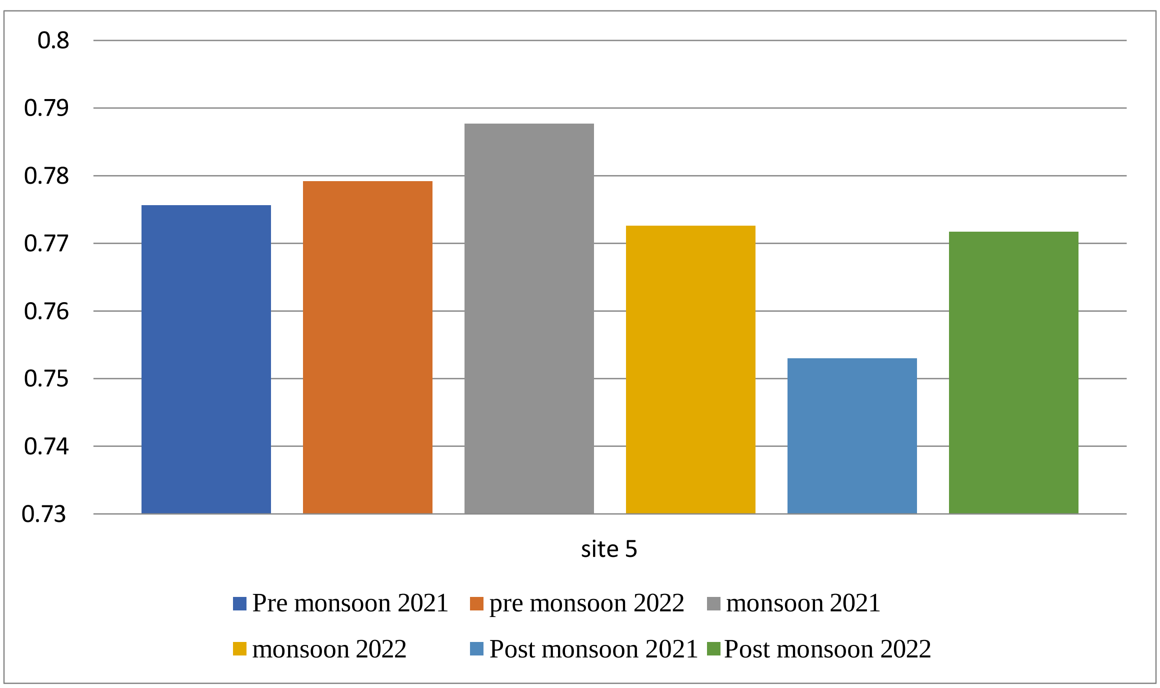


Fig. 5.6.5 : The Simpson index of site 5- Tea estate in 2021-22

At the site- 5 the value of Simpson index varies from 0.753 to 0.7877. The value fluctuates between 0.7756 to 0.7792 in the pre monsoon period, between 0.7877 to 0.7726 in the monsoon and between 0.753 to 0.7717 in the post monsoon period.

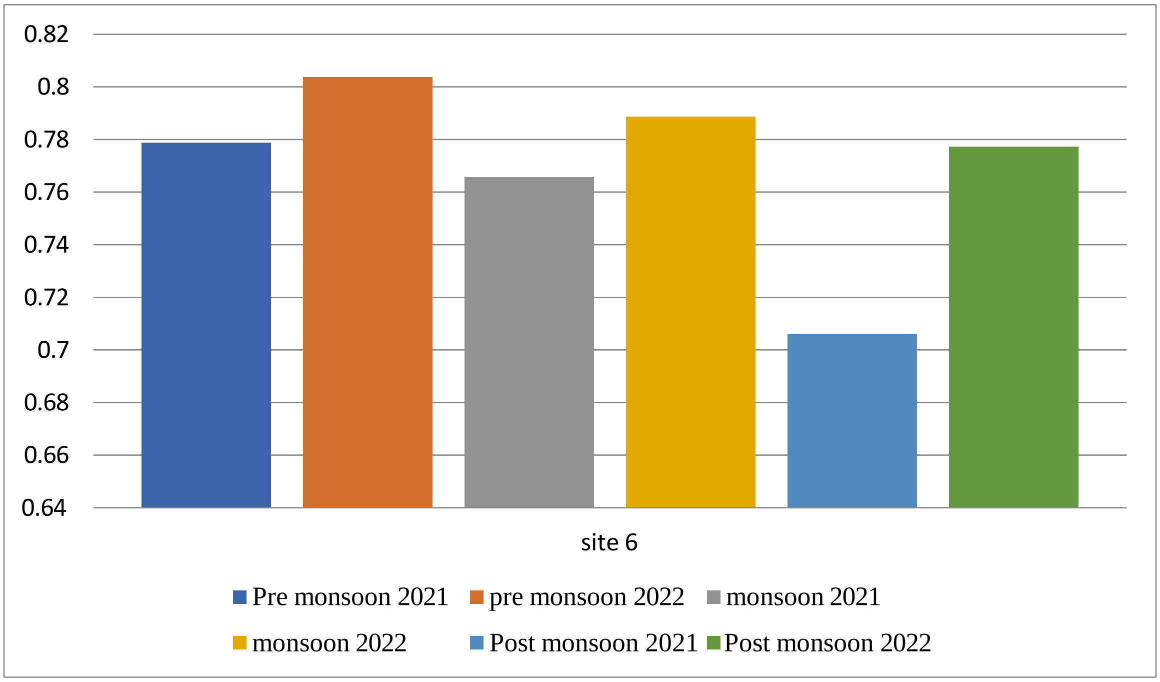


Fig. 5.6.6: The Simpson index of site 6- Thano in 2021-22

At the site- 6 the value of Simpson index varies from 0.706 to 0.8036. The value fluctuates between 0.7788 to 0.8036 in the pre monsoon period, between 0.7657 to 0.7887 in the monsoon and between 0.706 to 0.7772 in the post monsoon period.

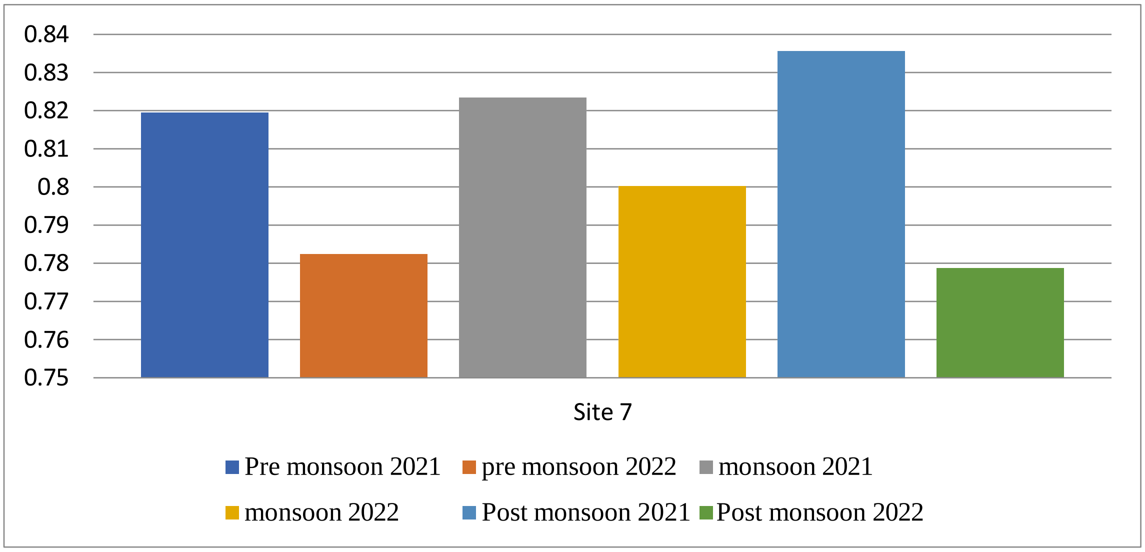


Fig. 5.6.7: The simpson index of site 7 - Chandrabani in 2021-22

At the site-7 the value of Simpson index varies from 0.7787 to 0.8356. The value fluctuates between 0.8195 to 0.7825 in the pre monsoon period, between 0.8235 to 0.8003 in the monsoon and between 0.8356 to 0.7787 in the post monsoon period.

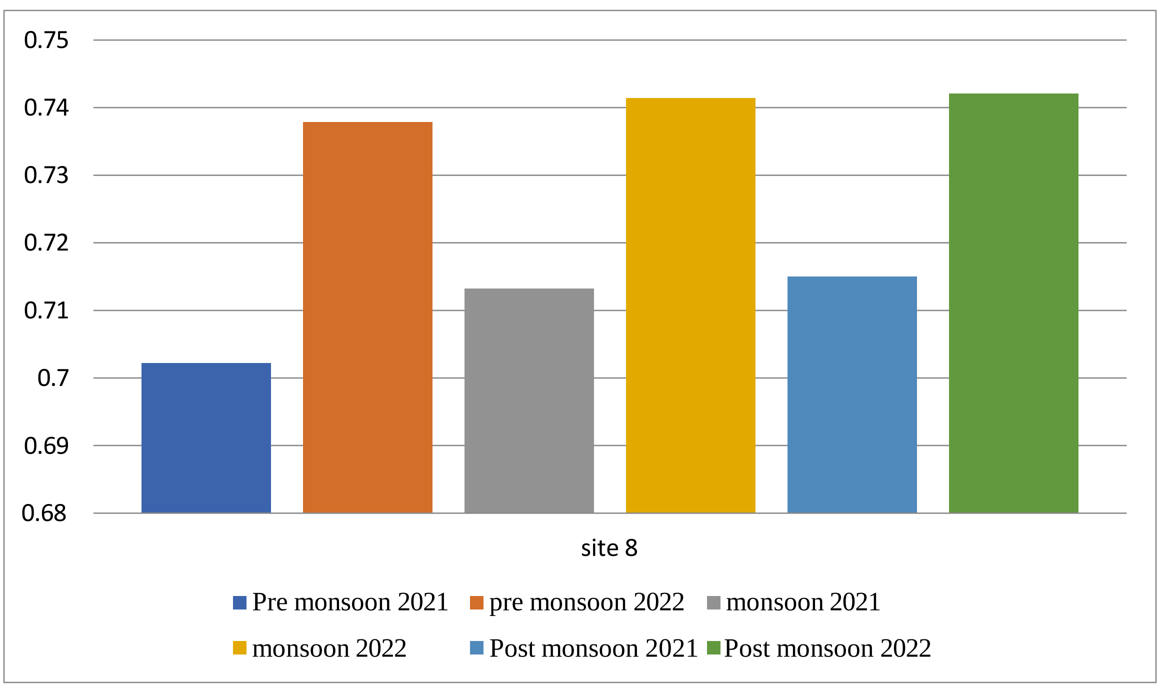


Fig. 5.6.8: The Simpson index of site 8- Jollygrant in 2021-22

At the site-8 the value of Simpson index varies from 0.7022 to 0.7421. The value fluctuates between 0.7022 to 0.7379 in the pre monsoon period, between 0.7132 to 0.7414 in the monsoon and between 0.715 to 0.7421 in the post monsoon period.

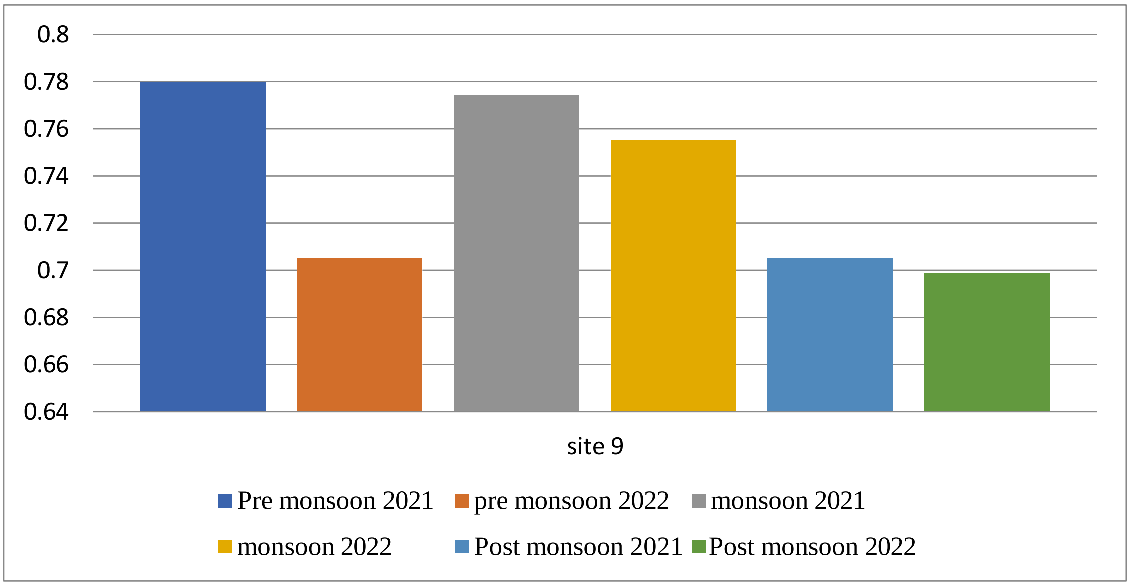


Fig. 5.6.9: The Simpson index of site 9- Selaqui in 2021-22

At the site-9 the value of Simpson index varies from 0.6989 to 0.7798. The value fluctuates between 0.7798 to 0.7052 in the pre monsoon period, between 0.7741 to 0.755 in the monsoon and between 0.7051 to 0.6989 in the post monsoon period

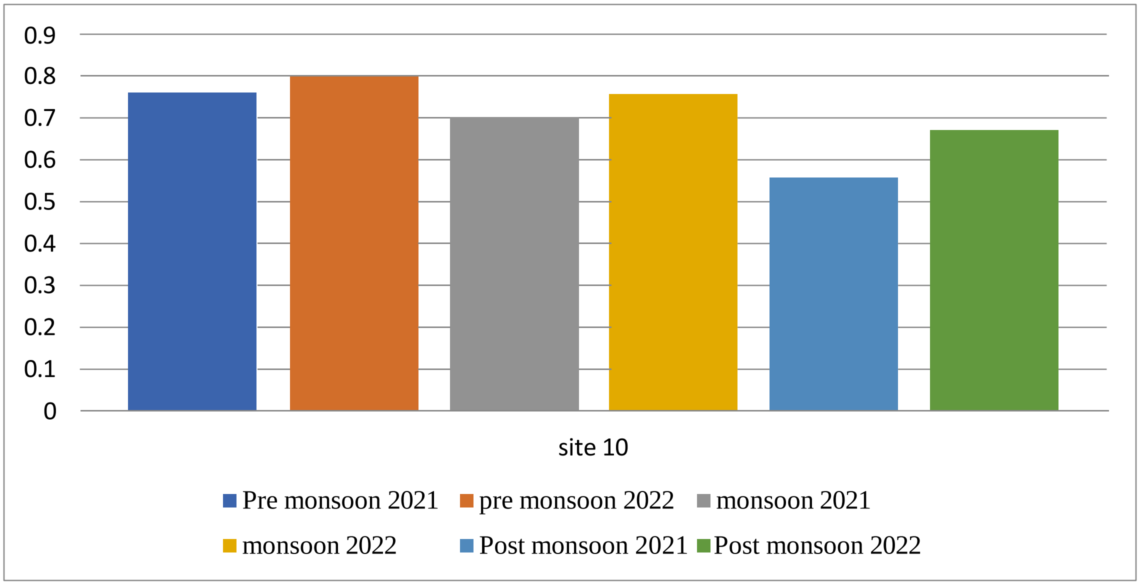


Fig. 5.6.10: The Simpson index of site 10- Benog Wildlife Sanctaury in 2021-22

At the site-10 the value of Simpson index varies from 0.5571 to 0.786. The value fluctuates between 0.7601 to 0.786 in the pre monsoon period, between 0.7101 to 0.7568 in the monsoon and between 0.5571 to 0.6713 in the post monsoon period.

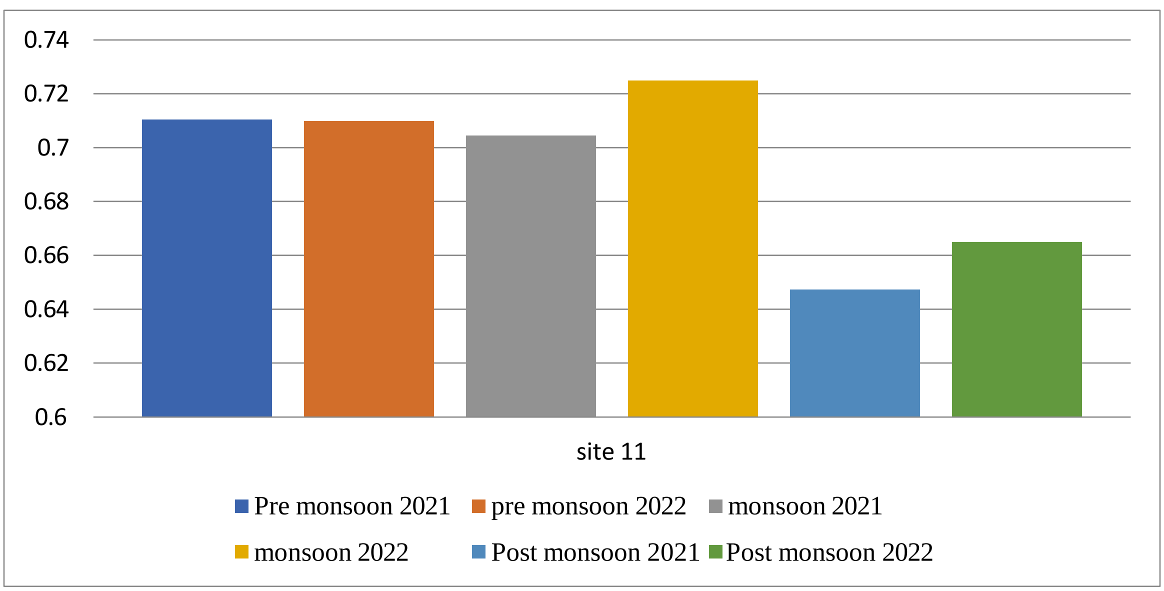


Fig. 5.6.11: The Simpson Index of site 11- Koruwa in 2021-22

At the site-11 the value of Simpson index varies from 0.6472 to 0.7248. The value fluctuates between 0.7103 to 0.7099 in the pre monsoon period, between 0.7044 to 0.7248 in the monsoon and between 0.6472 to 0.6648 in the post monsoon period.

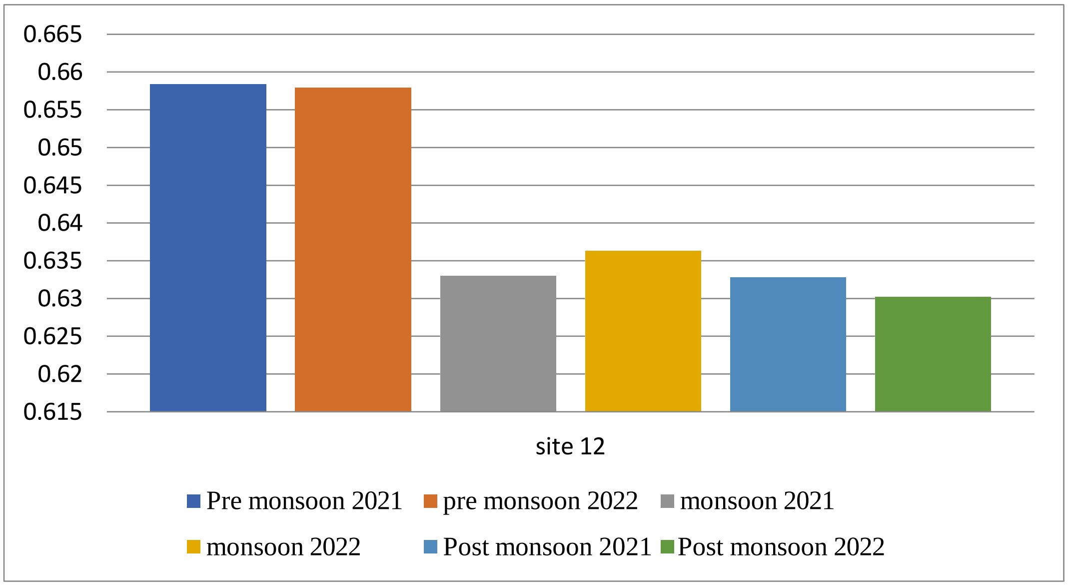


Fig. 5.6.12: The Simpson Index of site 12- Mohand in 2021-22

At the site-12 the value of Simpson index varies from 0.6302 to 0.6584. The value fluctuates between 0.6584 to 0.6579 in the pre monsoon period, between 0.6330 to 0.6363 in the monsoon and between 0.6328 to 0.6302 in the post monsoon period.

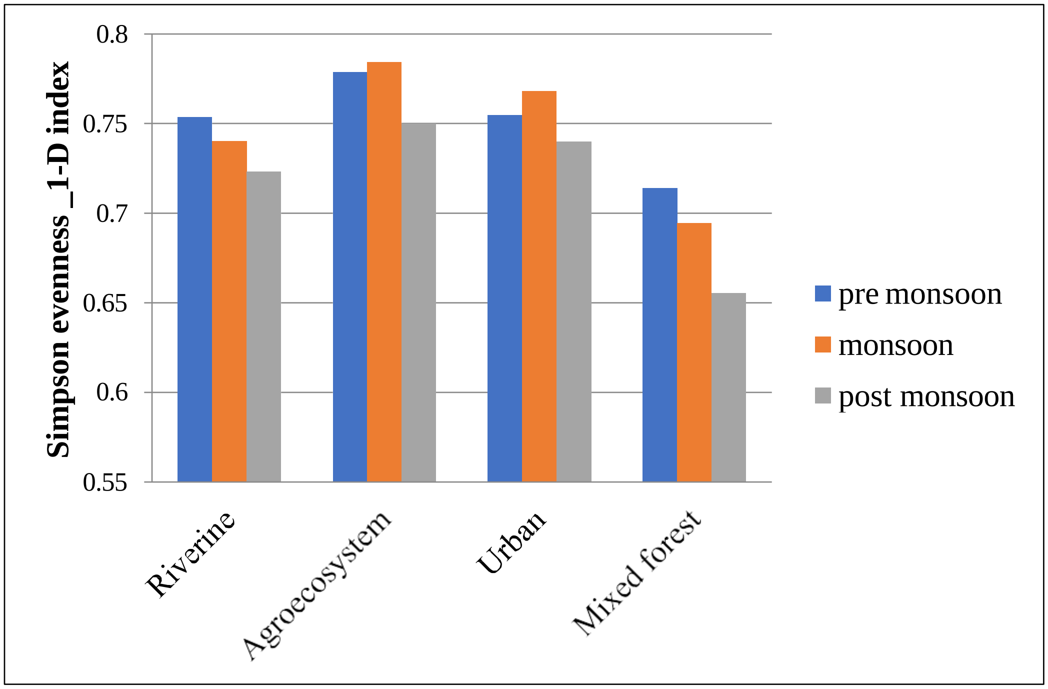


Fig. 5.6.13 : Simpson evenness _1-D index in different habitats during different seasons of 2021-2022

During study period (2021-2022) riverine areas shows gradual decline (0.75-0.72) in species distribution and evenness during pre monsoon to post monsoon season. Agaroecosystem shows highest evenness among all habitats. Monsoon season shows highest distribution and evenness index (0.79). Urban areas shows diversity index between 0.74-0.77 with maximum distribution during monsoon season. Mixed forests show least evenness index (0.65-0.71) with least distribution during post monsoon season.

Objective 2: Identification of habitats of Genus *Bombus* and *Xylocopa* particularly the availability of food plants which support high level of diversity

Pollinators are one of the key components of biodiversity. Flowering plants reproduce by means of pollination. Most of the plants need assistance from outer means for their reproduction. The means could be biotic or abiotic. Abiotic means includes air, water and biotic means includes animals, birds and insects like bees, butterflies, moths, beetles and flies. Insects are significant pollinators as they can pollinate a wide range of flowers. Among insect pollinators bees are the most significant group both ecologically and economically.

Within this group, the genera *Bombus* (bumblebees) and *Xylocopa* (carpenter bees) are characterized by their large size, their pollination efficiency, buzz pollination behavior and their generalist foraging ability. *Bombus* species are largely adapted to temperate and alpine habitat, whereas *Xylocopa* can thrive well in warmer tropical and subtropical habitats. The abundance and distribution of both *Bombus* and *Xylocopa* is largely influenced by habitat quality and availability of food plants that assure their sustainability throughout their life cycle.

5.7. Habitats of genus *Bombus* and *Xylocopa*

The study area was divided into four habitat zones viz: riverine forest, agroecosystem, urban area and mixed forest. These habitat zones further subdivided into three study locationseach. In total 1748 individuals of bumblebees were recorded from riverine areas, 2346 from agroecosystem, 684 from urban areas and 890 from mixed forest. The distribution of carpenter bees is slightly different than bumblebees. 3080 individuals of carpenter bees are recorded from riverine areas, 3770 from agroecosystem, 3718 from urban areas and 987 from mixed areas.

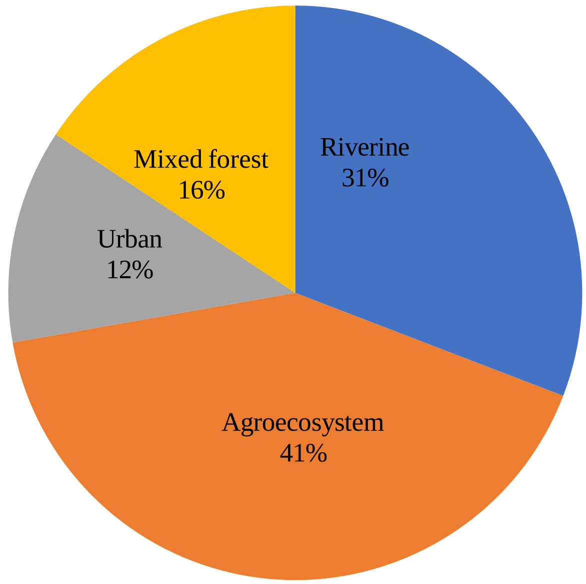


Fig. 5.7.1: Habitat wise distribution of bumblebees

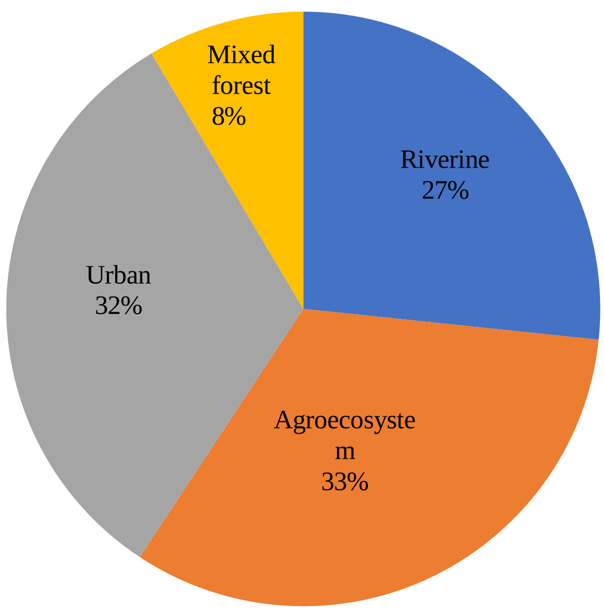


Fig. 5.7.2: Habitat wise distribution of carpenter bee

5.8. Foraging resources of genus *Bombus* and *Xylocopa*

Bees are important pollinators of both wild and cultivated plants. Both Bumblebees and carpenter bees are generalist foragers and forage on a wide range of plants for nectar and pollens. The surveys were conducted to document the preferable foraging resources of bumblebees and carpenter bees in the study area during the study period. The results showed a variety of plants identified and classified as wild, cultivated, exotic and native. Native plants are plants which are grown naturally in an area, whereas exotic plants were imported to an area from somewhere else. Wild plants can grow anywhere without any care but cultivated plants are grown in gardens, orchards, horticulture areas and agriculture fiels and need proper care.

Bees serve as the principal pollinators in most terrestrial ecosystems and play a crucial role in maintaining their structure and functioning. They also act as valuable bioindicators, reflecting the impacts of environmental and climatic changes. The presence and diversity of pollinators within an ecosystem provide important insights into its overall health. Shifts in vegetation patterns often result in alterations in community composition, leading to reduced species richness and diminished ecosystem quality. As key pollinators, bees depend on floral nectar and pollen for survival. Different bee species exhibit preferences for specific plant families, thereby supporting the pollination of a broad range of plant species.

Table. 5.8.1: Foraging resources of genus Bombus and Xylocopa

Family	Plant species	Common name	Bee sp. Visited
Acanthaceae	*Diclipteraroxburghiana*	Magenta plant	*B.haemorrhoidalis, X.fenestrata, X.aestuans*
	Justicia adhatoda	Malabar Nut	*B. haemorrhoidalis, B.trifasciatus, B. rotundiceps*
Amaranthaceae	*Gomphrena globosa*	Globe amaranth	*B. haemorrhoidalis, X. fenestrata, X.sp.nov.1*
	Celosia argentea	Silver cock's comb	*B.haemorrhoidalis*
	Calotropis gigantean	Crown flower	*X.fenestrata, X. aestuans, X. tenuiscapa, X. sp.nov.1, X.sp.nov.3*
	Calotropis procera	Apple of Sodom	*X.fenestrata, X. aestuans, X. tenuiscapa, X. sp.nov.1, X.sp.nov.3*
Apocynaceae	*Cascabelathevetia*	Yellow oleander	*X.fenestrata, X.tenuiscapa, X.sp.nov.1, X.sp.nov.3*
	Vallarissolanacea	Kuntze	*B.haemorrhoidalis,*
	Wrightia tinctoria	Dyer's oleander	*B.haemorrhoidalis, B. trifasciatus*
Asteraceae	*Aster himalaicus*	Himalayan aster	*B. haemorrhoidalis, X. fenestrata,*
	Carduus edelbergii	Edelberg or cotton thistle	*B. haemorrhoidalis*
	Carduus nutans	Musk thistle	*B. haemorrhoidalis*
Asteraceae	*Cirsium arvense*	Creeping thistle	*B. haemorrhoidalis, B. trifasciatus, B.rotundiceps*
	Cosmos sulphureus	Sulphur cosmos	*X.fenestrata, X.sp.nov.1*
	Dahlia variabilis	Dahlia	*B. haemorrhoidalis, X. fenestrata, X.aestuans*

	Leucanthemum vulgare	Oxeye daisy	*B. haemorrhoidalis*
	Matricaria chamomilla	German chamomile	*B.haemorrhoidalis, B.trifasciatus*
Balsaminaceae	*Impatiens glandulifera*	Himalayan balsam	*B. haemorrhoidalis, X. fenestrata, X aestuans, X.sp.nov.1, X.sp.nov.3*
Berberidaceae	*Berberis lycium*	Indian berberry	*B.haemorrhoidalis, B. trifasciatus, B. flavescens, X.sp.nov.2*
	Berberis chitria	Daruharidra	*B.haemorrhoidalis, B. trifasciatus, B. flavescens, X.sp.nov.2*
Bignoniaceae	*Monosaalliacea*	Garlic vine	*X. fenestrata, X. aestuans, X.tenuiscapa, X.sp.nov.3*
	Tecoma stans	Yellow elder	*B. haemorrhoidalis*
Convolvulaceae	*Ipomoea nil*	Morning glory	*B.haemorrhoidalis, X.fenestrata, X. aestuans, X.sp.nov.1, X.sp.nov.3*
Cucurbitaceae	*Cucumis sativus*	Cucumber	*B. haemorrhoidalis, X. fenestrata, X. aestuans, X. tenuiscapa, X.sp.nov.1, X.sp.nov.3*
	Cucurbita pepo	Pumpkin	*B haemorrhoidalis, X. fenestrata, X aestuans, X. tenuiscapa, X.sp.nov.1, X.sp.nov.3*
	Calabash	Bottle gourd	*B haemorrhoidalis, X. fenestrata, X. aestuans, X. tenuiscapa, X.sp.nov.1, X.sp.nov.3*
	Luffa acutangula	Sponge gourd	*B. haemorrhoidalis, X. fenestrata, X. aestuans, X. tenuiscapa, X.sp.nov.1, X.sp.nov.3*
Ericaceae	*Rhododendron*	Burans	*B. haemorrhoidalis, B. trifasciatus*
	Punica granatum	Pomegranate	*B.haemorrhoidalis, B.trifasciatus*
Fabaceae	*Bauhinia variegata*	Kachnar	*B.haemorrhoidalis*
	Cassia fistula	Golden shower	*B. haemorrhoidalis*

	Phaseolus vulgaris	common bean	*B. haemorrhoidalis, X. fenestrata, X.tenuiscapa, X.nasalis, X.sp.nov.1, X.sp.nov.3*
	Senna occidentalis	Coffee senna	*B.haemorrhoidalis, B.rotundiceps*
	Trifolium pratense	Red clover	*B. haemorrhoidalis, X. fenestrata, X. aestuans, X.sp.nov.1, X.sp.nov.3*
	Trifolium rubens	Ruddy clover	*B. haemorrhoidalis, X. fenestrata, X. aestuans, X.sp.nov.1, X.sp.nov.3*
	Vicia faba	Shivchane, bakla	*B.haemorrhoidalis*
Hypericaceae	*Hypericum subalatum*	Subalpine St. John's wort	*B.haemorrhoidalis*
	Anisomeles indica	Cat mint	*B. haemorrhoidalis, B. flavescens, B. trifasciatus*
Lamiaceae	*Lamium album*	White dead nettle	*B. haemorrhoidalis, B.flavescens, B.trifasciatus*
	Salvia officinalis	Sage	*B. haemorrhoidalis*
	Phlomis sp.	-	*B. haemorrhoidalis, X. fenestrata*
	Prunella vulgaris	Common self heal	*B. haemorrhoidalis, X. aestuans, X.sp.nov.1*
	Leucas aspera	Thumba	*X. fenestrata, X.nasalis, X.sp.nov.1*
	Lagerstroemia floribunda	Thai crepe myrtle	*X.fenestrata, X.tenuiscapa, X.aestuans, X.nasalis, X.sp.nov.1, X.sp.nov.3*
Lythraceae	*Lagerstroemia speciosa*	Queens crepe myrtle	*X.fenestrata, X.tenuiscapa, X.aestuans, X.nasalis, X.sp.nov.1, X.sp.nov.3*
	Abelmoschus esculentus	Lady finger, Okra	*X. fenestrata, X. aestuans, X.nasalis, X.sp.nov.1*
Malvaceae	*Hibiscus rosa sinensis*	China rose	*X. fenestrata, X. tenuiscapa*

	Hibiscus lobatus	Lobed leaf mallow	*X. fenestrata*
	Sida cordifolia	Heartleaf sida	*B.haemorrhoidalis*
	Sida rhombifolia	Arrowleafsida	*B.haemorrhoidalis*
Myrtaceae	*Psidium guajava*	Guava	*B.haemorrhoidalis*
Onagraceae	*Oenothera biennis*	Common evening primrose	*B.haemorrhoidalis, X. fenestrata*
Papaveraceae	*Argemone mexicana*	Prickly poppy	*B.haemorrhoidalis, B.flavescens*
Pedaliaceae	*Sesamum radiatum*	Black sesame	*X. fenestrata, X.aestuans, X.sp.nov.1, X.sp.nov.3*
Ranunculaceae	*Ranunculus repens*	Creeping buttercup	*B.haemorrhoidalis, B. trifasciatus, B. flavescens*
	Malus domestica	Apple	*B.haemorrhoidalis, B.flavescens, B.trifasciatus*
Rosaceae	*Rosa moschata*	Musk rose	*B.haemorrhoidalis, B.flavescens, B.trifasciatus*
	Rosa alba	White rose	*B.haemorrhoidalis*
Rutaceae	*Citrus limon*	Lemon	*B.haemorrhoidalis*
	Lycopersicon esculentum	Tomato	*B.haemorrhoidalis, X.fenestrata, X.aestuans, X.sp.nov.1*
Solanaceae	*Solanum melongena*	Brinjal	*B. haemorrhoidalis, X. fenestrata, X.sp.nov.1*
	Solanum nigrum	Black nightshade	*B.haemorrhoidalis, X.fenestrata, X.sp.nov.1, X.sp.nov.3*
	Solanum torvum	Turkey berry	*B. haemorrhoidalis, X. fenestrata, X.sp.nov.1, X.sp.nov.3*

	Solanum tuberosum	Potato	*B.haemorrhoidalis, X.sp.nov.1*
Tropaeolaceae	*Tropaeolum majus*	Nasturtium	*B. haemorrhoidalis, B.rotundiceps*
Verbenaceae	*Lantana camara*	Wild sage	*B. haemorrhoidalis*

Plate No- 10: Bumblebee Foraging plants

Bombus on *Cassia fistula*

Bombus on *Cucurbita pepo*

Bombus on *Tropaeolum majus*

Bombus on *Luffa acutangula*

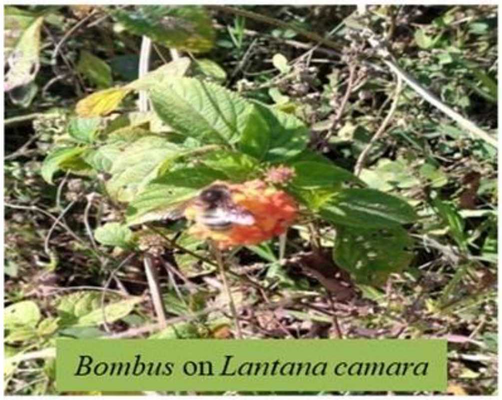
Bombus on *Cirsium arvense*

Bombus on Citrus limon

Bombus on *Rosa alba*

Bombus on *Tecoma stans*

Plate No- 11: Bumblebee Foraging plants



Bombus on *Lantana camara*

Bombus on *Senna occidentalis*

Bombus on *Justicia adhatoda*

Bombus on Solanum melongena

Bombus on Vicia faba

Bombus on Psidium guajava

Bombus on *Oenothera biennis*

Bombus on *Carduus nutans*

Table.5.8.2: Plant families and the no. of *Bombus* sp. foraging on them

	Plant Family	No. of foraging Bombus species
1	Acanthaceae	3
2	Amaranthaceae	1
3	Apocynaceae	2
4	Asteraceae	2
5	Balsaminaceae	1
6	Berberidaceae	3
7	Bignoniaceae	1
8	Convolvulaceae	1
9	Cucurbitaceae	1
10	Ericaceae	2
11	Fabaceae	1
12	Hypericaceae	1
13	Lamiaceae	3
14	Malvaceae	1
15	Myrtaceae	1
16	Papavaraceae	2
17	Ranunculaceae	3
18	Rosaceae	3
19	Rutaceae	1
20	Solanaceae	1
21	Tropaeolaceae	2
22	Verbenaceae	1

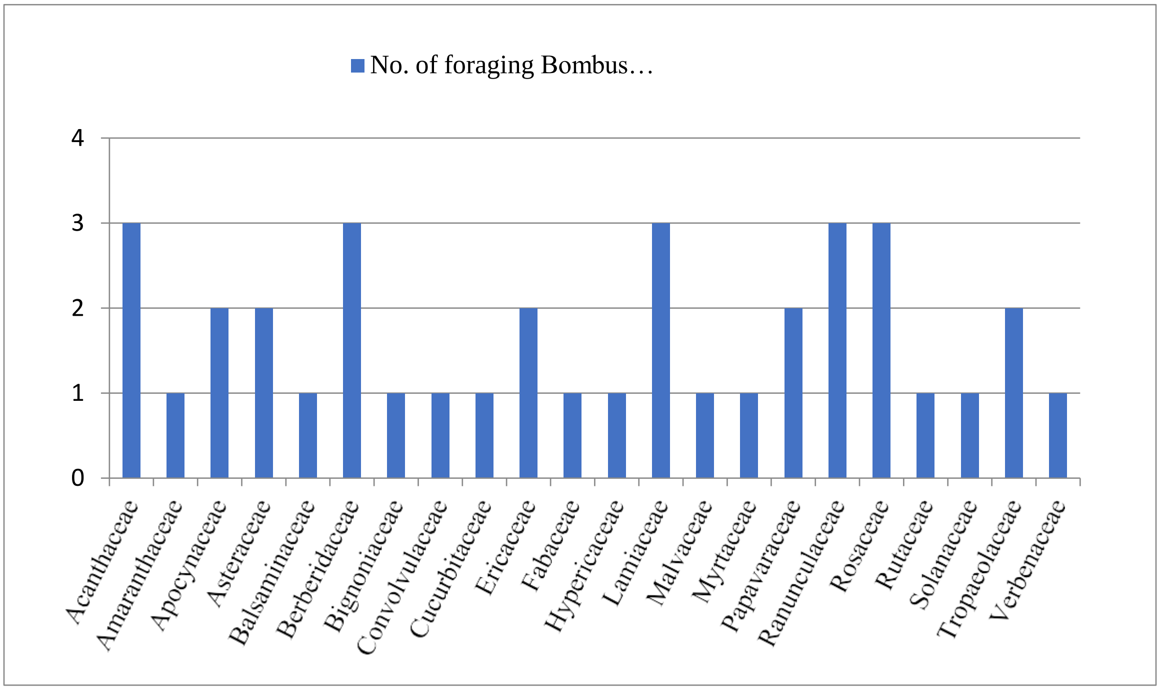


Fig.. 5.8.1: No of *Bombus* sp. foraging on different plant families

In total 22 preferred foraging plant families were recorded for 4 *Bombus* species. Plant families with the highest association with 3 species each are Acanthaceae, Berberidaceae, Lamiaceae, Ranunculaceae and Rosaceae. 12 plant families (Amaranthaceae, Balsaminaceae, Bignoniaceae, Convolvulaceae, Cucurbitaceae, Fabaceae, Hypericaceae, Malvaceae, Myrtaceae, Rutaceae, Solanaceae and Verbenaceae) were visited by single *Bombus* species, 5 plant families (Apocynaceae, Asteraceae, Ericaceae, Papavaraceae and Tropaeolaceae) were visited by 2 *Bombus* species.

The most preferred plants for Bombus are *Cirsium arvens*, *Lantana* sp., *Justicia adhatoda*, Nasturtium and plants of Cucurbitaceae family (*Cucumis sativus*, *Cucurbita pepo*, *Calabash* and *Luffa acutangula)* and Fabaceae family (*Bauhinia variegata*, *Cassia fistula*, *Senna occidentalis and Vicia faba).*

Plate No- 12: *Xylocopa* Foraging plants

Xylocopa on *Calotropis gigantean*

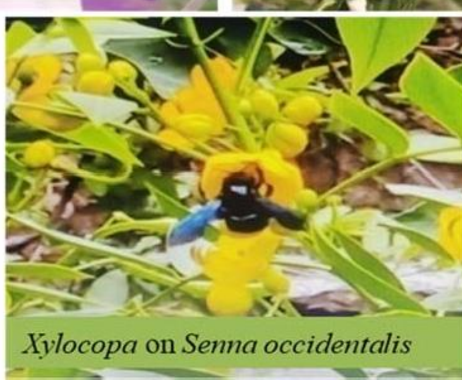
Xylocopa on *Luffa acutangula*

Xylocopa on *Phaseolus vulgaris*

Xylocopa on *Oenothera biennis*

Xylocopa on *Monosa alliacea*

Xylocopa on Solanum torvum



Xylocopa on *Senna occidentalis*

Table.5.8.3: Plant families and the no. of *Xylocopa* sp. foraging on them

	Plant families	**No. of foraging Xylocopa species**
1	Acanthaceae	1
2	Amaranthaceae	2
3	Apocynaceae	5
4	Asteraceae	3
5	Balsaminaceae	4
6	Berberidaceae	1
7	Bignoniaceae	4
8	Convolvulaceae	4
9	Cucurbitaceae	5
10	Fabaceae	5
11	Lamiaceae	4
12	Lythraceae	6
13	Malvaceae	5
14	Onagraceae	1
15	Pedaliaceae	4
16	Solanaceae	4

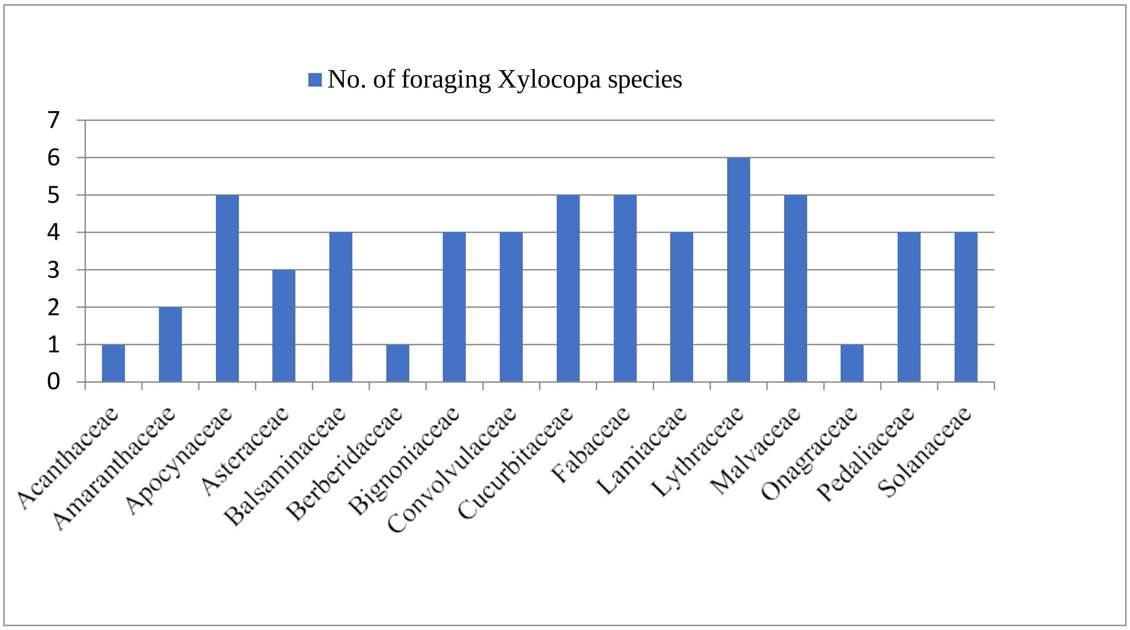


Fig. 5.8.2: No of *Xylocopa* sp. foraging on different plant families

For 7 species of Xylocopa 16 prefereed foraging plant familiesare recorded. Plant family which was visited by maximum no. of *Xylocopa* species i.e. 6 is Lythraceae(preferred foraging plants are *Lagerstroemia floribund a* and *Lagerstroemia speciosa).* Plant families visited by 5 *Xylocopa* species are Apocynaceae (preferred foraging plants are *Calotropis gigantean* and *Calotropis procera),* Cucurbitaceae (preferred foraging plants are *Cucumis sativus, Cucurbita pepo, Calabash* and *Luffa acutangula),* Fabaceae (preferred foraging plant is *Phaseolus vulgaris)*and Malvaceae (preferred foraging plant is *Abelmoschus esculentus).*

In total 25 plant families and 66 plant species are recorded as preferred foraging plants for Bombus and Xylocopa species. Out of that 22 families are recorded for *Bombus* and 16 are recorded for *Xylocopa* species.

Objective 3: Molecular identification and DNA barcoding of the collected samples from the study area

Molecular studies have become a fundamental component of modern biological research, offering insights that surpass the limitations of traditional morphological and ecological approaches. Molecular research has become essential for advancing knowledge of bee biology, ecology, and conservation. Genetic and genomic tools allow researchers to investigate questions that are difficult or impossible to resolve through morphology or field observations alone. Accurate identification of bee species is often complicated by morphological similarities and the presence of cryptic species. Molecular markers, particularly DNA barcoding based on the mitochondrial COI gene**,** provide a reliable means of distinguishing species and clarifying ambiguous classifications (Hebert *et.al*., 2003; Packer *et.al*., 2009). This approach is especially valuable for documenting bee biodiversity in underexplored tropical regions, where species richness is high and traditional taxonomy may be limited.

Molecular approaches are invaluable in **assessing** genetic diversity, population structure, and gene flowwithin and among bee populations. This information is critical for conservation, particularly in the face of threats such as habitat loss, fragmentation, and climate change (Estoup*et.al.*,1995; Zayed,2009). By identifying genetically distinct populations and levels of inbreeding, molecular studies guide strategies for maintaining the long-term viability of both wild and managed bee species.

In the present study mitochondrial gene fragments of Cytochrome Oxidase subunit 1 (CO1) was amplified and sequenced. COI gene is widely accepted marker for DNA barcoding as it provides a universal standardized method for species identification, differentiation and biodiversity assessment. It can be amplified from almost all animal species and the gene's mutation rate is very high enabling clear species level discrimination. A specific length (around 650bp) is used for the universal DNA barcode, providing a standard fragment length for comparison. Being a mitochondrial gene, it is present in multiple copies within each cell, increasing the chance of successful DNA extraction and amplification, even from degraded samples (Avise, 2000).

Total 75 samples of bumblebees and carpenter bees were processed for sequencing. Of these 43 sequences were generated for bumblebee and carpenter bees. Among 50 bumblebee samples processed for DNA sequencing, 30 sequences could be generated. Of these 26 sequences were generated for *Bombus haemorrhoidalis* (PP256389- PP256414), 1 sequence was generated for *Bombus trifasciatus* (PP256418) and 3 sequences were generated for *Bombus rotundiceps* (PP256415-PP256417).

Among 25 carpenter bees samples processed for DNA sequencing, 13 sequences could be generated for carpenter bees, of which 7 sequences were generated for *Xylocopa fenestrate* (PP256420, PP256421, and PP256423 - PP256427), 4 were generated for *Xylocopa tenuiscapa* (PP236429- PP256432) and 1 sequence each was generated for *Xylocopa aestuans* (PP256419) and *Xylocopa nasalis* (PP256428).

All the obtained sequences of bumblebee and carpenter bee species were submitted to NCBI GenBank database and accession numbers were extracted.

5.9 Phylogenetic analysis of Bombus speciesinferred from CO1 gene

For phylogenetic analysis of *Bombus* genus 37 sequences were downloaded from GenBank to show relationship between different *Bombus* species. Additionally, a sequence of *Apis mellifera* was also downloaded and used as outgroup. Phylogenetic tree was constructed and visualized in Beast and Fig tree software. The phylogenetic tree clearly separated the outgroup (*Apis mellifera*) indicating the reliability of clustering. The main node has posterior probability (PP) value of 0.98 showing strong support.

Clade containing *B. haemorrhoidalis* samples (brown colour) showed high posterior probability value of 1 showing strong support for this clade. *B. rotundiceps* (blue colour) showed PP value of 0.67 showing moderate support for this clade.

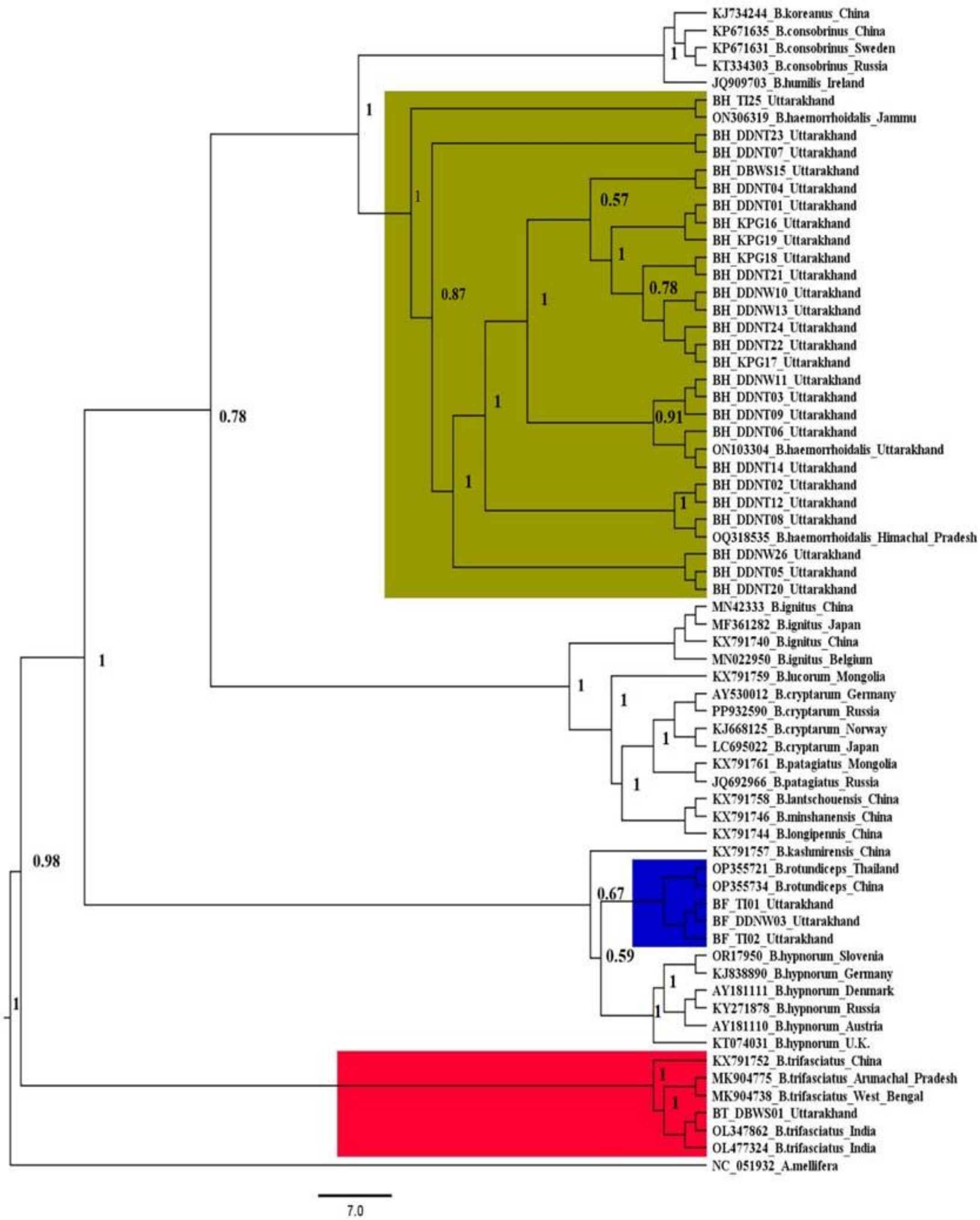


Fig..5.9.1: Phylogenetic tree of Bombus inferred from COI gene

5.10 Genetic distance between different Bombus species

Table. 5.9.1: Genetic distance between bumblebee species from study area

Species	1	2
B.haemorrhoidalis		
B.rotundiceps	0.118	
B.trifasciatus	0.132	0.128

The Bombus species collected from the study area were significantly distant genetically. Genetic distance between *B. haemorrhoidalis* and *B. rotundiceps* was 11.8% and that between *B. haemorrhoidalis* and *B. trifasciatus* was 13.2%, whereas *B. rotundiceps* and *B. trifasciatus* were 12.8% distant.

Table.5.9.2: Genetic distance between bumblebee Species from India and other countries

Species from India	Species from Other countries
B.haemorrhoidalis	0.0125
B.rotundiceps	0.00441
B.trifasciatus	0.0447

Genetic distance between *B. haemorrhoidalis* from India and other countries wa s low that is 1.25% whereas *B. rotundiceps* collected from India was 0.44% distant from species collected from other countries. The maximum genetic distance was between *B. trifasciatus* from India and other countries i.e. 4.47%.

Morphologically *B. hemorrhoidalis* was closely related to *B. trifaciatus* but genetically it was more distant to it as compared to *B. rotundiceps*.

All the above data concludes that *Bombus* species were significantly distant genetically from each other but same species collected from different regions were genetically and morphologically similar.

5.11 Phylogenetic analysis of *Xylocopa* species inferred from CO1 gene

The phylogenetic tree constructed based on COI sequences showed the relationships among *Xylocopa* species from Uttarakhand and reference sequences from GenBank and an outgroup of *Apis mellifera*.The basal node had Posterior probability (PP) value of 1 showing strong support for the tree.

All the species i.e. *X .nasalis* (light blue coour), *X. fenestrata* (dark blue colour), *X. tenuiscapa* (green colour) and *X. aestuans* (brown colour) showed high PP value of 1 showing strong support for the clades.

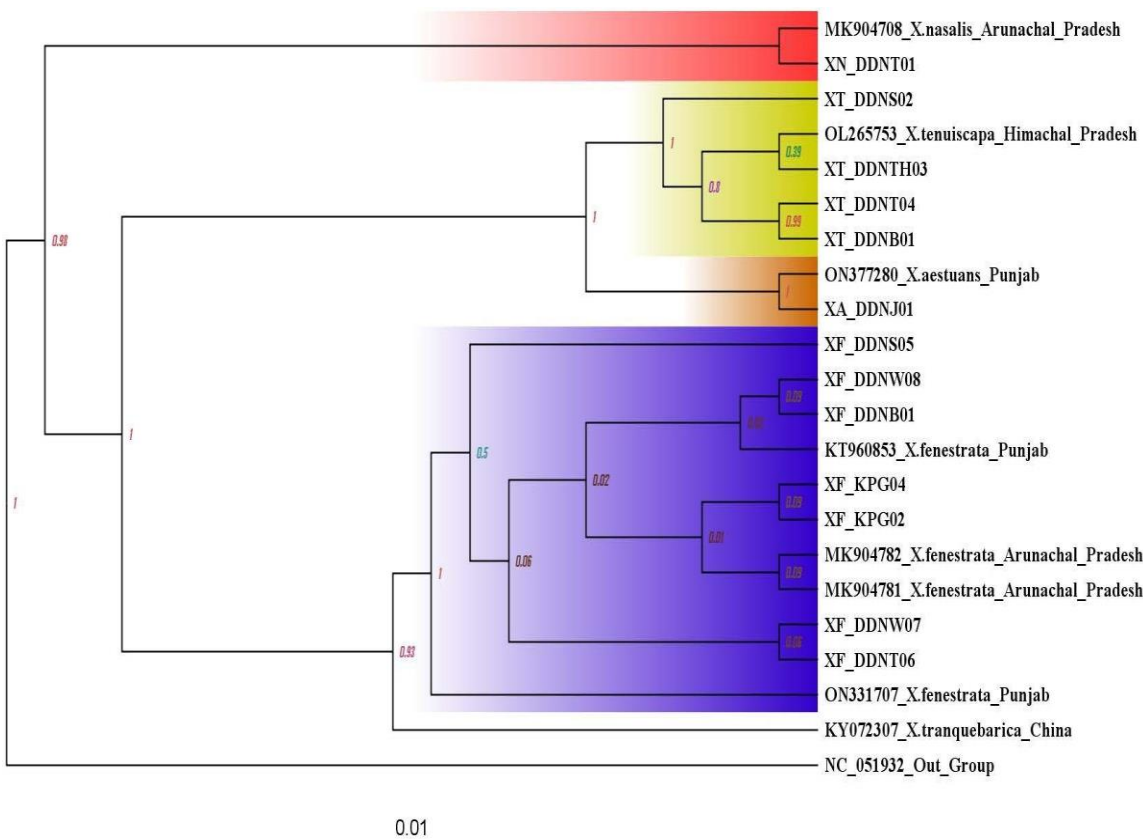


Fig. 5.9.2: Phylogenetic tree of *Xylocopa* inferred from COI gene

5.12 Genetic distance between different Xylocopa species

Table 5.9.3: Genetic distance between different *Xylocopa* species

Species	1	2	3
X.fenestrata			
X.nasalis	0.1055		
X.tenuiscapa	0.0849	0.1073	
X.aestuans	0.1052	0.1047	0.0718

Genetic difference between different *Xylocopa* species collected from Uttarakhand was between 7-11 %. Genetic distance of *X. fenestrata* with *X. nasalis* was 10.55%, with *X. tenuiscapa* was 8.49% and with *X. aestuans* was 10.52%. *X. nasalis* was 10.73% distant to *X. tenuiscapa*, and 10.47% distant to *X. aestuans*. *X. tenuiscapa* was 7.18% distant to *X. aestuans*.

Table 5.9.4: Genetic distance between *X. fenestrata* from different states

Species	1	2
*X. fenestrata*_UK		
*X. fenestrata*_AP	0.000717	
*X.fenestrata*_Punjab	0.004895	0.004174

X. fenestrata collected from Uttarakhand (UK), Arunachal Pradesh (AP) and Punjab showed very low genetic distance. All was below 1%. So, it showed that all species were genetically and morphologically similar.

Table 5.9.5: Genetic distance between *X.aestuans* from different states

Species	1
*X.aestuans*_UK	
*X.aestuans*_Punjab	0.00836

X. aestuans collected from Uttarakhand (UK) and Punjab showed very low genetic distance i.e. 0.8% so they were genetically and morphologically similar.

Table 5.9.6: Genetic distance between *X. tenuiscapa* from different states

Species	1
*X. tenuiscapa*_UK	
*X. tenuiscapa*_HP	0.00550

X. tenuiscapa collected from Uttarakhand (UK) and Himachal Pradesh (HP) were genetically and morphologically similar. The genetic distance between them was only 0.5%.

From all the above data it is concluded that different species of *Xylocopa* are genetically distant from each other but same species collected from different states are genetically similar.

Objective 4 – Impact of anthropogenic activities and various other threats to bumblebees and carpenter bees

The diversity and richness of a population in a particular area depends on various factors including some natural and anthropogenic factors. The rapid expansion of urban area and other anthropogenic factors have changed the ecosystem of Dehradun in the last two decades which is adversely affecting bee populations. The factors are responsible for the loss of suitable habitats of bees leading to their decline. The population of Dehradun has been increased by 426 percent from 1880 to 1980 (Richards, 1987). According to a report by Global Forest Watch (2024), Dehradun has lost 577 hectares of tree cover.

5.13. Causative factors for bee decline in the study area

1. Habitat degradation and fragmentation

   Habitat loss due to habitat fragmentation is considered to be the greatest threat to species. Dehradun has seen a tremendous urbanization in the last two decades which results in rapid loss of suitable habitat for bees. Wild bees and other pollinators are facing a risk for their sustainability from human disturbances. Loss and isolation of suitable habitat of wild bees like bumblebees and carpenter bees is a major threat for their diversity (Winfree *et.al.* 2009; Williams *et.al*. 2010). Habitat degradation often leads to loss of bee's foraging and nesting sites. Thus small and fragmented habitats provide less food resources to the bees leading to their decline.
2. Invasive species

   Invasive plant species can change the habitat structure and food availability for the native wildlife. They pose threat to native species by outcompeting them for food resources which lead to a decline in native bee species richness. These plants can even spread to higher ecosystems responding to higher elevation temperature and human disturbances. Some of the invasive species reported in the study area are *Lantana sp., Parthenium hysterophorus, Ageratum conyzoides, Ageratina adenophora, Broussonetia papyrifera etc.*

3. Pesticide overuse

   Pesticides are commonly used in urban and agricultural ecosystems to kill invertebrates' pests, diseases and weeds. However some pesticides are very harmful to pollinators and other beneficial insects.These chemical pesticides affect the health of bee reproduction rates and life span.

4. Climate change

   Climate change leading to rise in temperatures affects the bee health and their sustainability. Early blooming of bees' foraging plants due to temperature changes often lead to bees with less or no food. Also, rise in temperatures cause stressful environment for bees which pose a threat to their survival. Rise in temperatures in low altitude regions often forces bumblebees to migrate to higher altitudinal regions which is yet another concerning issue as the migrating bees could compete with the native bees for habitat and foraging resources. High temperatures and drought like conditions often left the bees with less floral resources (pollen and nectar) which in turn impact their survival, development and reproduction.

5. Pathogens and parasites

   Social bees like bumblebees and solitary bees like carpenter bees are hosts to a wide diversity of mites and parasites. Pathogens like *Nosema bombi* and *Crithidia bombi* can affect bumblebees by reducing their lifespan, reproduction, and foraging.Mites like *Locustacarus buchneri* harm bumblebees by reducing oxygen supply as they affect their tracheae.

   Fungus sp. like *Ascosphaera* spp. can infect larvae of carpenter bees developing inside wooden tunnels and can cause their death thereby reducing the colony size.

6. Forest fire

   One of the major harmful effects of forest fire is the loss of habitat and foraging resources leading to the loss of biodiversity. Due to forest fires both bumblebees and carpenter bees lose their natural habitat as bumblebeeesmake nests in the ground and carpenter bees make their nests in wooden cavities. The intense heat, ash and smoke produced during forest fire can impact the bee population by damaging their respiratory tract and their visibility to assess their foraging resources and nests.

7. Environmental pollution

   Due to rapid urbanization and industrialization in Dehradun district environmental pollution is also rapidly increasing which is negatively hampering bee population. The traces of harmful pollutants in air strikes the respiratory system and immunity of bees.

Plate No- 13: Various factors for bee decline

a. Construction activity

b. Deforestation

c. Pesticide overuse

d. Forest fire

e. Mites on Bumblebee

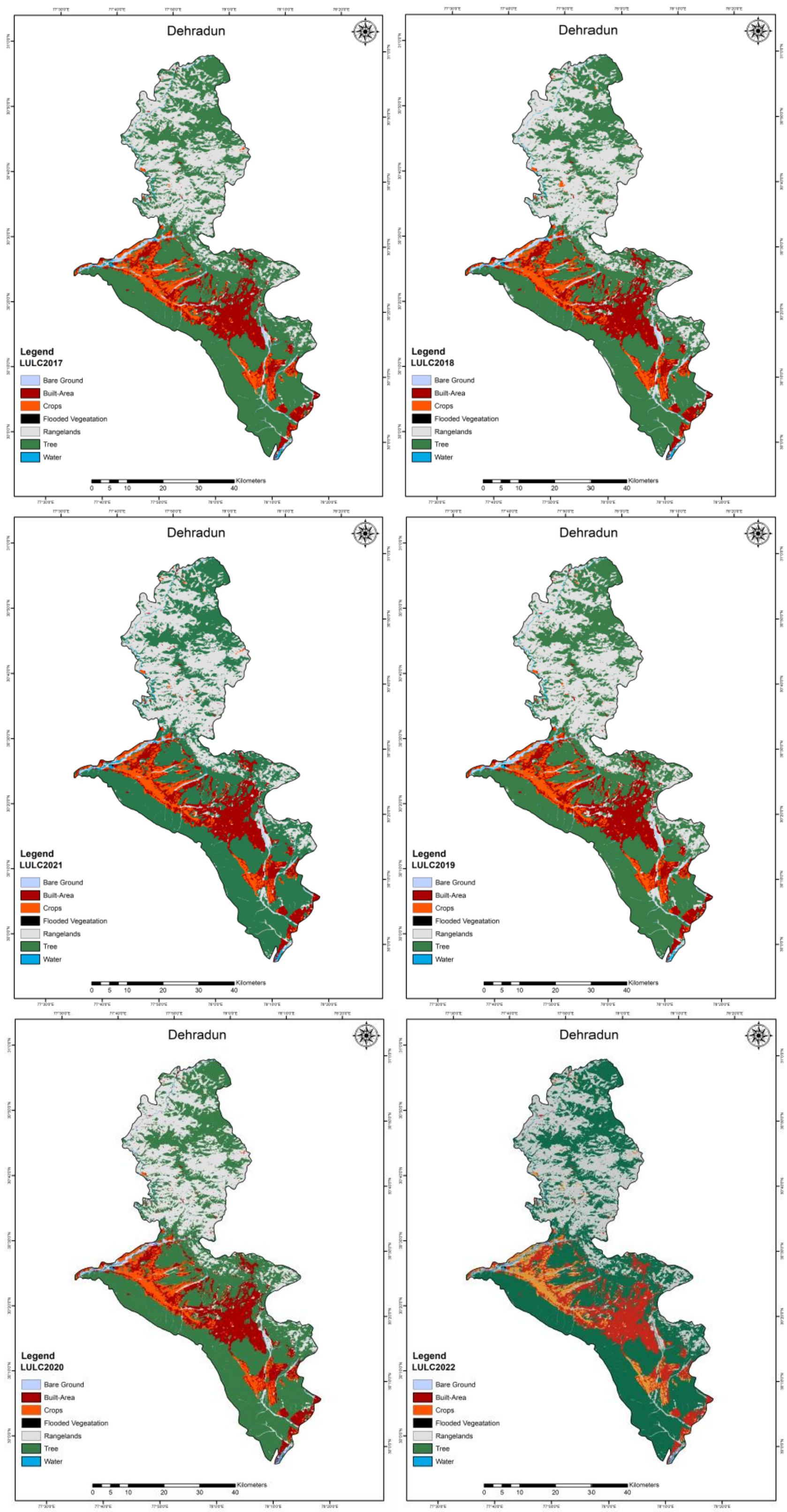


Fig. 5.10.1: Land Use Land Cover data of Dehradun dist. (2017-2022)

Thses maps shows the changes in bare grounds, built area. Crop covered area, flooded vegetation, rangelands, waerbody and tree cover from 2017-2022.

Table 5.10.1: Change in various physical measures of Dehradun from 2017-2022

Sr. No.	Class	2017	2018	2019	2020	2021	2022
1	**Water**	22.74	21.69	24.05	24.83	22.99	24.73
2	**Tree**	1653.86	1493.24	1505.46	1609.14	1492.79	1552.05
3	**Flooded Vegetation**	0.25	0.33	0.41	0.41	0.34	0.35
4	**Crops**	195.46	201.81	189.75	187.01	178.24	165.96
5	**Built-area**	366.38	380.57	396.34	396.25	395	412.05
6	**Bare Ground**	29.69	30.49	31.57	22.88	21.37	26.73
7	**Rangelands**	801.44	942.26	923.36	830.09	876	805.02

Table 5.10.2: Percentage change in various physical measures of Dehradun from 2017-2022

Class	Change (sq km)	Change (%)
Water	+1.99	+8.75%
Tree	-101.81	-6.15%
Flooded Vegetation	+0.01	+40.00%
Crops	-29.5	-15.09%
Built-area	+45.67	+12.47%
Bare Ground	-2.96	-9.97%
Rangelands	+3.58	+0.45%

Land use land cover data of six years (2017-2022) is taken for Dehradun district to analyze the effect of urbanization and changes in land use.

Waterbody cover see fluctuations and changes from 22.74 sq.km in 2017 to 24.73 sq.km in 2022 showing an overall increase of 8.75%.

Tree cover also shows fluctauating trend and decrease from 1653.86 sq.km in 2017 to 1552.05 sq.km in 2022 showing overall decline of 6.15%. Sharp declines from 1653.86 sq.km to 1493.24 sq.km in 2018 and from 1609.14 sq.km to 1492.79 sq.km in 2021 have been seen in tree cover.

Flooded vegetation has fluctuating rise from 0.25 sq.km in 2017 to 0.35 sq.km in 2022 showing overall rise of 40%.

Crops have seen a loss of 195.46 sq.km area in 2017 to 165.96 sq km. in 2022 and sharp decline after 2020 with overall loss of 15.09%.

Built areas have shown significant rise from 366.38 sq.km in 2017 to 412.05 sq.km in 2022 and overall rise of 12.47% showing rise in urbanization.

Bare grounds have decreased from 29.69 sq.km in 2017 to 21.37 sq.km in 2021 and a rise to 26.73 in 2022 but overall decline 0f 9.97%.

Rangelands have seen fluctuating trends from 801.44 sq.km to 805.05 sq.km with a sharp decline from 923.36 sq.km in 2019 to 805.02 sq.km in 2022 with overall rise of 0.45%.

The decline in tree cover and crop cover results in loss of foraging plants of bees resulting in their decline. Also increase in build area over the years cause habitat loss which in turn results in loss of nesting sites and preferable foraging resources leading to their decline in the study area.

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List of Publications, conferences, surveys, grants and workshops

Publications

1. Purohit. A., Uniyal. V.P. 2022. Preliminary Assessment of Foraging Behavior of *Bombus haemorrhoidalis* Smith in Doon Valley, Uttarakhand, India. *Biology and Life Sciences Forum*. 15. 10.3390/IECD2022-12438.
2. Uniyal. V.P., Gautam.R.K., Kahera. N.S., Purohit.A., Sarkar. I.D., Dey. K., Chandra.A., Sangela. V., Singh.A.P. 2022. *Insect Bioindicators Along River Ganga.* Wildlife Institute of India, Dehradun, Uttarkhand.

Conference, Summer School and Survey

3. Oral presentation in International Mountain Conference (IMC) 2022, in Innsbruck, Austria from 10-15 Sept'2022.
4. Participated in S4SSS (Summer school) 2022 in Obergurgl, Austria from 5-9 Sept'2022.

Grants

1. Equipment grant from Idea Wild Equipment Grant Committee, USA.
2. Grant from Prakriti Research Fellow(PRF), for Assessment and Conservation of Bumblebees through community participation adopting citizen science in the Proposed Biodiversity heritage area, Ghimtoli, Rudraprayag, Uttarakhand.

Workshops conducted

Citizen science workshops and awareness programs were conducted with school children and local community members at Centre of Sustainable Ecology and Biodiversity Research (CSEBR) in Ghimtoli,
Rudraprayag dist.

Conference and surveys attended

Certificate of Recognition

This certificate is proudly awarded to

Abha Purohit

For participating in the 'First Mushroom Survey'
in Kalesar National Park, Yamunanagar on
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To Whom It May Concern

Dear Madam or Sir,

We confirm that **abha purohit** sucessfully participated at Students4Students Summer School from 5.-9.9.2022 which corresponds to a workload of 32 hours + preperation time.

abha purohit is author/co-author of the following accepted contribution(s):

Study on foraging behaviour of bumblebees in Doon Valley, Uttarakhand, Western Himalaya, India
Author(s): Purohit, Abha; Uniyal, V.P.
Submission Type / Conference Track: Mountain Biology

With best regards,

Student for Student Summerschool – S4SSS 2022 Organizers
Prof. Stefan Mayr (President of IMC2022 & S4SSS)

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To Whom It May Concern

Dear Madam or Sir,

We confirm that **Abha Purohit** participated at International Mountain Conference 2022.

Abha Purohit is author/co-author of the following accepted contribution(s):

Study on foraging behavior of bumblebees in Doon Valley, Uttarakhand, Western Himalayas, India.
Author(s): Purohit, Abha; Uniyal,V.P.
Submission Type/Conference Track: List of Focus Sessions
Session Details: FS65II, **Time:** Wednesday, 14/Sept/2022: 1:30pm-3:00pm, **Location:** THEOLOGIE - Madonnensaal

With best regards,

IMC 2022 Organizers
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Proceeding Paper

Preliminary Assessment of Foraging Behavior of *Bombus haemorrhoidalis* Smith in Doon Valley, Uttarakhand, India †

Abha Purohit [1,*] and V.P. Uniyal [2]

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† Presented at the 2nd International Electronic Conference on Diversity (IECD 2022)—New Insights into the Biodiversity of Plants, Animals and Microbes, 1–15 March 2022; Available online: https://iecd2022.sciforum.net/.

Abstract: Pollination and pollinators are major keys in the working of almost all terrestrialecosystems. Bumblebees are the key pollinators belonging to family Apidae. Their large and fuzzy body makes them efficient pollinators than any other bee.Because of their thermoregulatory abilities they can efficiently and effectively work in the cold climate of Himalayan region. This study has been conducted inDehradun valley of Uttarakhnad, India which is situated in the foothills of Shiwalik hills of Himalaya. It is a preliminary study of foraging behavior of bumblebees in this region and it is observed that they mainly forage on species of family Asteraceae, Verbenaceae, Tropaeolaceae, Solanaceae and Bignoneaceae.

Keywords: *Bombus haemorrhoidalis*; Doon Valley; floral resources

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1. Introduction

Insects are the most diverse group of animal kingdom. They are important indicators for assessing, managing and monitoring biodiversity in natural ecosystems. The Hymenoptera is second largest group of insects, which includes bees and wasps. They are not only the most successful plant pollinators but also help in protecting the plant diversity in nature and increase productivity of different agriculture and horticulture products like crops, vegetables and fruits. Bees and wasps play an important role in pollination of plant species, which fulfill the requirement of animals as well as humans and their livelihood. There are 12,605 species of Hymenoptera in India out of which 4872 are found in Indian Himalayas. A total of 337 bee species are found in Indian Himalayas. The world bumblebee fauna consists of approximately 250 known species (Williams 1985, 1994, 1998; Pedersen, 1996) out of which 49 species of bumblebees has been reported from this region (Chandra, 2012).In the Himalayan regions bumblebee general distribution has been started from 400 m to 5600 m (William, 1999 & William et al. 2010). They are most abundantly distributed in the mountains to the east of Tibet and in the mountainsof central Asia (Williams 1994).

The Himalayas, the longest mountain range in the world is home to high bumblebee diversity due to its variety of suitable habitats. They are efficient pollinators as their large and fuzzy body can carry a larger load of pollen than any other bee. Because of their thermoregulatory abilities they can thrive well inthe high altitude and cold ambient temperatures of Himalayan region and can carry out pollination when no other bee is able to do so. They are generalist forager and can forage on a wide range of plants. Bumblebees are also used for pollination of tomatoes and other Solanaceous crops in greenhouses and of some leguminous crops. However, some plants do rely on Bumblebees to achieve pollination. Loss of Bumblebees can have far ranging ecological impacts due to their role as pollinators. Around the world Bumblebee number isdeclining due to a number of factors like- anthropogenic activities, habitat loss, climate change, excessive pesticide uses, introduction of invasive bees, overgrazing of foraging plants etc. Studies showed that decline in Bumblebee number also results in the decline of plants pollinated by them.

2. Materials and Methods

Preliminary study on foraging behavior of *Bombus haemorrhoidalis* smith has been conducted in Doon Valley, Dehradun, Uttarakhnad, which is surrounded by agroecosystem and subtropical temperate landscape situated at the foothills of outer Himalayan region with an altitudinal gradient of 640 m amsl. The studywas conducted from October 2020–April 2021. It is conducted covering four different habitats with the fields; forest area and semi urban areas of Doon Valley.

The insects were collected from the study areas using systematic net sweeps. They were collected in special transparent killing jars so as to preserve the colour of the pubescence, as the colour of the pubescence in bumblebees holds great importance in identification of species. After coming to the laboratory, the specimens were pinned with the help of entomological pins of different sizes, keeping in view the size of specimen. After stretching the specimens were appended with data label containing the important informationregarding its locality, altitude, date of collection and name of the collector. Lateron, stretched specimens were transferred to the storage boxes, poisoned with ethyl acetate soaked cotton and naphthalene powder filled in the side grooves of boxes.

Collected samples were examined under stereoscopic microscope in the laboratory and identified using published keys for adjoining areas eg. Nepal(William, 2010), India (Saini et al. 2015), Kashmir (William 1991).

3. Results and Discussion

Bumblebees are most active during early morning and late noon hours during summer and during winter they are active during late morning till early eveningtime. They are most active than any other bee like honeybee during winter and can be seen foraging on the available flowering plants. They are generalist foragers and they can efficiently pollinate from late winter (February) to late autumn (November). In the months of October and November they were very abundant and during winter (December–January) their abundance declined dueto less availability of foraging plants but even then they were more active than other bees. From early spring (March onwards) their activity increased with theabundance of foraging plants. Since they are active for so many months, they must be able to forage on a wide range of plant species. Their abundance significantly depends on the temperature and weather conditions of that particular area. There is positive correlation between foraging of bumblebee and humidity because nectar secretion rates were higher at high humidity (Peat and Goulson, 2005). It is also observed that bumblebees avoid collecting pollenwhen the foliage is covered in dew or rain-water droplets, which would make grooming pollen into the corbiculae harder.

Bumblebee on *Lantana* sp.

Bumblebee on *Cirsium arvense*

Bumblebee on *Tecoma stans*

Bombus haemorrhoidalis is the predominat species of genus Bombus in Doon Valley. Its preferred foraging plant species during the studied period are *Cirsium arvense* (Asteraceae), *Lantana* sp. (Verbenaceae), *Tropaeolum majus*(Tropaeolaceae), *Solanum melongena* (Solanaceaa) and *Tecoma stans* (Bignoneaceae). Their foraging activity depends on seasonal availability of floral resources in the study area.

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11. *Fauna of Uttarakhand*; State Fauna Series, 18(Part-2); Zoological Survey of India: Kolkata, India, 2010; pp. 691–748.

Workshops conducted

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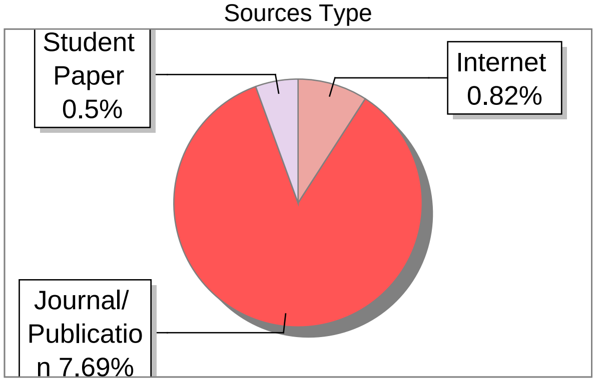

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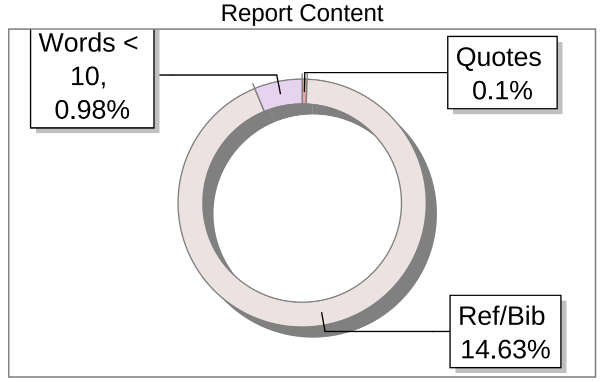

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66	Thesis Submitted to Shodhganga, shodhganga.inflibnet.ac.in	<1	Publication
69	Thesis Submitted to Shodhganga Repository	<1	Publication
70	documents1.worldbank.org	<1	Publication
71	etd.cput.ac.za	<1	Internet Data
72	Genetic diversity in cultivars and landraces of Oryza sativa subsp. i By S R Prashanth, M Parani, B P, Yr-2002,6	<1	Publication

73	Thesis Submitted to Shodhganga Repository	<1	Publication
74	A Further Contribution to the Classification of the North American Spider Parasi by Curti-1948	<1	Publication
75	Thesis submitted to shodhganga - shodhganga.inflibnet.ac.in	<1	Publication
76	Thesis Submitted to Shodhganga Repository	<1	Publication
77	www.frontiersin.org	<1	Publication
78	www.jetir.org	<1	Publication
79	ACM Press the 8th ACM conference- Atlanta, Georgia, USA (2011.11.0, by Gabora, Liane Sabe- 2011	<1	Publication

EXCLUDED PHRASES

1	**wildlife institute of india**