

**TAXONOMIC DIVERSITY AND COMMUNITY
STRUCTURE OF INSECT POLLINATORS IN
SHIVAPURI-NAGARJUN NATIONAL PARK,
CENTRAL NEPAL**



**A THESIS SUBMITTED TO THE
CENTRAL DEPARTMENT OF ZOOLOGY
INSTITUTE OF SCIENCE AND TECHNOLOGY
TRIBHUVAN UNIVERSITY
NEPAL**

**FOR THE AWARD OF
DOCTOR OF PHILOSOPHY
IN ZOOLOGY**

**BY
URMILA DYOLA**

DECEMBER, 2022

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TRIBHUVAN UNIVERSITY
Institute of Science and Technology
DEAN'S OFFICE

Kirtipur, Kathmandu, Nepal



Reference No.:


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DECLARATION

Thesis entitled “**Taxonomic Diversity and Community Structure of Insect Pollinators in Shivapuri-Nagarjun National Park, Central Nepal**” which is being submitted to the Central Department of Zoology, Institute of Science and Technology (IOST), Tribhuvan University, Nepal for the award of the degree of Doctor of Philosophy (Ph.D.), is a research work carried out by me under the supervision of Prof. Dr. Kumar Sapkota. of Central Department of Zoology, Tribhuvan University and Co-supervised by Assoc. Prof. Dr. Chitra Bahadur Baniya of Central Department of Botany and Asst. Prof. Dr. Pushpa Raj Acharya of Central Campus of Science and Technology, Faculty of Science and Technology, Mid-West University, Surkhet, Nepal.

This research is original and has not been submitted earlier in part or full in this or any other form to any university or institute, here or elsewhere, for the award of any degree.

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Date: 15/12/ 2022

RECOMMENDATION

This is to recommend that **Urmila Dyola** has carried out research entitled “**Taxonomic Diversity and Community Structure of Insect Pollinators in Shivapuri-Nagarjun National Park, Central Nepal**” for the award of Doctor of Philosophy (Ph.D.) in **Zoology** under our supervision. To our knowledge, this work has not been submitted for any other degree.

She has fulfilled all the requirements laid down by the Institute of Science and Technology (IOST), Tribhuvan University, Kirtipur for the submission of the thesis for the award of Ph.D. degree.

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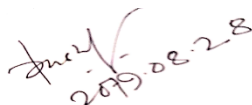
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LETTER OF APPROVAL

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On the recommendation of **Prof. Dr.Kumar Sapkota** and **Co-supervisors Assoc. Prof. Dr.Chitra Bahadur Baniya** and **Asst. Prof. Dr. Pushpa Raj Acharya**, this Ph.D. thesis submitted by **Urmila Dyola** entitled **Taxonomic Diversity and Community Structure of Insect Pollinators in Shivapuri-Nagarjun National Park, Central Nepal** is forwarded by Central Department Research Committee (CDRC) to the Dean, IOST, T.U..

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.....

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ABSTRACT

Insect pollinators are important agents mediating useful services for human and the ecosystem. Large number of wild plants and agricultural crops depend on the pollinators for their pollination. Global trend has shown decline of several taxa of pollinators and indicating habitat loss as major driving factor. Several studies have been done on pollinators in agricultural and natural areas however there are very few works describing their distribution and diversity in protected area despite the fact that these areas are globally important for preserving disturbance-intolerant pollinators.

Wild flowering plants of the park may play an important role for conservation of pollinators. This study explored the taxonomic diversity and the community structure of insect pollinators; bees, butterflies, and hoverflies of Shivapuri-Nagarjun National Park (SNNP). Furthermore, five least collected wild bees during two years of survey were used as model pollinators to check the distribution. The research also documented plant-pollinators interaction to find out the key pollinators, plants that serve as hubs of pollinators, and seasonal variations of pollinators. The survey was done in SNNP for two consecutive years (2018–2019) in four different habitats; Open trail, Forest trail, Managed habitat, and Grassland using both belt transect and colored pan traps methods in three different elevations that ranges from 1,400m–2,700m. The results showed 42 and 34 species of bees and hoverflies respectively. Out of them, 11 species: *Amegilla candida*, *A. fallax*, *A. insularis*, *A. quadrifasciata*, *Elaphropoda impatiens*, *Ceratina perforatrix*, *Colletes similis*, *Megachile conjuncta*, *Nomia iridescens*, *Xylocopa collaris*, and *X. violacea* are new country records of bee and *Graptomyza nigripes*, *Lycastris albipes*, and *Volucella trifasciata* are new country records of hoverflies. Likewise, community structure of pollinators presented a total of 167 different species; the butterflies being the most dominant group (48.50%) followed by bees (29.94%) and hoverflies (21.56%). Diversity indices in alpha level was analysed; the Open trail was comparatively more diverse (4.85), followed by the Managed habitat (4.30). Whittaker Beta diversity analyzed the high species turnover between Forest trail and Managed habitat. Environmental variables like humidity, atmospheric temperature, and flower resources in different elevation have a significant effect ($p < 0.05$) on pollinating insects. The species distribution model showed *Nomada mutabilis*, *Thyreus decorus*, *T. himalayensis*, *Megachile femorata*, and *X. violacea* are spread out across a broad region

in the park. The accuracy of model predictions for all five bees are statistically well specified (AUC is greater than 0.07). The plant-pollinator interactions were complex and asymmetrical showing *Eristalis tenax*, *E. cerealis*, and *Pieris canidia* as key pollinators. *Ageratina adenophora*, *Bidens pilosa*, and *Trifolium repens* were observed as the most visited plants by pollinators. Seasonal comparisons showed that there is high species turnover of bees and hoverflies between spring and autumn seasons ($p < 0.05$).

Based on these results, it is clear that the park provides suitable habitats for many species of pollinators. Open trials with a rich herb and shrub coverage can provide foraging habitat to pollinators. High diversity and abundance of insects in Open trial can aid good pollination service in this habitat. Other habitats like managed area, grassland, and forest can be important determinants of wild bees resulting different pollinator community. Frequent visits of pollinators in exotic plants compared to native plants could alter the native plant- pollinator interaction in long term if former plants are not managed.

LIST OF ACRONYMS AND ABBREVIATIONS

Adonis	: Permutational Multivariate Analysis of Variance
ANOSIM	: Analysis of Similarities
ASL	: Above Sea Level
AUC	: Area Under the Curve
B.L	: Body Length
CDZ	: Central Department of Zoology
CDZMTU	: Central Department Zoology Museum of Tribhuvan University
DCA	: Detrended Correspondence Analysis
DHM	: Department of Hydrology and Meteorology
FT	: Forest trail
GL	: Grassland
LULC	: Land use and land cover
MaxEnt	: Maximum Entropy
MH	: Managed habitat
MSI	: Multi Spectral Instrument
NMDS	: Non-Metric Multidimensional Scaling
OT	: Open trail
PAST	: Paleontological Statistics
RDA	: Redundancy Analysis
ROC	: Receiver Operating Characteristics
SDM	: Species Distribution Modelling
SIMPER	: Similarity Percentage Analysis
SNNP	: Shivapuri-Nagarjun National Park
TSS	: True Skill Statistics

LIST OF SYMBOLS

* : Asterisk

♀ : Female

♂ : Male

Σ : Summation

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CHAPTER 1

1. INTRODUCTION

1.1 Background

Pollinators are important agents of natural ecosystems and they are responsible for sexual reproduction of 87% of the world's plant species (Ollerton *et al.*, 2011). Animal pollinated crops account for about 35% of the global plant-based food supply (Klein *et al.*, 2007). These pollinators improve pollination services in both cultivated and wild plant populations (Corbet *et al.*, 1991; Aguilar *et al.*, 2006; Bentrup *et al.*, 2019), while absence of these pollinators results in inbreeding depression among plants (Michener, 2007). The most important pollinators include beetles (Coleoptera), bees and wasps (Hymenoptera), butterflies and moths (Lepidoptera), and hover flies (Diptera: Syrphidae) as stated by Stanley, 2013; Soh and Ngiam, 2013; Sydenham *et al.*, 2022. Beside these insect, other biotic pollinators include bird species (Whelan *et al.*, 2015), bats (Kunz *et al.*, 2011), primates, rodents (Carthew & Goldingay, 1997), and lizards (Gomes *et al.*, 2014). Pollinators' economic value is difficult to quantify (Proesmans *et al.*, 2019). Nonetheless, the studies proved that pollinator-dependent plants produce more products than pollinator-independent plants on average (Gallai *et al.*, 2009). Several studies show that pollinators are more important in agriculture than previously thought (Lautenbach *et al.*, 2012). For example, pollination is required for the fruit production of almonds (Inouye & Ogilvie, 2001), bumblebee (*Bombus terrestris*) pollinates white clover (Plowright & Plowright, 1997), honeybees pollinates summer squash (Morse & Calderone, 2000), and hoverflies such as *Eristalis tenax* pollinate vegetable plants such as *Brassica rapa*, kiwi fruit, and onion (Howlett & Gee, 2019).

Aside from their economic relevance, pollinators play an important role in natural systems. Wild bees are positively associated with heterogeneous landscape (Bergholz *et al.*, 2022). Bees pollinate the flowers of tiny trees, shrubs, and herbs in tropical forests, whereas they pollinate the flowers of small trees, bushes, and herbs in temperate forests (Michener, 2007). They provide considerable ecological services (Kremen, 2005; De Groot *et al.*, 2010), as well as a diverse spectrum of biodiversity and environmental stability (Potts *et al.*, 2016). *Bombus* spp. are essential pollinators of forest flowers such as Rhododendron (Li *et al.*, 2018), while the genus *Amegilla* pollinates epiphytic flowers (Orchid) in the forest (Ushimaru *et al.*, 2008; Jin *et al.*,

2012). *Xylocopa*, too, visits the flowers of shrubs and trees (Kato, 2000). These are only a few examples of pollinators' importance in natural ecosystems.

1.1.1 Bees

Bees are flying pollinators that belong to the Anthophila group, which includes over 20,000 species (Cheng & Ashton, 2021; Orr *et al.*, 2021; Zattara & Aizen, 2021). They are important terrestrial pollinators (Patricio-Roberto & Campos, 2014) providing pollination service to entomophilous plants (Winfree, 2010; Winfree *et al.*, 2011). In comparison to non-bee pollinators, bees maximize pollination by visiting plants frequently (Rader *et al.*, 2016) and bringing the most pollen load (Stavert *et al.*, 2018). Bees pollinate a many portion of the human dependent crops (Howlett *et al.*, 2021). However pollination efficiency among bees vary. *Bombus* transfers significantly more pollen grains than *Apis* and *Xylocopa* (Adler & Irwin, 2006). They eat nectar and pollen, moving pollen from plant to plant to pollinate them resulting in the development of fruit and food. Honeybees, bumblebees, mason bees, carpenter bees, stingless bees, plasterer bees, sweat bees, and leafcutter bees are among the several types of bees. Honey bees are the most studied and often the most numerous visitors among bees. Bumblebees and solitary bees are equally important, but they are generally less plentiful and difficult to identify (Corbet *et al.*, 1991). Similarly, stingless bees are other effectual crop pollinators (Slaa *et al.*, 2006).

The majority of bees build nests to protect and provide shelter for their offsprings (Rader *et al.*, 2020). Centris bees use floral oil to build strong brood cells that protect them from attack by cuckoo bees (Policarová *et al.*, 2019). Stingless bees build immovable, long-lasting nests (Roubik, 2006). *Osmia* bees build their nests in timber holes or in abandoned Hymenoptera nests (Cane *et al.*, 2007). Solitary bees, on the other hand, close the brood cell after supplying progenies and do not require any more parental care (Gezon *et al.*, 2015).

Female non-parasitic bees spend the majority of their lives collecting pollen to feed their offspring (Winfree *et al.*, 2011). Some stingless bees are obligate kleptoparasites, which means they do not forage for resources and instead steal from other bee nests (James *et al.*, 2022).

1.1.2 Butterflies

Butterflies are known for their huge, vividly colorful wings, and there are an estimated 14,500 species worldwide (Winfree *et al.*, 2011). Although butterflies are the best-studied group (Konvicka *et al.*, 2003; Warren *et al.*, 2021), there is little evidence available for their role in pollination (Jennersten, 1984). Regarding the butterfly's role in pollination, mixed arguments are documented. Few researchers documented them as ineffective pollinators (Goldblatt & Manning, 2007), while others found them as choosy pollinators and pollinate only those plant species which possesses long tubes (Johnson & Bond, 1994), limiting their pollination service. Butterfly pollination is effective in flowers like *Mandevilla tenuifolia* (De Araujo *et al.*, 2014). The quantity of butterflies in the forest system, on the other hand, appears to play an essential role in pollination, according to research (Hanula *et al.*, 2016). Pollen and nectar from flowers are their primary sources of nutrition (Gilbert, 1972). Although, they do not carry as much pollen load as bees, but can distribute pollen over longer distances (Herrera, 1987; Barrios *et al.*, 2016).

1.1.3 Hoverflies

Another common flower visitor, the hoverfly or syrphidfly with approximately 6200 species globally (Pape & Evenhuis, 2019), is a significant pollinator of agricultural crops and many wild flowers, albeit they are less specialized pollinators (Larson *et al.*, 2001; Meyer *et al.*, 2009; Jauker *et al.*, 2012; Jauker *et al.*, 2019; Raguso, 2020). Adults feed on nectar and pollen (Winfree *et al.*, 2011; Doyle *et al.*, 2020); larvae of some hoverflies are aphidophagous (Rodríguez-Gasol *et al.*, 2020); and starved larvae feed on pollen and honey (Winfree *et al.*, 2011; Vosteen *et al.*, 2018; Doyle *et al.*, 2020). Such visit of these flies in plant make them important pollen carrier (Kendall, 1973). Although they are shorter distance pollen transferer (Horiuchi *et al.*, 2022) yet, can transfer a wide range of pollen grains and perform pollination (Lucas *et al.*, 2018). Rodríguez-Gasol *et al.* (2020), found that hoverflies provide extra pollination services in the absence of bees (Proesmans, 2019). Hoverflies are well-known and recognized not just for their vibrant colors, incredible hovering activity, and flower-visiting habits, but also as ecological, environmental, and economic service providers (Rotheray & Gilbert, 2011).

1.1.4 Importance of habitat types in distribution of pollinators

Many studies have been conducted around the world to examine the impact of various habitat and landscape elements on pollinator communities. Habitat types influence pollinator community structure. Landscape heterogeneity allows access to a variety of resources (Dunning *et al.*, 1992) such as nesting places and materials, as well as food for different life stages such as nectar for adults and pollen for larvae (Westrich, 1996). Wild pollinators, for example, prefer undisturbed areas for roosting and foraging (Kluser & Peduzzi, 2007). Pollinator abundance, diversity, and richness vary widely across habitat types. In comparison to Diptera, Hymenoptera have been found to be abundant in a variety of forest types in numerous studies (Liow *et al.*, 2001; Sajjad *et al.*, 2012; Bashir *et al.*, 2013; Proesmans *et al.*, 2019;). However, research of the diversity of bee species in forests have shown mixed results. Kambach *et al.* (2012), found a great diversity of bee species in the forest, whereas Liow *et al.* (2001), found a low diversity of bee species in the primary forest.

Similarly, due to resource heterogeneity, a large diversity of hoverfly species was seen in a diversified landscape (Ouin *et al.*, 2006; Meyer *et al.*, 2009). Hedgerows, pasturelands, ponds, woods, and other diverse landscape features may provide a feeding site for hoverfly larvae (Schweiger *et al.*, 2007). A variety of hoverfly species use forest areas for larval development and overwintering (Branquart & Hemptinne, 2000). In forest, hoverflies are both detritivorous and herbivorous in feeding (Alison *et al.*, 2022).

Many hoverfly species take advantage of microhabitats such as rotting woods, aphids, and basidiomycete fungi in various trees, and ponds between woodlands (Speight *et al.*, 2006). Hedgerows provide nesting options for many native bees and hoverflies (Morandin, & Kremen, 2013), as well as an overwintering place for butterflies (Dover & Sparks, 2000). Small butterflies commonly visit forest road, while large butterflies have a negative reaction to it. Other than *Lantana* spp., huge size butterflies are closely associated with forest deep flowered plants (Attiwilli *et al.*, 2022).

Similarly, grassland conservation (semi-natural grassland) is critical for wild bees (Sydenham *et al.*, 2022). Food choices for wild bees are attributed to perennial wild flower belts in the agricultural landscape, which encourages their diversity (Hellwig *et al.*, 2022).

1.1.5 Pollinators sharing between different habitats

Pollinators are not reliant on a single plant species, rather on a varied range of plants found in wild, semi-natural, and controlled environments. Diverse habitat provides a variety of nesting supplies such as shrubs, trees, and soil, as well as prevent pollinators from starving by giving alternate food sources (Senapathi *et al.*, 2015). The interconnected mobility of pollinators between wild and farmed crops is essential for the diversity of insect pollinators and pollination services (Senapathi *et al.*, 2015) because if there is agricultural land nearby, for example, some wild plants produce more fruit (Cussan *et al.*, 2010). Wild plants, on the other hand, are crucial for pollinators in agricultural areas. The majority of pollinators depend on wild plants for food and breeding sites (Roberts, 2004; Gibson *et al.*, 2006; Jacobs *et al.*, 2009; Power & Stout, 2011). There is a strong link between pollinator diversity and abundance with farmland that surrounds semi-natural and natural environment (Carvalho *et al.*, 2010; Klein *et al.*, 2012). For example queen bumble bees frequently visit forest and field boundaries, open uncultivated areas and open lands (Svensson *et al.*, 2000).

The diverse habitats signify rich biodiversity (Benton *et al.*, 2003). Pollinators such as butterflies (Weibull *et al.*, 2000; Oliver *et al.*, 2010) and bumblebees (Rundlof *et al.*, 2008) benefit the most from a heterogeneous landscape. Crop yields can be improved if the surrounding landscape of cropland is natural or semi-natural. Pollinators rely on a variety of plants found in natural and semi-natural surroundings (Senapathi *et al.*, 2015). Natural habitat like forest provides breeding areas, refuges, and dispersing corridors for pollinators (Benton *et al.*, 2003).

1.1.6 Pollinators decline

Pollinator (wild and domestic) declines have been documented all across the world (Carvalho *et al.*, 2013; Mudri-Stojnić *et al.*, 2014). This primarily comprises bumblebees (Fitzpatrick *et al.*, 2007; Cameron *et al.*, 2011; Wagner, 2020), butterflies (Van Swaay *et al.*, 2010; Warren *et al.*, 2021; Dartnell *et al.*, 2022), and honeybees (Vanengelsdrop *et al.*, 2008; Gregorc, 2020). While hoverfly population loss is, less severely affected than that of other pollinating insects such as wild bees (Doyle *et al.*, 2020). Studies show a wide range of natural and anthropogenic factors, threatened pollinators health, abundance, and diversity (Vanbergen & Initiative, 2013). Habitat loss, landscape change, pesticides in agriculture, agriculture intensification, disease,

introduction of exoctic species, and changing climate are some of the important factors (Kearns *et al.*, 1998; Broun & Paxton, 2009; Potts *et al.*, 2010; Wagner, 2020; van der Sluijs, 2020). As a result, there is significant evidence of detrimental ecological and economic consequences, such as a decrease in wild plant diversity, ecosystem stability, food supply, and human well-being (Lautenbach *et al.*, 2012).

1.1.7 Habitat suitability mapping

Wild bees represent the important pollinators for major group of flowering plants. For decades, wild bees have been suffering from a global decline caused primarily by a variety of human activities (Tadey, 2015). Parallel to this, public interest in preservation of wild bees grew significantly, owing to various scientific investigation. Despite this widespread interest, there remains a scarcity of information on these bees. Species conservation requires the proper understanding of the distribution of the species and their habitat (Eken *et al.*, 2004). Species Distribution Modelling (SDM) is numerical tools that integrate data of species presence with environmental estimations to create species distribution models (Elith & Leathwick, 2009; Jones *et al.*, 2016) without making any contact with species under investigation (Maharjan *et al.*, 2017). These approaches are used to estimate the spatial distribution of a species using field presence point and associated environmental predictor variables (Beckham & Atkinson, 2017). Among the SDM approaches, the Maximum Entropy (MaxEnt) approach stands out for its simple application and its ability to creat strong distribution models (Phillips *et al.*, 2004).

1.1.8 Plant- pollinator interaction

Plant-pollinator interaction is one of the crucial mutualistic relation between plants and pollinators. There are some fascinating examples, which show perfect match between morphology of flower with insects that pollinate them. The relation between fig wasps and figs (Cook & Rasplus, 2003), Yucca moths and Yucca (Pellmyr, 2003) are remarkable examples, which show that the removal of one can cause extinction of the other. Forest with various flora and fauna support different flower visitors and thus trend and nature of plant-pollinator web are likely to be influenced by the regional biota. In the forest, majority of canopy trees switch into flowering after long period of non-flowering period. This natural phenology limits the floral resources for pollinators. They in turn subsist on understory perennial flowers or belt of flowers present in the

forest edges (Kato *et al.*, 2008; Proesmans *et al.*, 2019). The differences plant diversity and reproduction phenology of flowers between seasons, results in variance in the pollinators of open edge of forest. This variation brings changes in plant-pollinator interaction seasonally. Different attributes of both plants and pollinators give the structure to the interaction network. Most important attribute for interaction network is the phenology of both plants and pollinators. For plants, species that live and are active for long are more connected and are important. They can interact with many species for long time (Guzman *et al.*, 2021). For pollinators, those pollinators, which are active for longer period, are generalized pollinators and contribute an important role in stabilizing network system (Cusser & Goodell, 2013).

1.1.9 Pollinators of Nepal

Diverse landscape of Nepal supports diverse insect fauna, insect population yet, studies on insects as pollinators are relatively new topic to the country. Honeybees are the most studied and widely dispersed pollinating insect in the Terai, Midhills, and High Hills (Woyke, 1999). Over 180 commercially significant plants are pollinated by a variety of pollinators (Thapa, 2006) and several orchids among wild plants are pollinated by bees and bumble bees (Sudedi *et al.*, 2020). Solitary bees, snout beetles, blowflies, wild bees, butterflies, beetles, thrips, and other pollinators are common in Nepal (Pokhrel, 2009; Thapa *et al.*, 2008). Few studies in Managed bees of Nepal have also demonstrated an increase in yields (Verma & Partap, 1993; Thapa, 2006; Devkota *et al.*, 2016) and help in biodiversity preservation (Devkota, 2020).

Pollinators visit increase productivity in both self-pollinated and cross-pollinated crops, implying that a lack of pollinators causes a decrease in fruit and seed production (Pratap, 2001; Thapa, 2006). Nepal, like the rest of the world, could face downfall of pollinators. Because some studies indicated different factors, like, habitat loss, honey hunting (Pokhrel, 2006), introduction of new species (*Apis mellifera* in Chitwan), diseases, pests, pesticides, and lack of public awareness are contributing factors of bee decline (Thapa, 2006) in the country. Recently, Gurung *et al.* (2020), in their short period survey showed the absence of honeybee in a park of heavily urbanized city; Kathmandu though these bees are dominating pollinators in many habitats.

1.1.10 Shivapuri- Nagarjun National Park.

Shivapuri-Nagarjun National Park (SNNP) is the only protected area in Central Nepal. The Shivapuri Watershed Conservation Area was established in 1976 and Shivapuri National Park (an area of 144 square kilometers), was renamed in 2002. Then, in 2009, SNNP was expanded to include the Nagarjun Forest (15 square kilometers). After that in 2016, the buffer zone (118.61 square kilometers) covering Dhading, Kathmandu, Nuwakot, and Sindhupalchok was included.

SNNP is located between 27°45' and 27°52' N latitude and 85°16' and 85°45' E longitude (Figure 1). The park encompasses both tropical and temperate zones and located 12 kilometers north of Kathmandu; Nepal's most densely populated city. It has an altitude range of 960 m to 2732 m ASL, indicating significant altitude fluctuation over a short distance.

SNNP's rugged topography, which has steep slopes of more than 30%, followed by 74.45% forest, 20.45% shrubland, 3.22 % grassland, 1.80 % cultivated area, and 0.055 % other features (SNNP, 2017; Khatiwada *et al.*, 2020). Four different types of forest are found at various altitudes of the park (SNNP, 2017). The park's primary vegetation includes *Schima walichii*, *Castanopsis indica*, *Alnus nepalensis*, *Pinus roxburghii*, *Myrica esculanta*, *Pyrus pasia*, *Quercus semicarpifolia*, *Rhododendron arboreum*, *Juglan regia* (Koirala *et al.*, 2017; Jha, 2020).

Shrub lands, grassland, crops, buildings, and ponds are some of the other features within park. Pollinators benefit from the resources available in the national park. The open lands of SNNP are restricted to walking routes at the forest's edge and a few open grasses. Nonetheless, the walking routes have dense stripes of herbs and shrubs. SNNP has a subtropical to moderate temperate climate, with temperatures between 19.9°C and 11.15°C, and annual precipitation of 236.5 mm (data from 1985 to 2017 AD; DHM).

SNNP is key source of freshwater supplier of Kathmandu valley, and many minor river. Rivulets drain it, with the Bagmati, Bishnumati, Sangla, and Syalmati being the most notable.

The park also has a wide range of animals. There are 320 bird species, including 117 migratory birds (SNNP, 2017) and endemic birds found in SNNP are the Spiny babbler and the Wren babbler (SPP, 2073). SNNP reports 124 species of butterflies, 27 species

of bugs, nine hymenoptera species, 53 species of beetles, 15 species of flies, 20 species of odonatan, only one species of thrips (SNNP, 2017), and 50 bee species and 37 hoverfly species (Dyola *et al.*, 2022a).

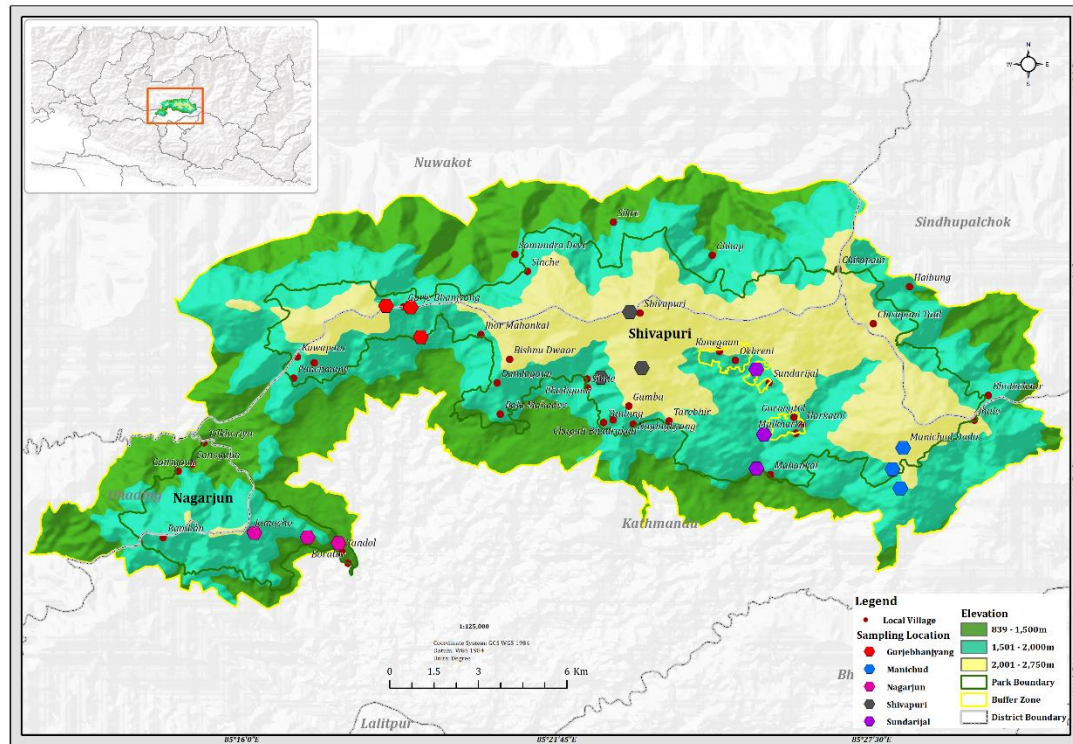


Figure 1: Map of Nepal showing the study Area (SNNP).

1.2 Rationale

Pollination and pollinators are well-known around the world, but sparsely studied in the country. With the exception of butterflies, two pollinator guilds (bee and hoverfly) in Nepal have unclear and sparse taxonomic records. In order to provide baseline data for subsequent study in ecology and conservation of these insects, taxonomic exploration of bee and hoverfly is carried out in National Park. National Park contains a large area of forest, as well as shrub areas, grassland, and other features. The forest area of the park supports the abundance, diversity, and richness of insect pollinators (Koneri *et al.*, 2021). Furthermore, much of the present studies focus on the managed bee in the agricultural landscape, leaving little knowledge of other pollinators like bee and non-bee and their role in natural systems. Temperate forests are probably never a good place for most bees because of the fact that they are dominated by plants that do not produce flowers (Michener, 2007). So, bees of such area depend on the flowers present in open edges of forest. Hence, pollinator research in the forest trails of the

National Park will add to the knowledge of wild pollinators. Despite the fact that wild bees are researched as agricultural pollinators, little is known about their distribution, habitat preferences, and plant preferences.

The wild bee habitat suitability model will aid in identifying hotspots of these bees and their associated landforms. This finding could aid in the development of policies for the conservation of wild bees by looking into land use types. Flowers are important resources of nectar and pollen for pollinators. The relationship of pollinators with flower types help to identify the flowers visited by pollinators. Hence, the investigation of plant- pollinator interaction could be the important approach to conserve the wild plants of SNNP to protect pollinators.

1.3 Objectives

1.3.1 General Objective

The broad objective is to investigate taxonomic diversity and community structure of insect pollinators in SNNP, Central Nepal

1.3.2 Specific objectives

1. To identify bee and hoverfly fauna of SNNP.
2. To find community structure of pollinating insects and its driving factors in different habitats.
3. To prepare habitat distribution map of wild bees to show their potential area in SNNP.
4. To examine seasonal variation in plant-pollinator interactions in forest of SNNP.

1.4 Thesis organization

In the thesis, every research questions are answered in a separate chapter. There are many insects' taxa that provide important role in pollination ecology. It is not possible to cover them all. Thus in the thesis work, only bees, butterfly and hoverfly are focused. These are arguably the most important pollinators of natural systems.

Chapter 1 outlines general introduction of thesis, highlights objectives, in-depth description of study area and rationales of study.

The taxonomic study on pollinators is an insufficiently researched topic in Nepal. The geographic diversity of the country supports broad spectrum of pollinator species. To explore them, this survey outlined the taxonomic diversity of pollinators. Chapter 2 contains the taxonomic list of bees and hoverflies. For this, SNNP was explored in three different elevations to sample the pollinators in the first year (2018) of the survey. Both hand sweeping and coloured pan traps were used.

Protected areas are globally important to preserve biodiversity, especially for disturbance-intolerant pollinators (Balogun *et al.*, 2022). Chapter 3 focuses on the community structure of insect pollinators (Bees, Butterflies, and Hoverflies) in different habitats of SNNP. Different environmental parameters are used to compare their influence in pollinators. This research was carried out for two years (2018-2019) in different elevations of the park that ranges from 1,400m–27,00m. Four different habitats; Forest trail (FT), Grassland (GL), Managed habitat (MH), and Open trail (OT) were investigated using both hand sweeping net and coloured pans. To show the influences of environmental conditions, temperatures, humidity, and vegetation analysis were also carried out in different elevations of the study sites.

Solitary bees and other wild pollinators regulate an essential ecological service that can improve both the natural and the agriculture industry. However, the populations of many solitary bees are declining, which has led to a general decline in the diversity of pollinator species in many regions. Among several factors, habitat loss is the primary driver of their decline (Kline & Joshi 2020). The use of species distribution model can predict the suitable habitats of wild bees. In Chapter 4, the SDM approach was used to investigate the suitable habitats of wild bees in SNNP. The bees were sampled in a fixed transect walk and presence point was recorded. Only five least reported bees during the survey were used in the model using Maxent.

There is species diversity within and between seasons, as there is a remarkable difference in floral composition. The flowering species of growing season deteriorate with time and are substituted by new flowers (CaraDonna *et al.*, 2017). The studies on plant-pollinator interactions have been done in many countries, but yet not in Nepal. Chapter 5 focuses on the different features of interaction dynamics. Additionally, the chapter discusses about species turnover between seasons, the key pollinators and plants that serve as hubs for pollinators in SNNP.

Chapter 6 highlights the findings of the research reviewed in the preceding chapters and discusses the importance of different habitats in distribution of pollinators. In order to maximize the usefulness of herbs and shrubs coverages of walking trials as pollinator habitat, the chapter also provides management guidelines for these areas and finally chapter 7 provides summary on whole thesis work. The overall conceptual framework is given in Figure 2.

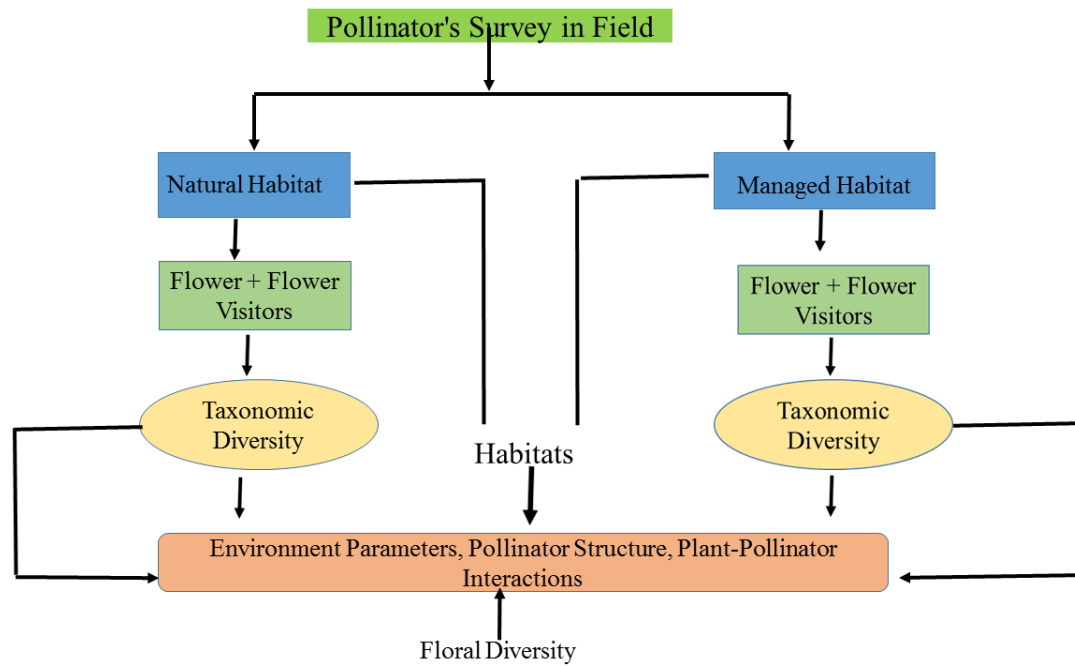


Figure 2: Conceptual framework of thesis

CHAPTER 2

BEE AND HOVERFLY FAUNA OF SHIVAPURI-NAGARJUN NATIONAL PARK

2.1 BEE (HYMENOPTERA: APOIDEA) FAUNA OF SHIVAPURI- NAGARJUN NATIONAL PARK, NEPAL

Abstract

The present study was carried out in SNNP to document the baseline data of bee fauna. The study was conducted during the year 2018 (spring and autumn). The specimens of bees were collected from different habitats; Open trail, Forest trail, Managed habitat, and Grassland of different elevations that ranged from 1,500–2,700 m. The sampling was done in belt transect using the sweeping net and colored pan traps. A total of 138 specimens were captured from the field and examined. These examined bees belong to 42 species, 14 genera, 12 tribes, and five families. Of these, 41 species are the first record from the park and 11 species: *Amegilla candida*, *A. fallax*, *A. insularis*, *A. quadrifasciata*, *Elaphropoda impatiens*, *Ceratina perforatrix*, *Colletes similis*, *Megachile conjuncta*, *Nomia iridescens*, *Xylocopa collaris*, and *X. violacea* are new records for Nepal. The present study demonstrates that bee fauna in SNNP is interestingly diverse and the park could be potential area for bees.

2. 1 INTRODUCTION

2.1.1 Background

Bees (Hymenoptera) are generally grouped in the section Aculeata (Michener, 2007). Most females have stings that are modified ovipositors from ancestral Hymenoptera. They have a close relationship with sphecoid wasps; however, there are several noticeable distinctions. Wasps are often more robust and hairy than bees, whereas certain bees (*Nomada*) are slender, sparsely haired, but have a colour similar to that of wasps. Bees are distinguished from sphecoid wasps by their branching body hairs and larger hind basitarsus (Wijesekara, 2001). Most genus of bee can be identified in the field due to differences in body structure and coloration (Michener, 2007). Their antennal segments can typically distinguish male and female bees. The majority of male bees have 13 antennal segments, while females have 12 segments. There are 20,507

documented bee species worldwide (Ascher & Pickering, 2021). From the time of Kirby description on *Melitta* until this day, many authors have categorized bees in different ways. According to Michener (2007), the superfamily Apoidea is divided into seven families: Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae, Melittidae, and Stenotritidae.

Bees exhibit a wide range of lifestyles from solitary to social. Honeybees, bumblebees, and some stingless bees are social bees. They live in colonies where the members follow the division of labor. However, carpenter bees and cuckoo bees are solitary (Danforth *et al.*, 2013). In solitary bees, female builds her own nest and feeds her young; she does not rely on the support of other bees and is usually self-sufficient, dies or abandons her offspring before they reach adulthood.

Other category of bees are robber bees and parasite bees. Some species of genera like *Lestrimelitta* and *Cleptotrigona* of Meliponini are robber bees and lack pollen carrying tibial corbiculae (Wittmann *et al.*, 1990; Sakagami *et al.*, 1993; Michener, 2013). They have their own nests; however, they feed on the nests of other Meliponini species rather than flowers (de Portugal-Arajo, 1958). Next group of bees are parasitic bees, which are distinct from robber bees. They are of two types, namely social parasites and cleptoparasites. A female social parasitic bee enters a social host's nest and replaces the queen in some way, making the host's workers to look after parasite young rather than young of their own species. Such parasite belongs to some species of group Allodapini and Bombini.

Cleptoparasites, which are also named as cuckoo bees, are next kind of parasitic bees and are largely present. Unlike social parasite, cleptoparasite enters a host's nest and lays an egg in one of the cells. The adult parasite usually exits after ejecting the host, although in certain circumstances it remains in the nest. The cleptoparasite larva feeds on the food of the host larva. Some genera of *Sphcodes* (Halictini) are Cleptoparasites.

2.1.2 Relation of flowers and bees

Bees use flowers for nectar, oil, and pollen grains. Adults take nectar mostly for energy while larvae fed on both nectar and oil. Pollen is a source of protein for both adults (particularly females) and larvae. There is a strong correlation between bees' floral preferences and flower blooming times. Depending on the visit of bees in flower type, they can be Generalists and Specialists. Most social and solitary bees live and forage

for a long time, they do not just rely on flowers that bloom for a limited time and hence feed on a variety of flowers. These bees are called floral generalists. Some solitary bees, on the other hand, are floral specialists (Michener, 2007). Adults of such floral specialists have a short foraging activity for short season and feed on their chosen flowers, which only bloom for a few days.

2.1.3 Bee's decline

Bees play an important role in natural and agricultural environments as pollinators (Grab *et al.*, 2019). Recent research suggests that the number of bees in the world is declining (Wood *et al.*, 2020). The study showed about 25% decrease in bee species between 2006 and 2015 (Zattara *et al.*, 2021). This has been a source of concern throughout the last decade. Various factors have been cited, including a lack of high-quality food (Biesmeijer *et al.*, 2006), habitat loss and pathogens (Potts *et al.*, 2010), climate change and deforestation (Nemésio *et al.*, 2016; Dew *et al.*, 2019), and pesticide use in agriculture (Goulson *et al.*, 2015).

2.1.4 Bees of Nepal

In Nepal, there have been very few attempts to investigate bee fauna. Foreign researchers have carried out the majority of studies on bees of Nepal: Matsumura, 1970; Tkalcu, 1974; Tadauchi and Matsumura, 2007; Shiokawa, 2008; Burger *et al.*, 2009; Williams *et al.*, 2010; Murao and Tadauchi, 2013; Murao *et al.*, 2015. Thapa (2015), who was the first to summarize the data on Nepal's bee species, is one of the few Nepalese researchers.

Roughly, 173 named species of bees have been reported from Nepal (Ascher & Pickering, 2021) however, the exact named species from the country could be more. It is reasonable to assume that study on bees of Nepal is a relatively unexplored and poorly understood field. As SNNP is one of the favorable park for biodiversity in Nepal, the work on bee fauna in SNNP could be a significant contribution to this subject. As a result, the goal of this study is to document the bee fauna of SNNP, which will serve as a baseline for future research on bee biodiversity, ecology, and conservation in the park.

2.1.2 MATERIALS AND METHODS

2.1.2.1 Study area (Described in chapter 1)

2.1.2.2 Collection methods

The bees were collected for two seasons; spring and autumn of 2018. They were collected from Sundarijal, Shivapuri, Gurje Bhanjyang, Nagarjun, and Manichud. Each site was divided into three elevations. In each elevation, five transects each of 100 X 5 meter were made. Bees were sampled using hand sweep net and pan traps of three different color (white, yellow, and blue) (Figure 3). Pan traps are ideal method for bee sampling in a variety of locations and across a large area (Westphal *et al.*, 2008). The detail description of collection method is given in chapter 3.

The collection of bees were done during its most active time that is hot and sunny days avoiding rainy and cloudy days. Bees collected by hand sweeping were transferred to a dry airtight vial and put in the icebox, while bees of pan collection were placed in a vial with 70% ethanol. Then these specimens were taken for the laboratory processing. In the lab, the specimens were dry mounted using standard insect pins.



Figure 3: Sampling tools: A; Sweeping net, B–C; colored pan traps

2.1.2.3 Identifications and deposition

The adult specimens of the bee were observed under a stereoscopic microscope (Olympus-SZ-61). Bee specimens were identified using published keys; Bingham,

1897; Tadauchi and Matsumura, 2007; Williams *et al.*, 2010; Bodlah *et al.*, 2016; Ngat *et al.*, 2017; Kumari *et al.*, 2018. The studied specimens were deposited in the Central Department Zoology Museum of Tribhuvan University (CDZMTU), Kirtipur, Kathmandu, Nepal.

2.1.2.4 Classification and arrangement of taxa

The nomenclature of bees is based on Michener (2007), and the latest available literature. In this list, the arrangement of specimens is done alphabetically with family and subfamily, followed by tribe, genus, and name of species.

2.1.2.5 Distribution data

The present list of bees from SNNP also presents distribution of bees from other part of the country. The species found exclusively in Nepal could be endemic so they were treated as such. In the list, an asterisk (*) indicates new records of bees from the country. The diagnostic features of those bees, which are new records for Nepal, are also given below in the list.

2.1.3 RESULTS

During the field study, 138 bee specimens belonging to 42 species were collected. These species belong to 14 genera, 12 tribes, and five families. The species under the family Apidae were the highest species while Colletidae comprised of single species (Figure 4; Appendix I).

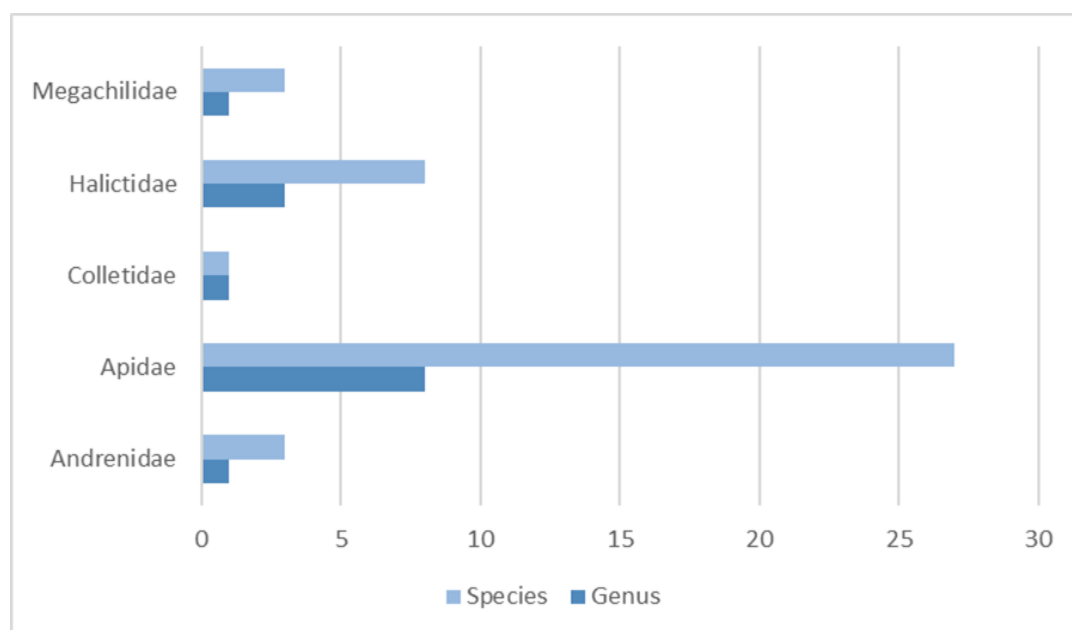


Figure 4: Families, genera, and species of superfamily Apoidea, recorded from SNNP.

In this study, except *Bombus (Pyrobombus) eximius*, all 41 species of bees are the first records from SNNP. Among these bees, 11 species: *Amegilla candida* (Smith, 1879) (Figures 5 A–C), *A. fallax* (Smith, 1879) (Figures 5 D–F), *A. insularis* (Smith, 1857) (Figures 5 G–I), *A. quadrifasciata* (de Villers, 1789) (Figures 6 A–C), *Elaphropoda impatiens* (Lieftinck, 1944) (Figures 6 D–F), *Ceratina perforatrix* Smith, 1879 (Figures 6 G–I), *Xylocopa collaris* Lepeletier, 1841 (Figures 7 A–C), *X. violacea* (Linnaeus, 1758) (Figures 7 D–F), *Colletes similis* Schenck, 1853 (Figures 8 A–C), *Megachile conjuncta* Smith, 1879 (Figures 8 D–F), and *Nomia iridescens* Smith, 1858 (Figures 8 G–I) are new records for Nepal.

Taxonomic accounts

2.1.3.1 Family Andrenidae Latreille, 1802

Subfamily Andreninae

Tribe Andrenini

Genus *Andrena* Fabricius, 1775

1. *Andrena (Zonandrena) flavipes* Panzer, 1799

Material Examined. 1♂, (CDZMTUHymB1), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; 2♀1♂, Sundarijal, 27.76°N, 85.42°E, 04.iv.2018, 1,500 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*.

Distribution. Nepal. Sindhupalchok: Pati Bhanjyang at 1,500 m and Barhabise at 1,300 m; Kathmandu: Balaju and Godawari at 1,400 m; Parsa: Birgunj at 100 m; Syangja: at 2,700 m; Palpa: at 750 m; Myagdi: Ghodepani at 1,900 m; Mustang: Marpha at 2,670 m, Tukuiche at 2,600 m and Lete at 2,440 m (Tadauchi & Matsumura, 2007).

2. *Andrena (Simandrena) gorkhana* Tadauchi & Matsumura, 2007

Material Examined. 2♀, (CDZMTUHymB2), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 4.iv.2018, 1,500 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*.

Distribution. Nepal. Kathmandu at 1,340 m; Parsa: Birgunj at 100 m; Gorkha: Arughat at 300–600 m, Bhanjyang at 1,200–1,500 m, and Kanchok at 900 m (Tadauchi & Matsumura, 2007; Ascher & Pickering, 2021).

Remarks: Endemic to Nepal.

3. *Andrena (Euandrena) kathmanduensis* Tadauchi & Matsumura, 2007

Material Examined. 1♀, (CDZMTUHymB3), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, Sundarijal, 27.76°N, 85.4234°E, 02.iv.2018, 1,500 m.

Floral association. *Ageratina adenophora*.

Distribution. Nepal. Sindhupalchok: Pati Bhanjyang at 1,500 m and Helambu at 2,400 m; Kathmandu Godawari and Balaju at 1,400 m; Palpa; Kaski: Ulleri at 2,200 m; Myagdi: Ghodepani at 2,750 m; Mustang: Lete at 2,400 m (Tadauchi & Matsumura, 2007; Ascher & Pickering, 2021).

Endemic to Nepal.

2.1.3.2 Family Apidae Linnaeus, 1758

Subfamily Apinae

Tribe Anthophorini

Genus *Amegilla* Friese, 1897

4. **Amegilla candida* (Smith, 1879)

(Figures 5 A–C).

Material Examined. 1♀, (CDZMTUHymB4), Kathmandu, Sundarijal, 27.79°N, 85.42°E, 12.x.2018, from 2,000 m.

Floral association. *Ageratum houstonianum*.

Diagnostic features:

Antennae piceous; pale yellow-white clypeus, labrum, and base of the mandibles, short dense pubescence; the mesonotum beneath pubescence is closely and irregularly punctate-striate, pale ochraceous thorax, almost white pubescence above; wings clear

hyaline, slightly milky in nature; abdomen coated with dense short pale ochraceous pubescence. B.L-13.5mm.

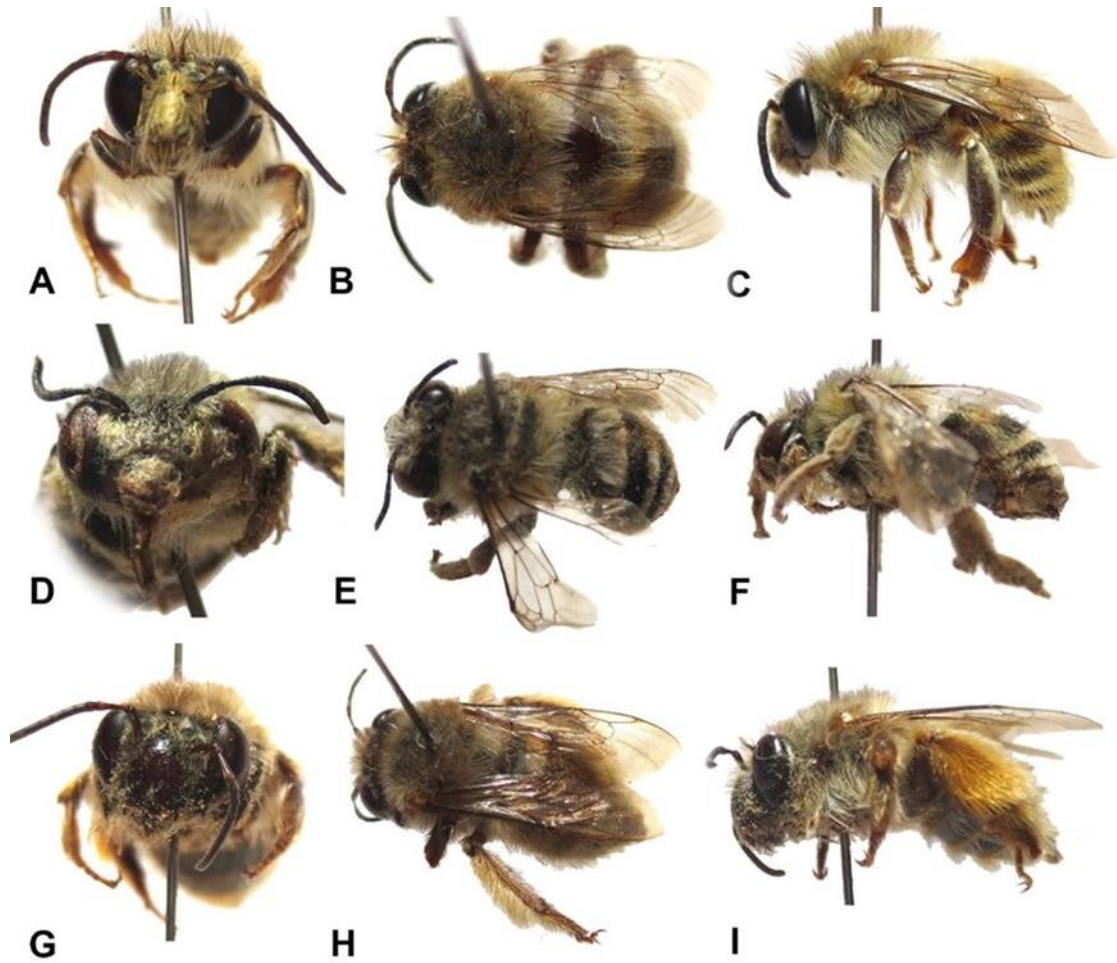


Figure 5: *Amegilla candida* female: A, Frontal habitus; B, Dorsal habitus; C, Lateral habitus; *Amegilla fallax* female: D, Frontal habitus; E, Dorsal habitus; F, Lateral habitus; *Amegilla insularis* female: G, Frontal habitus; H, Dorsal habitus; I, Lateral habitus (Dyola *et al.*, 2022a).

5. *Amegilla (Zonamegilla) cingulifera* (Cockerell, 1910)

Material Examined. 1♀, (CDZMTUHymB5), Kathmandu, Manichud, 27.75°N, 85.46680°E, 14.x.2018, 1,800 m; Nagarjun, 1♀, 27.68°N, 85.28741°E, 24.x.2018, 1,500 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1,500 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 03.x.2018, 1,900 m.

Floral association. *Ageratum houstonianum* and *Bidens pilosa*.

Distribution. Nepal (Ascher & Pickering, 2021).

6. *Amegilla (Zonamegilla) confusa* (Smith, 1854)

Material Examined. 1♀, (CDZMTUHymB6), Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,500 m; 2♀, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1,900 m; 1♀, Sundarijal, 27.80°N, 85.42°E, 07.x.2018, 2,000 m.

Floral association. *Ageratum houstonianum* and *Bidens pilosa*.

Distribution. Nepal (Ascher & Pickering, 2021).

7. **Amegilla (Zebramegilla) fallax* (Smith, 1879)

(Figure 5 D–F)

Material Examined. 1♀, (CDZMTUHymB7), Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m.

Diagnostic features:

The vertex and the clypeus are sparsely and finely punctured, the mandibles at the base, labrum, and clypeus pale yellow; dense pubescent in anteriorly thorax, above with black-tipped ochraceous, beneath whitish; wings subhyaline, nervures brown; transverse bands on the abdomen are densely pubescent. B.L-13mm.

Floral association. *Ageratum houstonianum*.

8. **Amegilla (Glossamegilla) insularis* (Smith, 1857)

(Figures 5 G–I)

Material Examined. 1♀, (CDZMTUHymB8), Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1,600 m.

Diagnostic features:

The front and vertex of the head with a sparse covering of longish hairs, finely punctured beneath it, clypeus medially carinate, the labrum except for a narrow border all round, a transverse triangular spot above it; thorax with long, erect and dense pubescent, rich with ferruginous, mixed with griseous, beneath white; wings flavo-hyaline, fluorescent towards the apical margins; black bases of 2-4 and 5th and 6th of abdominal segments. B.L-15.5mm.

Floral association. *Bidens pilosa*.

9. **Amegilla (Amegilla) quadrifasciata* (de Villers, 1789)

(Figures 6 A–C)

Material Examined. 1♀, (CDZMTUHymB9), Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m; 1♀, Sundarijal, 27.79°N, 085.42°E, 12.x.2018, 2,000 m.

Diagnostic features:

Black, more densely pubescent, the labrum, clypeus, and front of the head are finely and closely punctured, two large subquadrate contiguous spots at the base of the clypeus black; thorax densely pubescent, wings pale fusco-hyaline; densely pubescent abdomen, the entire 5th and 6th segments covered with thin black pubescence, the apical margins of 1-4 segments have pale fulvous-white pubescence. B.L-12 mm.

Floral association. *Ageratum houstonianum* and *Bidens pilosa*.

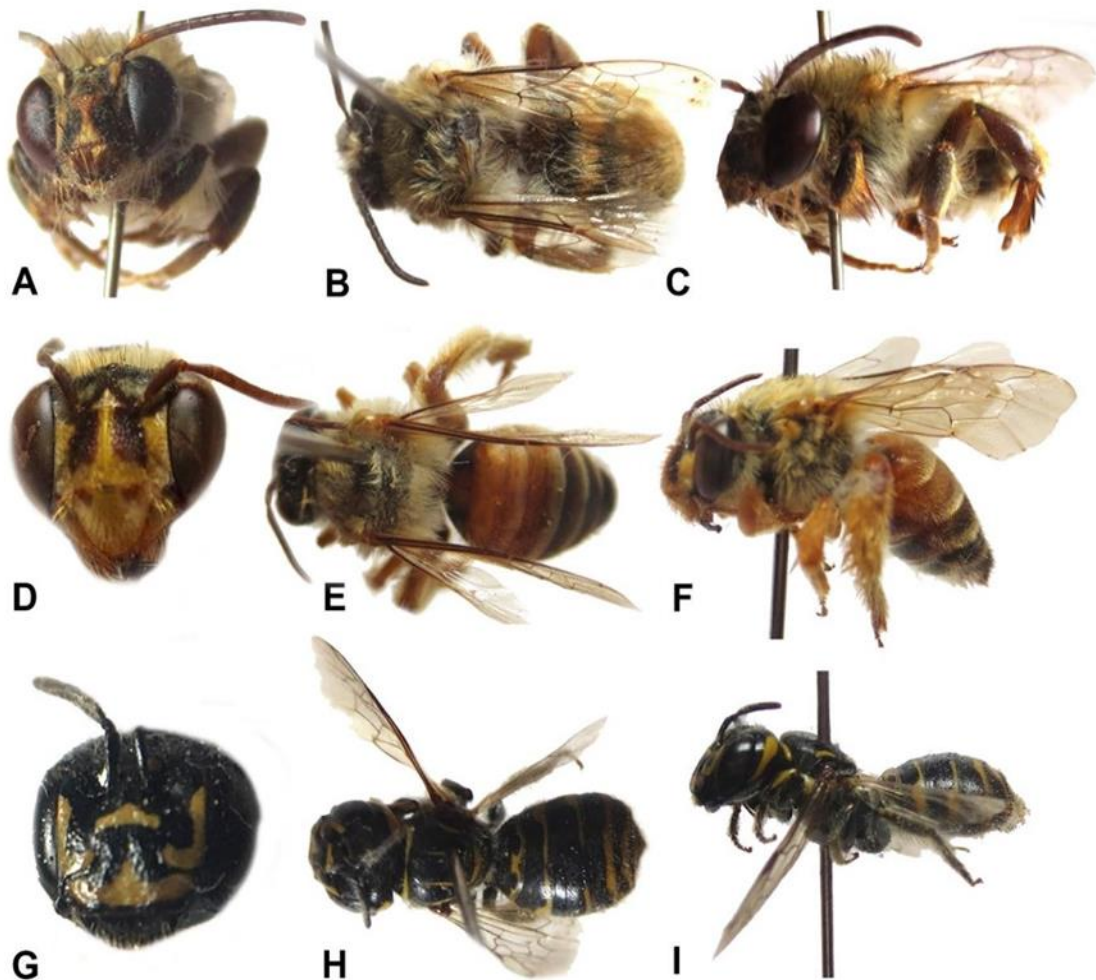


Figure 6: *Amegilla quadrifasciata* female: A, Frontal habitus; B, Dorsal habitus; C, Lateral habitus; *Elaphropoda impatiens* female: D, Head in frontal view; E, Dorsal habitus; F, Lateral habitus; *Ceratina perforatrix* female: G, Head in frontal view; H, Dorsal habitus; I, Lateral habitus (Dyola *et al.*, 2022a).

10. *Amegilla (Zonamegilla) zonata* (Linnaeus, 1758)

Material Examined. 1♀, (CDZMTUHymB10), Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m; 1♀, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m; 1♀, Sundarijal, 27.79°N, 85.42°E, 12.x.2018, 2,000m,

Floral association. *Ageratum houstonianum* and *Bidens pilosa*.

Distribution. Nepal (Kumari & Sidhu, 2020).

Genus *Elaphropoda* Liefstinck, 1966

11. **Elaphropoda impatiens* (Liefstinck, 1944)

(Figures 6 D–F)

Material Examined. 1♀, (CDZMTUHymB11), Kathmandu, Manichud, 27.75°N, 85.46680°E, 14.x.2018, 1,800 m; 1♀, Sundarijal, 27.79172°N, 85.4211 °E, 12.x.2018, 2,000m.

Diagnostic features:

Having a pair of conspicuous dark blotches on the clypeus; the first gastral segment and a pair of transverse spots (one on either side) at the base of the second, are "red", the hind margins of 2-6 being broadly bordered with ochraceous. B.L- 16-17 mm.

Floral association. *Lantana camara*.

Tribe Apini

Genus *Apis* Linnaeus, 1758

12. *Apis cerana* Fabricius, 1793

Material Examined. 1♀, (CDZMTUHymB12), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800m; 1♀, Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m; 2♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,500 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,500 m; 1♀, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1,600 m; 2♀, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 28.ix.2018, 1,700 m; 2♀, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1,900 m; 1♀, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m; 2♀, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m; 2♀, Sundarijal, 27.76°N, 85.42°E,

07.x.2018, 1,500 m; 1♀, Sundarikal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m; 1♀, Sundarikal, 27.79°N, 85.42°E, 12.x.2018, 2,000 m; 2♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m; 2♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1,600 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, and *Bidens pilosa*.

Distribution. Nepal. From Terai 3,500 m. Kathmandu (Thapa, 2015).

13. *Apis mellifera* Linnaeus, 1761

Material Examined. 1♀, (CDZMTUHymB13), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii. 2018, 1,800 m; 2♀, Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m; 2♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,500 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 24. x 2018, 1,500 m; 1♀, Nagarjun, 27.74°N, 85.29°E, 28.iii. 2018, 1,600 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 28 .ix. 2018, 1,700 m; 2♀, Shivapuri, 27.80°N, 85.39°E, 17.iv. 2018, 1,900m; 2♀, Sundarikal, 27.76°N, 85.42°E, 02. iv. 2018, 1,500 m; 2♀, Sundarikal, 27.76°N, 85.42°E, 07.x.2018, 1,500 m; 1♀, Sundarikal, 27.79°N, 85.42°E, 02. iv. 2018, 2,000 m; 1♀, Sundarikal, 27.79°N, 85.42°E, 12.x. 2018, 2,000 m; 2♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08 .iv. 2018, 1,600 m; 2♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01. xi. 2018, 1,600 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, and *Bidens pilosa*.

Distribution. Nepal. Terai–3,000 m (Thapa, 2015).

Tribe Bombini

Genus *Bombus* Latreille, 1802

14. *Bombus (Alpigenobombus) breviceps* Smith, 1852

Material Examined. 1♀, (CDZMTUHymB14), Sundarikal, 27.79°N, 85.42°E, 12.x.2018, from 2,000 m.

Floral association. *Plectranthus barbatus*.

Distribution. Nepal. From 980–3,000 m. Kathmandu: Gokarna Safari (Thapa, 2015).

15. *Bombus (Pyrobombus) eximius* Smith, 1852

Material Examined. 1♀, (CDZMTUHymB15), Kathmandu Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2,300 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,500 m; 1♀ Shivapuri, 27.79°N, 085.38°E, 28.ix.2018, 1,700 m; 2♀, Sundarijal, 27.77°N, 85.42°E, 02.iv.2018, 1,500 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 10.iv.2018, 1,900 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 085.31°E, 12.iv.2018, 2,000 m.

Floral association. *Lantana camara*, *Rubus ellipticus*, *Strobilanthes atropurpureus*, and *Viola serpens*.

Distribution. Nepal. From 914–2,700 m. Sankhuwasabha: Arun valley Uwa at 1,600 m; Solukhumbu: above Gudel at 2,000–2,500 m; Kathmandu: Shivapuri at 1,600 m, Nagarjun forest, Sundarijal, and Lalitpur: Phulchoki at 1,800–2,000m; Kaski: Pothana at 2,000m; Myagdi: Thulo Khola Rakhor at 1,700–2,100 m, Bega to Bega Deurali at 1,700–2,400 m; Dailekh: Bharin at 2,400 m (Burger *et al.*, 2009; William *et al.*, 2010; Thapa, 2015).

16. *Bombus (Pyrobombus) flavescens* Smith, 1852

Material Examined. 1♀, (CDZMTUHymB16), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.x.2018, 2,300 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,500 m; 1♀, Shivapuri, 27.61°N, 85.37°E, 03.x.2018, 2,300 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m; 1♀, Sundarijal, 27.79°N, 85.42°E, 12.x.2018, 2,000 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.x.2018, 2,000 m..

Floral association. *Lantana camara* and *Strobilanthes atropurpureus*.

Distribution. Nepal. From 1,400–2,950 m. Kaski: Ulleri at 2,000 m (Burger *et al.*, 2009; Williams *et al.*, 2010; Thapa, 2015).

17. *Bombus (Orientalibombus) haemorrhoidalis* Smith, 1852

Material Examined. 1♀, (CDZMTUHymB17), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2,300 m; 1♀, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1,600 m; 1♀, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1,900 m; 2♀ Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2,300m; 1♀, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m; 1♀,

Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m.

Floral association. *Plectranthus barbatus*, *Rubus ellipticus*, *Strobilanthes atropurpureus*, and *Viola serpens*.

Distribution. Nepal. From 830m recorded up to 4,000 m. Dailekh Bharin at 2,400 m; Kalikot: Gamkhet at 1,850 m; Mugu: Rara at 2,990 m; Jumla: Tatopani at 200 m; Surkhet at 1,700 m; Humla: Simikot at 2,200 m (Burger *et al.*, 2009; Thapa, 2015).

Tribe Melectini

Genus *Thyreus* Panzer, 1806

18. *Thyreus decorus* (Smith, 1852)

Material Examined. 1♀, (CDZMTUHymB18), Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m; 1♀, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1500 m.

Floral association. *Lantana camara*.

Distribution. Nepal. Chembu at 1,650 m (Thapa, 2015).

19. *Thyreus himalayensis* (Radoszkowski, 1893)

Material Examined. 1♀, (CDZMTUHymB19), Kathmandu, Shivapuri, 27.80°N, 85.39°E, 30. ix.2018, 1,900 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 03. xi.2018, 1,900 m.

Floral association. *Lantana camara*.

Distribution. Nepal. From 750–1,600 m. Kathmandu: Godawari at 1,450 m; Kaski: Rupakot at 750 m; Sanopakha at 1,600 m, Namuto at 1,400 m (Thapa, 2015).

20. *Thyreus histrio* (Fabricius, 1775)

Material Examined. 1♀, (CDZMTUHymB20), Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m; 1♀, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1,500 m.

Floral association. *Lantana camara*.

Distribution. Nepal. Kathmandu at 1,340 m (Thapa, 2015).

Subfamily Nomadinae

Tribe Nomadini

Genus *Nomada* Scopoli, 1770

21. *Nomada mutabilis* Morawitz, 1871

Material Examined. 1♀, (CDZMTUHymB21), Kathmandu, Nagarjun, 27.74°N, 85.29°E, 24.x.2018, 1,600 m.

Floral association. *Bidens pilosa*.

Distribution. Nepal (Proshchalykin & Schwarz, 2017).

Subfamily Xylocopinae

Tribe Ceratinini

Genus *Ceratina* Latreille, 1802

22. *Ceratina (Ceratinidia) bryanti* Cockerell, 1919

Material Examined. 1♀, (CDZMTUHymB22), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 04.iv.2018, 1,500 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, and *Bidens pilosa*.

Distribution. Nepal. Lower warm-temperate zone from 1,300–1,400 m. Kathmandu (Shiokawa, 2008).

23. *Ceratina (Neoceratina) dentipes* Friese, 1914

Material Examined. 1♀, (CDZMTUHymB23), Kathmandu, Sundarijal, 27.764531°N, 85.4234°E, 02.iv.2018, 1,500 m.

Floral association. *Ageratina adenophora*.

Distribution. Nepal. Warm-temperate zone at an altitude of about 1,500 m. Naudanda, Central Nepal (Shiokawa, 2008).

24. **Ceratina (Catoceratina) perforatrix* Smith, 1879

(Figures 6 G–I)

Material Examined. 1♀, (CDZMTUHymB24), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2,100 m; 1♀, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, and *Bidens pilosa*.

Diagnostic features:

Head distinctly wider than high; more extensively marked with yellow, vertex impunctate, margined posteriorly by a fine, sharp carina, median part of clypeus shiny; mesoscutum black, second abdominal tergite black, pregradular area of tergites 2-4 often entirely or partly yellow; post scutellum often yellow. B.L- 10mm.

Tribe Xylocopini

Genus *Xylocopa* Latreille, 1802

25. *Xylocopa (Mesotrichia) acutipennis* Smith, 1854

Material Examined. 1♀, (CDZMTUHymB25), Kathmandu, Shivapuri, 27.80°N, 85.39°E, 17. iv.2018, 1,900 m.

Floral association. *Lantana camara*.

Distribution. Nepal. From Terai–2,200 m. Kathmandu; Nuwakot: Nagarkot at 2,200 m; Rupandehi: Bhairahawa (Thapa, 2015).

26. *Xylocopa (Koptortosoma) aestuans* (Linnaeus, 1758)

Material Examined. 1♀, (CDZMTUHymB26), Kathmandu, Shivapuri, 27.79°N, 085.38°E, 15. iv.2018, 1,700 m.

Floral association. *Lantana camara*.

Distribution. Nepal. Kathmandu (Thapa, 2015).

27. *Xylocopa (Zonohirsuta) collaris Lepeletier, 1841

(Figures 7 A–C)

Material Examined. 1♀, (CDZMTUHymB27), Kathmandu, Sundarijal, 27.76°N, 85.42°E, 02. iv.2018, 1,500 m.

Diagnostic features:

Punctured, very finely and closely, a fine medial vertical carina from the apex of the clypeus to between the base of the antenna; punctured, the pronotum anteriorly, and the front of the mesonotum covered with straight dense white pubescence; wings dull fuscous, with a moderate purple effulgence, punctured, very finely. B.L-19-20 mm.

Floral association. *Lantana camara*.

28. Xylocopa (Ctenoxylocopa) fenestrata (Fabricius, 1798)

Material Examined. 1♀, (CDZMTUHymB28), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1,600 m; 1♀, Sundarijal, 27.79°N, 085.42°E, 05.iv.2018, 2,000 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 085.31°E, 12 .iv.2018, 2,000 m.

Floral association. *Lantana camara*.

Distribution. Nepal. Kathmandu, also in Terai: Pipal Hali (Thapa, 2015).

29. Xylocopa (Mesotrichia) tenuiscapa Westwood, 1840

Material Examined. 1♀, (CDZMTUHymB29), Kathmandu, Nagarjun, 27.74415°N, 85.29023°E, 28.iii.2018, 1,600 m; 1♀, Sundarijal, 27.79172°N, 85.4211°E, 05.iv.2018, 2,000 m.

Floral association. *Lantana camara*.

Distribution. Nepal. Kathmandu (Thapa, 2015).

30. *Xylocopa (Xylocopa) violacea (Linnaeus, 1758)

(Figures 7 D–F)

Material Examined. 1♀, (CDZMTUHymB30), Kathmandu, Manichud, 27.77°N, 85.47°E, 20 iii 2018, 2,000 m.

Diagnostic features:

Head transverse, a triangular ocelli just below the vertex; body with black pubescence, wing with violet reflection; scape blackish, black antennal segment; posterior tibiae and tarsi always densely pubescent. B.L- 20mm.

Floral association. *Lantana camara*.



Figure 7: *Xylocopa collaris* female. A. Head in frontal view; B. Dorsal habitus; C. Lateral habitus; *Xylocopa violacea* female. D. Head in frontal view; E. Dorsal habitus; F. Lateral habitus (Dyola *et al.*, 2022 a).

2.1.3.3 Family Colletidae Lepeletier, 1841

Subfamily Colletinae

Tribe Colletini

Genus *Colletes* Latreille, 1802

31. **Colletes similis* Schenck, 1853

(Figures 8 A–C)

Material Examined. 1♀, (CDZMTUHymB31) Kathmandu, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1,600 m; 1♀, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m.

Diagnostic features:

Facial fovea narrow; metasomal terga with apical bands; propodeum laterally mostly covered with sparse long erect hairs; vertex behind eyes rounded, posterior margin of T1 opaque dark brown to black. B.L- 13.5mm.

Floral association. *Ageratina adenophora*.

2.1.3.4 Family Halictidae Thomson, 1869**Subfamily Halictinae****Tribe Halictini****Genus *Halictus* Latreille, 1804****32. *Halictus (Seladonia) propinquus* Smith, 1853**

Material Examined. 1♀, (CDZMTUHymB32), Kathmandu, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,500 m.

Floral association. *Bidens pilosa*.

Distribution. Nepal. From 1,350–2,050 m. Kathmandu: Kalimati, Swayambhu, Gokarna Safari and Godawari Botanical Garden; Dolpa: Tripurakot at 2,050 m (Murao & Tadauchi, 2013; Thapa, 2015).

33. *Halictus (Seladonia) vicinus* Vachal, 1894

Material Examined. 1♀, (CDZMTUHymB33), Kathmandu, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,500 m.

Floral association. *Ageratum houstonianum*.

Distribution. Nepal. From 2,450–3,115 m. Solukhumbu: Ringmo at 2,900 m and Junbesi at 2,700–2,780 m; Jumla at 2,450 m and Talpi at 3,115 m (Murao & Tadauchi, 2013; Thapa, 2015).

Genus *Lasioglossum* Curtis, 1833

34. *Lasioglossum (Ctenonomia) albescens* (Smith, 1853)

Material Examined. 1♀, (CDZMTUHymB34), Kathmandu, Shivapuri, 27.80°N, 85.39°E, 17. iv.2018, from 1,900 m.

Floral association. *Lantana camara*.

Distribution. Nepal. From Terai–1,600 m. 1,500 m; Bara: Adhabar at 183 m; Parsa: Birgunj at 100 m; Chitwan: Sauraha at 180 m; Banke: Hotel Batika at 170 m. Nepalgunj; Kaski: Pokhara at 830 m; Sanopakha at 1,600 m (Thapa, 2015).

35. *Lasioglossum (Evyllaesus) marginatum* (Brullé, 1832)

Material Examined. 1♀, (CDZMTUHymB35), Kathmandu, Manichud, 27.75°N, 85.47°E, 14 x 2018, 1,800 m; 1♀, Sundarijal, 27.79°N, 85.42°E, 12 x 2018, 2,000 m.

Floral association. *Ageratum houstonianum* and *Bidens pilosa*.

Distribution. Nepal. Jumla: Churta at 3,800 m and Gothichaur at 2,800 m and at 2,900–3,050 m (Thapa, 2015); India (Ascher & Pickering, 2021).

36. *Lasioglossum (Evyllaesus) villosulum* (Kirby, 1802)

Material Examined. 1♀, (CDZMTUHymB36), Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 03.xi.2018, 1,900 m.

Floral association. *Ageratum houstonianum* and *Bidens pilosa*.

Distribution. Nepal. Jumla: Gothichour at 2,650 m and 2,850 m (Thapa, 2015).

Subfamily Nomiinae

Tribe Nomini

Genus *Nomia* Latreille, 1804

37. *Nomia (Acunomia) formosa* Smith, 1858

Material Examined. 1♀, (CDZMTUHymB37), Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m; 1♀, Sundarijal, 27.79°N, 85.4211 °E, 12.x.2018, 2,000 m.

Floral association. *Ageratum houstonianum* and *Lantana camara*.

Distribution. Nepal (Murao *et al.*, 2015).

38. *Nomia (Hoplonomia) incerta* Gribodo, 1894

Material Examined. 1♀, (CDZMTUHymB38), Kathmandu, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m.

Floral association. *Alternanthera sessilis*.

Distribution. Nepal. Godawari, Kathmandu valley (Murao & Matsumura, 2012).

39. **Nomia (Acunomia) iridescens* Smith, 1858

(Figures 8 G–I)

Material Examined. 1♀, (CDZMTUHymB39), Kathmandu, Sundarijal, 27.79°N, 85.42°E, 12.x.2018, 2,000 m.

Diagnostic features:

Black head, very finely and densely punctured, clypeus convex with rough punctures, most dense on the sides of the face, the cheeks, finely and densely punctured; mesonotum broad, slightly convex; wings glassy and iridescent abdomen with fine and densely punctured, shining, luminous in certain lights; segments 2-4 with transverse bright green or blue fasciae on their apical margins. B.L-9-10 mm.

Floral association. *Ageratum houstonianum*.

Distribution. India (Prakash *et al.*, 2020).

2.1.3.5 Family Megachilidae Latreille, 1802

Subfamily Megachilinae

Tribe Megachilini

Genus *Megachile* Latreille, 1802

40. **Megachile (Aethomegachile) conjuncta* Smith, 1853

(Figures 8 D–F)

Material Examined. 1♂, (CDZMTUHymB40), Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m.

Diagnostic features:

Integument black, pubescence over face, clypeus, hypostome fuscous; the sides of the prothorax covered with white, at the sides of the last sometimes with yellowish pubescence; first abdominal segment, scutum, scutellum, basal fasciae on terga 2-3 lightly reddish brown. B. L-10 mm.

Floral association. *Bidens pilosa*.

41. *Megachile femorata* Smith, 1853

Material Examined. 1 ♀, (CDZMTUHymB41), Kathmandu, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m.

Floral association. *Alternanthera sessilis*.

Distribution. Nepal (Kumari & Sidhu, 2020).

42. *Megachile (Callomegachile) umbripennis* Smith, 1853

Material Examined. 1 ♀, (CDZMTUHymB42), Kathmandu, Sundarijal, 27.76°N, 85.42°E, 12.x.2018, 1,500 m.

Distribution. Nepal (Thapa, 2015).

Floral association. *Cuphea hyssopifolia*.

2.1.4 DISCUSSION

The field collection of bees from SNNP comprised of 42 species belonging to 14 genera, and five families (Figure 4). The maximum species were recorded under family Apidae. This could be because of the fact that it is the largest family of bees (Aslam *et al.*, 2017; Kelber & Somanathan, 2019). Rest of the collected bees were wild species except *Apis cerana* and *A. mellifera*. Some *Bombus* spp. and solitary bees are managed bees (Pitts-Singer & Cane 2011; Mallinger *et al.*, 2017; Pereira *et al.*, 2019), but it has not yet been established as these bees being managed in Nepal. Wild bees were categorized into social bees (four) and solitary bees (36). Among solitary bees, four of the species were cuckoo bees.

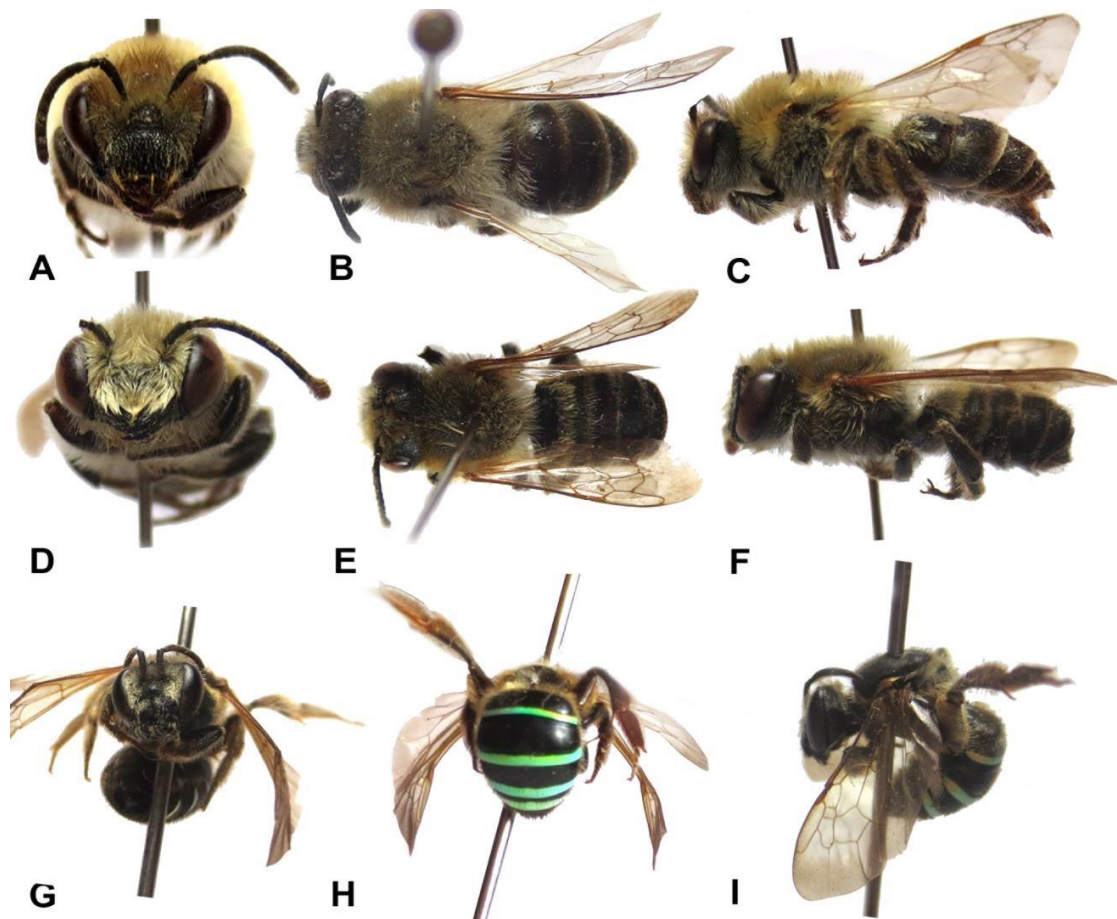


Figure 8: *Colletes similis* female. A. Frontal habitus; B. Dorsal habitus; C. Lateral habitus; *Megachile conjuncta* male. D. Frontal habitus; E. Dorsal habitus; F. Lateral habitus; *Nomia iridescens* female. G. Frontal habitus; H. Dorsal abdomen; I. Lateral habitus (Dyola *et al.*, 2022a).

2.1.4.1 Social bees

Six social bees were recorded from SNNP. They belong to two genera; *Apis* and *Bombus*. Although both of them show social behavior, they present different types of living in a colony. The former was found living in permanent colonies made up of a queen and many daughter workers while the other was observed to be living in small colonies usually started by solitary females. In Nepal, the previous findings showed five species of *Apis* (Thapa, 1997) however, there were only two species; *Apis cerana* and *Apis mellifera* collected during this study. These two bees are mainly managed for honey and wax in the country. Local people of managed habitat of the park also rear these species hence this could be the probable reason of presence of these bees. Whereas *Apis dorasata* and *A. laboriosa* are migratory and nest at high cliff (Woyke *et al.*, 2012; Kitnya *et al.*, 2020) so not frequently seen. *A. laboriosa* has been collected from elevation of 4,267 m ASL. in Nepal (Kitnya *et al.*, 2020). Hence, this is the probable

reason of their absence in SNNP. Similarly, among *Bombus* spp., 37 species were reported previously from the country and the present work documented only four species; *Bombus breviceps*, *B. eximius*, *B. haemorrhoidalis*, and *B. flavescens* from the study area. Maximum area of SNNP is covered by forest, which is humid and rich in tree flowers like *Rhododendron* in spring season. The *Bombus* spp. has a wide range for foraging in deep forest and some species (*B. eximius*) frequently visit *Rhododendron* flower (Kjellsson *et al.*, 1985). Furthermore, *B. breviceps* is polylectic (Liang *et al.*, 2020). Similarly, *B. haemorrhoidalis* prefers to forage both natural habitats (forest and grassland) and managed habitat (agricultural field) rather than home garden (Ghimire & Bhusal, 2021) showing their heterogenous distribution. Similarly, in this study, these bees were also collected from different habitats and elevations within SNNP.

2.1.4.2 Solitary bees

The bees of *Andrena*, are also termed as the mining bee and cosmopolitan in distribution. They are ground nesting solitary bees. Approximately, there are about 1,552 species of bees belonging to this genus (Ascher & Pickering, 2021) and, out of these 12 species have been documented from Nepal. The present study collected only three species: *Andrena flavipes*, *A. gorkhana*, *A. kathmanduensis*. *A. gorkhana* and *A. kathmanduensis* could possibly be endemic to the country, as they were not reported elsewhere earlier. Furthermore, IUCN Red List categorized *A. kathmanduensis* as the "Least concern". The species of *Andrena* compensate the pollination service in *Brassica* spp. and cherry orchards during low temperature and in absence of maximum honeybees (Güler & Sorkun, 2010).

Most *Amegilla* are called as blue-banded bees. Globally, about 225 species have been reported and only four species were previously reported from Nepal. However, the present work collected seven species of *Amegilla* from SNNP. Similarly, global records showed 376 species of *Xylocopa* and the present collection in SNNP reported six species. The species of these wild bees are also abundantly recorded from different habitats of Vietnam (Le Van Tho, 2021) also.

Next, *Megachile*, which is also, called a leafcutter that prepare nests in old wooden holes. The species of *Megachile* utilize leaves of trees, shrubs, and climbers for cutting (Soh *et al.*, 2019). Worldwide records of *Megachile* showed nearly 1,489 species (Ascher & Pickering 2021) and three species of this genus were listed in present study.

Finally, the present work listed three species of *Nomia*. The genus is mainly found in Africa and south to Southeast Asia. These bees are potential pollinators of alfalfa (Cane, 2008; Dar & Sofi, 2022).

2.1.4.3 Cuckoo bees and parasitic bee

Globally, there are approximately, 106 *Thyreus* species. *Thyreus decorus*, *T. himalayensis*, and *T. histrio* were three species recorded from SNNP. They are cuckoo bees especially parasitize *Amegilla* species (Straka & Engel, 2012). Species of *Nomada* are parasitic; the habitat preference of these bees generally correspond with their host (Collado *et al.*, 2019). Only one species i.e, *Nomada mutabilis* was recorded from SNNP.

2.1.5 CONCLUSIONS

The exploration of bees in four different habitats of SNNP presents diverse fauna with 11 new records; *Amegilla candida*, *A. fallax*, *A. insularis*, *A. quadrifasciata*, *Elaphropoda impatiens*, *Ceratina perforatrix*, *Xylocopa collaris*, *X. violacea*, *Colletes similis*, *Megachile conjuncta*, and *Nomia iridescens* for Nepal. This finding shows probability of finding much interesting bees in SNNP. This is the first list of bees using the most recent nomenclature, which may help other researchers to work in different aspects of bees from this area.

2.2 A FAUNISTIC STUDY ON THE HOVERFLIES (DIPTERA: SYRPHIDAE) OF SHIVAPURI-NAGARJUN NATIONAL PARK, CENTRAL NEPAL

Abstract

Hoverflies (Diptera: Syrphidae) comprise one of the most abundant, speciose, and conspicuous group of true flies. The vivid habitat of Nepal seems to possess high diversity of hoverflies (Diptera: Syrphidae), however, little investigation has been done on these flies in the country. The present study aims to explore the hoverfly fauna based to provide taxonomic diversity of them. The study was conducted in three different elevations that ranges from 1,400m–2,700m including four different habitats. The hoverflies were collected during spring and autumn seasons of year 2018. The collection was done in belt transect and by using both sweeping net and color pan traps. The field collection includes 454 hoverfly specimens belonging to 34 species with three new country records: *Graptomyza nigripes*, *Lycastris albipes* and *Volucella trifasciata*. The study indicates SNNP could harbor diverse hoverfly fauna.

2.2 INTRODUCTION

2.2.1 Background

Hoverflies (Diptera: Syrphidae) comprise one of the most abundant, speciose, and conspicuous group of true flies, including 209 genera with more than 6,300 species distributed worldwide, except Antarctica and remote oceanic islands (Pape *et al.*, 2011; Thompson 2019; Mengual *et al.*, 2022). Mengual *et al.* (2015) classified hoverfly into four subfamilies: Syrphinae, Pipizinae, Eristalinae, and Microdontinae. Except Pipizinae, all representatives of the three subfamilies are found in Nepal. All subfamilies are recovered as monophyletic in recent studies except Eristalinae (Hippa & Ståhls 2005; Mengual *et al.*, 2015, 2022; Young *et al.*, 2016; Pauli *et al.*, 2018; Moran *et al.*, 2022; Mullens *et al.*, 2022). The adult hoverflies are smaller to larger in body size, ranging from 4–25 mm long, and greatly diverse in morphology and environmental requirements. Most of them can be easily identified by their hovering behavior and the presence of a spurious vein between the radial and medial vein branches (Szymank & Jordaens, 2021). They are popular ‘non-bee’ pollinators in the world and visit 72% of global crop plants (Doyle *et al.*, 2020). Besides their vivid colors, amazing hovering behavior, and flower-visiting habits, they also provide

services in ecological, environmental, and economic aspects (Rotheray & Gilbert 2011; Mengual *et al.*, 2022). Adult hoverflies feed on pollen and nectar as a source of energy, but their larvae have diverse modes of feeding habits (Mengual *et al.*, 2022). Eristalinae larvae, for example, can be found near ponds with decaying leaves, wood, and rotting seaweed, as well as marshes and wetlands (van Veen 2010). Other Eristalines within the genera *Cheilosia* and *Merodon* eat hard plant parts like stem and root tunneling larvae (Rotheray & Gilbert 2008), as well as bulbs, leaf miners, stem, and tuber borers (Thompson & Vockeroth 1989). Syrphinae larvae, unlike Eristalinae, are important biocontrol agents that feed on Hemiptera, as well as Acari, Thysanoptera, and Lepidoptera larvae (Rojo *et al.*, 2003), with the exception of two *Toxomerus* species that feed on pollen (Riley & Howard 1888; Marín, 1969; Reemer & Rotheray 2009). Some Microdontinae have slug-like larvae that live as inquilines in ant nests (Reemer 2012; Cannings *et al.*, 2021; Ssymank *et al.*, 2021).

Nepal is situated in the central and eastern Himalayas with varied faunal and floral diversity, the country shares the world's two major biogeographical regions: the Oriental and Palearctic. A number of naturalists have studied Nepal's flora and fauna during the last 200 years. European and Indian Scientists have mostly done previous research on hoverflies of Nepal. Among the series of published articles on the Syrphidae of the Indian subcontinent, Brunetti (1907, 1908, 1913, 1915, 1923, and 1925) listed 21 species with three new species from Nepal. Following Brunetti, Bhatia (1933), Coe (1964), Thompson (1966, 1974, 2012), Vockeroth (1971), Lambeck and Kiauta (1973), Knutson *et al.* (1975), Wiegmann (1986), Claussen and Wiepert (2003, 2004), Steenis & Hippa (2012), Ghorpadé (2015a), and Nielsen (2016) added number of hoverfly species that are new records for Nepal. Then, Kapoor *et al.* (1979) presented 22 species from their field work in Nepal. Their updated list contained 11 new records for the country. Thereafter, Thapa (2015) and Ghorpadé (2015a) updated the checklist with 134 species under 55 genera and 157 species in 71 genera respectively. Steenis *et al.* (2018) reported five new species from Nepal. Recently Barkalov and Ståhls (2022) revised the genus *Cheilosia* from Nepal and recorded 37 species, of which 29 species are described: 26 species have been assigned at subgeneric level while the remaining three new species only described based on female specimens are not included in any generic group. The recent additions of new hoverfly species to the fauna of Nepal by Steenis *et al.* (2018) and Barkalov and Ståhls (2022) show that the country have a great

potential of unexplored hoverfly fauna. Present study of hoverflies has been carried out in different habitat types and altitudinal gradient of SNNP, which has not yet been done. At the same time, data from previous work show the number of known hoverfly species in Nepal is much lower than that in India (Ghorpadé, 2015b; 357 species) and almost double that of Pakistan. Pakistan has almost similar ecology, topography and environmental conditions (Hassan *et al.*, 2021; 82 species). This indicates that there remains a lot to discover in Nepal to fulfill the gap in knowledge of hoverflies.

This work on different species of hoverflies collected from different study sites of SNNP with the elevation and associated flower. The current research could provide a better platform for future research in Nepal on several aspects of hoverflies.

2.2.2 MATERIALS AND METHODS

2.2.2.1 Methods

The adult specimens were collected from SNNP during the year 2018 (spring and autumn seasons). Sundarijal, Shivapuri, Gurjebhanjyang, Nagarjun, and Manichud were selected in the study area as they represent different vegetation and habitat types to collect different species. There are human settlements in some areas of Sundarijal and Manichud with croplands, the most suitable habitats for saprophagous and aphidophagous hoverflies. While Shivapuri, Nagarjun, and Gurjebhanjyang are dominated by forest habitats. Patches of grassland is present in Sundarijal, Nagarjun, and Manichud in the sampling transect. The field study was started from 1,400m ASL to the Shivapuri peak i.e, 2,700m ASL. Each collection site was further divided into three different elevations and for each elevation, five sampling belt transects of 100×5 m was fixed. In this transect, the hoverflies were collected by sweeping net and colored pan traps (white, yellow, and blue) for two consecutive days. The specimens collected by sweeping net were kept in vials individually. These vials were transferred in an icebox. The pan traps were fixed in the transect for 24 hours. The insects trapped in pans after 24 hours were poured in white enamel tray. The hover fly specimens were handled carefully by brush and were placed into the vial containing 70% ethanol. The study area's map was created in ArcGIS (Geographic Information System) 10.5 version. Photographs of dorsal and lateral habitus of each representative for 34 species collected were taken by using Canon camera EOS 60D DSLR, attached with 60mm EF-Macro lens, Flash: GODOX TT 685C speedlight in the specimen holder stage.

2.2.2.2 Identification

The collected specimens were identified by using the following available literatures: Brunetti (1923), Speight (2017; 2020), Hassan *et al.* (2018a), and Steenis *et al.* (2021) for the most common species. Ghorpadé (1994) is used for the genera and species of Syrphini. Sengupta *et al.* (2017) and de Geer *et al.* (2020), for the genera and species of Syrphinae and Eristalinae. Claussen and Weipert (2003), for *Rhingia siwalikonsis*, Hassan *et al.* (2019) for *Baccha maculata* and Sankararaman *et al.* (2020), for *Volucella trifasciata*. Few of the identified specimens were confirmed by taking help from reference collections of museum and in personel collection of Dr. Asghar. The collected specimens (each one of representative species) were deposited in the Central Department Zoology Museum of Tribhuvan University (CDZMTU), Kirtipur, Kathmandu, Nepal as voucher specimens.

2.2.2.3 Nomenclature.

The nomenclature used is based on recently available literature: Yang *et al.* (2020), Dawah *et al.* (2020), Mengual *et al.* (2020), and Steenis *et al.* (2018, 2021).

2.2.2.4 Classification and arrangement.

The classification of subfamilies is followed of Mengual *et al.* (2015). Synonyms with type localities are given as far as they have been used in the literature dealing with the Nepalese fauna.

2.2.2.4 Floral association and local distribution

The flowers from which these specimens collected are also presented in the paper. The distribution of the species within Nepal are given as district named followed by local area with the elevation as far as they are available.

2.2.3 RESULTS

A total of 454 specimens including 291 females and 163 males were collected from SNNP during 2018 (Appendix II). These belong to 34 species under 20 genera (Table 1). Among these, three species, *Graptomyza nigripes* Brunetti, 1913 (Figures 11A–B), *Lycastris albipes* Walker, 1857 (Figures 11C–D) and *Volucella trifasciata* Wiedemann, 1830 (Figures 14A–B) are recorded for the first time in Nepal.

Table 1: List showing total number of Sub families, Genera, Sub genera and Species

Family	Subfamilies	Genera	Subgenera	Species		
Syrphidae	Eristalinae	<i>Eristalis</i>	<i>Eoseristalis</i>	<i>Cerealis</i>		
				<i>Himalayensis</i>		
						<i>Tenax</i>
		<i>Eristalinus</i>	<i>Eristalinus</i>	<i>Aeneus</i>		
				<i>Arvorum</i>		
				<i>Taeniops</i>		
		<i>Graptomyza</i>		<i>Nigripes</i>		
		<i>Lycastris</i>		<i>Albipes</i>		
				<i>Flavohirta</i>		
		<i>Mesembrius</i>		<i>Bengalensis</i>		
	<i>Phytomia</i>		<i>Errans</i>			
			<i>Zonata</i>			
	<i>Rhingia</i>		<i>Siwalikensis</i>			
	<i>Syritta</i>		<i>Indica</i>			
			<i>Orientalis</i>			
			<i>Pipiens</i>			
	<i>Volucella</i>		<i>Trifasciata</i>			
	Syrphinae	<i>Asarkina</i>			<i>Incisuralis</i>	
					<i>Porcina</i>	
		<i>Baccha</i>		<i>Maculate</i>		
<i>Betasyrphus</i>			<i>Serarius</i>			
<i>Dasyrphus</i>			<i>Orsua</i>			
<i>Episyrphus</i>			<i>Balteatus</i>			
			<i>Viridaureus</i>			
<i>Eupeodes</i>			<i>Bucculatus</i>			
<i>Melanostoma</i>			<i>Oriente</i>			
			<i>Scalare</i>			
			<i>Univittatum</i>			
<i>Meliscaeva</i>			<i>Cinctella</i>			
<i>Scaeva</i>			<i>Pyrastri</i>			
<i>Sphaerophoria</i>			<i>Bengalensis</i>			
		<i>Indiana</i>				
		<i>Scripta</i>				
<i>Syrphus</i>		<i>Torvus</i>				
2 subfamilies	20 genera	34 species				

List of Hoverflies of SNNP

2.2.3.1 Family Syrphidae Latreille, 1802

Subfamily Eristalinae

Genus *Eristalis* Latreille, 1804

Subgenus *Eoseristalis* Kanervo, 1938

1. *Eristalis (Eoseristalis) cerealis* Fabricius, 1805

Eristalis cerealis Fabricius, 1805:232. Type locality: India.

Eristalis solitus Walker, 1849:619. Type locality: Nepal.

(Figures 9 A–B)

Material Examined. 1♀, (CDZMTUDipS1), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♂, Kathmandu, Manichud, 27.76°N, 85.47°E, 14.x.2018, 1,800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 20.iii.2018, 2,000 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 19.x.2018, 2,000 m; 2♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2,300 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.x.2018, 2,300 m; 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,400 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,400 m; 1♀, 1♂, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1,600 m; 1♀, 1♂, Nagarjun, 27.74°N, 85.29°E, 26.x.2018, 1,600 m; 1♀, Nagarjun, 27.75°N, 85.27°E, 28.x.2018, 2,100 m; 1♀, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 28.ix.2018, 1,700 m; 2♀, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1,900 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m; 1♀, 2♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2,300 m; 1♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 03.x.2018, 2,300 m; 2♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m; 2♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1,500 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 03.iv.2018, 1,800 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 09.x.2018, 1,800 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.4211°E, 12.x.2018, 2,000 m; 2♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1,600 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 10.iv.2018, 1,900 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 3.xi.2018, 1,900 m; 1♀, Nuwakot,

Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m; 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL. Taplejung District: Sanghu at Tumlingtar plateau at 609 m, Sankhuwasabha District: Chichila Arun valley; Lalitpur District: Godawari Botanical Garden at 1,400 m/Phulchoki at 2,300–2,500 m and Hotel Norrbu Linka at 1,350 m, Kathmandu District: Thamel, Kritipur, Tribubvan at 1400m; Kaski District: Ulleri at 2,070 – 1,800 m and Pokhara at 900 m, Myagdi: Ghodepani at 2,855 m and Sikha at 2,850 – 1,920 m; Dolpa District: Kaigaon to Rimi at 2,800–3,100 m, Jumla District at 2,400 m and Uthu at 2,500 m (Coe, 1964; Lambeck & Kiauta, 1973; Kapoor *et al.*, 1979; Thapa, 2015; Ghorpadé, 2015a).

2. *Eristalis (Eoseristalis) himalayensis* Brunetti, 1908

Eristalis himalayensis Brunetti, 1908:70. Type locality: India.

(Figures 9 C–D)

Material Examined. 1♀, (CDZMTUDipS2), Kathmandu, Shivapuri, 27.80°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, Kathmandu, Shivapuri, 27.60°N, 85.36913°E, 20.iv.2018, 2,300 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL. Taplejung District: Sanghu at 1,981m and 2,804 m Sankhuwasabha District: Chichila at 1,600–1,900 m to Num, Solukhumbu District: Thangboche Gonda at 3,850 m; Makawanpur District: Chitlang at 1,600 m; Kaski District: Pipar and Ulleri at 2,070–1,800 m, Myagdi District: Ghodepani at 2,855 m and Simikot at 2,300 m, Dandaphaya Dharapani; Dolpa District: Gurung valley Hurikot at 3,100–3,600 m, Humla District: Simikot at 2,200 m, Phunki Drangka at 3,400 m (Coe, 1964; Lambeck & Kiauta, 1973; Thapa, 2015; Ghorpadé, 2015a).

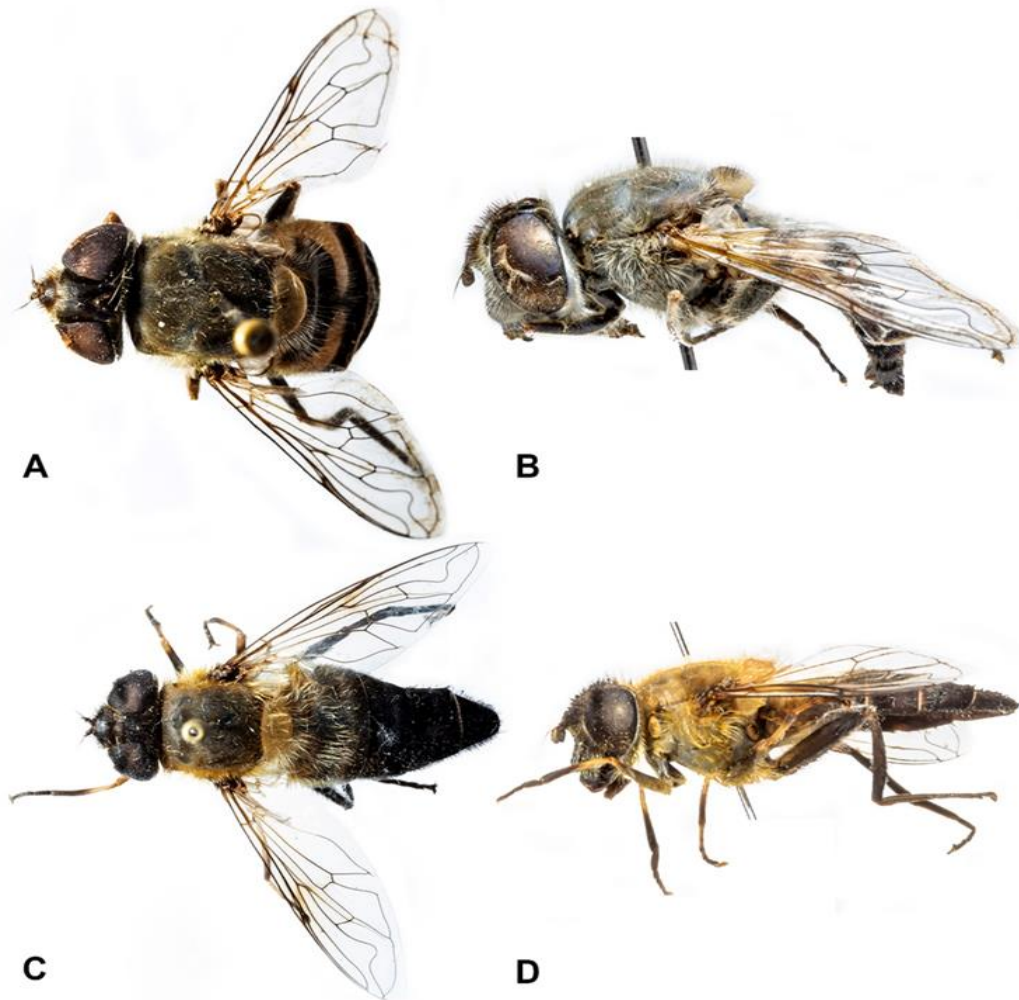


Figure 9: Dorsal and lateral habitus: A-B. *Eristalis (Eoseristalis) cerealis*; C-D. *Eristalis (Eoseristalis) himalayensis*

Subgenus *Eristalis* Latreille, 1804

3. *Eristalis (Eristalis) tenax* (Linnaeus, 1758)

(Figures 10 A–B)

Material Examined. 1♀, (CDZMTUDipS3), Kathmandu Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m; 2♀, Kathmandu Manichud, 27.77°N, 85.47°E, 20.iii.2018, 2,000 m; 1♂, Kathmandu Manichud, 27.77°N, 85.47°E, 19.X.2018, 2,000 m; 1♀, Kathmandu Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2,300 m; 1♀, 1♂, Kathmandu Manichud, 27.77°N, 85.47°E, 22.x.2018, 2,300 m; 1♀,; Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,400 m; 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,400 m, 1♀, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1,600 m; 1♀, 1♂, Nagarjun, 27.74415°N, 85.29°E, 26.x.2018, 1,600 m, 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2,100 m; 1♀, Nagarjun, 27.75°N, 85.27°E, 28.x.2018, 2,100 m, 2♀, 1♂, Shivapuri, 27.80°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, 27.79°N,

85.38°E, 28.ix.2018, 1,700 m; 1♀, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1,900 m; 1♀,1♂, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m; 1♀,1♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2,300 m, 2♀, Sundarijal, 27.76°N, 85.4234°E, 02.iv.2018, 1,500 m; 1♀,1♂, 27.76°N, 85.42°E, 07.x.2018, 1,500 m; 1♀,1♂, Sundarijal, 27.77°N, 85.42°E, 03.iv.2018, 1,800 m; 1♀,1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1,600 m; 1♀,1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 10.iv.2018, 1,900 m; 2♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 03.xi.2018, 1,900 m; 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL. Taplejung District: above Sanghu at 1,890 m and 2,134 m; Sankhuwasabha District: Arun Valley, Tumlingtar at 610 m; Dolakha District: Hurikot Garpung valley at 2,700–3,000 m and Churta at 3,400 m, Sindhupalchok District: Helambu at 2,400 m, Kathmandu District: Balaju, Kirtipur, Chhauni at 1,400 m and Gokarna Safari, Lalitpur District: Godawari Botanical Garden at 1,400m, Phulchoki at 2,300–2,500 m; Myagdi District: Sikha Ghodepani at 1,920–2,850 m, Jumla at 2,200–2,400 m, Uthi at 2,500 m, Kaigaon at 3,000 m, Tatopani at 2,200m; Humla District: Simikot at 3,100 m and Tuling Kermi at 2,300–2,700 m, Jumla District: Gothichour at 2,700–3,200 m (Coe, 1964; Lambeck & Kiauta, 1973; Kapoor *et al.*, 1979; Thapa, 2015; Ghorpadé, 2015a).

Genus *Eristalinus* Rondani, 1845

Subgenus *Eristalinus* Rondani, 1845

4. *Eristalinus (Eristalinus) aeneus* (Scopoli, 1763)

(Figures 10 C–D)

Material Examined. 1♀,(CDZMTUDipS4)1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m, 1♀, Nuwakot Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m; 1♀, 1♂, Nuwakot Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL (Ghorpadé, 2015a).

5. *Eristalinus (Eristalinus) arvorum* (Fabricius, 1787)

Syrphus arvorum Fabricius 1787:335. Type locality: India.

Material Examined. 1♀, (CDZMTUDipS5), Kathmandu, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m.

(Figures 2.8 E–F)

Floral association. *Ageratina adenophora*.

Distribution. NEPAL. Taplejung District: Sanghu at 1,889 m; Sankhuwasabha District: below Tumlingtar at 548 m Arun valley; Chitwan District: Sauraha at 180 m, Makawanpur District: Hetauda at 430 m, Kathmandu District: Chhauni and Taudaha at 1,350 m, Phulchoki at 2,300–2,500 m and Hotel Norbu Linka at 1,350 m Thamel; Jumla District: Gothichour at 2,800 m (Coe, 1964; Lambeck & Kiauta, 1973; Thapa, 2015; Ghorpadé, 2015a).

6. *Eristalinus (Eristalinus) taeniops* (Wiedemann, 1818)

Eristalis taeniops Wiedemann, 1818:42. Type locality: South Africa.

(Figures 10 G–H)

Material Examined. 2♀, (CDZMTUDipS6), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800m.

Floral association. *Ageratina adenophora*, *Bidens pilosa*.

Distribution. NEPAL (Thapa, 2015; Ghorpadé, 2015a).

Genus *Graptomyza* Wiedemann, 1820

7. *Graptomyza nigripes* Brunetti, 1913

Graptomyza nigripes Brunetti, 1913a: 167. Type locality: India.

(Figures 11 A–B)

Material Examined. 1♀, (CDZMTUDipS7), Kathmandu, Sundarijal, 27.79°N, 85.42°E, 12.x.2018, 2,000m.

Diagnostic features:

No spurious vein between R and M, open marginal cell; clearly visible plumose arista; thorax blackish; dull humeri; large transverse spot rounded in second abdominal segment that extends forward. B.L-7.5mm.

Floral association. *Cuphea hyssopifolia*.

Remark: New species record for Nepal.

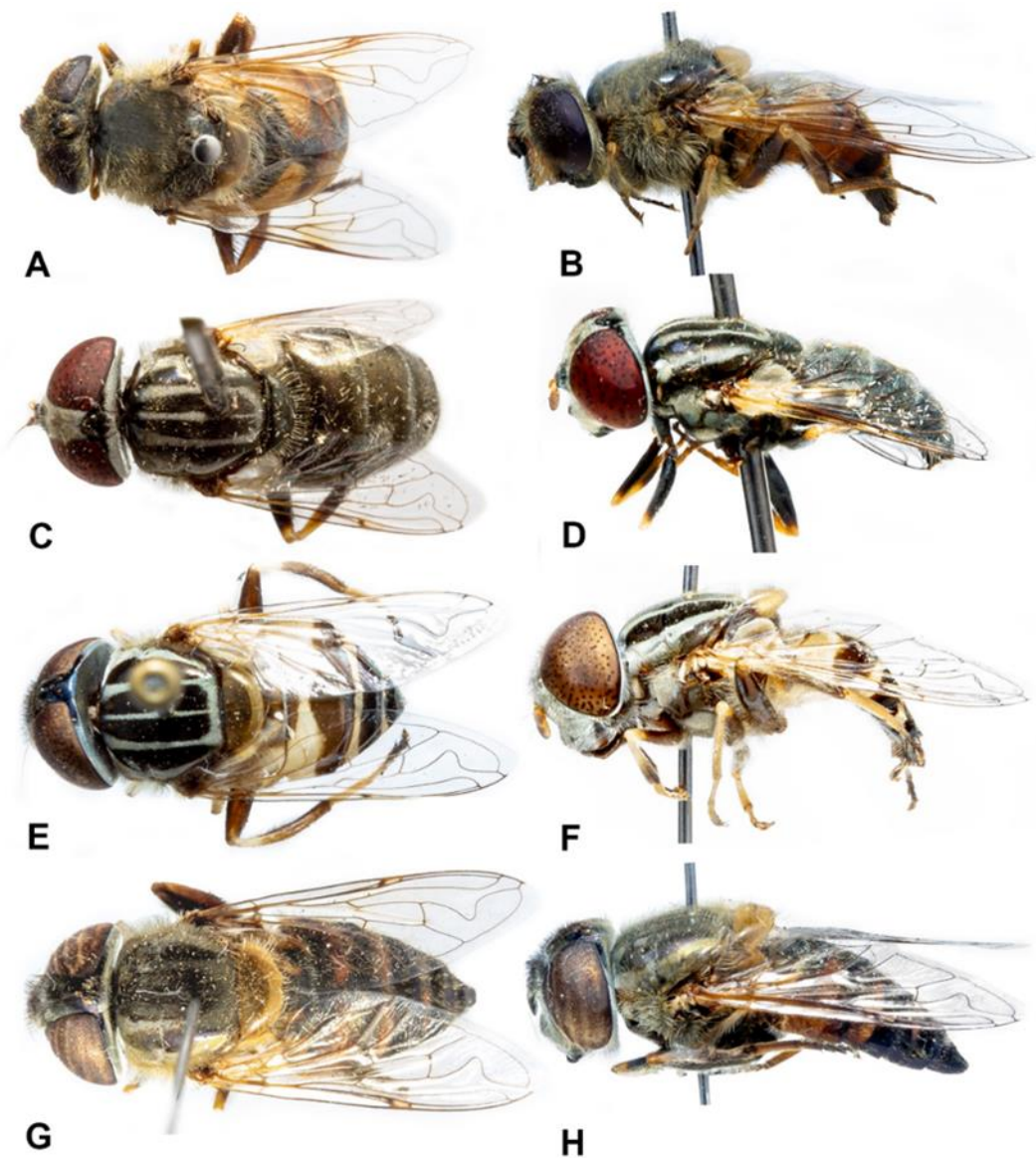


Figure 10: Dorsal and lateral habitus: A–B. *Eristalis* (*Eristalis*) *tenax*; C–D. *Eristalinus* (*Eristalinus*) *aeneus*; E–F. *Eristalinus* (*Eristalinus*) *arvorum*; G–H. *Eristalinus* (*Eristalinus*) *taeniops*

Genus *Lycastris* Walker, 1857

8. *Lycastris albipes* Walker, 1857

Lycastris albipes Walker, 1857: 155. Type locality: India.

(Figures 11 C–D)

Material Examined. 1♂,(CDZMTUDipS8), Kathmandu, Shivapuri, 27.61°N, 85.37°E, 20.iv.2018, 2,300 m; 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m.

Diagnostic features:

Eyes bare, adjoining living short space; yellowish grey to black colour; scutellum clothed with dense and quite long bright yellow pubescence; blackish abdomen blackish with aeneous, deep blue tint on its dorsal surface, anterior margin of the 2nd segment is elongated into V shaped spots; yellow anterior part of leg, entire black hind femora, legs clothed with bright yellow to whitish pubescence; wing grey in colour, halteres slightly yellowish grey. B.L- 15mm.

Floral association. *Ageratina adenophora*.

Remark. New species record for Nepal.

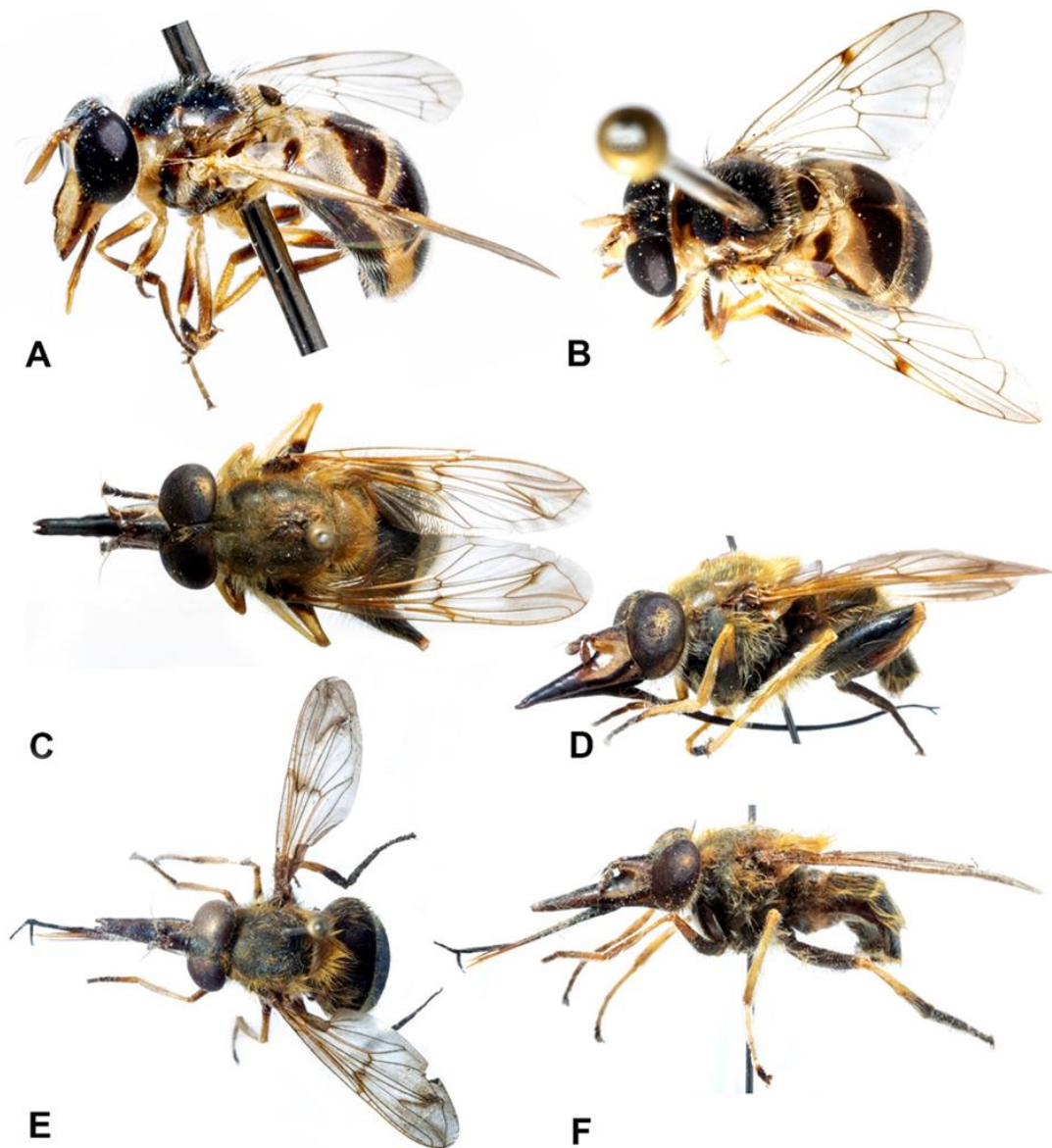


Figure 11: Dorsal and lateral habitus: A–B. *Graptomyza nigripes*; C–D. *Lycastris albipes*; E–F; *Lycastris flavohirta*

9. *Lycastris flavohirta* Brunetti, 1907

Lycastris flavohirta Brunetti, 1907: 16. Type locality: India.

(Figures 11 E–F)

Material Examined: 1♀, (CDZMTUDipS9), Kathmandu, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, Sundarijal, 27.77°N, 85.42°E, 02.iv.2018, 1,500 m.

Floral association. *Bidens pilosa*.

Distribution. NEPAL. Taplejung District: above Sangu at 2,804 m (Coe, 1964; Thapa, 2015; Ghorpadé, 2015a).

Genus *Mesembrius* Rondani, 1857

10. *Mesembrius bengalensis* (Wiedemann, 1819)

Eristalis bengalensis Wiedemann, 1819:16. Type locality:India.

(Figures 12 A–B)

Material Examined. 1♀, (CDZMTUDipS10), Kathmandu, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1900 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1,500 m.

Floral association. *Alternanthera sessilis*, *Lantana camara*.

Distribution. NEPAL. Kathmandu District; Banke District: Hotel Batika at 170 m Nepalgunj (Thapa, 2015; Ghorpadé, 2015a).

Genus *Phytomia* Guérin–Méneville, 1833

11. *Phytomia errans* (Fabricius, 1787)

Syrphus errans Fabricius, 1787: 337. Type locality: China.

(Figures 12 C–D)

Material Examined. 1♀,(CDZMTUDipS11), Kathmandu, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1,600 m.

Floral association. *Alternanthera sessilis*, *Lantana camara*.

Distribution. NEPAL. Taplejung District: between Sanghu at 1,850 m, Sankhuwasabha District: Arun Valley, Tumlingtar at 610 m; Kathmandu District: Chhauni at 1,400 m (Coe, 1964; Lambeck & Kiauta, 1973; Thapa, 2015; Ghorpadé, 2015a).

12. *Phytomia zonata* (Fabricius, 1787)

Syrphus zonatus Fabricius, 1787:337. Type locality: India.

(Figures 12 E–F)

Material Examined. 1♀, (CDZMTUDipS12), Kathmandu, Manichud, 27.75°N, 85.467°E, 14.x.2018, 1,800 m; 1♀, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2,300 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1,500 m.

Floral association. *Alternanthera sessilis*, *Lantana camara*.

Distribution. NEPAL. Taplejung District: Sanghu at 1,850 m and Dobhan at 2,076 m; Kathmandu District: Chhauni at 1,400 m (Coe, 1964; Lambeck & Kiauta, 1973; Thapa, 2015; Ghorpadé, 2015a).

Genus *Rhingia* Scopoli, 1763

13. *Rhingia siwalikensis* Nayar, 1968

Rhingia siwalikensis Nayar, 1968:126. Type locality: India.

(Figures 13 A–B)

Material Examined. 1♀, (CDZMTUDipS13), Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*.

Distribution. NEPAL. Myagdi District: Ghodepani at 2,855 m (Claussen & Weipert, 2003; Thapa, 2015; Ghorpadé, 2015a).

Genus *Syritta* Lepeletier & Serville, 1828

14. *Syritta indica* (Wiedemann, 1824)

Eumerus indica Wiedemann, 1824:33. Type locality: India.

(Figures 13 C–D)

Material Examined. 1♂, (CDZMTUDipS14), Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,400 m; 1♀, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1,600 m; 1♀, Nagarjun, 27.74°N, 85.29°E, 26.x.2018, 1,600 m; 1♀, Nagarjun, 27.75°N, 85.27°E, 28.x.2018, 2,100 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 28.ix.2018, 1,700 m; 1♀, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m; 1♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2,300 m; 1♂, Shivapuri, 27.60°N, 85.37°E, 03.x.2018, 2,300 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1,500 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 09.x.2018, 1,800m; 1♀, Sundarijal, 27.79°N, 85.4211°E, 05.iv.2018, 2,000 m; 1♀, 1♂, Sundarijal, 27.79°N,

85.42°E, 12.x.2018, 2,000 m, 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1,600 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 10.iv.2018, 1,900 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 03.xi.2018, 1,900 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2,000 m.

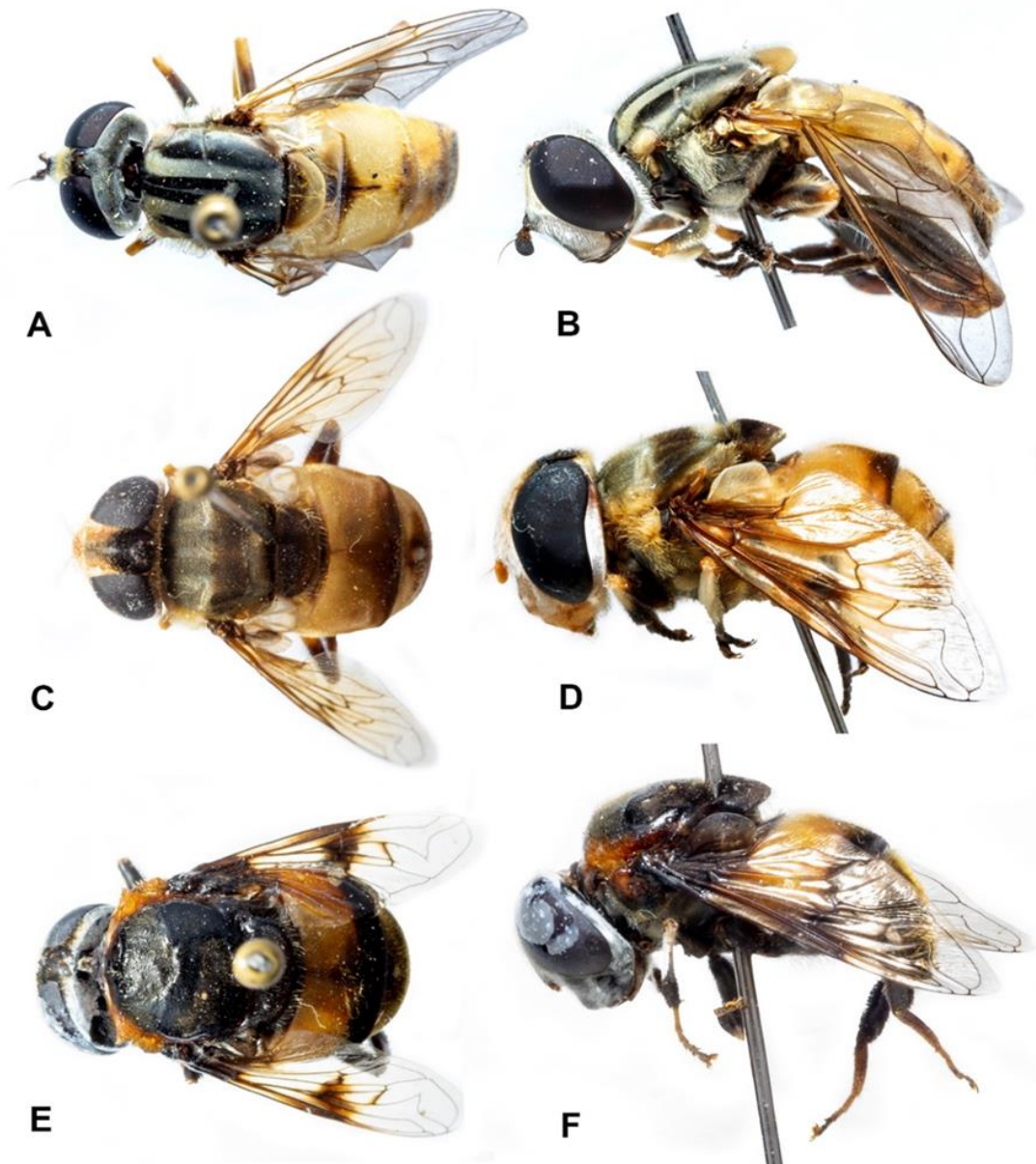


Figure 12: Dorsal and lateral habitus: A–B. *Mesembrius bengalensis*; C–D. *Phytomia errans*; E–F. *Phytomia zonata*

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL (Thapa, 2015; Ghorpadé, 2015a)

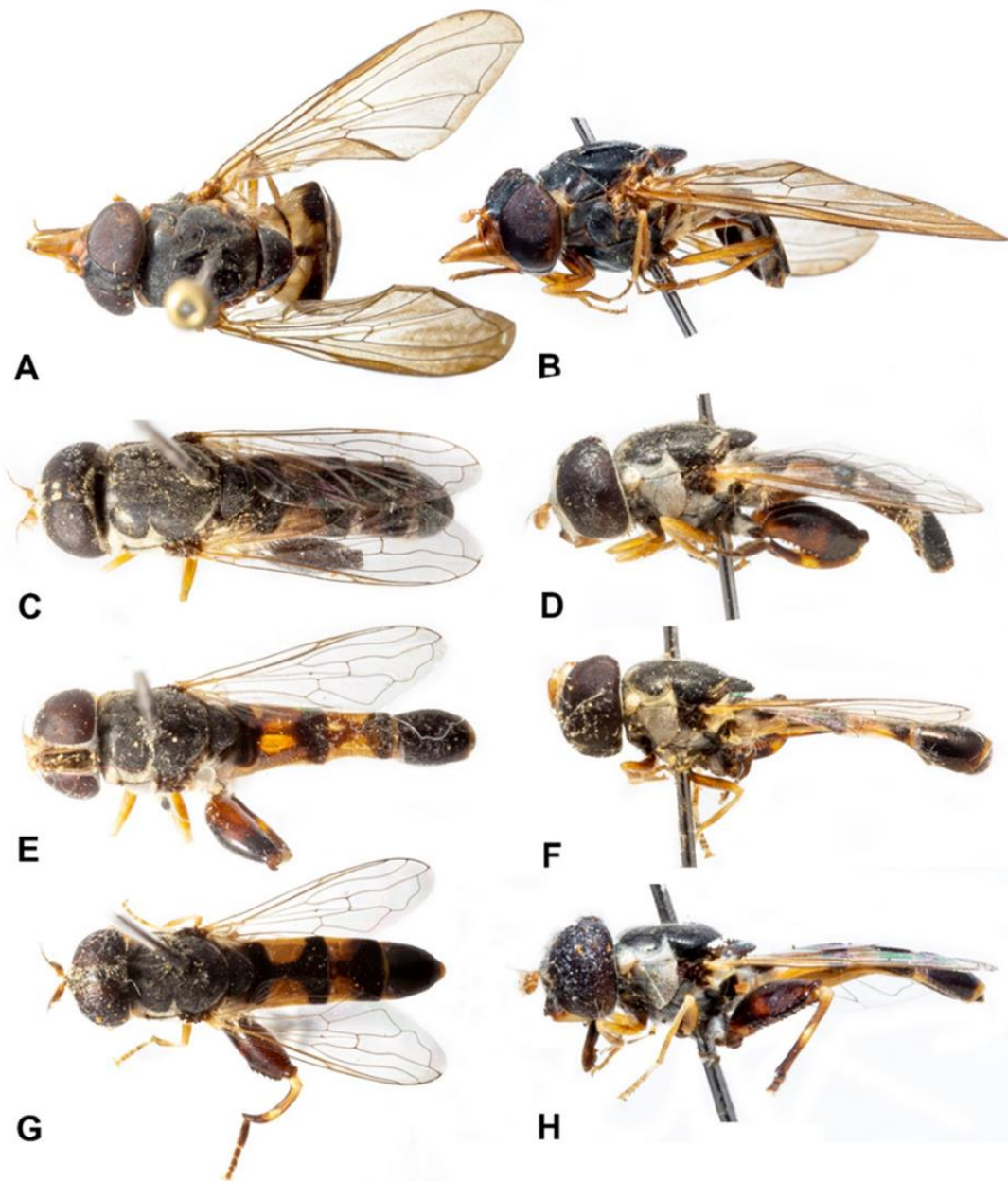


Figure 13: Dorsal and lateral habitus: A–B. *Rhingia siwalikensis*; C–D. *Syrirta indica*; E–F. *Syrirta orientalis*; G–H. *Syrirta pipiens*

15. *Syrirta orientalis* Macquart, 1842

Syrirta orientalis Macquart, 1842:76. Type locality: India.

(Figures 13 E–F)

Material Examined. 1♀, (CDZMTUDipS15), Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 19.x.2018, 2,000 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.x.2018, 2,300 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,400 m; 1♂, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,400 m; 1♀, Nagarjun, 27.74°N, 85.29°E, 26.x.2018,

1,600 m; 1♀, Nagarjun, 27.75°N, 85.27°E, 28.x.2018, 2,100 m, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, Shivapuri, 27.79°N, 85.37°E, 28.ix.2018, 1,700 m; 1♂, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1,900 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m, 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 12.x.2018, 2,000 m, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1,600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 03.xi.2018, 1,900 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL (Ghorpadé, 2015a, b; Hassan *et al.*, 2017; Shehzad *et al.*, 2017).

16. *Syritta pipiens* (Linnaeus, 1758)

Musca pipiens Linnaeus, 1758: 594. Type locality: Sweden.

(Figures 13 G–H)

Material Examined. 1♀, (CDZMTUDipS16), Kathmandu, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,400 m; 2♀, 1♂, Kathmandu, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,400 m; 1♀, Kathmandu, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1,600 m, 1♀, Shivapuri, 27.79°N, 85.38°E, 28.ix.2018, 1,700 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m; 1♀, 2♂, Shivapuri, 27.60°N, 85.36°E, 20.iv.2018, 2,300 m; 1♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 03.x.2018, 2,300 m, 1♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1,500 m; 1♂, Sundarijal, 27.769°N, 85.42°E, 09.x.2018, 1,800 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 12.x.2018, 2,000 m, 1♀, Nuwakot, Gurjebhanjyang 27.80°N, 85.32°E, 08.iv.2018, 1,600 m; 1♀, Nuwakot, Gurjebhanjyang 27.80°N, 85.32°E, 01.xi.2018, 1,600 m; 2♀, Nuwakot, Gurjebhanjyang 27.81°N, 85.33°E, 3.xi.2018, 1,900 m; 1♀, Nuwakot, Gurjebhanjyang 27.81°N, 85.31°E, 12.iv.2018, 2,000 m; 1♀, Nuwakot, Gurjebhanjyang 27.81°N, 85.31°E, 05.xi.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL. Kathmandu District: Chauni at 1,400 m; Jumla District: Gothichour at 2,900–3,050 m and Tripurakot at 2,500 m, Humla District: Simikot at 3,100 m (Lambeck & Kiauta, 1973; Thapa, 2015; Ghorpadé, 2015a).

Genus *Volucella* Geoffroy, 1762

17. *Volucella trifasciata* Wiedemann, 1830

Volucella trifasciata Wiedemann, 1830: 196. Type locality: Java.

(Figures 14 A–B)

Material Examined. 1♀, (CDZMTUDipS17), Kathmandu, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1,500 m.

Diagnostic features:

Tawny head, face projecting forward and downwards, yellow brown frons; orange with black hairs antennal arista, wide above antenna and narrowing at vertex; scutum smooth, black medially, rest of the thorax tawny; numerous long black setae on lateral side, membrane hyaline wing; except femur and tibiae with medial black ring, all tarsi brown; abdomen black, entirely pale yellow tergite I. B.L-18.5mm. Floral association. *Bidens pilosa*.

Remark: New species record for Nepal.

Subfamily Syrphinae

Genus *Asarkina* Macquart, 1842

18. *Asarkina incisuralis* (Macquart, 1855)

Syrphus incisuralis Macquart, 1855:94. Type locality: Inde.

(Figures 14 C–D)

Material Examined. 1♂, (CDZMTUDipS18), Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m.

Floral association. *Bidens pilosa*.

Distribution. NEPAL (Ghorpadé, 2015a).

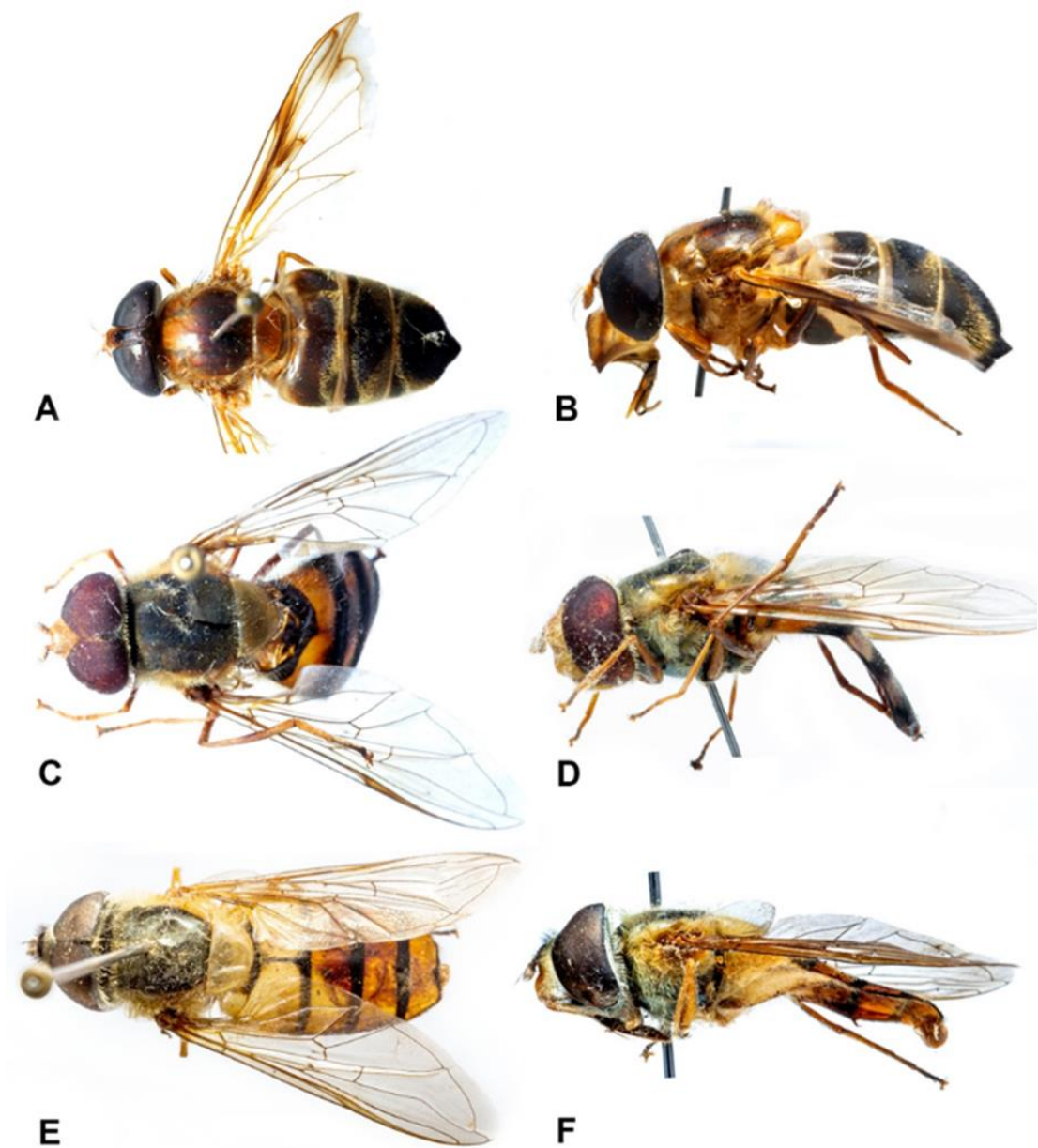


Figure 14: Dorsal and lateral habitus: A–B. *Volucella trifasciata*; C–D. *Asarkina incisuralis*; E–F. *Asarkina porcina*

19. *Asarkina porcina* (Coquillett, 1898)

Syrphus porcina Coquillett, 1898:322. Type locality: Japan.

(Figures 14 E–F)

Material Examined. 2♀, (CDZMTUDipS19), Kathmandu, Nagarjun, 27.74°N, 85.29°E, 28.iv.2018, 1,600 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85. 32°E, 08.iv.2018, 1,600 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL (Ghorpadé 2015a).

Genus *Baccha* Fabricius, 1805,

20. *Baccha maculata* Walker, 1852

Baccha maculata Walker, 1852:223. Type locality: East Indies.

(Figures 15 A–B)

Material Examined. 1♂, (CDZMTUDipS20), Kathmandu, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,400m.

Floral association. *Ageratum houstonianum*.

Distribution. NEPAL. Taplejung District: Sanghu at 1,890m (Coe, 1964; Thapa, 2015; Ghorpadé, 2015a).

Genus *Betasyrphus* Matsumura & Adachi, 1917

21. *Betasyrphus serarius* (Wiedemann, 1830)

Syrphus serarius Wiedemann, 1830:128. Type locality:China.

(Figures 15 C–D)

Material Examined. 1♀, (CDZMTUDipS21), Kathmandu, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m.

Floral association. *Brassica compestris*.

Distribution. NEPAL. Taplejung District: Sanghu at 1,900 m; Bhaktapur District: Nagarkot at 2,200 m, Kathmandu District: Sundarijal at 1,400–2,000 m (Coe, 1964; Thapa, 2015).

Genus *Dasysyrphus* Enderlein, 1938

22. *Dasysyrphus orsua* (Walker, 1852)

Syrphus orsua Walker, 1852:231. Type locality: India.

(Figures 15 E–F)

Material Examined. 1♀(CDZMTUDipS22)1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2,300 m, 1♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,400 m; 1♂, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1,600 m; 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2,100 m, 1♀1♂, Shivapuri, 27.80°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1,900 m; 2♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2,300 m, 1♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m, 1♀,

Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL. Taplejung District: Sanghu at 1,585 m and above at 1,890 m; Myagdi District: Ghodepani at 2,855 m; Jumla District: Churta at 2,900–3,500 m, Gothichour at 2,900 m, Khari at 3,285 m and Maharigaon at 3,220 m (Coe, 1964; Thapa, 2015; Ghorpadé, 2015a).

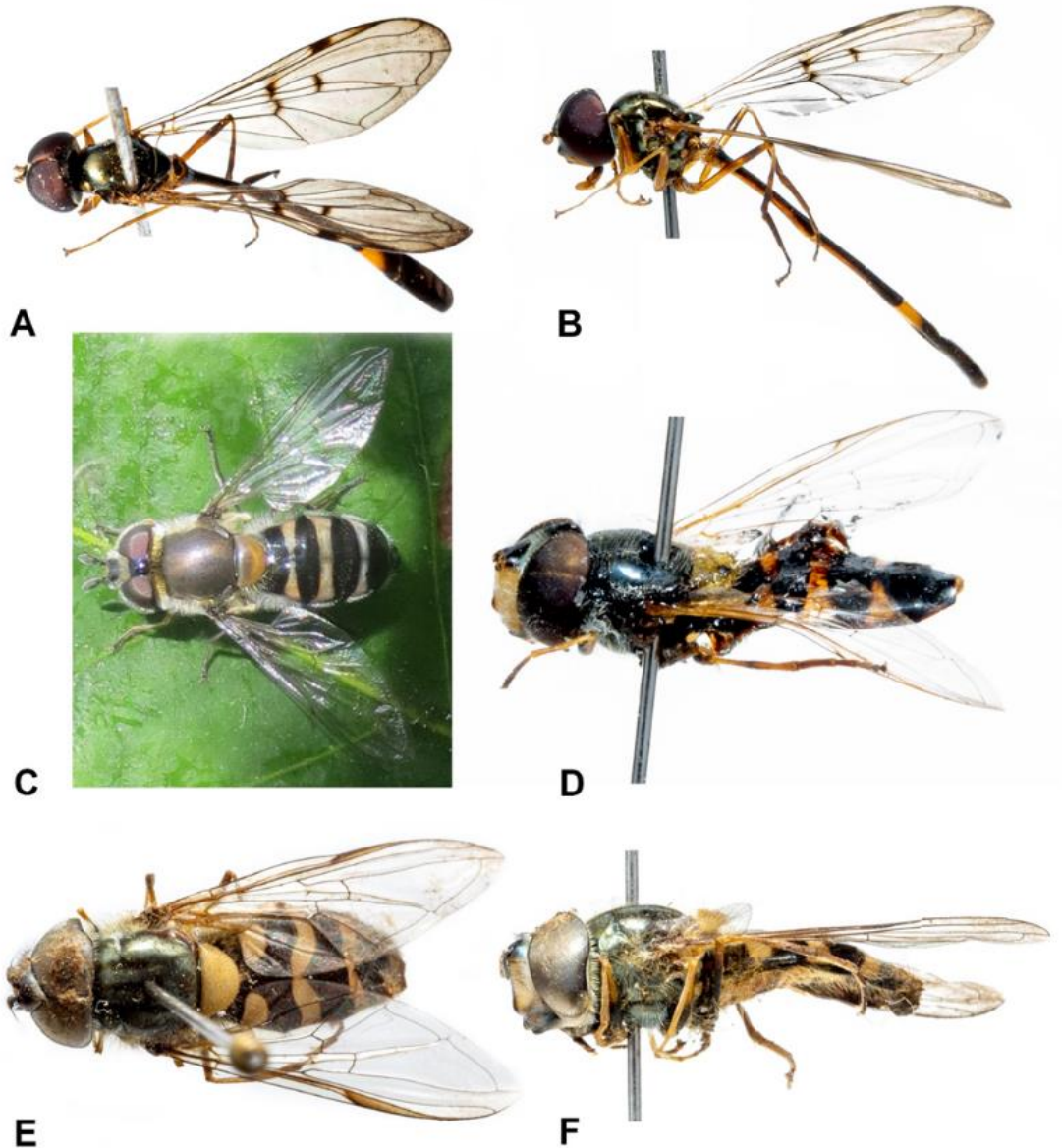


Figure 15: Dorsal and lateral habitus: A–B. *Baccha maculata*; C–D. *Betasyrphus serarius*; E–F. *Dasysyrphus orsua*

Genus *Episyrphus* Matsumura & Adachi, 1917

23. *Episyrphus balteatus* (De Geer, 1776)

Musca balteata De Geer, 1776:116. Type locality: Sweden.

(Figures 16 A–B)

Material Examined. 1♀, (CDZMTUDipS23) 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 20.iii.2018, 2,000 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 19.x.2018, 2,000 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2,300 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.x.2018, 2,300 m, 1♀, 2♂, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,400m; 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,400m; 1♀, 1♂, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1,600m; 1♀, 1♂, Nagarjun, 27.74°N, 85.29°E, 26.x.2018, 1,600m, 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2,100 m; 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 28.x.2018, 2,100 m, 2♀, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 28.ix.2018, 1,700 m; 2♀, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1,900 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m; 1♀, 2♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2,300 m, 1♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 03.x.2018, 2,300 m, 2♀, 2♂, Sundarijal, 27.77°N, 85.42°E, 02.iv.2018, 1,500 m; 2♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1,500 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 03.iv.2018, 1,800 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 09.x.2018, 1,800 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 12.x.2018, 2,000 m, 2♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m; 2♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1,600 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.32°E, 10.iv.2018, 1,900m; 2♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.32°E, 03.xi.2018, 1,900 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL. Taplejung District: Sanghu and Tamrang at 1,585 m; Kathmandu District: Guheswari at 1,300 m, Godawari, Chhauni, Kirtipur and Balaju, Sindhupalchok District: Helambu at 2,400 m; Manang District: Chame at 2,700–3,200 m Pisang; Mugu District: Rara lekeide at 2,945 m; Jumla: Gothichour at 2,800–3,100

m and Maharigaon at 3,220 m; Bajura District: Kuwadi Khola at 2,900 m (Coe, 1964; Lambeck & Kiauta, 1973; Kapoor *et al.*, 1979; Thapa, 2015; Ghorpadé, 2015a).

24. *Episyrrhus viridaureus* (Wiedemann, 1824)

Syrphus viridaureus Wiedemann, 1824: 35. Type locality: Indonesia (Java).

(Figures 16 C–D)

Material Examined: 1♂, (CDZMTUDipS24), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 2♀, 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 20.iii.2018, 2,000 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 19.x. 2018, 2,000 m, 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2,300 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.x.2018, 2,300 m, 1♀ 1♂, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,400 m; 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,400 m; 1♀, 1♂, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1,600 m; 1♀, 1♂, Nagarjun, 27.74°N, 85.29°E, 26.x.2018, 1,600 m; 1♀, 1♂, Nagarjun, 27.74°N, 85.27°E, 30.iii.2018, 2,100 m; 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 28.x.2018, 2,100 m, 2♀, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 28.ix.2018, 1,700 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1,900 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m; 1♀, 2♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2,300 m; 1♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 03.x.2018, 2,300 m, 1♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m; 1♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1,500 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 03.iv.2018, 1,800 m, 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 09.x.2018, 1,800 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.4211°E, 12.x.2018, 2,000 m, 2♀, 1♂, Nuwakot Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m; 2♀, 1♂, Nuwakot Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1,600 m; 1♀, 1♂, Nuwakot Gurjebhanjyang, 27.81°N, 85.33°E, 10.iv.2018, 1,900 m; 2♀, 1♂, Nuwakot Gurjebhanjyang, 27.81°N, 85.33°E, 03.xi.2018, 1,900 m; 1♀, Nuwakot Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m; 1♀, 1♂, Nuwakot Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL. Sankhuwasabha District; Kaski District; Dailekh District, Jumla District, Mugu District; Bajura District (Thapa, 2015; Ghorpadé 2015a).

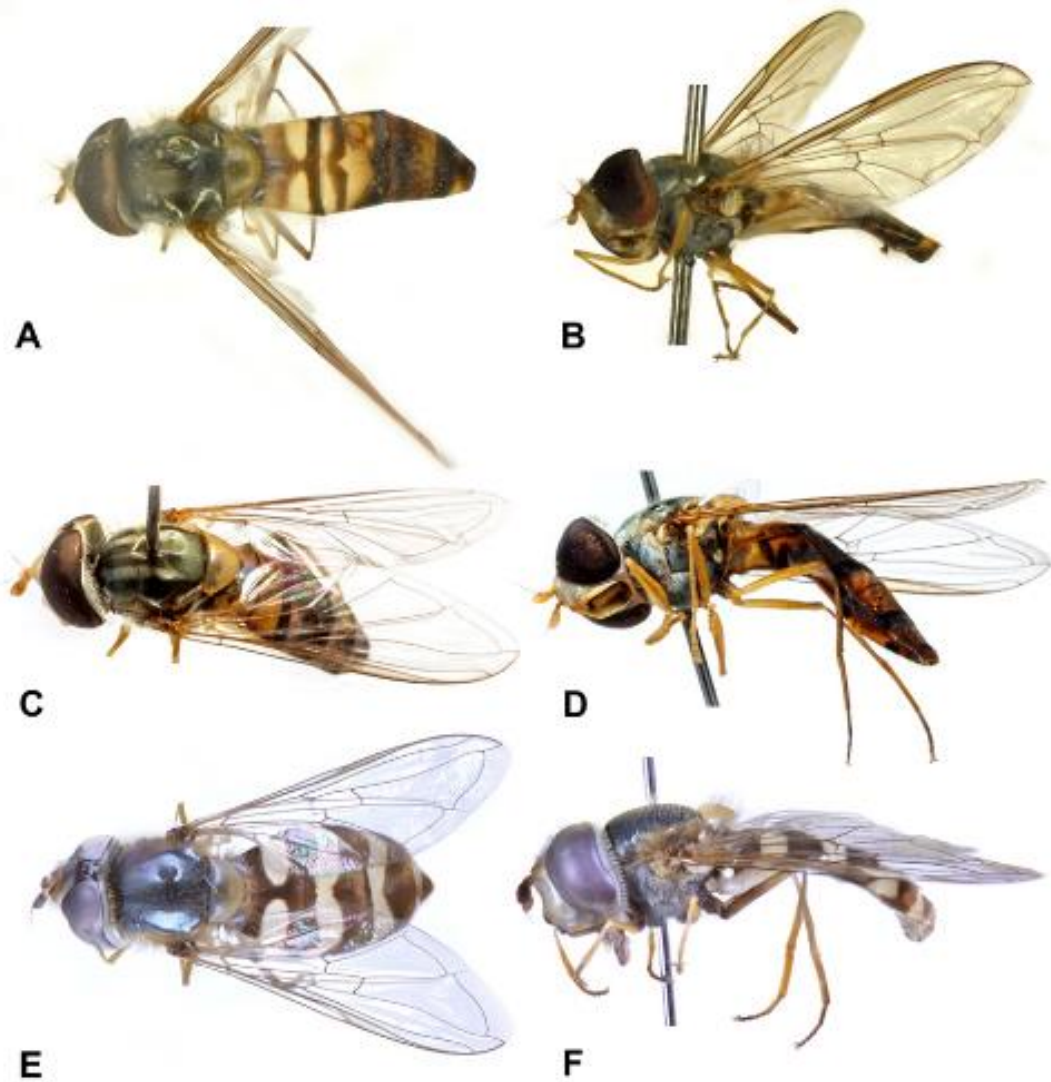


Figure 16: Dorsal and lateral habitus: A–B. *Episyrphus balteatus*; C–D. *Episyrphus viridaureus*; E–F. *Eupeodes bucculatus*

Genus *Eupeodes* Osten Sacken, 1877

25. *Eupeodes bucculatus* (Rondani, 1857)

Syrphus bucculatus Rondani, 1857:134. Type locality: Italy.

(Figures 16 E–F)

Material Examined. 1♀, (CDZMTUDipS25), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m, 1♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,400 m, 1♀, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL. Jumla District: Gothichour at 2,800–3,050 m, Maharigaon at 2,800–3,200 m and Khari La small valley at 3,250 m, Humla District: Simikot at 3,050 m, Soli Khola at 2,900 m, Sankha La at 4,300 m, Kuwadi Khola Saipal at 3,600 m (Thapa, 2015; Ghorpadé, 2015a).

Genus *Melanostoma* Schiner, 1860

26. *Melanostoma orientale* (Wiedemann, 1824)

Syrphus orientalis Wiedemann, 1824:36. Type locality: India.

(Figures 17 A–B)

Material Examined. 1♀,(CDZMTUDipS26) 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1,800m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.x.2018, 2,300 m, 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 26.iii. 2018, 1,400 m; 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1,400 m; 1♀, Nagarjun, 27.74°N, 85.27°E, 24.x.2018, 2,100 m, 1♀, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, Shivapuri, 27.60°N, 85.37°E, 03.x.2018, 2,300 m, 1♀, 2♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.4211 °E, 12.x.2018, 2,000 m, 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m.; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL. Taplejung District: Sangu (=Sanghu) at 1,890 m, Dobhan at 1,067 m (Coe 1964), Sankhuwassabha District: Chichila at 1,600–1,900 m; Solukhumbu District: Lukla at 2,800 m; Kathmandu District: Gokarna Safari at 1,350; Lalitpur District: Godawari Botanical Garden at 1,400 m, Phulchoki at 2,300–2,500 m; Kaski District: Pokhara at 900 m; Dolpa District: Rimi Kaigaon at 2,900–3100 m; Humla District: Simikot at 3,100m, Jumla District: Gothichour at 2,800m, Gothigaon at 2,600 m, Tatopani at 2,200m, Chala Sankha at 4,400–4,700 m; Bajura District: Kuwadi khola at 2,900 m (Thapa, 2015; Ghorpadé, 2015a).

27. *Melanostoma scalare* (Fabricius, 1794)

Syrphus scalare Fabricius, 1794:308. Type locality: Denmark.

(Figures 17 C–D)

Material Examined. 2♀, (CDZMTUDipS27), 2♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2,300 m, 2♀, 1♂, Nagarjun, 27.68°N, 85.27°E, 26.iii.2018, 1,400 m; 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2,100 m, 2♀, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2,300 m, 2♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 04.iv.2018, 1,500 m; 1♀, 1♂,

Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m, 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m, .

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL (Thapa, 2015; Ghorpadé, 2015a).

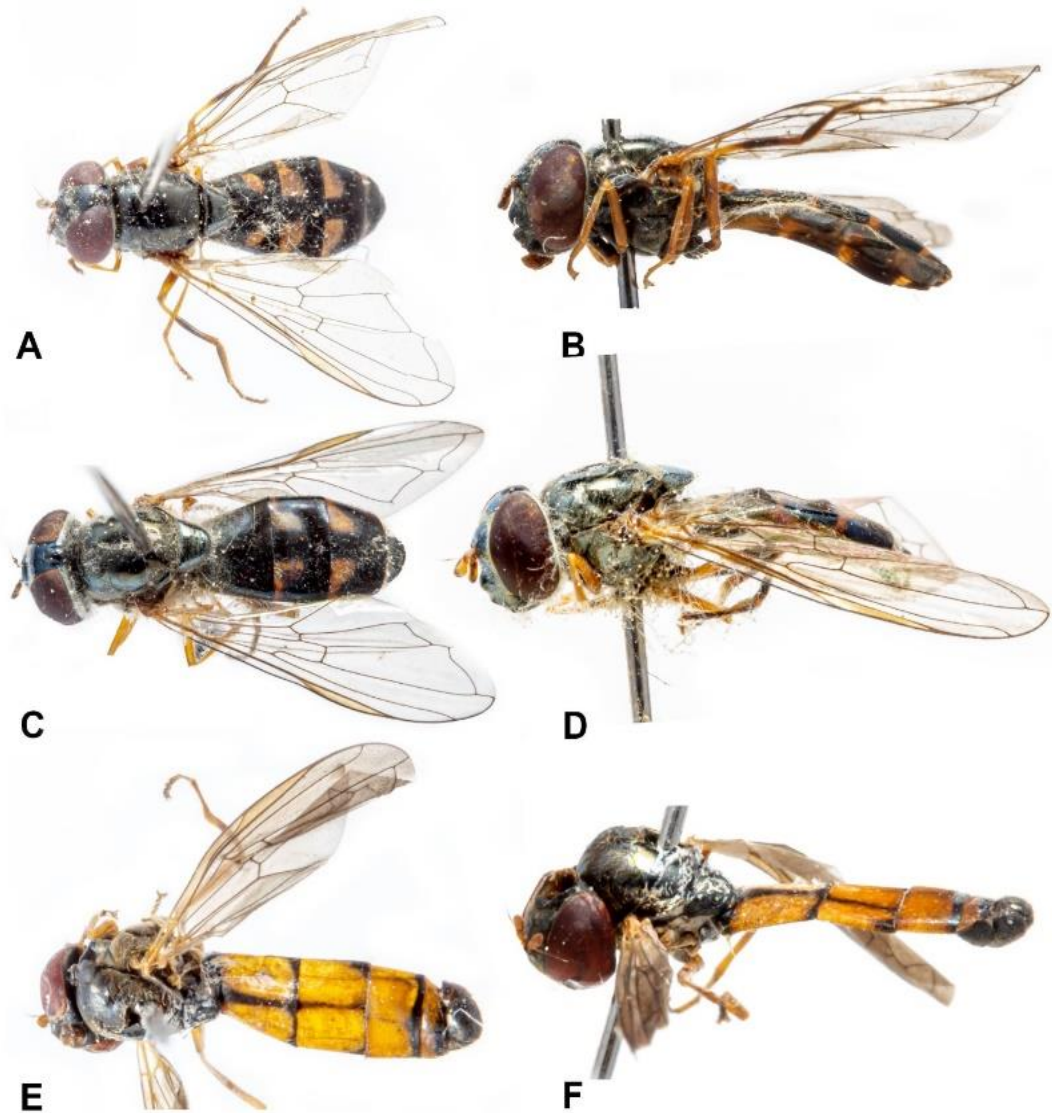


Figure 17: Dorsal and lateral habitus: A–B. *Melanostoma orientale*; C–D. *Melanostoma scalare*; E–F. *Melanostoma univittatum*

28. *Melanostoma univittatum* (Wiedemann, 1824)

Syrphus univittatum Wiedemann, 1824:36. Type locality: India.

(Figures 17 E–F)

Material Examined. 2♀, (CDZMTUDipS28), 2♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, 2♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2,300 m, 1♀, 2♂, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,400 m; 1♀,

1♂ Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1,600 m, 2♀, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; Shivapuri, 2♀, 1♂, 27.60°N, 85.37°E, 20.iv.2018, 2,300 m, 1♀, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m; 2♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m, 2♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa*.

Distribution. NEPAL. Taplejung District: Arun Valley below Tumlingtar, River Sabhaya at 549 m (Coe, 1964); Kathmandu District, Kirtipur, Lalitpur District: Godawari (Kapoor *et al.*, 1979; Thapa, 2015; Ghorpadé, 2015a).

Genus *Meliscaeva* Frey, 1946

29. *Meliscaeva cinctella* (Zetterstedt, 1843)

Scaeva cinctella Zetterstedt, 1843:742. Type locality: Sweden.

(Figures 18 A--B)

Material Examined. 1♂, (CDZMTUDipS29) Kathmandu, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,400 m, 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m.

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*.

Distribution. NEPAL. Taplejung District: Sanghu at 1,890 m; Solukhumbu District: Dudhkosi valley at 3,154 m; Bagamati Province: East of Kathmandu (Coe, 1964; Thapa, 2015)

Genus *Scaeva* Fabricius, 1805

30. *Scaeva pyrastris* (Linnaeus, 1758)

Material Examined. 1♀, (CDZMTUDipS30), Kathmandu, Sundarijal, 27.77°N, 85.42°E, 03.iv.2018, 1,800 m.

(Figures 18 C–D)

Floral association. *Ageratina adenophora*.

Distribution. NEPAL (Ghorpadé 1994).

Genus *Sphaerophoria* Lepeletier & Serville, 1828

31. *Sphaerophoria bengalensis* Macquart, 1842

Sphaerophoria bengalensis Macquart, 1842:104. Type locality: Bangladesh.

Sphaerophoria flavobdominalis Brunetti, 1915: 214. Type localities: India & Nepal.

(Figures 18 E–F)

Material Examined. 1♂, (CDZMTUDipS31), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2,300 m, 1♀, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2,100 m, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1,700 m; 1♀, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2,300 m, 1♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m, 2♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*.

Distribution. NEPAL. Kathmandu District: Tribhuvan at 1,400 m, Chhauni at 1,400 m (Lambeck & Kiauta, 1973; Thapa, 2015; Ghorpadé, 2015a).

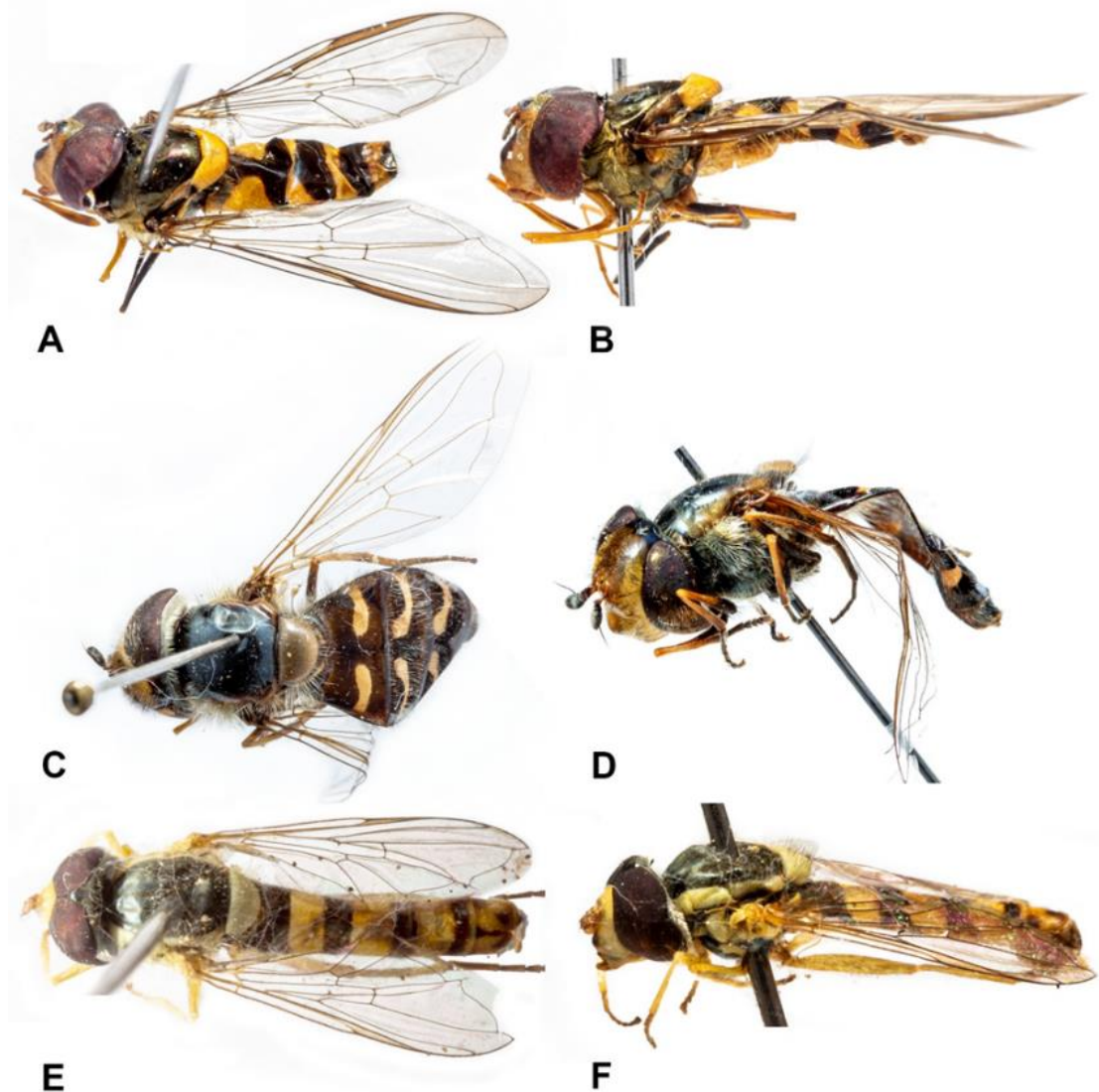


Figure 18: Dorsal and lateral habitus: A-B. *Meliscaeva cinctella*; C-D. *Scaeva pyrastris*; E-F. *Sphaerophoria bengalensis*

32. *Sphaerophoria indiana* Bigot, 1884

Sphaerophoria indiana Bigot, 1884. Type locality: India.

(Figures 19 A–B)

Material Examined. 1♀, (CDZMTUDipS32), Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1,800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 20.iii.2018, 2,000 m, 1♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1,400 m; 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2,100 m, 1♀, 1♂, Shivapuri, 27.79°N, 85.376°E, 15.iv.2018, 1,700 m; 1♀, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2,300 m, 1♀, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1,500 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m, 2♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1,600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*.

Distribution. NEPAL. Taplejung District: Sanghu; Sankhuwasbha District: Uwa at 1,600 m; Kathmandu District: Kirtipur, Lalitpur District: Godawari Botanical Garden; Dolpa District: Rimi Kaigaon at 2,800–3,100 m; Humla District: Simikot at 2,200 m (Kapoor *et al.*, 1979; Thapa, 2015; Ghorpadé, 2015a).

33. *Sphaerophoria scripta* (Linnaeus, 1758)

Musca scripta Linnaeus, 1758:594. Type locality: Sweden.

(Figures 19 C–D)

Material Examined. 1♀, (CDZMTUDipS33), Kathmandu, Manichud, 27.77°N, 85.47°E, 20.iii.2018, 2,000 m, 1♀, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2,100 m, 1♀, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1,900 m, 1♀, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m, 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Bidens pilosa*.

Distribution. NEPAL. Lalitpur District: Godawari at 1,400 m; Jumla District: Tatopani at 2,200 m (Thapa, 2015; Ghorpadé, 2015a).

Genus *Syrphus* Fabricius, 1775

34. *Syrphus torvus* Osten Sacken, 1875

Syrphus torvus Osten Sacken, 1875:139. Type locality: Canada.

(Figures 19 E–F)

Material Examined. 1♀,(CDZMTUDipS34), Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2,300 m, 1♀, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2,100 m, 1♀, Shivapuri, 27.61°N, 85.37°E, 20.iv.2018, 2,300 m, 1♀, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m.

Floral association. *Ageratina adenophora*, *Bidens pilosa*.

Distribution. NEPAL. Taplejung District: Sangu at 1,900 m, Solukhumbu District: Tengpoche Gonda at 3,850 m; Jumla District: Gothichour at 2,900–3,100 m, Maharigaon at 3,680 m, Khari La small valley at 3,285 m; Mugu District: Rara Lakeside at 2,945 m; Bajura District: Kuwadi Kholā at 2,900 m (Coe, 1964; Lambeck & Kiauta, 1973; Thapa, 2015; Ghorpadé, 2015a).

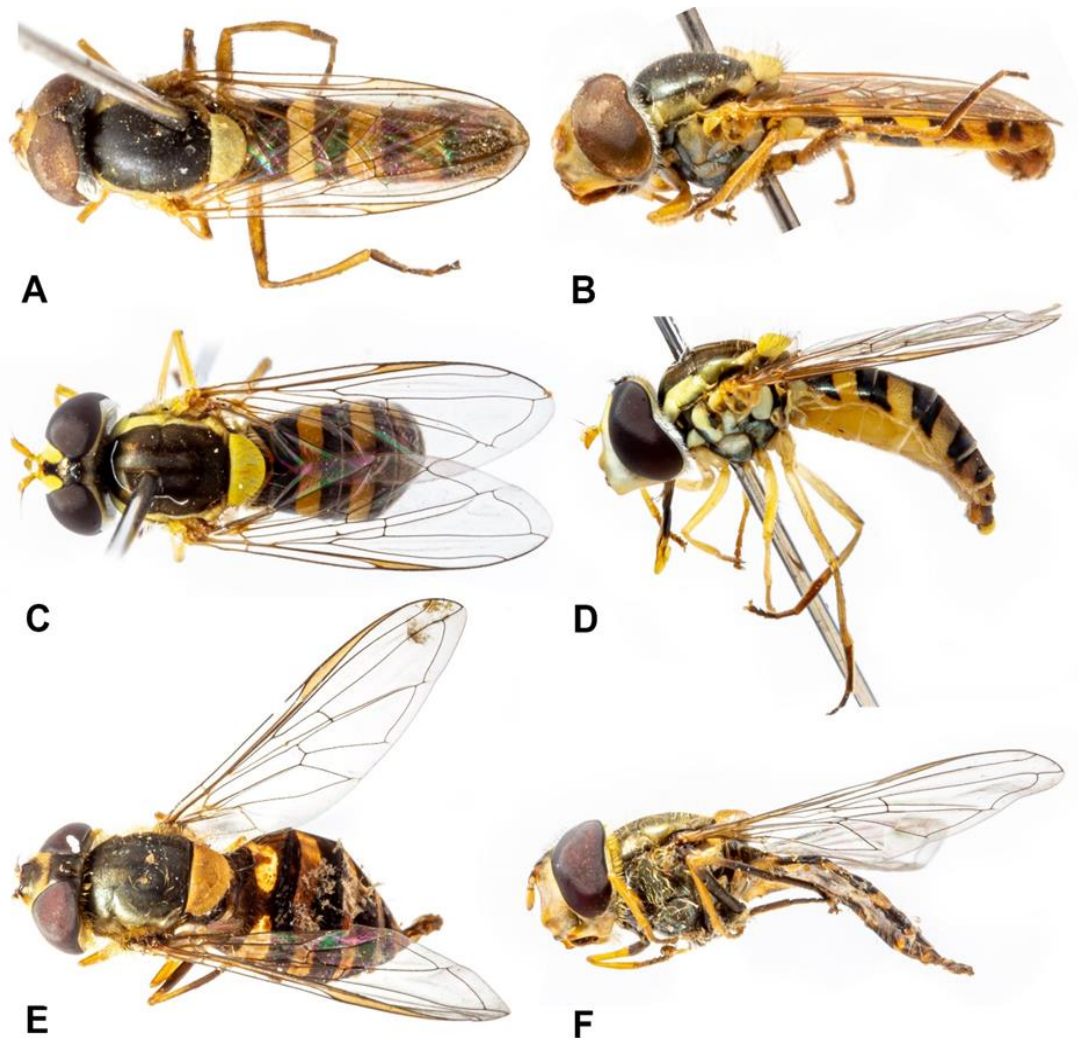


Figure 19: Dorsal and lateral habitus: A–B. *Sphaerophoria indiana*; C–D. *Sphaerophoria scripta*; E–F. *Syrphus torvus*

4. DISCUSSION

The present work of hoverfly fauna shows very interesting collection with mix faunal diversity in different elevation providing the firsthand information from the park. It documents 34 species for the first time from SNNP. Among them, three species, *Graptomyza nigripes*, *Lycastris albipes*, and *Volucella trifasciata* are new country records. Hoverfly fauna of SNNP account for only 20% of all Nepalese Syrphidae (34 out of 169 species) and the surface area of SNNP (159 km²) accounts for 0.096% of total surface area (147,516 km²) of Nepal. Therefore, despite the lower surface area of SNNP, the distribution pattern is interestingly diverse. New findings are possible in SNNP, adding to the list that could make study of hoverflies appealing, important, and exciting.

The field collection showed an equal number of species in the Eristalinae (17 species) and Syrphinae (17 species), but no species of Microdontinae were found. Adult Microdontinae are unlike most other Syrphidae are rarely found on flowers (Reemer, 2012). While there is diverse species in Eristalinae and Syrphinae (Kazerani *et al.*, 2013; Reemer, 2016). From fieldwork, two abundantly collected species are *Episyrphus balteatus* (64) and *E. viridaureus* (61), which are the most common species among the oriental aphidophagous hoverflies and cosmopolitan in distribution (Fazlullah *et al.*, 2018).

The association of hoverflies with flowers of SNNP found that many hoverfly species were collected from densely populated flowers of the forest trail. This is obvious as increase flower resources mean high opportunities for feeding resources of adult hoverflies (Lucas *et al.*, 2017). However, most of the species were captured from the exotic plants of the walking trails. These are human disturbance area of SNNP compare to other part of the park and likely the area for proliferatin of exotic plants (Burke & Grime, 1996).

5. CONCLUSIONS

Hover flies are subject of curiosity in public and scientific field, environmental services, and economic welfare. The collection of 34 different species reflects diversity of these insects in SNNP. The finding of three new country records shows that SNNP could be potntial area for hoverflies. To provide a clearer view, extensive investigation in different areas of SNNP is required. Furthermore, this is the first list of hoverflies of

SNNP using the most recent nomenclature pattern. Therefore, this work may aid other workers in their research on these fascinating flies.

CHAPTER 3

COMMUNITY STRUCTURE OF POLLINATING INSECTS AND ITS DRIVING FACTORS IN DIFFERENT HABITATS OF SHIVAPURI - NAGARJUN NATIONAL PARK

Abstract

Insect pollinators are important component of healthy ecology. Habitat types influence all pollinator community composition, abundance, diversity, and species richness. The current study at SNNP searched the diversity and abundance of insect pollinators along with environmental variables, in order to determine the pollinator community composition. The collection of pollinators was conducted during spring and autumn seasons for two years; 2018 to 2019. Four different habitats; Open trail, Forest trail, Managed habitats, and Grassland present in different elevations (1500 m to 2700 m) were selected. Pollinators were collected in the fixed belt transect with sweeping net and color pan traps. A total of 8,720 individual insect pollinators belonging to 167 species were sampled. Species richness (158) and diversity (4.58) were found to be higher in Open trail compared to other habitats. The Open trail possessed an even distribution of pollinator species, followed by the Grassland. To demonstrate the relationship between insect pollinators and environmental variables Non-Metric Multidimensional Scaling (NMDS) and Redundancy Analysis (RDA) were used. A strong positive relation was seen between flower resources and pollinator abundance. Open trails at a lower elevation have diverse insect pollinators compared to upper elevation. The study showed that pollinator community is significantly influenced by flowers of trails which suggests that these trails could be beneficial to conserve pollinators.

3. INTRODUCTION

3.1 Background

Pollinators play an important role in maintaining a healthy ecology (De Groot *et al.*, 2010). They are beneficial insects to mankind by increasing agricultural production by improving pollination for both wild and domesticated flowering plants (Kevan *et al.*,

1990; Corbet *et al.*, 1991; Widhiono *et al.*, 2016). These are beneficial insects supporting economy, adding beauty to nature, and as cultural elements (Gill *et al.*, 2016). Bees, both social and solitary, butterflies and moths, beetles, and flies are the most common pollinators (Vanbergen & Initiative, 2013; Wojcik, 2021). Bees (56.5 %), flies (19 %), and butterflies (4 %) pollinate the majority of cultivated plants around the world (Bashir *et al.*, 2019). Honeybees are well recognized pollinators compared to wild pollen bees (Losey & Vaughan, 2006; Potts *et al.*, 2010), bumble bees are valuable pollinators of perennial and annual plants (Dramstad & Fry, 1995; Carvell *et al.*, 2006; Deserres *et al.*, 2014) whereas flies and butterflies are least recognized as pollinating insects (Jennersten, 1984; Larson *et al.*, 2001). Several research studies alarmed of global decline of pollinators (Carvalho *et al.*, 2013; Dirzo *et al.*, 2014). Bumblebees (Fitzpatrick *et al.*, 2007; Cameron *et al.*, 2011) and butterflies (Warren *et al.*, 2001; Van Swaay *et al.*, 2010) populations are declining globally due to both natural and anthropogenic impacts. Habitat loss, landscape modification, agricultural intensification, and even climate change have been considered as key factors of pollinator loss (Kearns *et al.*, 1998; Potts *et al.*, 2010; Kovács-Hostyánszki *et al.*, 2017). As a result, preserving pollinators in a given environment needs a good understanding of pollinator diversity patterns as well as habitat types.

The local environment influences pollinator species richness, diversity, distribution, and community structure (Williams *et al.*, 2010; Neumüller *et al.*, 2020). When comparing pollinators across ecosystems, flower resources, humidity, and temperature must be considered (Neumüller *et al.*, 2020). Pollinator activity is significantly influenced by air temperature, plant species richness, (Hudewenz *et al.*, 2012) and humidity (Pellissier *et al.*, 2010). Kühnel and Blüthgen (2015) found that bees and butterflies were active in warmer temperatures than flies. Similarly, insect pollinator abundance and community structure are also influenced by elevation (Forister *et al.*, 2010; Adedija *et al.*, 2020). Different groups of insect pollinators have an intriguing geographical pattern. Hymenoptera dominates lowland pollinators, while Lepidoptera and Diptera (Warren *et al.*, 1988) dominate highland pollinators. This type of dispersion over a variety of environments is most likely to meet their ecological requirements, which are highly species specific (Proesmans *et al.*, 2019). Bees, for example, prefer to forage near their breeding location on flowering plants (Gathmann & Tscharrntke, 2002; Greenleaf *et al.*, 2007). They also build their nests in deadwood (Sydenham *et*

al., 2016) and sunny ground (Everaars *et al.*, 2011). Hoverflies and butterflies, on the other hand, fly far away from the egg-laying sites to forage and live without building nest. Aphidophagous hoverflies like *Episyrphus* and *Sphaerophoria* rely on cultivated areas (Jauker *et al.*, 2009; Pinheiro *et al.*, 2015), whereas saproxylic syrphidae like *Xylota* benefit from the forest (Reemer, 2005). Similarly, butterflies have the ability to fly longer distances (Herrera, 1987). They fly such a wide range in search of pollen (Gilbert, 1972) plus nectar (Tiple *et al.*, 2005) from many types of flowers. Furthermore, the location of an oviposition plant determines the habitat selection. For example, smaller and less flying butterflies like the blues. Whilst larger butterflies, such as *Erebia epipsodea* and *Colias*, are likely to search a wider area for their ovipositing plants present in different distance (Sharp *et al.*, 1974). The examples above indicate that pollinators share a variety of habitats. Hence habitat types may have an important impact on pollinator community composition, abundance, diversity, and their richness. Plenty of works on pollinators have shown at how pollinator composition is influenced by environmental conditions. Many environmental factors, however, might have highly diverse effects on pollinator composition depending on climatic and vegetation zones (Senapathi *et al.*, 2017; Neumüller *et al.*, 2020). SNNP, which is located in the southern foothills of the Himalayas. The park's unique geography may host an intriguing pollinators, and a variety of environmental conditions may affect their composition in diverse ways. Hence, in SNNP, it is vital to assess the effects of these factors on pollinators. The general understanding about natural environment is that, if free of pesticides, it will likely have higher diversity than managed habitat. However, because the connection between plant and pollinator is particular (Rundlöf *et al.*, 2008; Oliver *et al.*, 2010; Weibull *et al.*, 2000), habitat heterogeneity would also alter the pollinator community. In this research species richness, abundance, and community composition of pollinating insects were studied in several environments throughout the elevation gradient. There is an expectation that habitat types had an impact on diversity, distribution, and composition of these insects

The research questions are:

1. What is the distribution pattern of pollinating insects?
2. Which environmental factors have a significant impact on pollinator distribution, diversity, and community composition?

3.2 MATERIALS AND METHODS

3.2.1 Sampling sites

The sample stations were selected at five main locations of SNNP namely, Sundarijal (27°.77' N, 85°.42' E), Shivapuri (27°.79' N, 85°.37' E), Gurjebhanjyang (27°.81' N, 85°.31' E), Nagarjun (27°.74' N, 85°.27' E), and Manichud (27°.77' N, 85°.46' E). These five sites represent the habitat and altitude chosen for survey. The sampling was done at three different elevations at each of the five stations. The elevation range of the transect was calculated based on the land structure and SNNP habitat types.

A lower transect was made between 1500 and 1700 meters, a medium transect was drawn between 1800 and 1900 meters, and an upper transect was drawn between 2000 and 2700 meters. These transects covered four different habitats: "Forest trail (FT), Grassland (GL), Managed habitat trail (MH), and Open path of the forest (OT)" along different elevations (Figure 20). FT means the forest with canopy coverage of more than 70% with a walking trail of 15 m width. Grassland habitat is herb-dominated open area transect with sparsely located surrounding trees. OT means a walking trail of forest with no canopy coverage. The edges of this trial possessed comparatively thicker belts of herb and shrubs than other trials of the park. The walking trail of the MH is the open areas with no canopy tree within 15 m width of the trail that incorporates the areas of buffer zone. This area is a human settlement with cultivated lands. In this area, the major crops cultivated during spring are mustard and coriander while mustard, buckwheat, balsam apple, and squash in autumn.

In each elevation, five transections each of 100 m x 5 m with a minimum inter-transect spacing of 100 m were fixed. In total, there were 75 transects were surveyed in SNNP for collection. The number of transects differ between elevations and habitats (Table 2).

3.2.2 Pollinators' sampling

Pollinators belonging to three primary groups: bees, hoverflies, and butterflies were sampled during spring and autumn seasons for two consecutive years, 2018 and 2019. The belt transects were made in walking trials of FT, OT, and MH while in GL, transects were drawn along the edge and in the centre, with a 20 m inter-transect distance (Stanley, 2013a). The collection was done for three consecutive sunny days from 9 a.m. to 4 p.m. in every transect in each season (Pollard & Yates, 1994).



Figure 20: Sampling habitats: A. Open trail(Shivapuri); B. Managed habitat (Sundarijal); C. Grassland (Nagarjun); D. Forest trail (Shivapuri).

Table 2: The number of sampling transects for pollinator collection along three different elevations in four different habitats of SNNP (Dyola *et al.*, 2022b)

Habitat	Elevation (meter)	Number of transects
Forest trail	1500–1700	11
	1800–1900	12
	2000–2700	10
Grassland	1500–1700	3
	1800–1900	6
	2000–2700	5
Open trail	1500–1700	4
	1800–1900	5
	2000–2700	6
Managed habitat	1500–1700	7
	1800–1900	2
	2000–2700	4

Aerial sweeping net and color pan traps were used to collect insects visiting flowers. OT, FT, and MH were surveyed by walking for about 30 minutes, GL, on the otherhand was sampled at the margin and in the centre (Stanley, 2013b). Butterfly (Pollard &

Yates, 1994), bumblebee (Fussell & Corbet, 1992), hoverfly, and other bees (Proesmans *et al.*, 2019) were caught using the sweeping method in the fixed transect. Besides those insects that could be confirmed upto species level in the field (Neumüller *et al.*, 2020) like common bees, almost all butterflies and common hoverflies, other insect pollinators feeding on flowers within 2 m of the observer were caught. These insects were kept in vials and put in the icebox for identification process in the lab. Next, in the fixed transect, pan traps were employed to trap insects. This trap approach allows for simultaneous sampling and coverage of a large region, and it is the best way for collecting bees (Westphal *et al.*, 2008; Neilsen *et al.*, 2011). The pans were non-toxic plastic bowls painted in blue, white, and yellow (LeBuhn *et al.*, 2003). Each pan had a diameter of around 15 cm and was fastened to a post in a cluster using a metal clamp to fit the bowl into the metal rim (Figure 21 A). Detergent water was poured into all three pans (about 400 ml). Three posts with cluster of three pans were placed 20 meters apart in each transect. The traps were set for a total of 24 hours. After 24 hours, the insects caught in the pans were poured in white enamel tray and picked by brush and placed in labelled vials containing 70% ethanol.

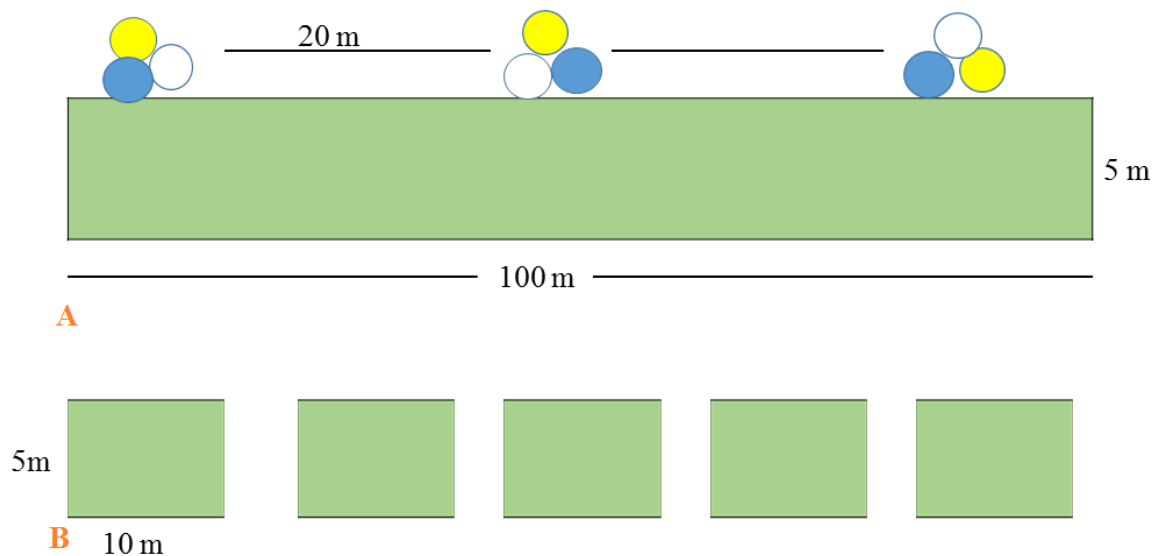


Figure 21: Sampling transect showing position of three pan traps yellow, white and blue (A), herb and shrub coverage was measured in 50 m² (B).

3.3.3 Survey of flower resources

Flower resources and pollinator abundance are highly associated (Tadey, 2015). The flower resources were assessed in the spring and autumn at each transect. In a sampling transect, five quadrats of 10m x 5 m each were made to estimate the availability of flower resources (Figure 21 B). In these quadrats, first the flowering herbs and shrubs

were identified with their genus and species. Then, the presence of flowering herbs and shrubs was visually scanned. In each quadrat, estimation of cover of flower resources were ranked from 1 to 6 (Szigeti *et al.*, 2016). The following are the ranking categories: very scarce=1, scarce=2, more or less scarce=3, more or less abundance=4, abundance=5, and extremely abundance=6. For each sampling transect, weightage of the abundance of flower resources was calculated as

$FLOWER = \sum_{i=1}^n t. taxon_i$ (t = mean of the rank of flowering plant of each transect).

3.3.4 Humidity and Temperature

In each sampling time, a digital Thermo-hygrometer (HTC-2) was used to monitor humidity and temperature (replication of five times both variables).

3.3.5 Identification of insect pollinators

In the laboratory, pollinators that could not be recognized in the field were identified upto species level using applicable keys. Pollinators were mostly identified using available literature like Bingham, 1897; Tadauchi & Matsumura, 2007; Williams *et al.*, 2010; Ngat *et al.*, 2017, and Kumari *et al.*, 2018. Hoverfly specimens were identified using Brunetti, 1923; Thomson and Ghorpadé, 1992; Ghorpadé, 1994; Claussen and Weipert, 2003; Sengupta *et al.*, 2017; Hassan *et al.*, 2019, 2020; Ghorpadé, 2019; Sankararaman *et al.*, 2020; Speight, 2020 and butterfly specimens were identified following Smith, 2010; 2011. Further few of the identified specimens were confirmed by taking help of Dr. Khanal of Natural History Museum and in personel collection of Dr. Asghar (See acknowledgments)

3.3.6 Statistical analysis

The community matrix was compiled by determining the cumulative species richness and abundance across all samplings for each habitat category. To verify the adequacy of sampling effort, the species accumulation curves were drawn using the package 'vegan', function specaccum. Using linear mixed effect models with habitats as predictor variables and pollinators as response variables, the richness and abundance of pollinators were compared between different habitats. The statistical analysis was carried out using the R programming language (R Core Team, 2021). Because the data

were not normal and the number of habitat types varied, the Kruskal-Wallis test was used to determine significance.

Paleontological Statistics (PAST) (Hammer *et al.*, 2001) calculated the diversity indices in version 3.17. The significance of variety between groups was determined by creating random matrices with two samples, each with the same row and column totals as the original data matrix.

Pollinator community compositions in different habitats (FT, GL, OT, MH) were analysed by Non-metric Multidimensional Scaling (NMDS) of the abundance data using the function 'metaMDS' from the statistics package 'vegan' (Oksanen *et al.*, 2013). NMDS results with sample plots of various abundance scores were fitted with various environments using the ggplot2 software (Wickham *et al.*, 2016).

Adonis (Permutational Multivariate Analysis of Variance), ANOSIM (Analysis of Similarities), and SIMPER (Similarity Percentage Analysis) were used after NMDS. Adonis was carried out following NMDS to see if the pollinator community differed between environments statistically. It gives the p-value, which is used to establish statistical significance. ANOSIM, on the other hand, was employed to see if the pollinator communities in the two habitats differed significantly. SIMPER analysis were performed in addition to significant difference testing to identify the species that contributed the most to the observed pollinator community differences (Clarke & Gorley, 2001).

On insect pollinators, ordinations were used to identify relationships between environmental variables and species composition. A Detrended Correspondence Analysis (DCA) was used to determine whether unimodal or linear ordination approaches were acceptable (Lepš & Šmilauer, 2003) for the pollinator community comprising 15 most abundant species, five from each category; bee, butterfly, and hoverfly (Appendix III). A gradient length of 2.5 was indicated by DCA analysis, showing that Redundancy Analysis (RDA) ordination was the best option. Environmental factors were backward selected ($p < 0.05$), and the significance of the ordination was determined using a Monte Carlo permutation test with 999 iterations. NMDS, RDA, and all three procedures (Adonis, ANOSIM, and SIMPER) were performed in R (R Core Team, 2021) using the 'vegan' package (Oksanen *et al.*, 2013).

Venn diagrams depicting species distribution between habitats were created using the package 'VennDiagram' and the function `draw.quad.venn` in R (R Core Team, 2021).

3.3 RESULTS

3.3.1 Insect pollinators in Shivapuri-Nagarjun National Park

A total of 8720 insect pollinators were collected over the course of two years of sampling. They were collected from both pan traps (1339) and sweeping nets (7381), and they belonged to 167 different species (Appendix III). The images of some representative pollinators from study area are given in figure 22.

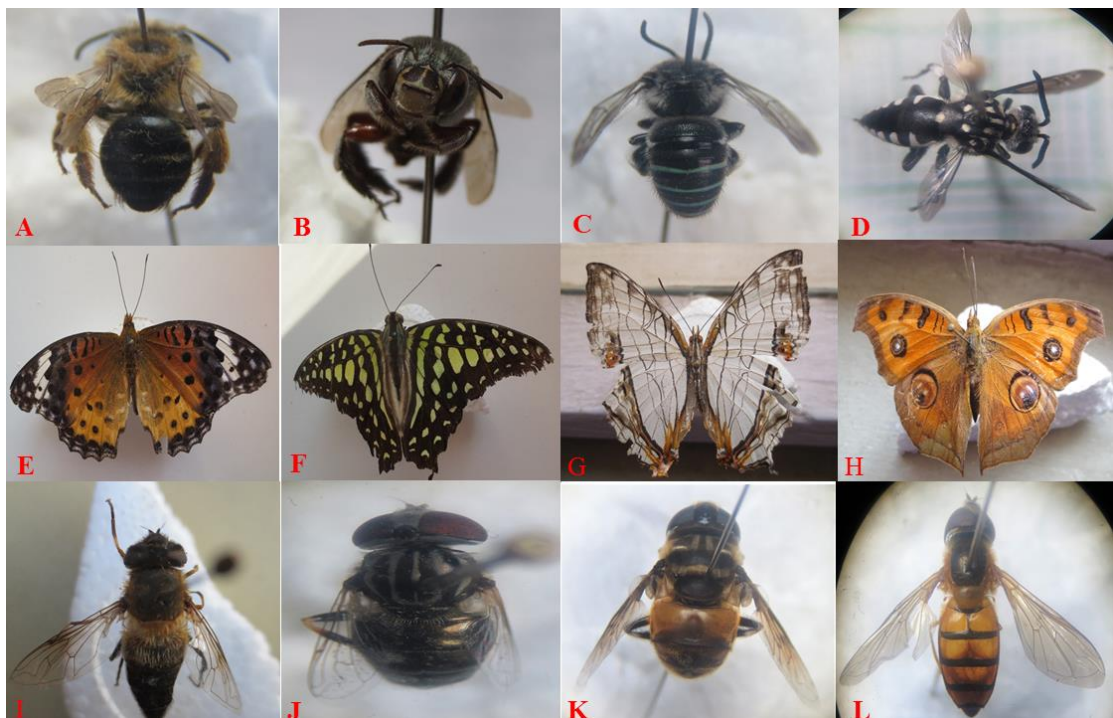


Figure 22: A range of insect pollinators collected from four different habitats of SNNP (Bees: A–D, Butterflies: E–H and Hoverflies: I–L) (Dyola *et al.*, 2022b)

Butterfly was the most common group (48%) followed by bee (30%) and hoverfly (22 %) (Figure 23). During the study period, sixty distinct varieties of flowering herbs and shrubs were recorded in sample transects in the spring and autumn seasons (Appendix IV). The abundance of flower resources varies according to habitats, elevations, and seasons (Appendix V). A sufficient sampling effort has been made as the pollinator species accumulation curves in all environments (FT, GL, MH, and OT) demonstrated saturation (Figure 24).

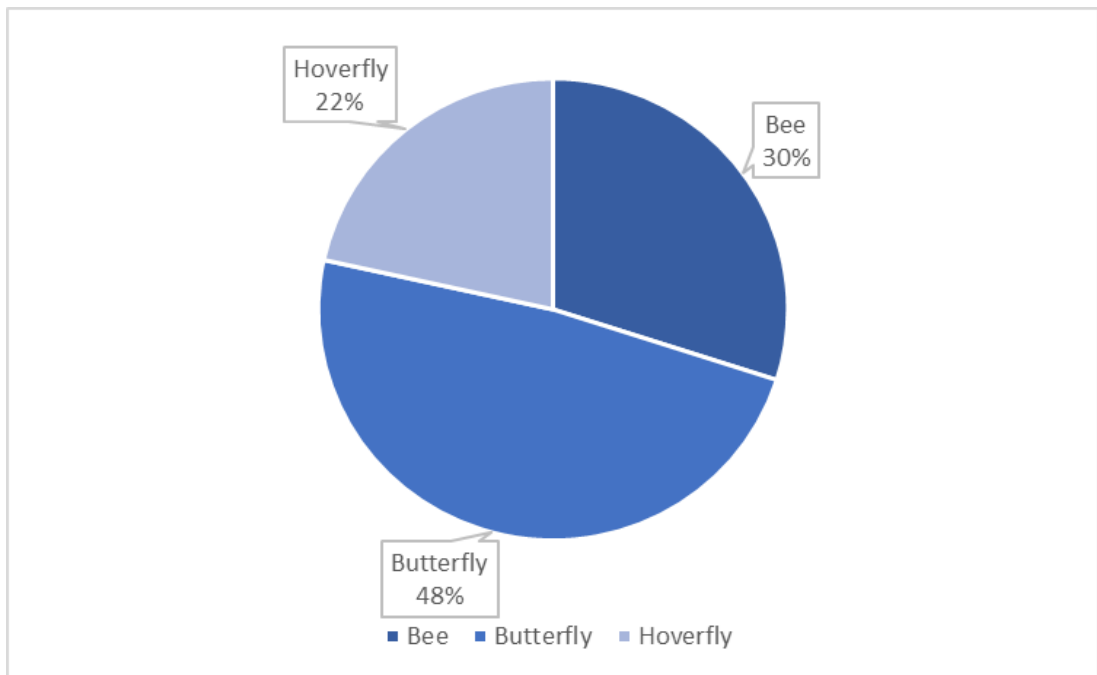


Figure 23: Composition of three different groups of insect pollinators; Bee, Butterfly, and hoverfly, in four habitats of SNNP

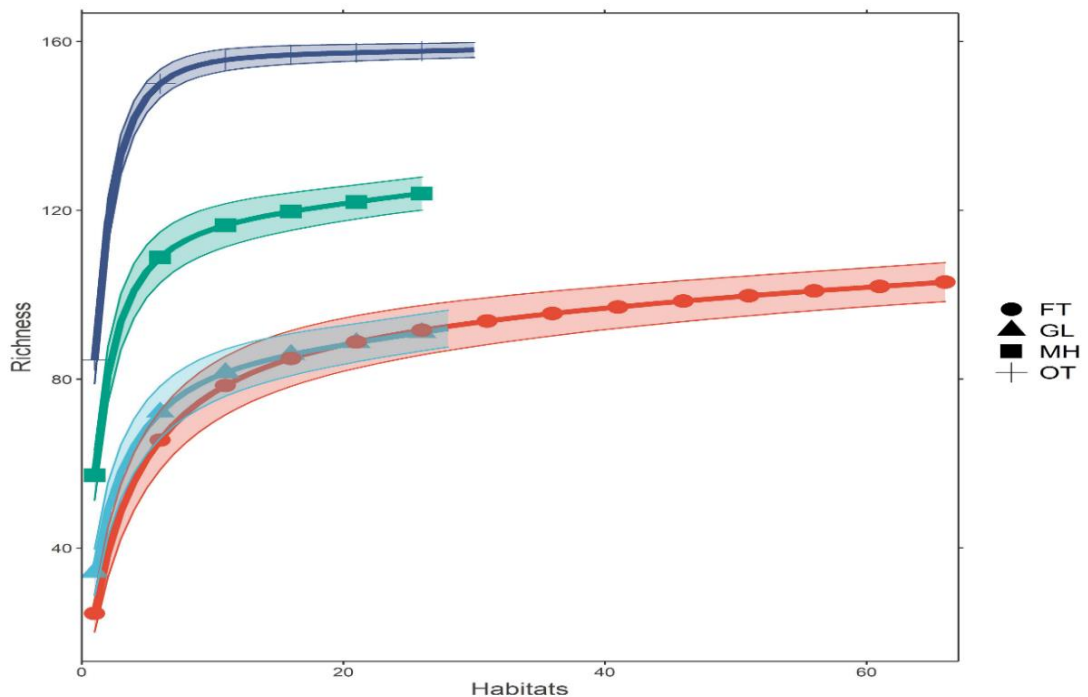


Figure 24: Species accumulation curve of pollinators in four habitats of SNNP. Each line symbolizes a different type of environment (Dyola *et al.*, 2022b)

3.3. 2 Abundance and species richness of insect pollinators in different habitats

Species richness and abundance were higher in Open trail than in other habitats (Figure 25). There is a significant difference in species richness (Kruskal-Wallis test, $\chi^2 = 104.96$, $df = 3$, $P = 0.0001$) and abundance between habitats.

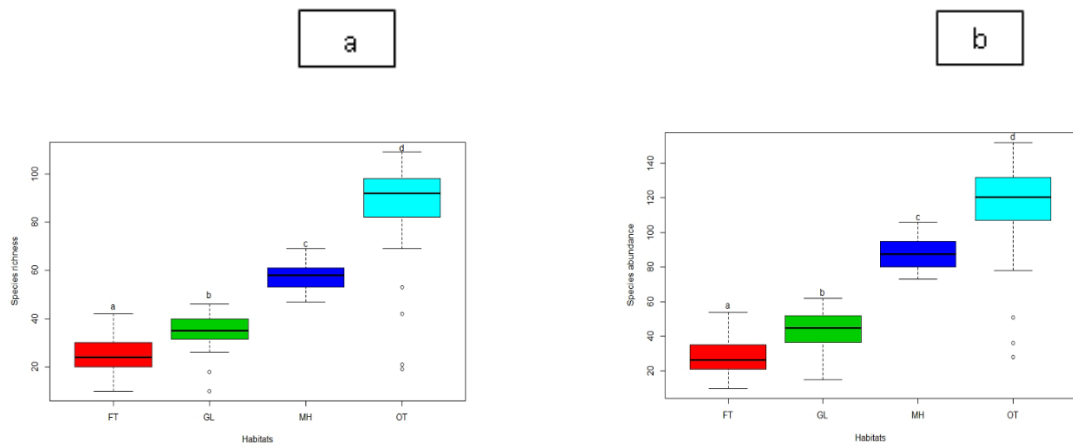


Figure 25: Species richness (a) and abundance (b) of insect pollinators in four different habitats of SNNP. The median is represented by a horizontal line across each box, the data range is represented by whiskers, and outliers are shown by circles (Dyola *et al.*, 2022b)

3.3.3 Diversity and Distribution pattern of insect pollinators

The open trail has a higher species richness and Shannon index (alpha level) than the managed habitat. The open trail is more diverse than the other habitats of SNNP. Pollinator distribution was even in the OT, which was followed by GL. In FT, GL, MH, and OT, the species richness and Shannon index were significant (t-test, $p < 0.05$). In FT and GL, a similar level of evenness was seen (Table 3).

Table 3: Species richness (S), Shannon–Weiner (H), Pielou's evenness (J), and Dominance (D) of insect pollinators. Values followed by distinct superscripted letters (a, b, c, d) are significantly different at $P < 0.05$ in a particular column. (Dyola *et al.*, 2022b)

		S	H	J	D
Habitat	MH	124 ^a	4.30 ^a	0.59 ^a	0.024 ^a
	FT	103 ^b	4.19 ^b	0.64 ^b	0.020 ^b
	GL	92 ^c	4.09 ^c	0.65 ^b	0.022 ^a
	OT	158 ^d	4.85 ^d	0.81 ^c	0.010 ^c

3.3.4 Pollinators sharing between different habitats

The OT had the most species (158), followed by the MH (124), FT (103), and GL (92). Sixty-one species shared common habitats, but species found in only one of the habitats was 12 for OT, 6 for FT, and 3 for MH (Figure 26). When comparing two habitats, OT and MH were shared by the most pollinators (121), OT and FT by 97 pollinators, GL and OT by 92 pollinators, and GL and MH by 82 pollinators.

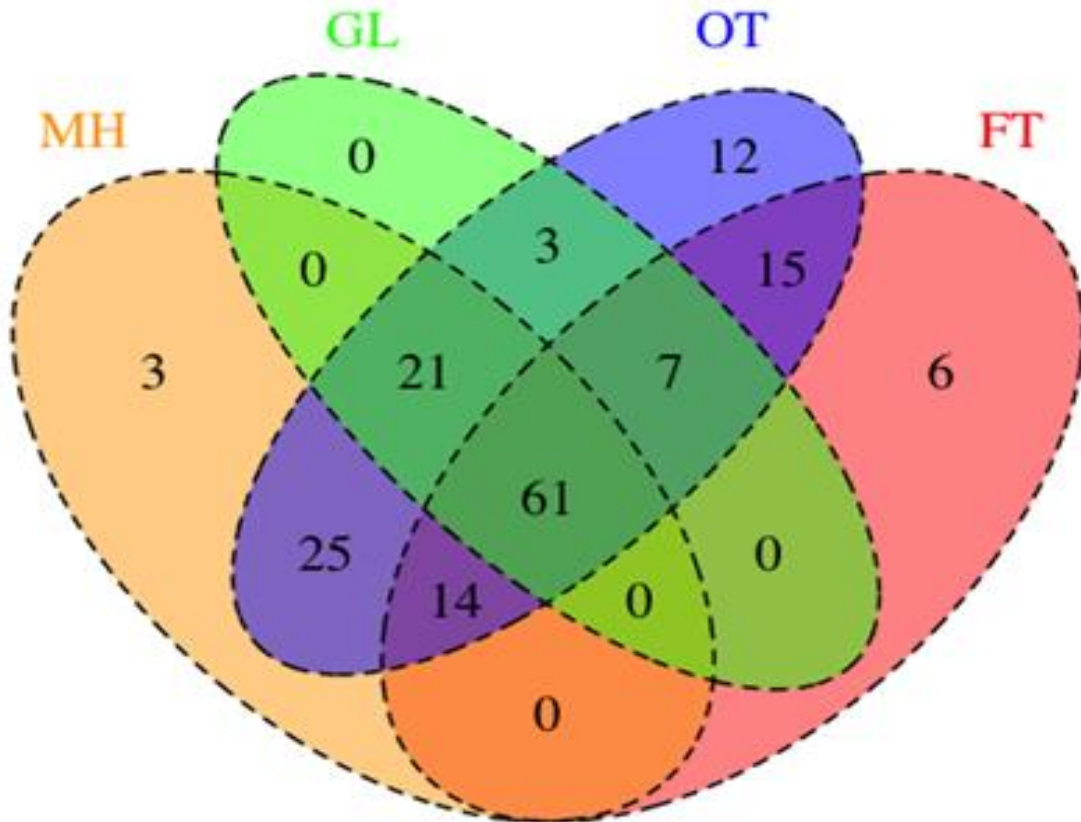


Figure 26: A Venn diagram depicting the sharing of insect pollinators among four different habitats of SNNP. FT (pink), GL (green), MH (skin), OT (orange) (Blue) (Dyola *et al.*, 2022b)

Whittaker Beta diversity presented the high species turnover between FT and MH, but showed low species turnover between MH and OT (Table 4). Gross Shannon Diversity of pollinators in study area (Gamma diversity) was 4.683 (Appendix III).

Table 4: Whittaker Beta diversity showing species turnover of insect pollinators in four different habitats (FT, GL, MH, and OT) of SNNP. (Dyola *et al.*, 2022b)

	FT	GL	MH	OT
FT	0	0.30	0.34	0.26
GL	0.30	0	0.24	0.26
MH	0.34	0.24	0	0.14
OT	0.26	0.26	0.14	0

3.3.5 Community composition of insect pollinators

3.3.5.1 NMDS

The NMDS of insect pollinator communities was plotted using the distance matrix of Bray-Curtis dissimilarity analysis in four different habitats. The convergence of NMDS ordination was indicated by a stress value of 0.15. Elevation, humidity, ambient temperature, and the abundance of flower resources all have a significant relationship with pollination insects, according to vector fitting of environmental factors (Table 5; Figure 27).

Flower had an NMDS1 score of 0.62 ($P < 0.001$, $R^2 = 0.63$), which was significantly higher than the rest of the group. With NMDS1 score values of -0.51 ($P < 0.009$, $R^2 = 0.07$) and -1.00 ($P < 0.001$, $R^2 = 0.10$), respectively, elevation and humidity were significantly negative (Table 3.4). At lower elevations, there was the strongest relationship between species abundance and flower resources (Positive end of NMDS1). At low elevation, there was also a strong relationship between species abundance with the MH and OT (Positive end of NMDS1).

The composition of pollinators in four habitats differs significantly (Adonis, $p < 0.001$) and has a significant strength (ANOSIM, $R = 0.62$, $p < 0.001$). *Xylocopa tenuiscapa* (0.70), *Danaus genutia* (0.70), and *Pelopidas agnatus* (0.69) were shown to have compositional differences between FT and MH in SIMPER analysis. *Ceratina dentipes* (0.70), *Xylocopa tenuiscapa* (0.69), and *Graphium sarpedon* (0.69) were the three species that contributed to the variation in composition between FT and OT, respectively. Furthermore, three species contributed to the change in composition between FT and GL: *Syricta orientalis* (0.70), *Eristalis himalayensis* (0.70), and *Lasioglossum albipes* (0.69). *Andrena kathmanduensis* (0.70), *Neptis hylas* (0.70), and *Andrena gorkhana* (0.69) were three species that changed the pollinator composition in MH and OT. *Elaphropoda impatiens* (0.70), *Lethe verma* (0.70), and *Precis iphita* (0.69) were three species that changed the pollinator composition in MH and GL. *Eristalinus taeniops* (0.70), *Pieris brassica* (0.70), and *Graphium sarpedon* (0.68) were three species indifferent in the composition of the OT and GL.

Table 5: Scores on the NMDS1 and NMDS2 axes, significant values and coefficients of determination for the environmental factors (Dyola *et al.*, 2022b)

	NMDS1	NMDS2	R ²	Pr(>r)
Elevation	-0.51	0.86	0.07	0.009**
Humidity	-1.00	-0.09	0.10	0.001***
Atmospheric Temperature	0.97	-0.25	0.05	0.036*
Flower	0.62	-0.79	0.63	0.001***

Signif. codes: 0'*** ' 0.001 '** ' 0.01 '* ' 0.05 '.' 0.1 ' ' 1

Permutation: free

Number of permutations: 999

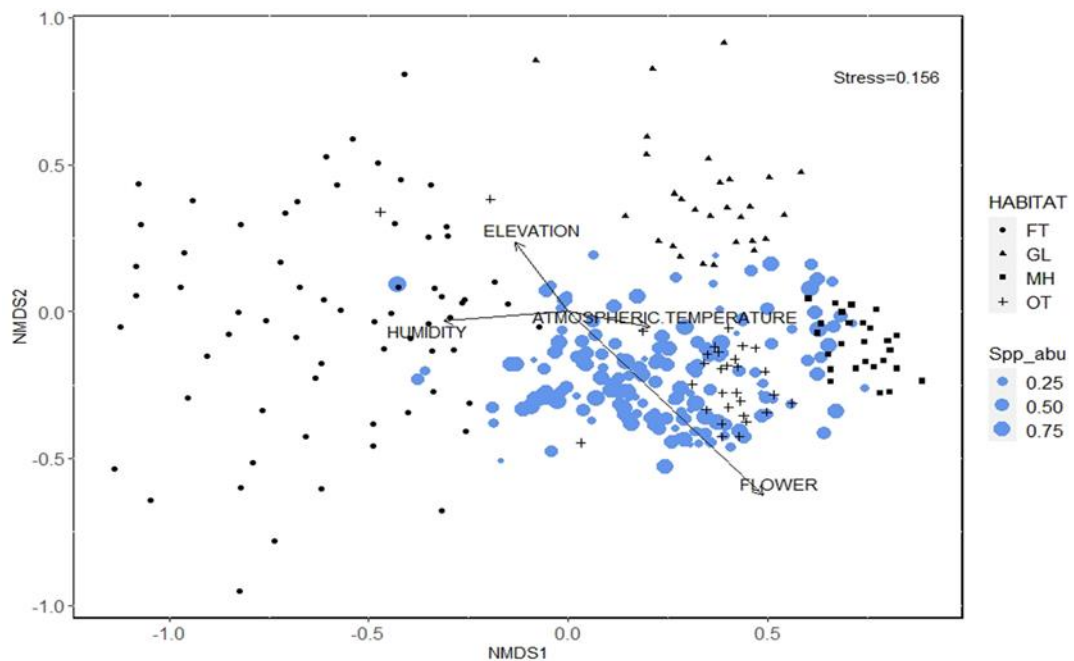


Figure 27: NMDS depicting the impact of environmental factors on insect pollinator community composition in four of SNNP (Dyola *et al.*, 2022b)

3.3.5.2 RDA

The RDA ordination approach was used to show the relationship between environmental variables and the top 15 most abundant pollinator communities (Figure 28). Active recruitment is used by *Apis mellifera* and *A. cerana* (Winfree *et al.*, 2007; Proesmans *et al.*, 2019), which can lead to an overabundance in some areas that does not reflect the species' true density, and vice versa. As a result, analyses were conducted with *Apis* spp. included and removed in order to determine the effect of *Apis* spp. on the parameters studied. There were no such disparities, according to the findings (Table

6). As a result, the *Apis* spp. were included in the study. In the pollinator-environmental interaction, two canonical axes of RDA analysis explained 12.83 percent of the variance, with the first axis accounting for 10.71 percent and the second axis for 2.12 percent of the variance, respectively. Among environmental parameters, elevation and the flower resources ($p < 0.05$), had shown significant relation with the top 15 most abundant pollinators although humidity and ambient temperature had no such effect on them. The higher abundance of flowers coupled with the large number of *Apis cerana* and the MH associated with *Apis mellifera*. *Pieris canidia*, on the other hand, was associated with both OT and GL, and *Vanessa cardui* in MH.

The FT, which was a relatively moist region, was more associated with *Bombus eximius*, *B. flavescens*, *E. tenax*, and *Ypthima baldus*. *Melanostoma univittatum*. *Episyrphus viridaureus* were found near the OT, while *Episyrphus balteatus* was found near the GL and MH.

Table 6: RDA presents correlation of environmental variables with the top 15 most abundance insect pollinators analysis including *Apis* spp. (In.) and excluding *Apis* spp. (Ex.) (Dyola *et al.*, 2022b)

	Df	variance		F		Pr(>F)	
		In.	Ex.	In.	Ex.	In.	Ex.
Elevation	1	0.006	0.004	3.248	2.052	0.002**	0.025*
Humidity	1	0.003	0.004	1.588	1.700	0.099	0.070.
Atmospheric Temperature	1	0.003	0.003	1.238	1.533	0.250	0.107
Flower	1	0.021	0.011	10.651	5.568	0.001***	0.001***
Residue	145	0.288	0.297				

Signif. codes: 0'*** ' 0.001 '** ' 0.01 '* ' 0.05 '.' 0.1 ' ' 1'

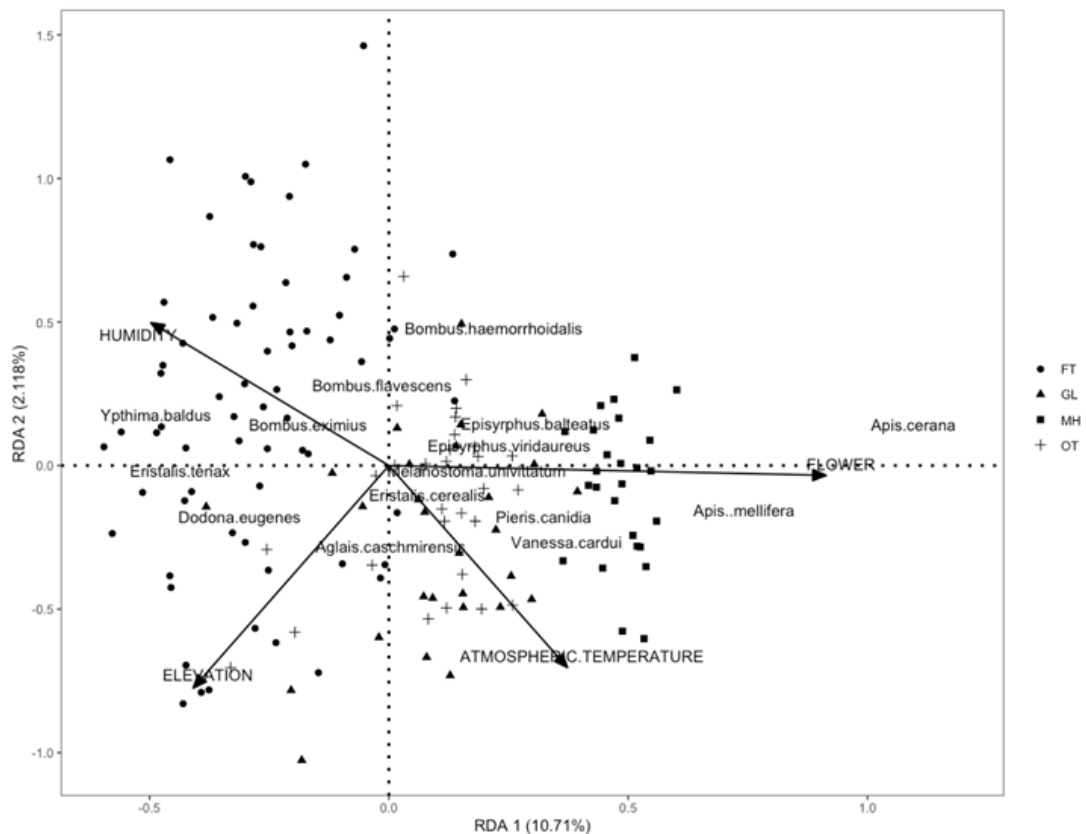


Figure 28: RDA - biplot showing the relationship between insect pollinator species and environmental variables. The figure only shows the top 15 most abundant species (five from each group; bee, butterfly, and hoverfly) (Dyola *et al.*, 2022b)

3.4 DISCUSSION

3.4.1 Abundance and species richness of pollinators in different habitats

The current data reveal that there are differences in pollinator abundance and species richness among SNNP habitat categories. Similar influence of habitat types in pollinators of megacity, Bangkok, Thailand, has been shown (Stewart *et al.*, 2018). According to present findings, the OT has the highest species richness of pollinating insects. The result demonstrates a direct relationship between the presence of flower resources and insects. The open forest trails have a comparably thick layer of herbs and bushes with a variety of wildflowers that provide nectar and pollen sources for pollinators.

Flower resources (Sjödín *et al.*, 2008; Baldock *et al.*, 2015) are one of the most consistent and important characteristics (Ahrne *et al.*, 2009; Hülsmann *et al.*, 2015; Stewart *et al.*, 2018) observed worldwide in determining the availability of food for insect visitors. Pollinators' presence is influenced by the quality and quantity of nectar

and pollen (Hicks *et al.*, 2016). OT was covered by *Ageratina adenophora* and other wild herbs, offering a rich resource for hoverflies and bees in particular. In addition, herbs such as *Ranunculus repens* and *Trifolium repens* were found in greater abundance on the OT compared to other habitats of SNNP. Both bees and butterflies preferred these flowers (Hicks *et al.*, 2016; Chaguthi & Dyola, 2018) for nectar and pollen (Erbar & Leins, 2013; Master & Emery, 2015). Adult hoverflies invest a lot of energy to hover, which they can get by visiting many flowers in the area (Haslett, 1989; Meyer *et al.*, 2009; Proesmans *et al.*, 2019). Low flower resources, on the other hand, are responsible for the decrease in pollinator numbers and species richness in the FT. Canopy cover in FT reduces sunlight intensity lowering the flower coverage and hence restricts pollinators in the forest's understory herb and shrub communities (Proesmans *et al.*, 2019).

The MH in SNNP is open sampling area, which is populated, and disturbed by certain human activity. Although, this is the second sampling area with maximum flower coverage, the pollinators movement in this habitat is fewer than OT, could be due to human activities. Human disturbances have also been shown to have a deleterious impact on diversity of butterfly in previous studies (Kambach *et al.*, 2013). Varieties of herbaceous plants in GL are food resources of butterflies and shelter of different other pollinators. However, the GL of SNNP is being encroached by forest and weeds leaving fewer open patches (SNNP, 2017), This could be the reason behind decreasing pollinators specially blue butterflies and Skippers which are indicator species of GL.

3.4.2 Diversity and distribution pattern of insect pollinators

In addition, our findings show that OT is more diversified than MT. Between these two habitats, there is very little species turnover. This could be explained once more by the impact of the local environment on habitats. These two habitat types are open, with thicker flower resource beds. The majority of pollinators have a significant preference for structurally varied land-use types that provide them with the range of supplies they need (Matteson & Langellotto, 2010; Bates *et al.*, 2011). However, floral resources are comparably lower in the FT and GL, which could explain why pollinators are less diversified and similar evenness of pollinators in these two habitats.

In the current study, pollinator distribution patterns differed among different species. In all of the habitats studied, 61 species of pollinators were found common. This result

represents the various behaviour pattern of pollinators. Wild bees have a diverse habitat selection while flies have a greater temporal range of activities (Willcox *et al.*, 2019). Many bee species require various nesting and foraging sites (Franzén *et al.*, 2009; Kells & Dave, 2003), as well as different spatial foraging distances (*Bombus* spp. and *Xylocopa* spp.) (Greenleaf *et al.*, 2007). This could be one of the reasons why some bee species can be found in a variety of habitats.

Hoverflies, too, eat a variety of food sources during different phases of their lives hence dwell in different habitats. For example, the larvae of some hoverflies develop at close proximity to the canopy, while the adults hover in open flower-rich biotopes (Gittings *et al.*, 2006). Furthermore, hoverfly abundance rises with closeness to the forest (Moquet *et al.*, 2018), and some flies are restricted to a single type of habitat, such as *Vollucella trifasciata* and *Bachha maculata*, which have only been found in forest habitats. These two species prefer to be in a shady region of the forest (Coe, 1964; Hassan, 2019). Butterflies during their life cycles too exhibit a predilection for diverse types of habitats (Janz, 2005). Females oviposit in grassland while foraging in flower-rich environments (Evan *et al.*, 2020).

3.4.3 The community composition of insect pollinators

3.4.3.1 NMDS

The community composition of pollinators is influenced by environmental conditions. The measured environmental variables (elevation, humidity, air temperature, and floral resources) show a significant relationship with the pollinator community, according to current findings. Pollinator species abundance was centered in the MT and OT, which were exposed to a lot of sunlight. Such sun exposures have a significant impact on the activities of insect pollinators (McKinney & Goodell, 2010; Sydenham *et al.*, 2016). In an open area, there is ambient temperature and solar radiation which are the important microclimates for heliothermic pollinators like butterfly (Bergman *et al.*, 1996). Most of the butterfly species generate their body temperature by basking on sun energy hence comparatively present abundantly in open lands. Bees are also found more abundant in ambient temperature (Rohde & Pilliod, 2021) as many bee collect the warm nectar (Shrestha *et al.*, 2018).

Similarly, for insect pollinators, floral resources were the next positive alluring factor. This could be strong reason for abundance of the pollinators in sites with thick coverage

of flower in SNNP. This finding is similar with Carreck and Williams, (2002) who findings showed that the mixture of wildflowers were the centre of attraction for different pollinators groups. Flower diversity plays vital role in communities of bee and hoverfly (Fründ, *et al.*, 2010). The abundance of diverse pollinator taxa is affected by the complex environmental gradient of high altitude (Warren *et al.*, 1988). Pollinator abundance decreased as the elevation increased. A decrease in the number of flowers that attract bees and either flies in high elevation, or a decrease in the number of flowering plants in higher altitudes (Arnold *et al.*, 2009) could explain the plausible reason for this kind of result. The previous studies have been shown that the plant communities at high altitude reduce the number of vascular plants and, as a result, insect pollinators (Mani, 1962). Elevation has a negative relationship with ambient temperature and the availability of flower resources. Temperature and humidity (two oppositely connected variables) are major determinants in determining plant composition at higher altitudes (Subedi *et al.*, 2020), and hence influence pollinator abundance.

Only a few species of hoverflies with no special food preferences (Kearns, 1992) and large bees, such as *Bombus* spp., that can thermoregulate (Bergman *et al.*, 1996) and forage at low temperatures, were detected in our study area's highest height.

3.4.4.2 RDA

In this study, pollinator species are associated with evaluated environmental variables (Elevation, Humidity, Atmospheric Temperature, and Flower) in distinct ways. Among pollinators, two species *Apis cerana* and *A. mellifera* were highly present in MH. This habitat of SNNP is human settlement and the walking trails were covered with flower resources. These species mostly forage near their nesting areas. The *Apis* spp. preference for floral resources near the nesting area, like little bees (Gathmann & Tschardt, 2002; Vulliamy *et al.*, 2006), could be explained by their need to gather as much nectar as possible to maintain the vast bee colony (Potts *et al.*, 2003). This kind of foraging behaviour of *Apis* spp. mean to budget the time and collect maximum nectar in short time as in long distances, there is no guarantee that suitable foraging ground will be available (Beekman & Ratnieks, 2000). This could be the probable reason for abundance of *Apis* spp. in MH.

Bombus eximius and *B. flavescens* on the other hand, were associated with humid forests. Large-bodied bees, such as *Bombus* spp., may leave the nesting region for foraging (Greenleaf *et al.*, 2007) and damp locations to avoid the harsher day temperatures (Willmer, 1983). Another probable reason of Bumblebees presence in forest is these bees are endothermic species and can make flights in low temperature (Bergman *et. al.*, 1996). The most common and plentiful butterfly in all types of habitats is *Aglais caschmirensis* (Irungbam *et al.*, 2017). This species is also frequently spotted in protected area of India with different microhabitats (Arya *et al.*, 2020) and in deciduous forest in another study (Thakur *et al.*, 2021). This could explain its occurrence in both the forest and managed environment in the research area. Similarly, *Episyrphus balteatus*' presence in the MH suggests that they prefer the blooms of vegetables like coriander and buckwheat (Pinheiro *et al.*, 2015) as a host plant. At the same time larva of *E. balteatus* are voracious feeders of aphids (Jalilian, 2015) which is the common agricultural pest.

3.5 CONCLUSIONS

Insect pollinator diversity, distribution, and community structure were investigated in four different habitats of SNNP, Nepal. Overall, habitats, humidity, ambient temperature, flower resources, and elevation all played a significant role in diversity, distribution, and community structure of these insects. Insect pollinators were closely linked to flower resources of an OT showing dependence of community structure of insect pollinators on the plant diversity of such trails. Hence, conservation of the flowering herbs and shrubs of this habitat is important to conserve diverse community of insect pollinators.

CHAPTER 4

PREPARE HABITAT DISTRIBUTION MAP OF WILD BEES TO SHOW THEIR POTENTIAL AREA IN SHIVAPURI - NAGARJUN NATIONAL PARK, NEPAL

Abstract

Shivapuri-Nagarjun National park is home for many species of wild solitary bee which are valuable agents of both cropland and natural habitat. The quality of habitat determines the restoration of bees. Assessing the habitat suitability of wild bees helps to determine the suitable areas for them in the park. However, the knowledge on distribution of wildbees from the park is limited. This study aimed to estimate and map the potential habitat for five wild bees: *Nomada mutabilis*, *Thyreus decorus*, *Thyreus himalayensis*, *Megachile femorata*, and *Xylocopa violacea* in the park on the basis of climatic variables and land use land cover data. The distribution models were created by presence-only technique in Species Distribution Modelling program, incorporating presence data of wild bees and excluded the highly correlated bioclimatic variables and land use and land cover classes. The finding shows annual precipitation (Bio 12) was the most influencing factor for presence of all five wild bees in the study area. The estimated total most suitable and suitable areas varied across the bee species, i.e., *Nomada mutabilis* (11.1 sq.km and 35.45 sq.km), *Thyreus decorus* (25.2 sq.km and 46.18 sq.km), *T. himalayensis* (3.73 sq.km and 31.62 sq.km), *Megachile femorata* (19.87 sq.km and 26.84 sq.km), and *Xylocopa violacea* (7.54 sq.km and 14.42 sq.km). According to the findings of this study, the existing potential distribution of chosen species in the National park is spread out across a broad region. As a result, a detailed scientific examination of wild bees is essential to fully comprehend their influence on the ecosystem and other pertinent topics.

4. INTRODUCTION

4.1 Background

Wild bees are one of the most important pollinating insects. They are valuable for pollinating crops (Biesmeijer *et al.*, 2006; Klein *et al.*, 2007; Li *et al.*, 2018) and plants

in the natural ecosystem (Koh *et al.*, 2016; Zattara & Aizen, 2021). Bees, unlike other taxa, obligatory need floral products like pollen and nectar in their life cycle (Michener, 1982); hence have a close association with flowering plants. The diverse pattern of resources in the foraging land plays vital role in the population of wild bees (Roulston & Goodell, 2011). The quality of habitat determines the restoration of bees. Despite the importance of wild bees in pollination ecology, evidences show the decline of global bee pollinators (Potts *et al.*, 2010; Winfree, 2010; Drossart & Gérard, 2020). Multiple factors have been identified as contributing to the loss of bee populations, including diseases (Meeus *et al.*, 2018), agricultural intensification (Duchenne *et al.*, 2020), global warming (Vasiliev & Greenwood, 2021). However, the truth of native bee declines is muddled by a lack of regular large scale bee sampling and inconsistent research results (LeBuhn *et al.*, 2007). Assessing the habitat suitability of wild bees helps to determine the suitable areas for them. Species conservation requires the proper understanding of the distribution of the species and their habitat (Eken *et al.*, 2004). Species Distribution Models (SDMs) are numerical tools that integrate data of species presence or abundance with environmental estimations to create species distribution models (Elith & Leathwick, 2009; Jones *et al.*, 2016) without making any contact with species under investigation (Maharjan *et al.*, 2017). These approaches are used to estimate the geographic distribution of a species using field observations and associated environmental predictor variables (Beckham & Atkinson, 2017). Over the last few decades, SDMs approaches have become increasingly valuable tools for conservation planning (Guisan & Thuiller, 2005; Yackulic *et al.*, 2013; Urbina–Cardona *et al.*, 2019). Among the SDMs approaches, the Maximum Entropy (MaxEnt) approach stands out because it is simple to apply and produces strong distribution models using only presence data and environmental variables associated with presence sites (Phillips *et al.*, 2004).

SNNP is home to different wild bee species. Habitat degradation and fragmentation are threatening the population of wild bees globally however to our best knowledge the study on these bees to state the current populations was in infant stage in Nepal. Limited data obtained from natural history collections, literature, and the recent surveys in the SNNP are the only sources of information on the wild bee. There is still huge knowledge gaps due to undersampled area and the range of wild bees. Hence, this study aimed to estimate and map the potentially suitable habitat for wild bee species in the SNNP. We

believe that this research will help to identify bee hotspots and their associated land uses. This discovery could aid in the development of policies for the conservation of wild bees by investigating into land use types.

4.2. MATERIALS AND METHODS

4.2.1 Wild Bee Presence Points

The presence points of wild bees were collected through direct field observation in the park and managed area of buffer zone in spring and autumn of 2018 and 2019, They were collected by a sweeping net and identified in the lab using the description given by Bingham, 1903; Tadauchi & Matsumura, 2007; Williams *et al.*, 2010; Ngat *et al.*, 2017; Kumari *et al.*, 2018 for bee specimens. The mobile and eTrex Garmin 30 channel GPS device were used to take the coordinate for each collected species except in the core park area due to slopy hill. Duplicate records were eliminated, as there were records with identical latitude and longitude coordinates. Outlying occurrences, i.e., any data outside the SNNP, were validated by reviewing spatial relationships in ArcGIS version 10.5 and outlying occurrences were eliminated. Finally, the combination of these kinds of GPS coordinate data was applied in the SDMs process. A total of 46 wild bee species were collected (Appendix III). Though the data were available on 46 wild bee species, we only modelled the distributions of the five species (identified upto species level) from SNNP: *Nomada mutabilis*, *Thyreus decorus*, *T. himalayensis*, *Megachile femorata*, and *Xylocopa violacea*. The major reason behind this selection was that these species were least abundant during filed collection and uncommon (Thapa, 2015). Altogether, 52 presence points of these species were compiled for SDMs. Spatial filtering was excluded because this study was conducted in a small area of nearly 276 sq km. with a buffer zone (Maharjan *et al.*, 2017).

4.2.2 Bioclimatic variables and Land Use and Land Cover data

Based on the static and dynamic features, as well as the variables affecting the distribution pattern of species in SNNP, both bioclimatic variables and land use and land cover (LULC) (Maharjan *et al.*, 2017) were used to examine spatial distribution of wild bees. The fact behind choosing these factors is habitat suitability, cannot only be determined by bioclimatic data in all case instead climate driven forecasts could be improved by combining them with remotely sensed LULC data (Abdi, 2020). Improved

findings from contributions of remotely sensed LULC data have been mixed in similar investigations. On a coarse scale, using land cover data increased the models' explanatory capacity and their predictive potential. Data with a finer resolution and a smaller spatial scope may offer better results.

Bioclimatic layers of 19 derived bioclimatic variables were downloaded from the WorldClim global climate database (www.worldclim.org) at a resolution of 30 arc seconds (~1sq.km) were clipped for the SNNP with buffer zone using the spatial analyst tool of ArcGIS 10.5 version. For the preparation of environmental layers, Sentinel-2 satellite imagery detected with the Multi Spectral Instrument (MSI) on February 10, 2019, with a spatial resolution of 10 meters was used. The following six objects i.e, agricultural land, bareland, built up areas, forest, grassland and waterbodies were taken into account for establishing training regions in this scenario, a normal approach for creating supervised image or maximum likelihood classification on Sentinel - 2 satellite imagery (Maharjan *et al.*, 2017). Then, as an Area of Interest training site (AOI) layer, several polygons representing each object class were drawn. In general, different training sites for the same class with various spectral properties were gathered. The histogram for each of the hallmark classes was examined to guarantee the training facility's excellence. By double checking the same location through Google Earth, the training area was also confirmed. Following the revision and deletion of some of the signature classes, supervised classification was then carried out once again. Additionally, supervised categorization was carried out by combining various training regions for each class (Figure 29).

After a classification exercise is finished, accuracy assessment was performed by creating 100 random points from the ground truth data (Figure 30).

Based on the same picture, an accuracy assessment using the reference dataset and compared it to the classified data using a confusion matrix was performed. Producers Accuracy, Overall Accuracy, and Kappa Coefficient were performed preparing a Keyhole Markup Language (KML) file that was uploaded to the Google Earth application. The formula is as follows for computing all accuracy assessments:

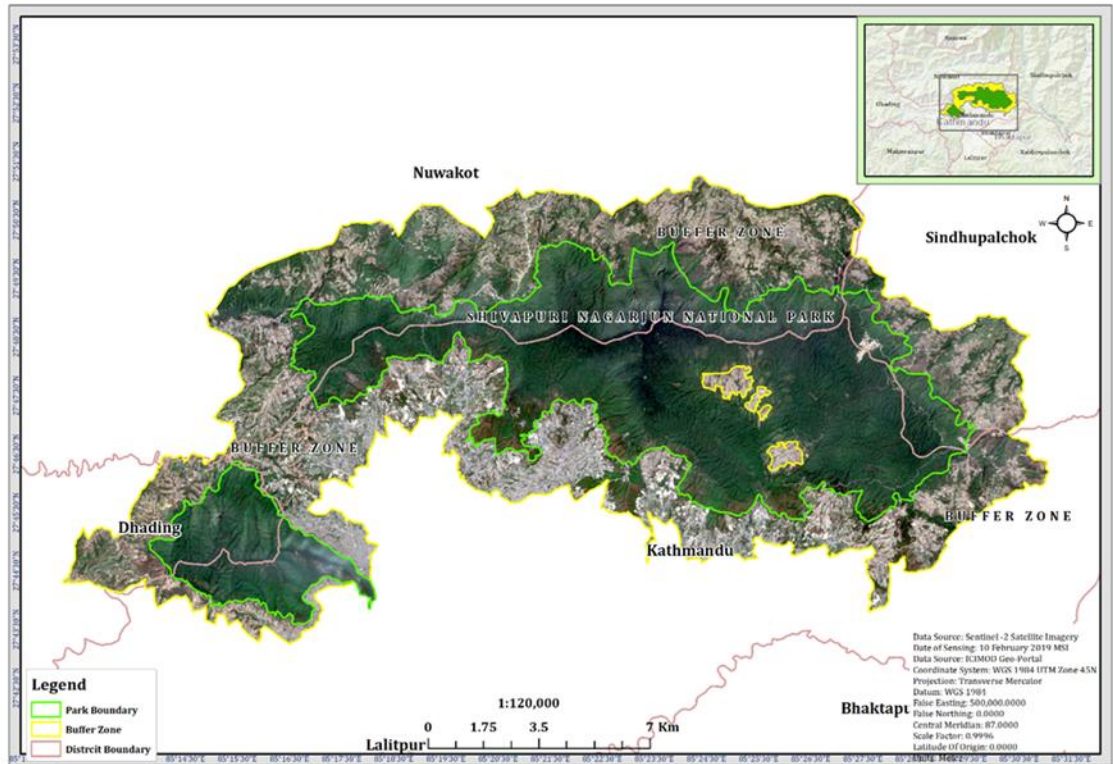


Figure 29: Sentinel-2 satellite imagery MSI of SNNP dated 10 February 2019

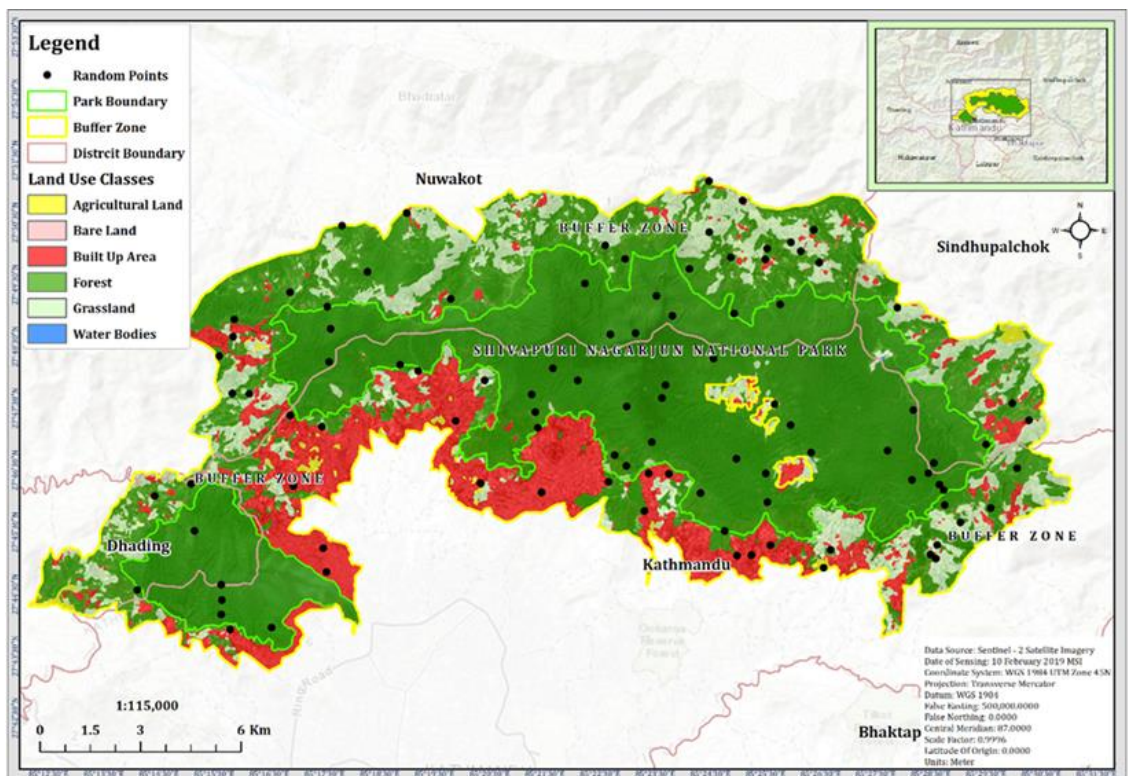


Figure 30: Generating 100 random points for accuracy assessment procedure after supervised image classification of Sentinel-2 satellite imagery of SNNP

Users Accuracy = (Number of Correctly Classified Pixels in each Category)/(Total number of Classified Pixels in that Category (The Row Total))×100(i)

Producer Accuracy=(Number of Correctly Classified Pixels in each Category)/(Total Number of Reference Pixels in that Category (The Column Total))×100.....(ii)

Overall Accuracy=(Total Number of Correctly Classified Pixels (Diagonal))/(Total Number of Reference Pixels)×100(iii)

Kappa Coefficient (T)=((TS ×TCS)- Σ(Column Total×Row Total))/(TS²- Σ(Column Total×Row Total))×100.....(iv)

The land use and landcover data obtained from Sentinel-2 satellite image classification and vegetation classification information collected from ICIMOD's regional database (<http://rds.icimod.org/>) (Figure 31) were used in geospatial analysis (GIS Identity Analysis tool) to determine final land use and land cover database by substituting forest cover by different vegetation layers (Figure 32) (Sapkota *et al.*,

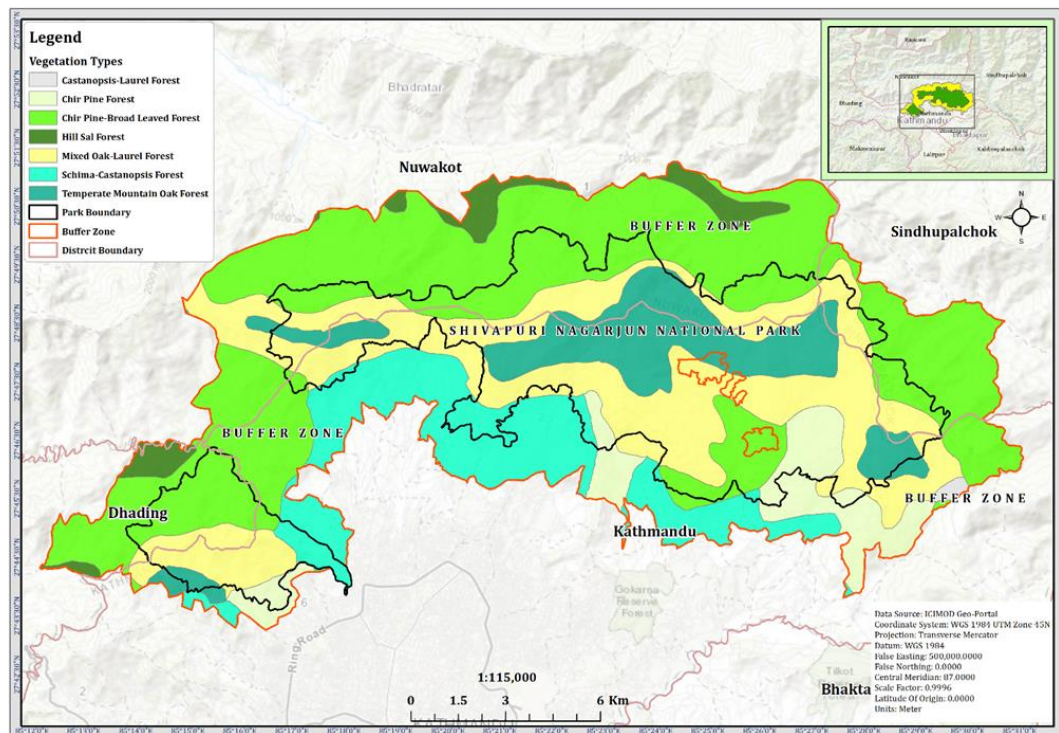


Figure 31: Vegetation types of SNNP data retrieved from ICIMOD Portal

Environmental settings in GIS were used to resample the layers to the same spatial extent and pixel. After resampling, data were converted into American Standard Code for Information Interchange (ASCII) format, which is readable by MaxENT algorithms using species distribution toolbox (SDMtoolbox) in ArcGIS 10.5 (Brown, 2014). The summary of method is given (Figure 33).

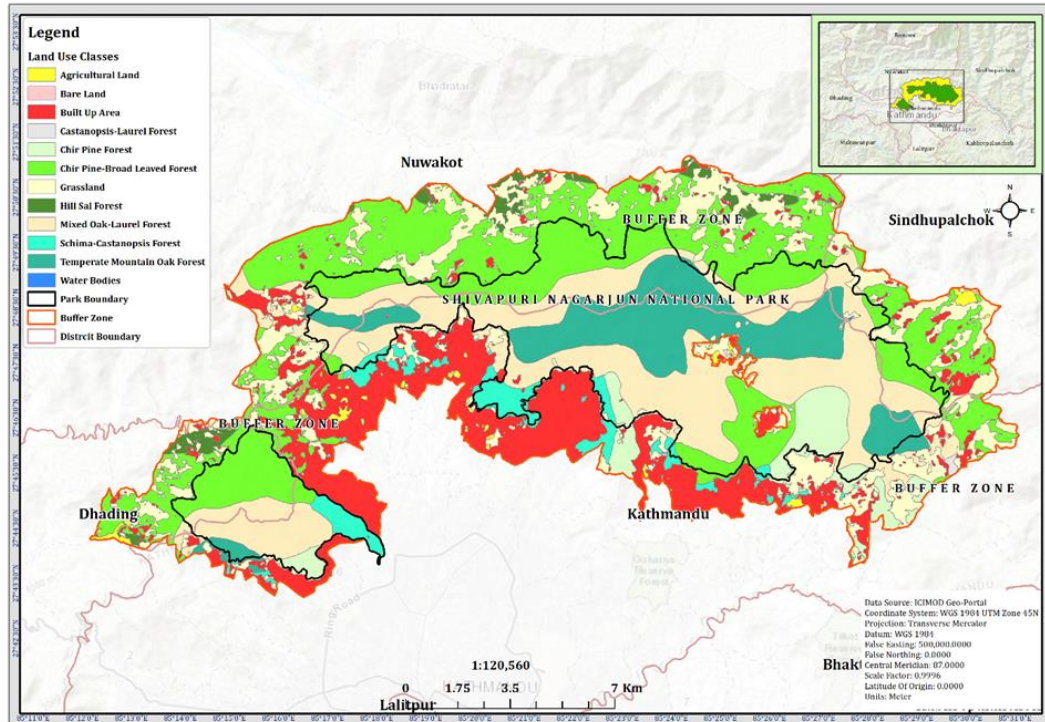


Figure 32: Final land use and land cover map of SNNP after geospatial identity analysis between vegetation types (ICIMOD geoportal) and supervised image classification of Sentinel-2 satellite imagery

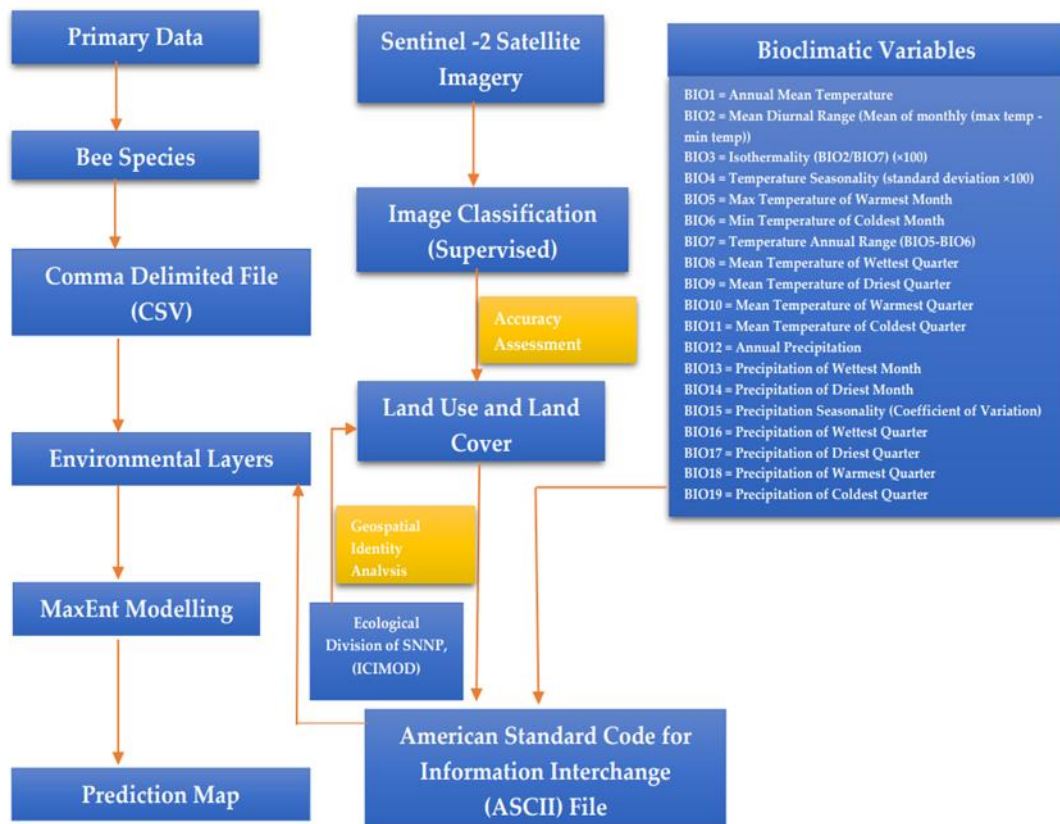


Figure 33: Flowchart showing processing of bioclimatic variables and LULC in Maxent Model

A multicollinearity test with a Pearson correlation coefficient (r) value less than 0.8 after setting up all the environmental layers was conducted to run the Species Distribution Modelling (SDM) toolbox. Only 5 of the 19 bioclimatic variables and 5 of the 12 classifications of land use and land cover were chosen (Sapkota *et al.*, 2021) (Table 7). The choice was made such that, as a general rule, Pearson's value shouldn't be higher than 0.8 (Thinley *et al.*, 2022).

Table 7: Influencing Bioclimatic variables and LULC used after Multicollinearity test for Species Distribution Modelling (SDM)

SN	Environmental Variables	Code	Source
1	Annual Mean Temperature (Bio1)	Bio1	WorldClim, 2020
2	Mean Diurnal Range (Bio2)	Bio2	WorldClim, 2020
3	Isothermality (BIO2/BIO7) (*100) (Bio3)	Bio3	WorldClim, 2020
4	Annual Precipitation (Bio12)	Bio12	WorldClim, 2020
5	Precipitation of Driest Month (Bio14)	Bio14	WorldClim, 2020
6	Agricultural Land		rds.icimod.org & Sentinel -2 imagery
7	Chirpine Forest		rds.icimod.org & Sentinel -2 imagery
8	Grassland		rds.icimod.org & Sentinel -2 imagery
9	Hillsal Forest		rds.icimod.org & Sentinel -2 imagery
10	Mixed Oak Laurel Forest		rds.icimod.org & Sentinel -2 imagery

4.2.3 MaxEnt Setting, Validation and Projection

Cross validation was chosen as a replicate type after the multicollinearity test, and the model was replicated ten times. Similarly, the maximum iterations are 500, the convergence threshold was 0.00001, and the default prevalence was 0.5. The Receiver Operating Characteristics (ROC) curve, the Area Under the Curve (AUC), and True Skill Statistics were used to evaluate the model's performance (TSS) (Young *et al.*, 2011). The AUC evaluated the model using web based software to provide an independent threshold assessment that spans from 0.5 to 1 (Radosavljevic & Anderson, 2014). If the AUC value is larger than 0.5, the model outperforms random estimation. AUC values between 0.9 and 1.0 indicate outstanding model performance; 0.8–0.9 indicate good; 0.7–0.8 indicate average; 0.6–0.7 indicate bad; and 0.5–0.6 indicate insufficient model performance (Sapkota *et al.*, 2021). Jackknife of regularized training of Wild Bee species was conducted. The SDM output was imported into ArcGIS and

converted to a binary map (suitable and unsuitable areas) projected using binary SDM toolbox distribution changes.

MaxEnt created a map of habitat suitability for all five species of bees. The different species occurrence probability threshold classes are then used to classify the map. From unsuitability having threshold (0.00–0.2), least suitable (0.20–0.38), moderately suitable (0.38–0.5), suitable (0.5–0.65), and more suitable area (0.65–0.8). Suitability maps are classified into different suitability classes using particular probability criteria. The MaxEnt predicted map, on the other hand, employs colors to show the likelihood that the conditions are adequate.

4.3 RESULTS

The overall accuracy, producer’s accuracy and kappa coefficient of the supervised maximum likelihood classification was 86%, 87.16% and 0.77 respectively (Table 8). The supervised maximum likelihood classification map of the research area is shown in figure 34 with as much user accuracy as possible, the supervised maximum likelihood categorization identified waterbodies, grassland, built-up areas, bare land, and agricultural land. The extraction of the forest class was likewise quite well, with a user accuracy of 85.71%.

Table 8: Accuracy Assessment of Supervised Image Classification of different LULC of SNNP

	Agricultural Land	Bare Land	Built Up Area	Forest	Grass land	Water Bodies	Total Users
Agricultural Land	1	0	0	0	0	0	1
Bare Land	0	5		0	1	0	6
Built Up Area	0	1	9	0	0	0	10
Forest	3	3	0	54	3	0	63
Grassland	1	0	0	1	12	0	14
Water Bodies	0	1	0	0	0	5	6
Total Producers	5	10	9	55	16	5	100
Producer's Accuracy	0.2	0.5	1	0.98	0.75	1	
Overall Accuracy	0.86						
Kappa Index	0.77						

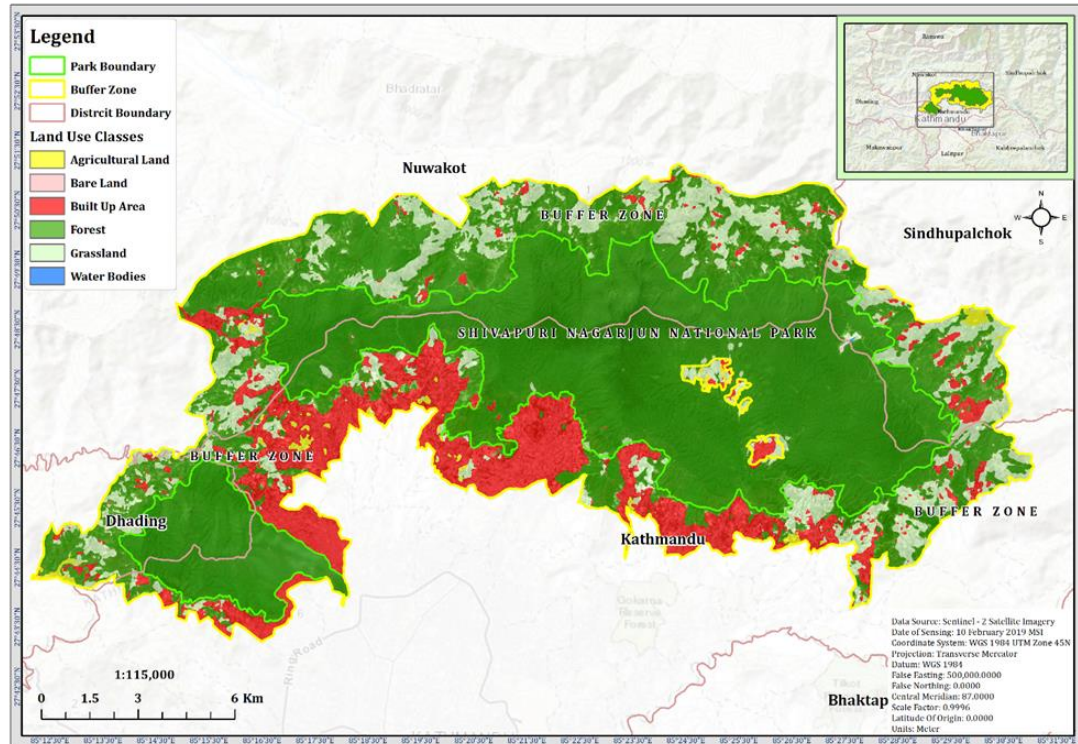


Figure 34: Land use and land cover map of SNNP after supervised image classification

4.3.1 Model Performance and Contribution of Environmental Variables

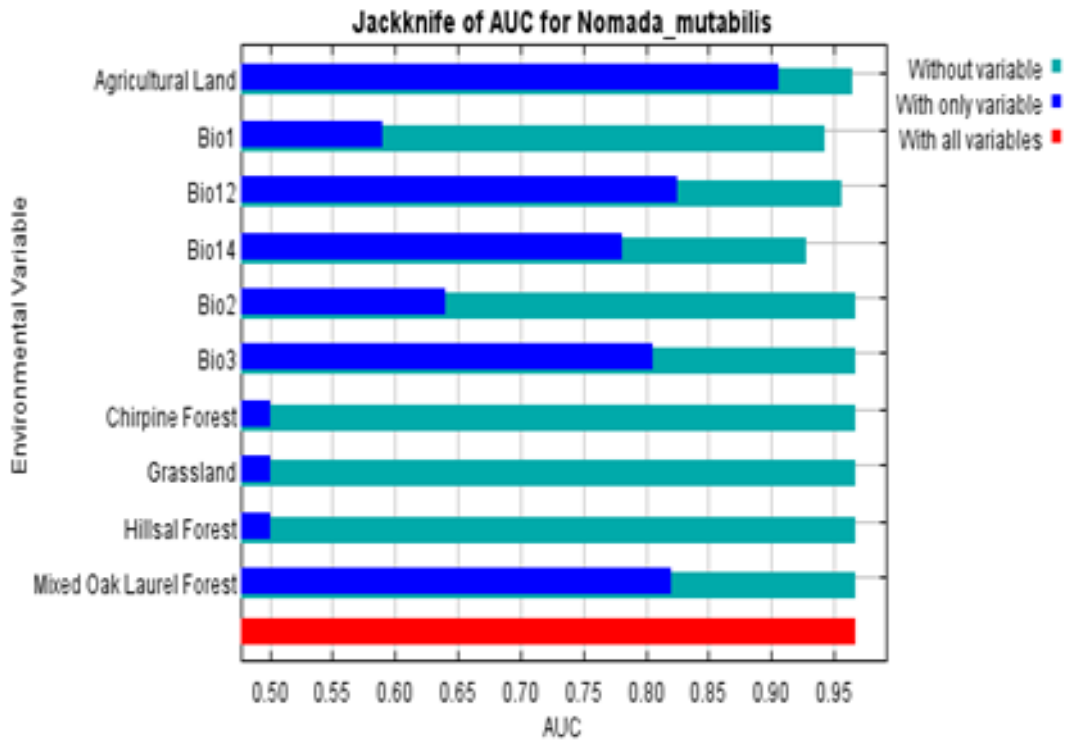
(Bioclimatic and LULC)

Model accuracy was good for all five-bee species: *Nomada mutabilis*, *Thyreus decorus*, *Thyreus himalayensis*, *Megachile femorata*, and *Xylocopa violacea*. According to the SDMs of these five wild bee species with five bioclimatic variables (after excluding other highly correlated variables), annual precipitation (Bio 12) contributed more in all components than the other, as evidenced by Jackknife of AUC (Figure 35).

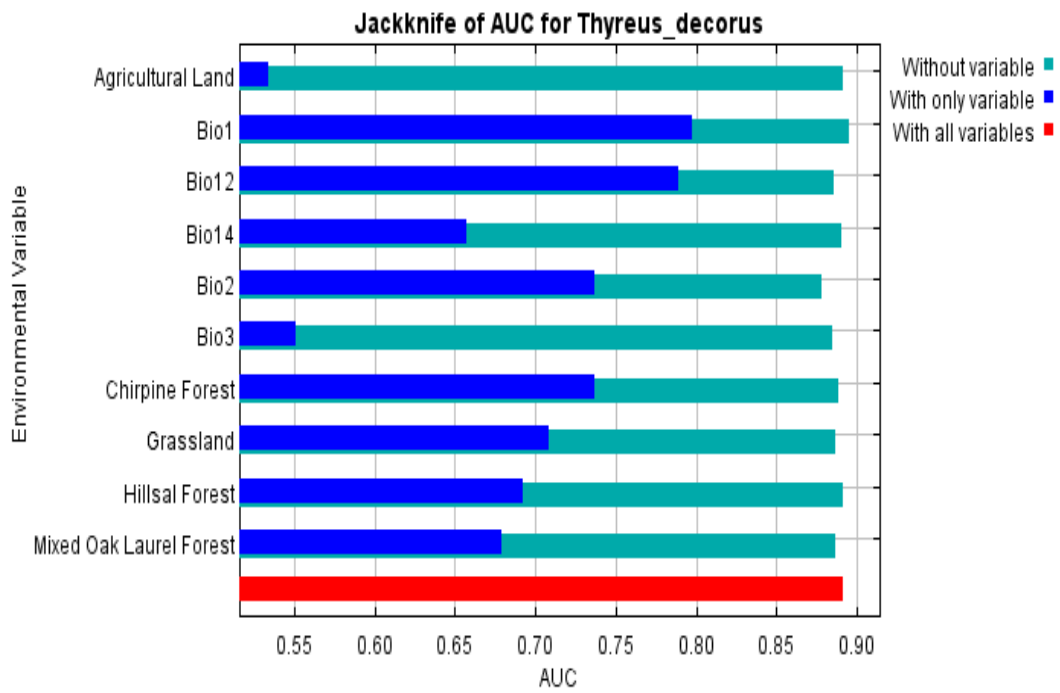
Another major aspect was the annual average temperature. The impact of these variables, however, vary per species. For instance, the jackknife test for *Nomada mutabilis* identified annual precipitation (Bio12), precipitation of driest month (Bio14), Isothermality (Bio3) as the most important bioclimatic variables for predicting the potential habitat suitability in the study area. In contrast, the jackknife test gain of *Thyreus decorus* recognizes annual mean temperature (Bio1), annual precipitation (Bio12), mean diurnal range (Bio2), as the most important bioclimatic variables for predicting the potential habitat suitability of it. Similarly, *Thyreus himalayensis*, *Megachile femorata*, *Xylocopa violacea* also acknowledged annual mean temperature

(Bio1), annual precipitation (Bio12), as the most significant bioclimatic variables for predicting the potential habitat suitability in the demarked area.

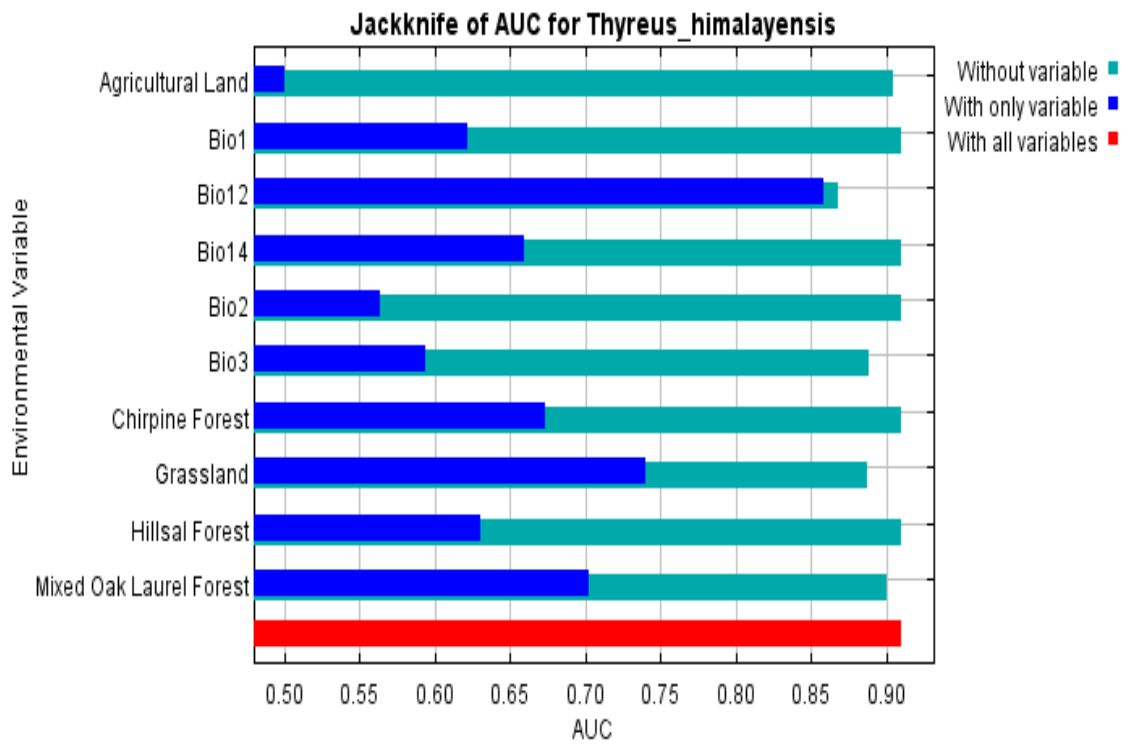
(a)



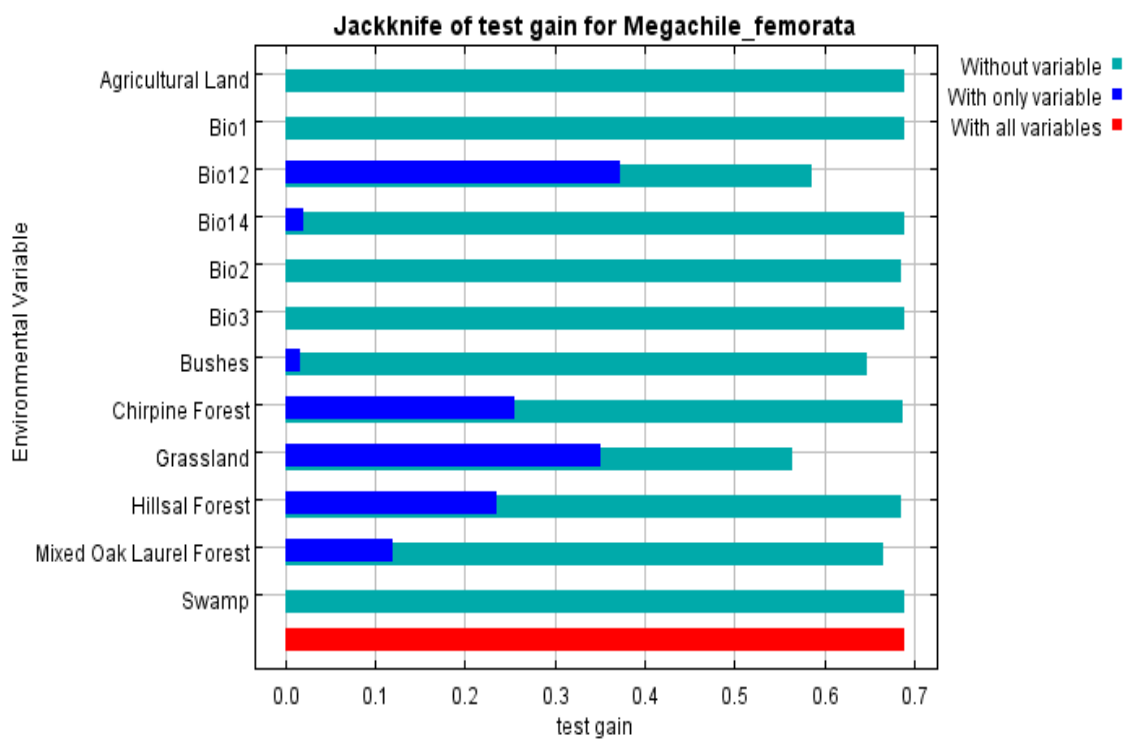
(b)



(c)



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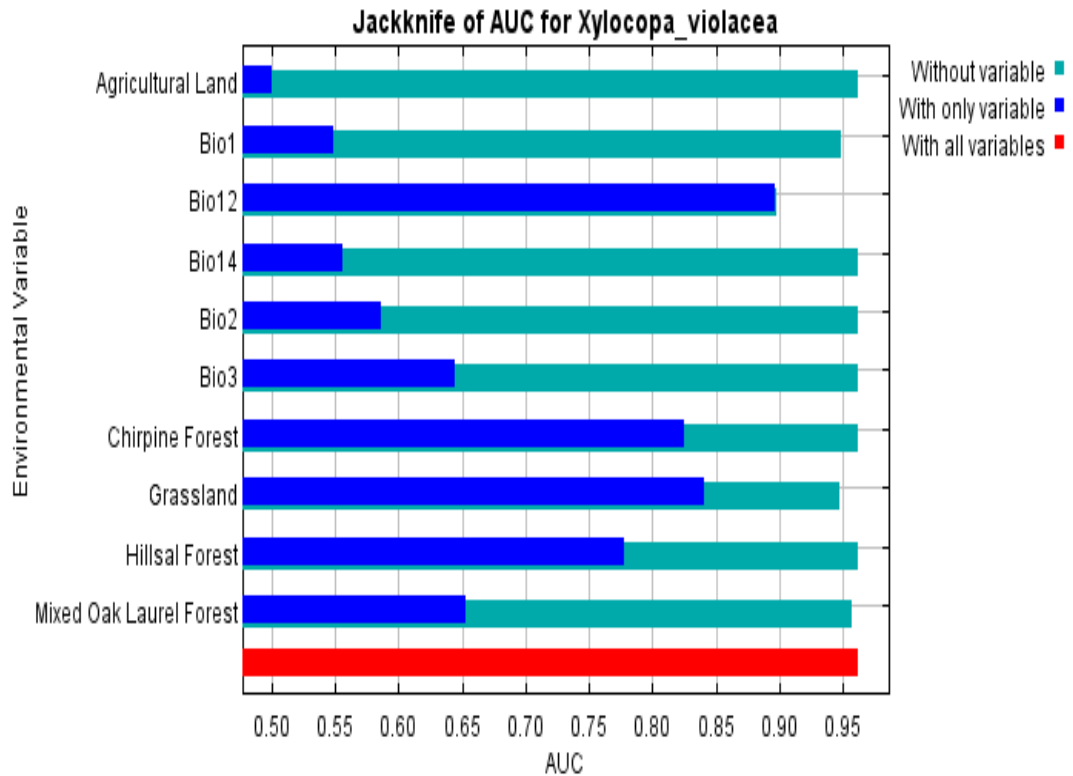


Figure 35: Jackknife of regularized training of Wild Bee Species. a:*Nomada mutabilis*; b:*Thyreus decorus*; c:*Thyreus himalayensis*; d:*Megachile femorata*; e:*Xylocopa violacea*. Warmer colors, such as blue and light blue, suggest a higher likelihood of favorable condition for the species, whereas lighter colors, such as red, yellow and orange, indicate a lower likelihood.

The influence of different LULC (Agriculture land, Chirpine forest, Grassland, Hill Sal Woodland and Mixed Oak Laurel Forest) vary among bee species as shown by the jackknife test. Agricultural land accounted for 24.5 percent of the LULC for *Nomada mutabilis*. The other four bees, *Thyreus decorus*, *Thyreus himalayensis*, *Megachile femorata*, and *Xylocopa violacea*, were also influenced by grassland (Table 9). Similarly, Mixed oak Laurel Forest contribute 8.6 per cent for *Thyreus decorus* while no contribution of forest for *Nomada mutabilis* and *T. himalayensis*.

4.3.2 Receiver Operating Characteristic (ROC) and Area Under Curve (AUC)

The accuracy of each model was determined by plotting and calculating the area under curve, or AUC value and the Receiver Operating Characteristic (ROC). All models carried AUC values above 0.85 and were considered to have strong predictive power.

Table 9: Environmental variables contribution in SDM of wild bees of SNNP

SN	Environmental Variables	<i>Nomada mutabilis</i>	<i>Thyreus decorus</i>	<i>Thyreus himalayensis</i>	<i>Megachile femorata</i>	<i>Xylocopa violacea</i>
1	Annual Mean Temperature (Bio1)	9.7	1.7	5	3.4	9.1
2	Mean Diurnal Range (Bio2)	0	7.2	0	0.6	5.6
3	Isothermality (BIO2/BIO7) (* 100) (Bio3)	0.1	0.1	2.4	1.9	0
4	Annual Precipitation (Bio12)	56.4	53.7	79.6	44.5	60
5	Precipitation of Driest Month (Bio14)	6.7	1.1	0	0	0
6	Agricultural Land	24.5	0.4	0.2	0	0
7	Chirpine Forest	0	2.9	0	1.4	12.6
8	Grassland	0	12.2	5.4	46.3	12.1
9	Hillsal Forest	0	2.2	0	2.3	0
10	Mixed Oak Laurel Forest	0	8.6	0	3.1	0.5

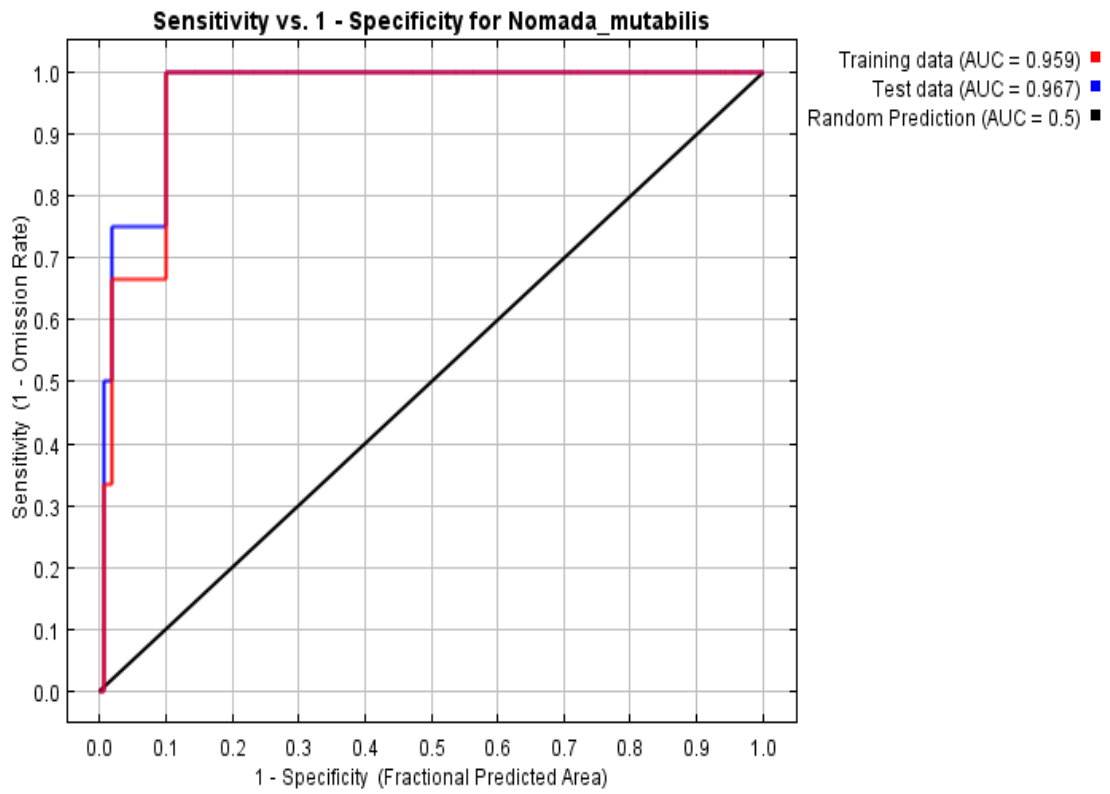
The test data closely resembled the ROC curve, and each of the final five wild bee species richness estimated value greater than 0.7 AUC criterion, which is statistically well specified. The fact that each model outperformed the standard is a strong case for their validity.

The logistic outputs of species distribution models produced in MaxEnt *Nomada mutabilis*, *Thyreus decorus*, *Thyreus himalayensis*, *Megachile femorata* and *Xylocopa violacea* as shown (Figure 36).

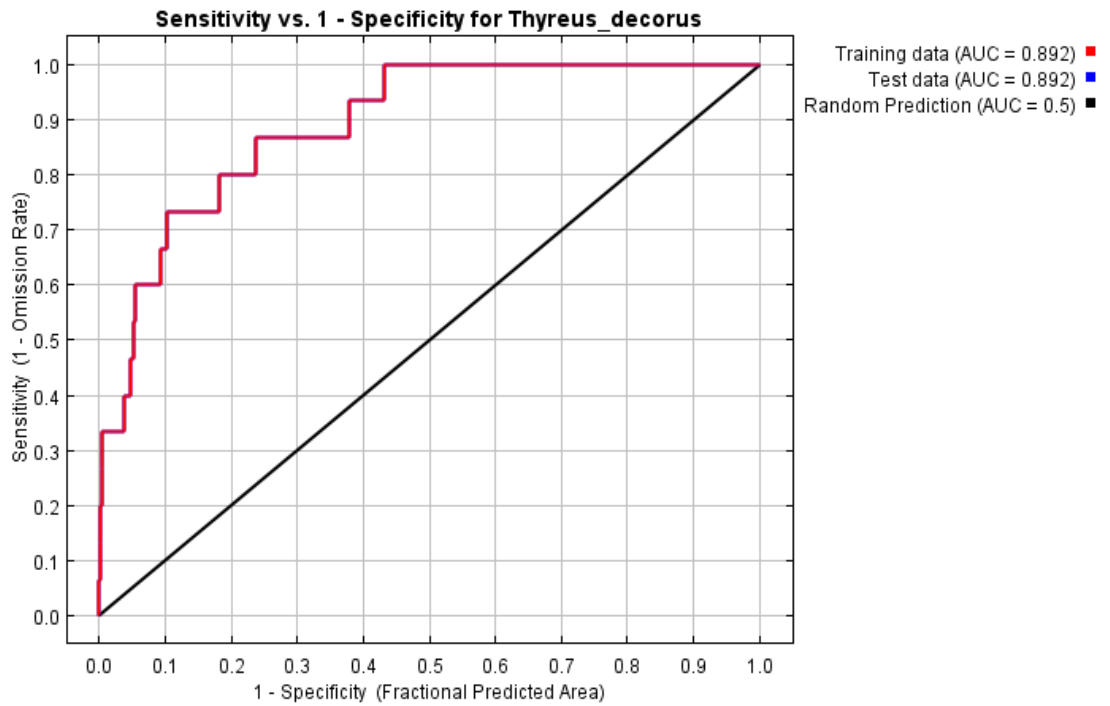
4. 3.3 Predictive Maps

Potential habitat maps were created by SDMs toolbox ArcGIS software, which was then categorized according to the various species occurrence probability threshold classes. Suitability maps were classified into different suitability classes using probability criteria (Figure 37).

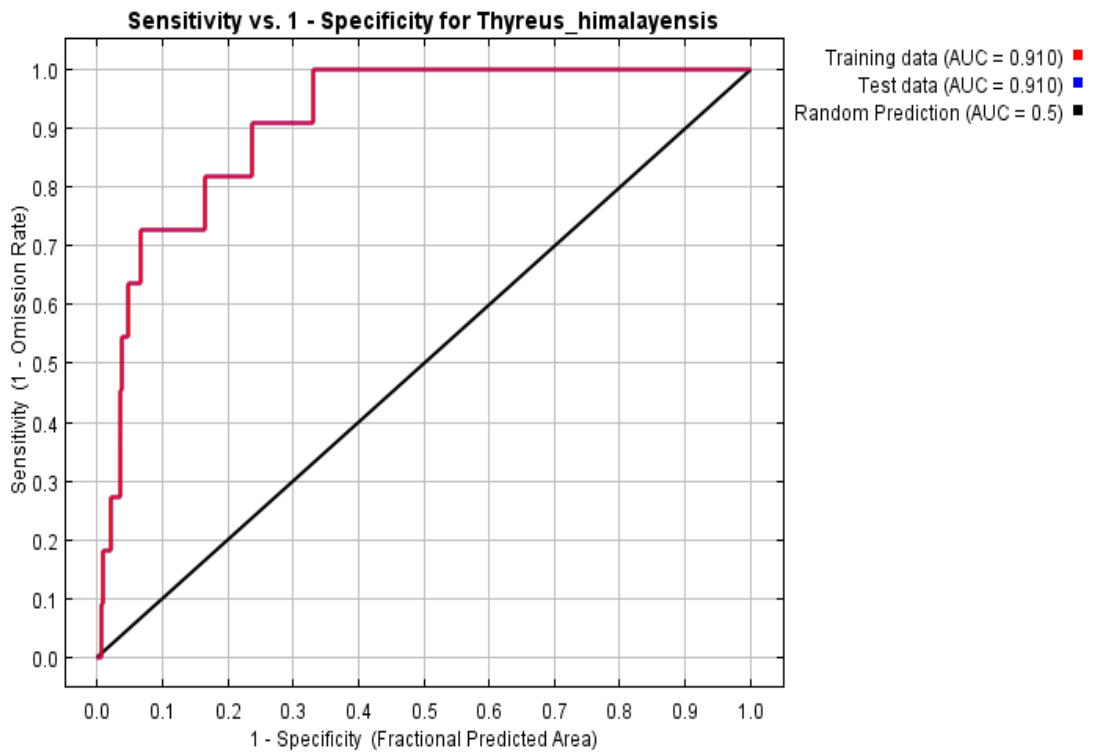
(a)



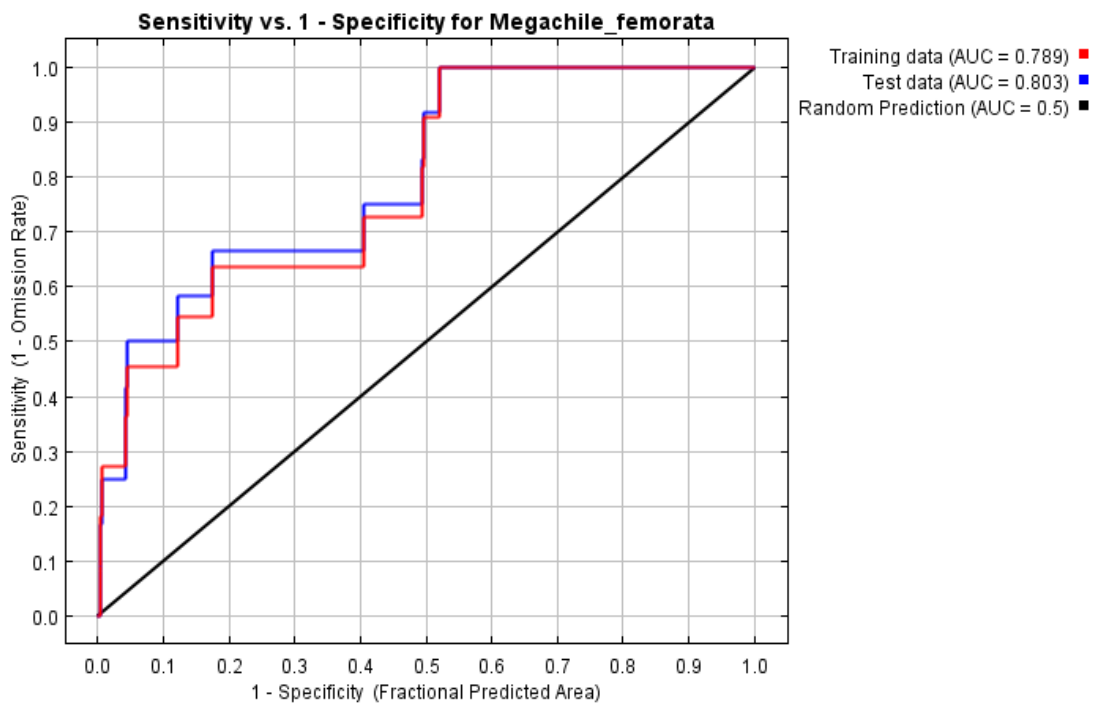
(b)



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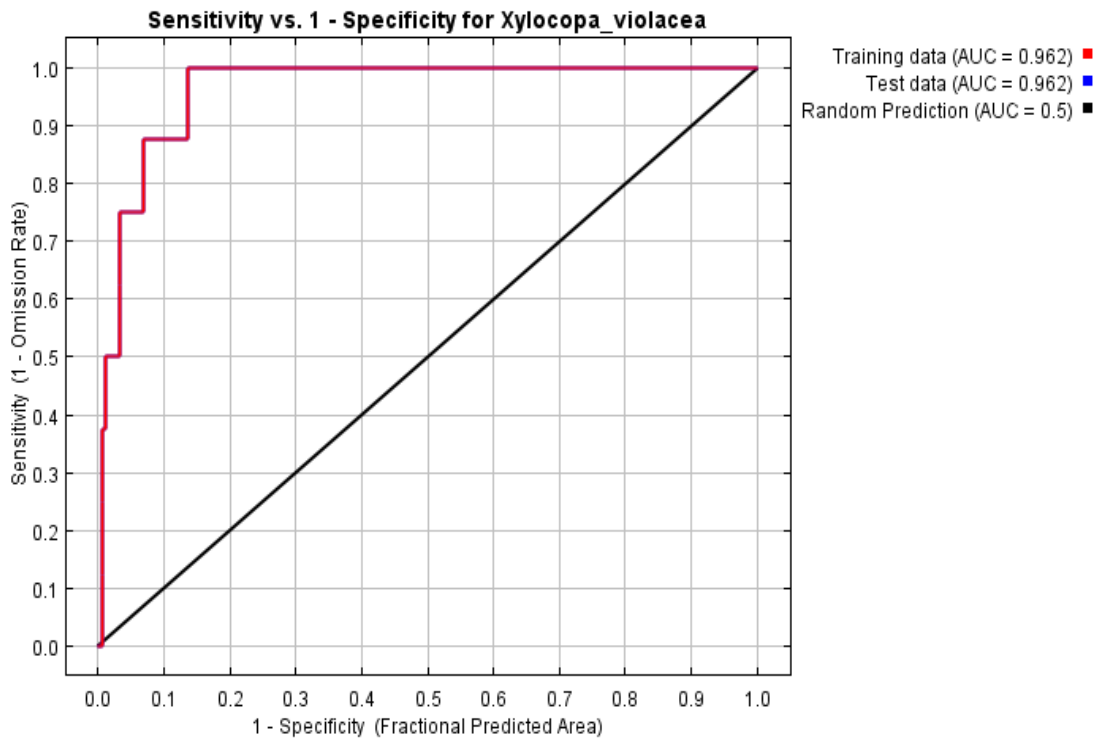
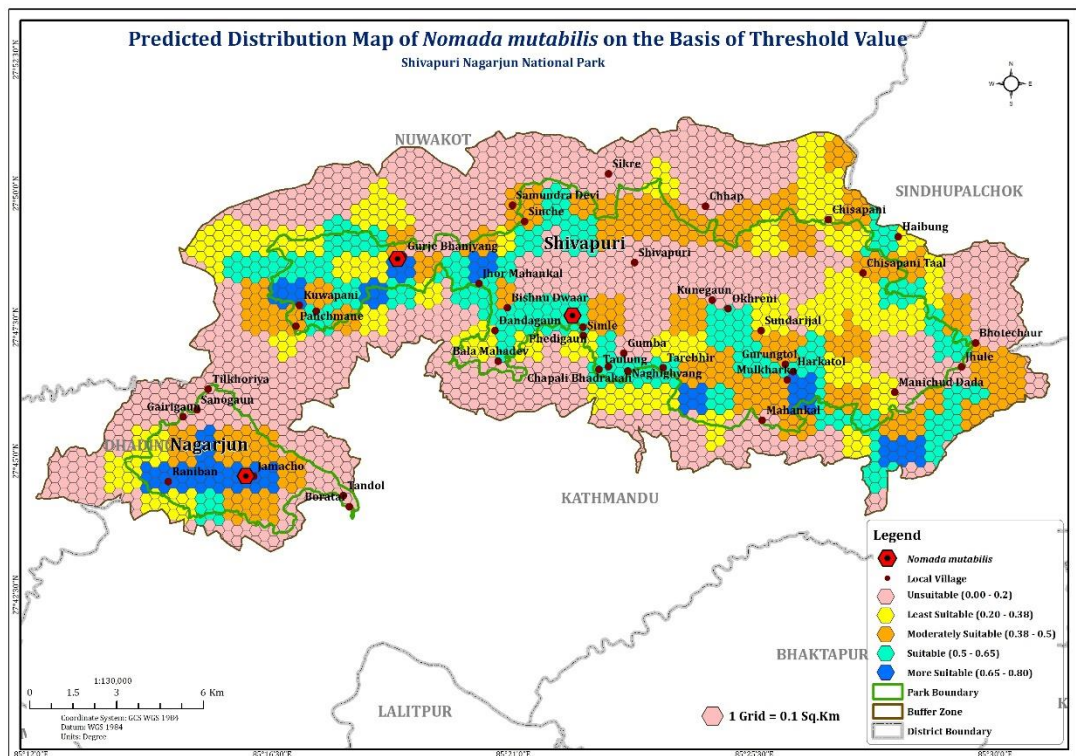
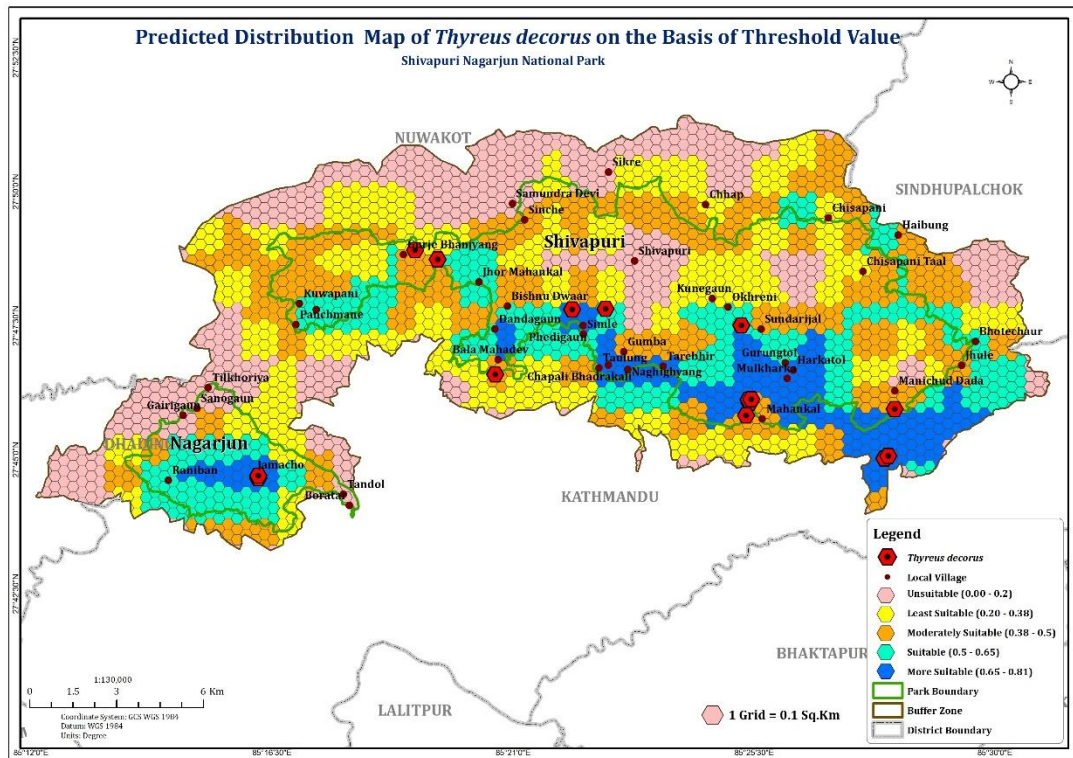


Figure 36: ROC. Maxent was set to align sensitivity vs specificity as a precaution against a biased or invalid result for all five bees. The red curves in each graph indicate the ROC, the blue curves reflect the test data, and the grey lines represent a random prediction: a: *Nomada mutabilis*; b: *Thyreus decorus*; c: *Thyreus himalayensis*; d: *Megachile femorata*; e: *Xylocopa violacea*

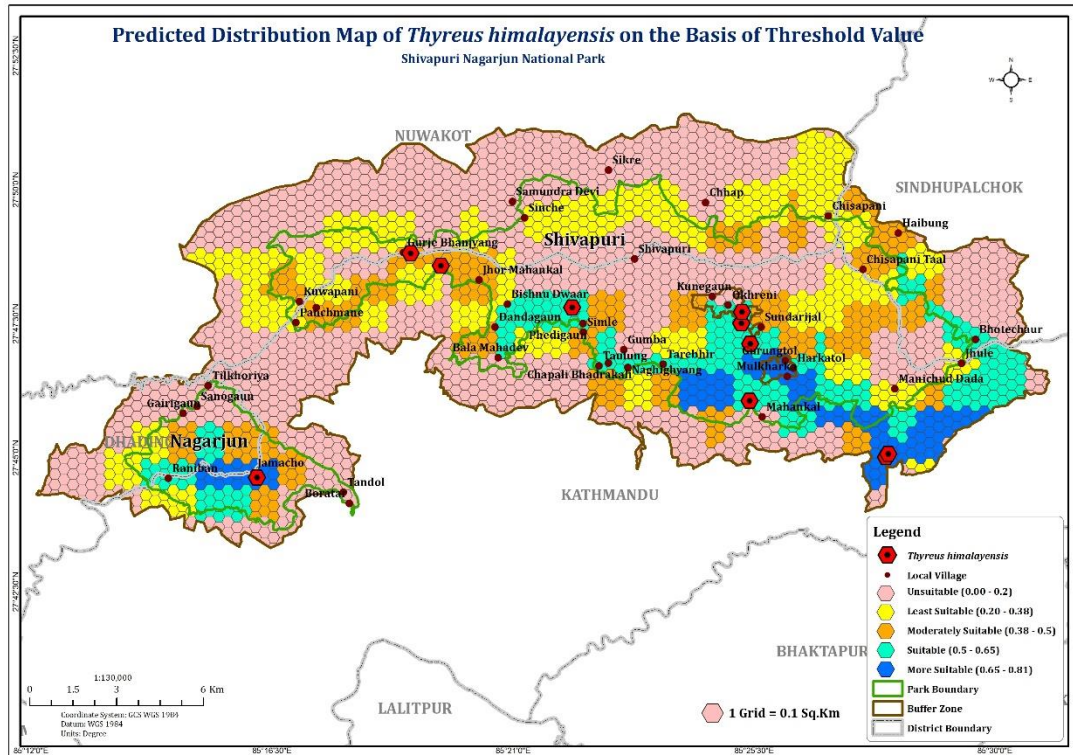
(a)



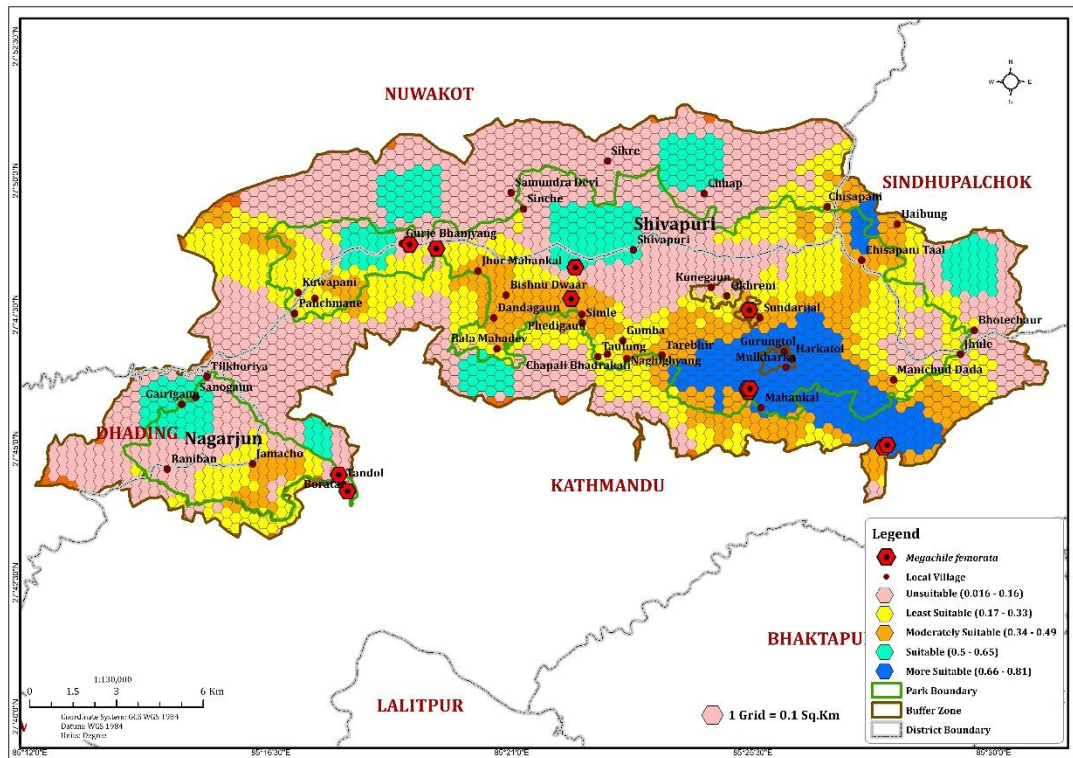
(b)



(c)



(d)



(e)

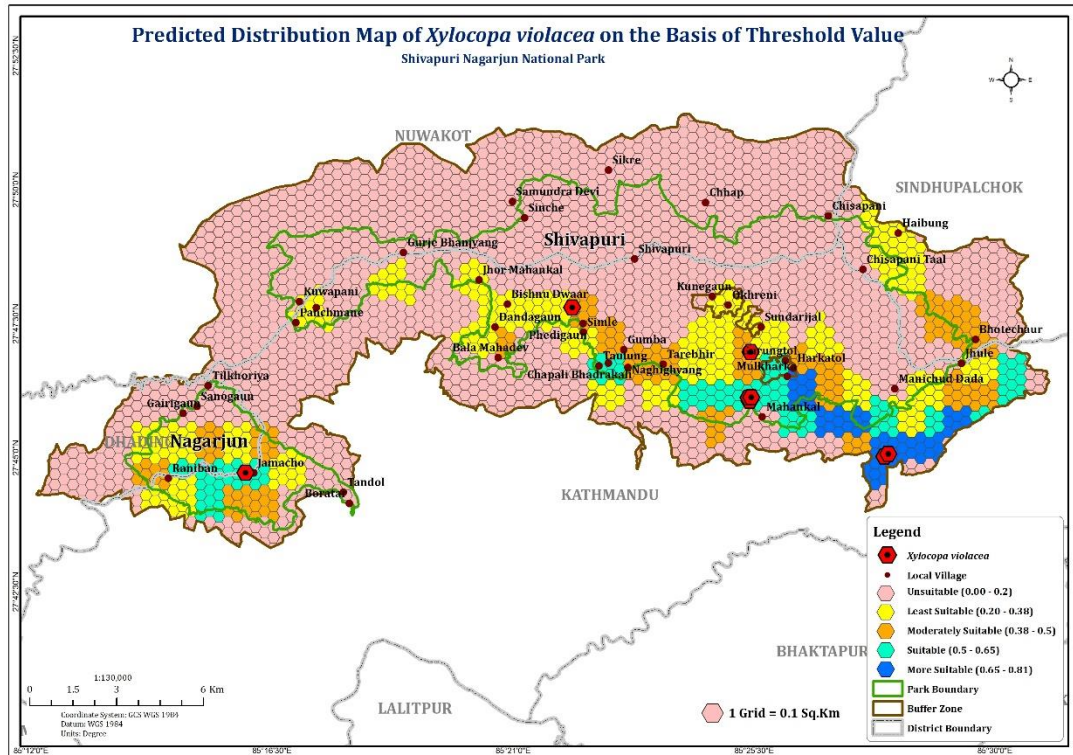


Figure 37: Potential habitat suitability of different wild bee species. a:*Nomada mutabilis*; b:*Thyreus decorus*; c:*Thyreus himalayensis*; d: *Megachile femorata*; e:*Xylocopa violacea*

Based on threshold classes, the total more suitable and suitable areas were calculated using Maxent. For *Nomada mutabilis* the total more suitable and suitable areas were 11.1 sq.km and 35.45 sq.km respectively (which is nearly about 4% and 12.77% of total area) (Table 10). Similarly, other information related from developed maps (Figure 37), the predicted main local villages areas of potential habitat suitability of this species lie in Lapse, Devasthan, Ghumrarichok, Raniban and Jamacho (Appendix VI). Field survey and model output indicated that high altitudes with elevation ranges from 1600m to 2300m were suitable for this species.

Table 10: Suitability categorization of wild bee species in study area

SN	Species	Unsuitable (Sq.Km)	Least Suitable (Sq.Km)	Moderately Suitable (Sq.Km)	Suitable (Sq.Km)	More Suitable (Sq.Km)
1	<i>Nomada mutabilis</i>	117.83	41.6	46.83	35.45	11.1
2	<i>Thyreus decorus</i>	63.63	73.28	70.08	46.18	25.2
3	<i>Thyreus himalayensis</i>	138.14	55.81	38.06	31.62	13.73
4	<i>Megachile femorata</i>	159.8	56.20	36.15	24.95	19.87
5	<i>Xylocopa violacea</i>	196.86	37.17	21.38	14.42	7.54

4. DISCUSSION

Wild bees are the center of interest for many ecologists, biological conservationists, and natural resource manager due to its growing importance in the natural and wild habitat as pollinators. However, their worldwide population is declining, posing a danger to biodiversity loss and possibly causing ecological harm. This research attempted to estimate the habitat appropriateness of five wild bee species in SNNP for the first time. Our study modelled five least collected bee species, assuming that various habitat types and local environments influence their presence in SNNP. Among the Bioclimatic variables, annual precipitation and mean temperature were the determinant factors for the five bee species. This result is consistent with (Kammerer *et al.*, 2021), who also found precipitation and temperature as the most important predicting factors in wild bee communities. They documented that solitary bees respond differently to increase precipitation. The precipitation and temperature also affect the flowering

phenology of plants (Lesica & Kittelson, 2010), hence altering bees' foraging and nesting behaviour.

Notably, the area and variety of habitats are important for wild bees (Kennedy *et al.*, 2013). In this study, the agricultural, grassland, and mixed oak Laurel forest contributed to the bees' presence. An agricultural area is a good place for many solitary bees, including *Nomada* spp.; the flowering crops provide maximum food resources for them (Le Féon *et al.*, 2010). Agricultural field margins are used by bees (pollinators) as the site of floral and nesting habitat (Stanley & Stout, 2013). The high abundance of wild bees was also recorded in the grassland and the temperate forest by (Koh *et al.*, 2016) in their modelling of bees of the USA. Grassland (Kwaiser & Hendrix, 2008; Carrié *et al.*, 2018) and the forest (Bailey *et al.*, 2014) are the potential areas for bees for nesting. Forest fragments having thick layer of herb provide feeding resources and nesting sites for bees (Proesmans *et al.*, 2019).

A second attempt was made to test the accuracy of chosen species distribution models by evaluating their predictions in various habitats. The findings show that land use classifications and bioclimatic data had affect on wild bee species. These results varied among bees and affected them as unsuitable, low suitable, moderately suitable, acceptable, and more suitable locations.

Based on this model, agricultural land, swamp area, bushes, chirpine forest, mixed oak forest, and the grassland of Lapse, Devisthan, Ghumrarichok, Raniban and Jamacho are target areas for studied bees. Generally these kind of habitats (Agricultural area, forest, grassland etc) are common and most suitable places explored by bees for nesting and foraging areas. Our study presented a broader understanding of the spatial distribution of wildbees in different habitats and the influence of local variables on them within SNNP. In addition to our current search on the spatial distribution of wild bees, further research and ecological studies are needed to include such factors into a model and produce more reliable and exact forecasts.

5. CONCLUSIONS

According to the findings of this study, the existing potential distribution of these species is spread out across a broad region. The accuracy of model predictions and projected maps varied depending on the species and their habitats; nonetheless, the

distribution models performed well in various settings. The finding showed that bioclimatic variables, specifically annual precipitation and temperatures were key drivers of the wild bees in SNNP. Similarly, agricultural land, grassland and forest are determining habitats of these bees.

Among the multiple pressures on wild bee populations, the relation between climatic conditions, increased landuse change and their effect on wild bees require research attention. This research will help to identify bee hotspots and their associated land used. This finding could aid in the development of policies for the conservation of wild bees in SNNP by investigating the land use types and the better understanding of climate variability.

CHAPTER 5

SEASONAL VARIATION IN PLANT-POLLINATOR

INTERACTIONS IN FOREST OF SHIVAPURI-NAGARJUN

NATIONAL PARK, NEPAL

Abstract

Flora and vegetation types in the forest edge harbor different pollinator communities and can present different plant-pollinator interactions. Ten Open trails of SNNP were explored from spring 2019 to autumn 2019 to examine plant-pollinator interaction, key pollinators, the plant species that serve as hubs of pollinators and seasonal variation of pollinators in the study area. Analysis of the network system depicts the general trend of interaction similar to the most other natural network systems. The bipartite indices show heterogeneous interaction, which is scale-free degree distribution and well nestedness. The study shows that very few floral resources supported many pollinators and maintained the interaction network system of the park. *Eristalis tenax*, *E. cerealis*, and *Pieris canidia* were seen as key pollinators and *Ageratina adenophora*, *Bidens pilosa*, and *Trifolium repens* were observed as most visited plants. Shannon index diversity of pollinators of autumn season was significantly higher ($p=0.0001$) than spring season with total species turnover Whittaker index 0.23. Shannon diversity index of bees in autumn was the highest followed by Lepidoptera. Whittaker beta diversity showed that there was the highest turnover of bees between two seasons followed by hoverflies. The study demonstrates flowers in the open trails serve maximum pollinators hence conservation of the plants in the Open trails helps to conserve plant-pollinator interaction. However, to describe further properties of the plant-pollinator interaction network of the park, intensive work is required.

5. INTRODUCTION

5.1 Background

Insect pollinators are important organisms in the ecosystem. They improve the quality and quantity of crop productions (Garibaldi *et al.*, 2011) in the agricultural system and plant reproduction and community assembly in the natural system (Fontaine *et al.*, 2006). More than 87.5% of angiosperms depend on animals for pollination (Ollerton *et*

al., 2011). Plant-pollinator interaction is one of the important ecological function that maintain biodiversity (Bascompte & Jordano, 2007). The quantified network analysis provides significant biological information like co-evolutionary adaptation, ecosystem stability, or resilience (Blüthgen *et al.*, 2007). Pollination is one of the commonly understood example of plant-pollinator interaction, however; there are several complex mechanisms with a multitude of interactions between pollinator and plant species depicting many kinds of significant relations between these two groups (Ballantyne *et al.*, 2017; Brown, 2021). A plant-pollinator network shows many distinct relations between species in interacting communities like complexity, cohesion, symmetry, and network uniformity (Bascompte & Jordano, 2007; Mitchell *et al.*, 2009; Kudo & Cooper, 2019).

The degree of interaction among different groups of pollinators with plants varies. This is because of various demands for resources, the use of plant resources by pollinators as well as the availability of resources within the active period of pollinators (Figure 38). Generally, mutualistic interaction in nature is diffused type, which means several insects can pollinate a single plant or a single insect can pollinate several plants. While specific mutualistic interaction is a very rare case in the ecosystem (Landry, 2010). Therefore, interacting pollinators fall into two categories: specialist or generalist. Specialist pollinators solely depend on a single plant or use a few plants for resources. They are sometimes called obligatory, for example, the Yucca moth (Pellmyr, 2003) and fig wasp (Cook & Rasplus, 2003). On the other hand, generalist pollinators like bees (facultative), utilize several flowers for resources. The generalist species role as a network hub, removal of which can bring a series of changes in the network system (Guzman *et al.*, 2021) while specific species are important for the resilience of the network (Gómez *et al.*, 2011). Generalize species are strong connectors of a network system that produce a robust and stable network. The loss of the most generalist species produces a fragile network in comparison to the loss of the specialist species (Guzman *et al.*, 2021). Both generalist and specialist species frequently interact with one another or other species in the same category in a network, resulting in an array of interactions (Bascompte & Jordano, 2007).

There is a spatial and temporal variation in interaction structure and participating individuals within a short period (Olesen *et al.*, 2008; Carstensen *et al.*, 2014).The flower types in different seasons are remarkably differ and study demonstrated that

pollinators are mostly determined by floral characters (Momose *et al.*, 1998). This kind of variation in the species composition between communities in different periods could be due to a change in the activity level of the species and the phenology of plants. Generalist (long flowering) plants and generalist pollinators (long flight periods) play key roles in seasonal and monthly networks (Figoni *et al.*, 2022). Species turnover is one of the important measure to show the role of species that can bring a change in temporal network system. Species turnover means a difference in the species occurring in two networks.

Plant-pollinator networks have been widely used in recent decades in conservation sectors. The new indices (nestedness, connectance and web symmetry) are developed to quantify the properties of network systems (Bascompte *et al.*, 2003; Dormann *et al.*, 2009). These indices could be evaluated to subject the appropriate strategy for conservation. For example, identifying the generalist and specialist species is very important in conservation. The network analysis also informs about the effect of the introduction of new species in the system and the elimination of existing species from the system.

Flora and vegetation types in the forest edge harbor different pollinator communities and can present different plant-pollinator interactions. The presence of different flowers in the walking Open Trail of SNNP can cause changes in species richness and abundance of different pollinator groups. This can bring an interesting interaction network to that area that has yet to explore. Therefore, in this study, the topology of plant-pollinator interactions was prepared and calculated some indices to answer the following research questions.

1. What are the patterns and characteristics of plant-pollinator interaction?
2. Which plant species are important hubs in interaction networks?
3. Which are the key pollinators of a network system?
4. Are there differences in the pollinators that visit plants during different seasons?



Figure 38: Range of pollinators in different flowers of SNNP: A. *Ceratina* sp., B. *Lasioglossum* sp., C. *Apis mellifera*, D. *Andrena* sp., E. *Eristalis cerealis*, and F. *Sphaerophoria scripta*

5.2 MATERIALS AND METHODS

This work was conducted in 10 Open Trails present in different elevations from 1,600 m–2,000 m of SNNP from spring 2019 to autumn 2019. Open Trail of SNNP means an area with no tree coverage within 15 m width on either side. Both sides of the trail were covered with thick coverage of herbs and shrubs. These Open Trails were selected from four representative study sites across the SNNP namely Sundarijal (27°.77'N Latitude and 85°.42' E Longitude), Shivapuri (27°.79' N Latitude and 85°.37' E Longitude), Gurjebhanjyang (27°.81' N Latitude and 85°.31' E Longitude), and Manichud (27°.77' N Latitude and 85°.46' E Longitude) (Figure 39). There were altogether 10 belt transects for sampling, one in each Open Trail. Each transect was about 100 m x 5 m.

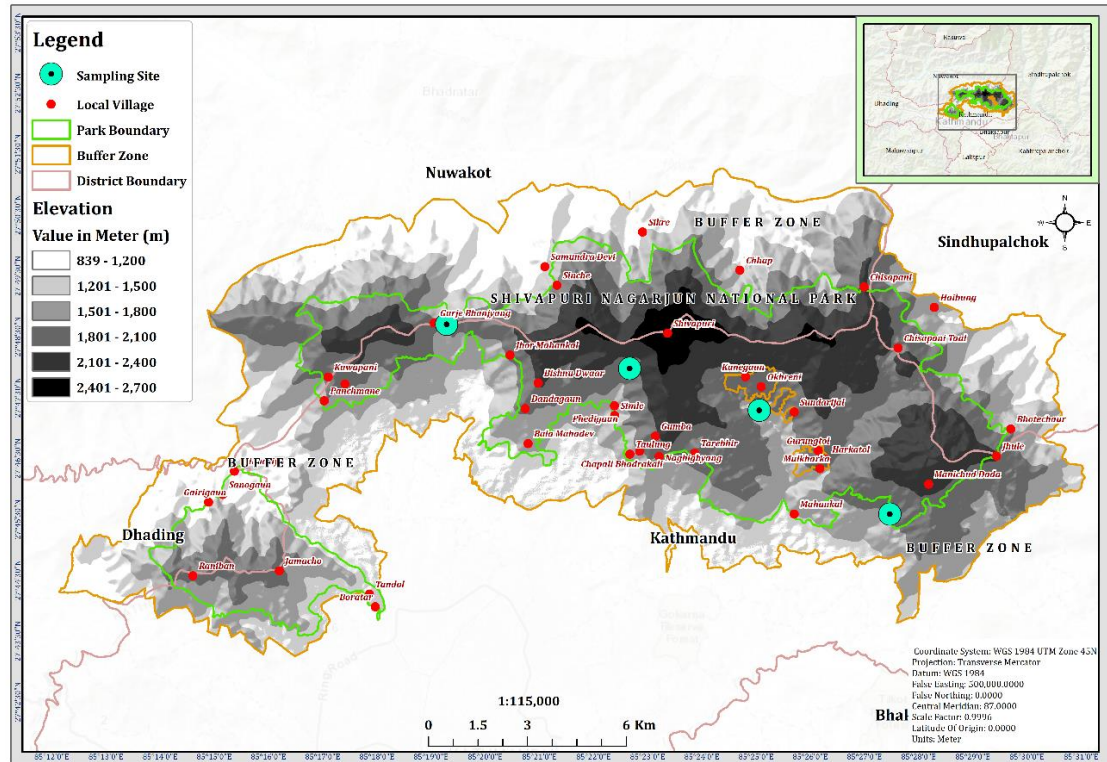


Figure 39: Map of the study area showing sampling sites

5.2.1 Vegetation analysis

During survey seasons (spring and autumn), an estimation of floral coverage was conducted before pollinator observation in sampling transects. In each sampling transect, five quadrats of 10 m×5 m were made for the estimation of flower coverage (Figure 40). These quadrats were plots. Insect pollinating herbs and shrubs in each plot were scanned and identified to species level. The cover of flower resources in each quadrat was ranked between 1–6 (Szigeti *et al.*, 2016). Rank: very scarcely=1, scarce=2, more or less scarce=3, more or less abundance=4, abundance=5, and extremely abundance=6 (Appendix VII).

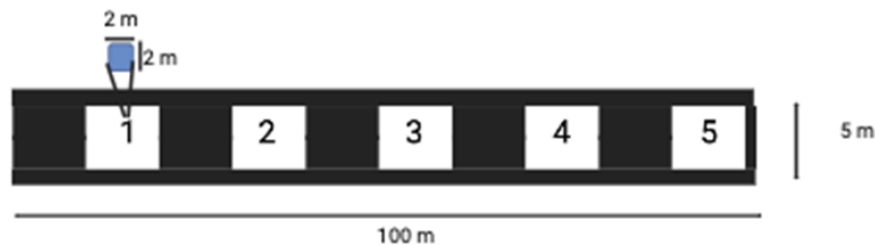


Figure 40: Belt transect showing five plots for Vegetation analysis and a subset for pollinator observation.

The plants of SNNP were also categorized as native and exotic according to their origin following literature (Shrestha, 2019; Pathak *et al.*, 2020) and Plants of the World Online (2020) (<http://www.plantsoftheworldonline.org>).

5.2.2 Observation of pollinators

The pollinator insects were observed two times in each season: spring and autumn as the phenology of flowers differ within the seasons. There were four sampling periods: Period 1= First week of March, Period 2= Second week of April, Period 3=First week of September, and Period 4 = Second week of October.

For pollinator observation in each plot, one subset each of 2mx2m was fixed in the place (Figure 40) where there was maximum flower coverage (as distribution of flowering herbs and shrubs was not uniform). Each subset was observed for pollinators for 10 minutes and any insect visitor in flowers within the subset was recorded (Stanley, 2013) and scored as a flower visit only if the flower-visiting insect was in contact with the flower (Staab, *et al.*, 2020). A total of 33.33 hours (10-minute x 1 plot x 5 x10 transects x4) were conducted. The insect pollinators (targeted group: Bees, butterflies, and hoverflies) longer than 3mm, visiting each flower type within the subset were observed and identified. Unidentified pollinators were collected by the sweeping net for further identification in the laboratory. The size threshold was determined as smaller insects were likely to miss in observation and were difficult to capture without disturbing visited plants (Dicks *et al.*, 2002). The observation was carried out between 9 am to 4 pm.

In the laboratory, pollinators were identified using relevant keys. Bee specimens were identified by using Bingham, 1897; Tadauchi & Matsumura, 2007; Williams *et al.*, 2010; Ngat *et al.*, 2017. Similarly, Brunetti, 1923; Thomson & Ghorpadé, 1992; Ghorpadé, 1994; Claussen & Weipert, 2003; Sengupta *et al.*, 2017; Hassan *et al.*, 2017 were used to identify hoverfly specimens and butterfly specimens were identified using Smith, 2011 pictures and keys. Experts' like Professor Dr. Bhaiya Khanal (Butterfly) and Dr. Muhammad Asghar Hassan (Hoverfly) confirmed several specimens.

5.2.3 Data analysis

A quantitative matrix with a row lower trophic level and a column with a higher trophic level was prepared for building a plant-pollinator interaction network. A cumulative matrix of all observed pollinators from 10 plots was produced. To investigate

differences in network structure in the spring and autumn seasons, two different seasonal matrices were also produced. All together 3 matrices: for all pollinators group (full) and all pollinators group in two different seasons (spring and autumn) were used to show plant-pollinator interaction in the study area. Both qualitative and quantitative bipartite indices were then calculated to measure and reveal the pattern of the network. Qualitative indices are the number of plant and pollinator species, connectance, nestedness, and network size and quantitative indices are the total number of interactions, generality, H_2 , interaction evenness, linkage density, specialization asymmetry, vulnerability, web asymmetry, and Shannon interaction density (Dormann *et al.*, 2008; 2009) were calculated. All the statistical analyses were performed in the R programming language (R Core Team, 2021). The ‘bipartite’ package (Dormann *et al.*, 2008), Bipartite D3, Function plot web. Network indices were calculated using the function, network level.

To test for species turnover during two seasons, the network dissimilarities index was calculated using the package Betalink, Whittaker Beta- diversity between networks by using the function betalink (Poisot *et al.*, 2012). Whittaker’s beta diversity ($bw = S/\alpha - 1$, where S is the total number of species across sites and α is the average number of species per site) of pollinators using PAST: Paleontological Statistics (Hammer *et al.*, 2001) version 4.10 computed the Whittaker beta diversity and Shannon index. A significant relationship between groups was tested by the t-test comparing diversity in software.

5.3. RESULTS

5.3.1 Vegetation analysis

In total, 42 plant species that interacted with pollinators were recorded from study transects. About 36% of plants were exotic (Appendix VIII) and 14% of plants were common in both seasons.

5.3.2 Plant-pollinator interactions

In total 1837, individuals (Appendix IX) belonging in 93 pollinator species were collected from the Open Trail during the entire study period. The highest species that visited flowers were a butterfly, followed by bees and hoverflies however; the hoverflies were the most frequent visitors among all (Appendix X).

5.3.3 Characteristics of plant-pollinator interactions

Majority of matrix values of interaction of SNNP shows a general trend of interaction like in many networks of ecosystems. All three networks: Full network (Total pollinators of entire study period), spring network (pollinators of spring), and autumn network (pollinators of autumn) presented degree distribution with a truncated power law (Figure 41) and highly nested (Table 11).

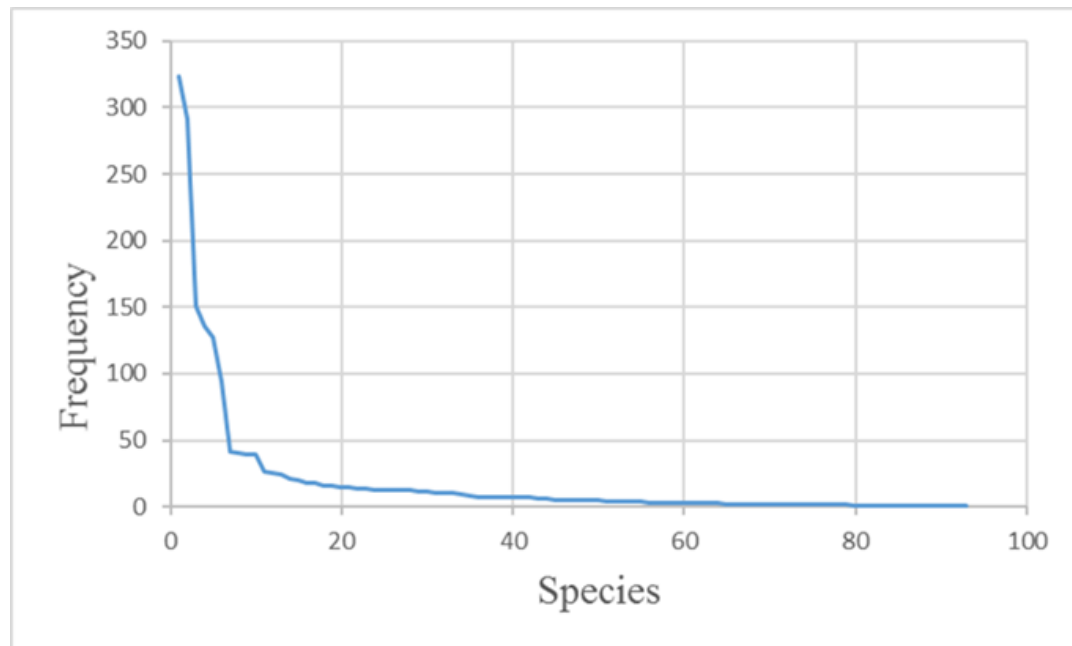


Figure 41: Frequency distribution of pollinator species showing the most frequent species are few and least frequent species are common in plant-pollinator interaction

During four sampling periods taken in the park, 558 pairwise interactions between 42 flowering plants and 93 pollinator species were found (Figure 42 A, Table 11).

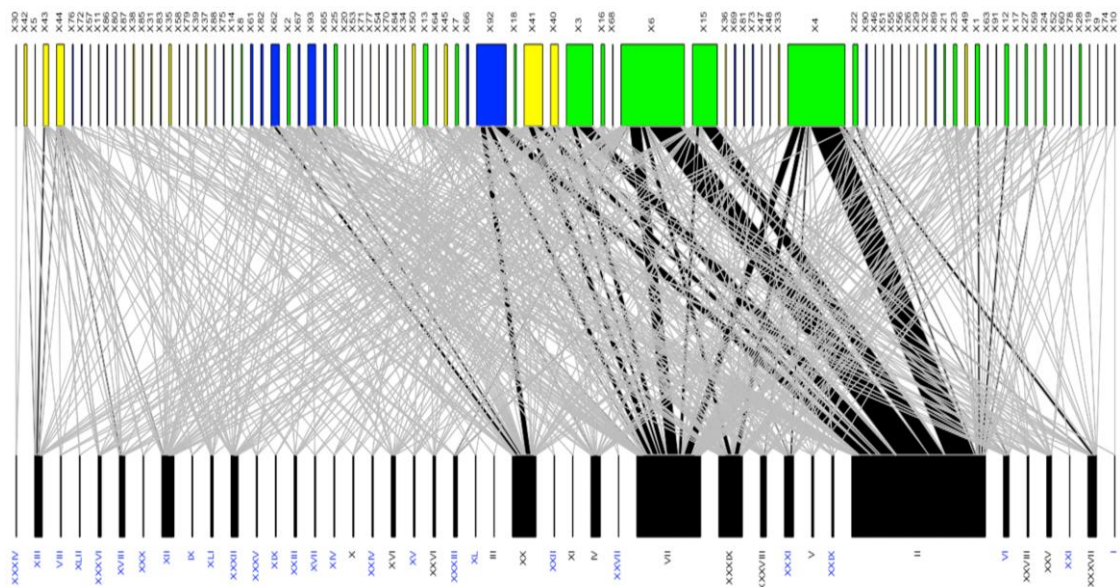
The web size ($I \times J$) and the number of observed pairwise interactions in three plant-pollinator matrices (Full network, spring network, and autumn network) depicted low connectance. In all three networks, few pairwise interactions were seen though there are many numbers of participants (plant and pollinator species) that could result for much interacting pairs. The network specialization (H_2) of each network was lower. Web asymmetry in all three interactions showed that many insect pollinators interacted few plant species and the interaction of autumn had a higher web asymmetry (0.56) compared to the other two interactions. There were asymmetrical plant-pollinator interaction in SNNP (positive value of interaction strength asymmetry in all three networks). Plants supported much in interaction providing many links per species than

pollinators. Similarly, plants showed higher interaction strength asymmetry and degree. Overall, the highest interaction strength symmetry was found in spring (0.10).

The number of flower species visited by pollinators in spring and autumn was 26 and 24 respectively (Appendix VIII). During spring, the most visited plant species by pollinators (49% of pollinators) was *Ageratina adenophora* (II) (Figure 42 B; Appendix XI) and in autumn *Bidens pilosa* (VII) was the most visited flower by pollinators (53% of pollinators) (Figure 42 C; Appendix XI). Similarly, the most frequent visitor of insect pollinators throughout the observation periods (Full network) was *Eristalis tenax* (X6) followed by *Eristalis cerealis* (X4) and *Pieris canidia* (X92) (Figure 42 A).

Species richness of insect pollinators in spring was 67 (Hoverfly: 23, Bee: 15, Butterfly: 29) while in autumn, the species richness was 84 (Hoverfly: 25, Bee: 30, Butterfly 29) (Figure 43). The diversity of pollinators in the autumn season, as measured by the Shannon index, was significantly higher (Hutcheson's t-test, $t = 10.41$, $p < 0.001$, $df = 1409$) than in the spring season, with a total species turnover Whittaker index of 0.23 (Table 12). Bees in autumn had the highest diversity with a Shannon H of 2.87, followed by Lepidoptera in autumn at 2.64, Hoverfly in autumn at 2.47, Lepidoptera in spring at 2.32 and Bees in spring at 2.24. The lowest diversity was observed among Hoverfly in spring with a Shannon H of 2.05.

A



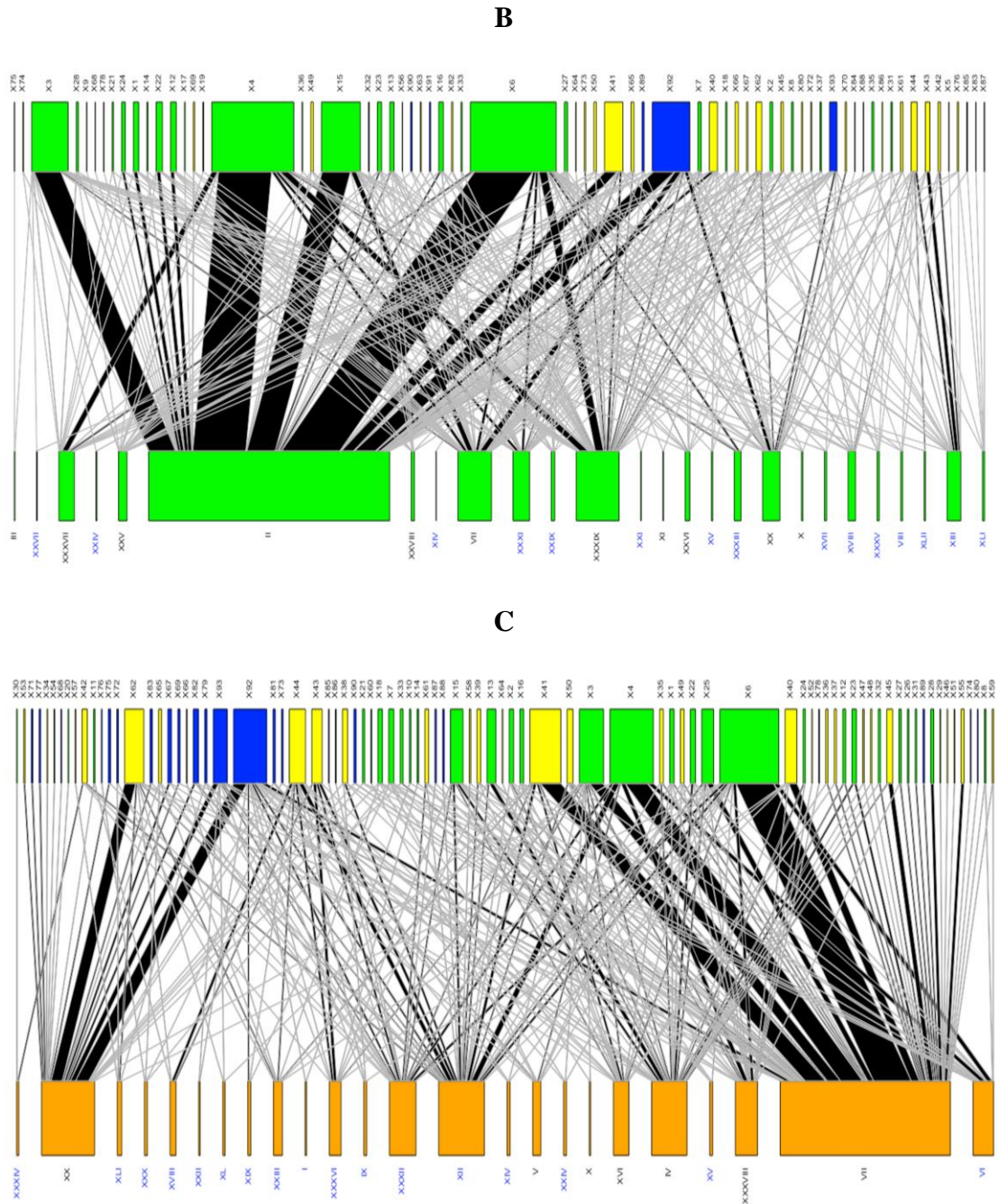


Figure 42: Quantitative interaction network- Full network (A), spring network (B), autumn network(C). Top row (Higher trophic): Green color bar - Hoverfly, Yellow color bar-Bees, and Blue color bar-butterfly. Lower row (Lower trophic): Green color bar-spring and Orange color bar-autumn. Lower row text: Exotic and Native plant are represented by black and blue color text respectively. The width of nodes (bars) correspond to the degree of a species. Lines between trophic levels represent links and the thickness of the lines indicate the relative quantitative visitation between interacting pairs. Networks are labelled with species codes (see Appendix VII for Plant species and Appendix IX for pollinators)

Table 11: Different network metric measures of Full network (Total pollinators of entire study period), spring network (pollinators of spring), and autumn network (Pollinators of autumn) (For Definition of metrics see Appendix XII)

Network Metric	Full network	Spring network	Autumn network
L (= pairwise interaction)	558	292	266
I	42	26	24
J	93	67	84
IXJ	3,906	1,742	2,016
C	0.14	0.16	0.13
Nestedness	7	10	8
Level of nestedness	0.93	0.9	0.92
T(Total number of interaction)	1837	1220	617
Generality	6	4.35	3.16
H2	0.20	0.20	0.30
Interaction evenness	0.60	0.57	0.65
Linkage density	10.52	8.09	10.32
Link per species	3.84	3.14	2.50
Vulnerability	14.80	12.30	16.35
W (web symmetry)	0.38	0.44	0.56
Interaction strength asymmetry	0.04	0.10	0.09
Shannon interaction density	5.0	4.25	5.0

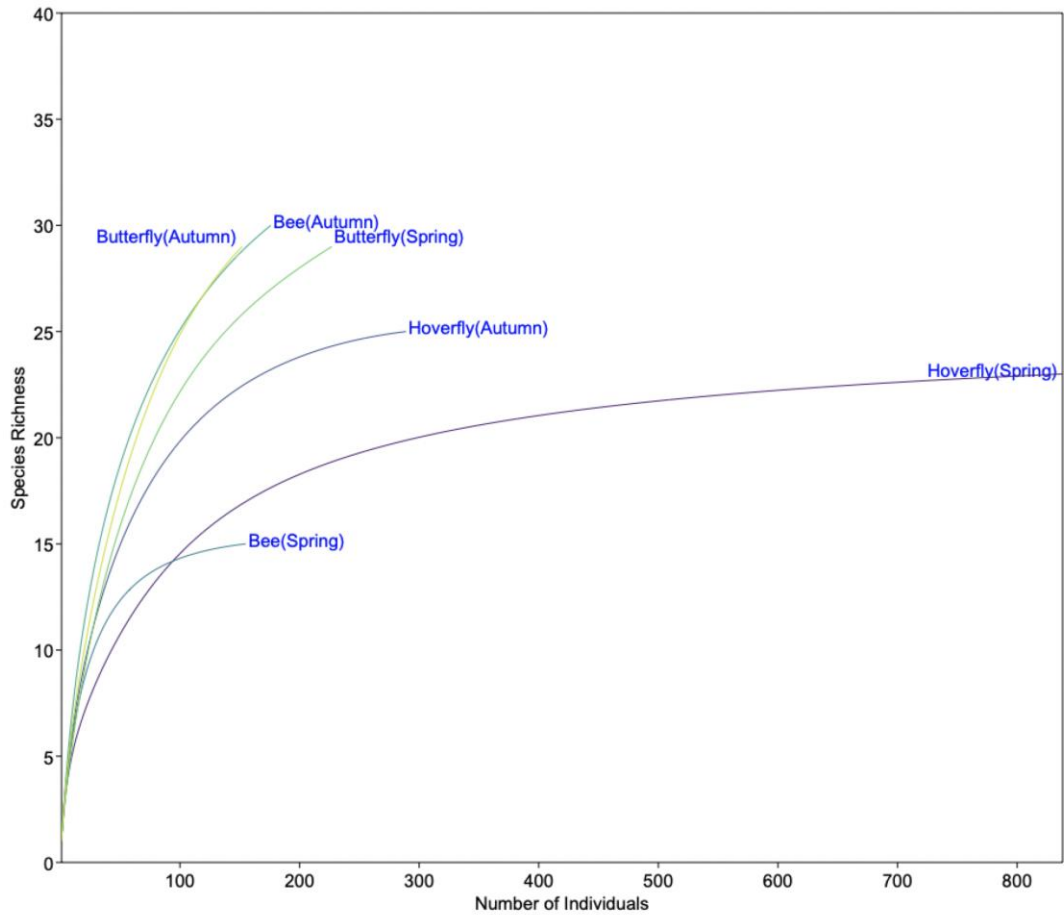


Figure 43: Individual rarefaction curve of pollinators groups in different seasons.

The highest species turnover between two seasons was observed in bee species followed by hoverflies and butterflies (Table 12). The Hutcheson’s t-test showed that the diversity of bees and hoverflies changed significantly between the two seasons, while the diversity of Lepidoptera remained largely the same (Table 12).

Table 12: Whittaker species turnover and Hutcheson’s t-test Shannon index diversity between spring and autumn seasons of given categories

Catetogories	Whittaker Beta diversity	Hutcheson’s t-test (t value, p-value, Degree of freedom)
Full pollinator	0.23	-10.41, < 0.0001, 1409
Bee	0.40	-5.03, < 0.0001, 331
Butterfly	0.14	-1.96, 0.082, 360
Hoverfly	0.21	-4.88, < 0.0001, 503

5.4 DISCUSSION

The objective of this study was to demonstrate the topology and dynamics of plant-pollinator mutualistic interaction.

The interaction networks show a typical characteristic that indicate degree distribution with power-law and nested structure. Power-law (a small occurrence of pollinators is common, while larger occurrences are rare) degree distribution means a small number of pollinators is clustered at the top of distribution. This kind of network is comparable with other ecological systems (Jordano *et al.*, 2003; Bascompte & Jordano, 2007; Stang *et al.*, 2009; Brown, 2021). The level of nestedness's value shows a highly cohesive network (Table 5.1) or heterogeneous system. This is a consistent kind of feature found in many recent studies (Stang *et al.*, 2009). A nested network decreases competition within plants and within pollinators, thus helping species richness and promoting biodiversity (Bastolla *et al.*, 2009).

Next index is connectance that determines the network complexity and extent of robustness. The higher the connectance of a network, the higher its robustness (Dunne *et al.*, 2002). However, the connectance value of this study showed low connectance. Lower connectivity shows lower resilience in community structure (Okuyama & Holland, 2008). This suggests the plant-pollinator networks found in SNNP are less complicated than would be expected with the diverse species. Open trails of SNNP is one of the most used walking routes and often disturbed. Therefore, this could be one of the reasons for lower connectance as this kind of result was reported in disturbed habitats (Vanbergen *et al.*, 2017). Furthermore, the plant community of the park has more influence in interactions compared to the pollinator community. This is proven by the value of species degree i.e. number of interactions of each network node (Soares *et al.*, 2017) and interaction strength asymmetry (Table 11). The positive value of interaction strength asymmetry reveals the higher specialization of the pollinator community (Dormann *et al.*, 2009). Open trails of SNNP have comparatively lower plant species (than pollinator species) in the interaction network which likely contributes to the asymmetry in interactions (value close to one) (Nielsen & Totland, 2013) and creates more dependence of pollinator species on plant species. This type of result is also shown in other ecosystems (Weiner *et al.*, 2014; Brown, 2021). There are very few plant species supporting many pollinator species. In such networks, there is a higher probability

of extinction due to removal of plant than removal of insects. This indicates that plant-pollinator webs are more robust to removal of insects than to removal of flowers (Guzman *et al.*, 2021). With this result, one can assume that alter in the community structure of plant species of the SNNP could bring a remarkable change in network system. However, further study is required to give specific conclusion of plant-pollinator interaction.

Lastly, all three interactions show a kind of specialization as the metric value of H_2 is close to one (Table 11). However, to conclude interaction of SNNP as specialization interaction would be too assumptive because metric has some ecological cons to interpret the ecological system. First, it is difficult to identify interacting insects as generalist or specialist species (Blüthgen *et al.*, 2006) because rarely observed species are regarded as specialist without actually knowing their association (Blüthgen *et al.*, 2007). Second, in this network analysis singleton species were not omitted. The singleton species show high dependence though they just represent rare species (Dormann *et al.*, 2009). Third, the metric does not consider behavioral curbs of species that may be influenced by environmental variables and the abundance of its interacting partners and available floral resources. Thus, the same species can behave as a specialist under one environmental conditions while differently under other conditions (Soares *et al.*, 2017).

The key pollinators throughout the study periods were *Eristalis tenax*, *E. cerealis*, and *Pieris canidia* and the most connected plants were *Ageratina adenophora* followed by *Bidens pilosa*, and *Trifolium repens* (Figure 42 A).

In the forest environment, members of hoverflies were important pollinators. Members like *Eristalis tenax* and *E. cerealis* are active and the most abundant visitors of forest and shrub lands (Bian *et al.*, 2018; Badoni & Arya, 2022). The palynophilic hairs of *E. tenax* carry a heavy pollen load in its body (Holloway, 1976) and are as efficient as honeybees (Rader *et al.*, 2009) in providing pollination services. *Eristalis tenax* is a cosmopolitan pollinator and regular visitor of flowers belonging Onagraceae, Asteraceae, and Rosaceae (Primack, 1978). However, the foraging behavior of *E. tenax* might vary from generalist to specialize or both. This labile forage habit of *E. tenax* depends on the density of the visited plants (Kunin, 1993). *E. cerealis* is a good

pollinator candidate. The densely matted woolly hairs on the back body of *E. cerealis* can load more than 48,800 grains per individual (Yuan *et al.*, 2022).

Among the bee group, *Apis cerana* and *A. mellifera* were dominant floral visitors. Both *Apis cerana* and *A. mellifera* interacted with 14 different flowers in SNNP. *A. cerana* was found efficient pollinators in the natural ecosystem compared to other *Apis* members. It visits many plant species at a time and carries their pollen (Nuriyah *et al.*, 2021). Although, less frequent flower visitors compared to *Apis* spp. in the study area, *Bombus haemorrhoidalis* interacted with more plant species. Altogether 18 different flower species were interacted by *B. haemorrhoidalis*. This shows a highly generalist visiting pattern similar to other bumblebees (Lavery & Plowright, 1988; Fontaine *et al.*, 2006). In addition, bumblebees are active for long period with multiple generations (Guzman *et al.*, 2021). Both these features of bumblebees make them important pollinators increasing connectance that stabilizes the network system (Cusser & Goodell, 2013), the removal of them can cause cascading consequences in the network (Guzman *et al.*, 2021). The previous studies also found bumble bees are important pollinators of Asian temperate forests limiting the role of *Apis cerana* in pollination (Kato *et al.*, 1990; Ramirez *et al.*, 2005). In a natural system, the worker bumblebees are reliable in foraging compared to *A. cerana* (Kato *et al.*, 2008).

Among butterflies, the most generalist and abundant species of the park was *Pieris canidia*. It made interaction with 26 flowers during the study period. It is one of the most abundant and common species of Himalaya (Chen & Cheng, 2022; Gautam & Kunte, 2020).

The presence of native plants was higher in SNNP (64%) (Appendix VIII). Generally, the visitation rate in native plant is higher compare to exotic. However, in the present study the most connected plant species in all network systems were exotic. *Ageratina adenophora* was the topmost well-connected plant species followed by *Bidens pilosa*, and *Trifolium repens*. These were the most visited plant species of SNNP by the pollinators. The putative reason could be their maximum coverage due to the fast colonization and encroachment. Stouffer *et al.* (2014) also found higher dependences of pollinators on exotic plant. The exotic plants promote generalist pollinators and negatively affect specialized interactions (Grass *et al.*, 2013). The presence of these exotic plants may support the pollination of the rare native plant by changing the

population of pollinators that feed on both native and exotic plants (Carvalho *et al.*, 2008). Though exotic flowers may supply flower resources for pollinators when native plants get scarce (Staab *et al.*, 2020), may affect how native plants interact with pollinators, which has massive effect for the ecology and evolution of plant species (Totland *et al.*, 2006). Hence, the risk of naturalization of such plants need to minimize. The unchecked exotic plants could elevate the risk to pollinators and their nutrition supply (Vanbergen *et al.*, 2018).

Whittaker beta diversity showed that there was the highest turnover of bees between the two seasons followed by hoverflies. However, Lepidoptera showed minimal species turnover between the two seasons. The phenology of plants varied between seasons which results floral turnover. In SNNP, there is variation in types of flowering plants during spring and autumn (Appendix VII). *Ageratina adenophora* was predominately present in spring while not in autumn. On other hands, *Bidens pilosa* bloomed in both seasons but maximum flowering was found in autumn. This change in flower types and their phenology in SNNP could be the reason for the species turnover of pollinators. Over time and space, the turnover of pollinator species is two times greater than that of floral species. Both species turnover and floral turnover finally lead to plant-pollinator interaction turnover. Plants may change over slowly, but when they do, the interaction network is significantly altered. Although plant turnover may be minimal, the effects of plant turnover are enormous (Simanonok & Burkle, 2014). In this study, only one variable i.e, plant phenology in two seasons was used to find the species turnover. Therefore, other environmental variables like weather conditions need to be considered in the future study to understand the impact of environmental variables in network systems.

5.5 CONCLUSIONS

This is the first study of plant-pollinator interaction networks across two different seasons in SNNP. The study demonstrates few plant species were benefitting many pollinator species and high species turnover of bees and hoverflies between seasons. Therefore to conserve stable plant-pollinator interaction, it is important to maintain plant diversity of OT. The study also shows that exotic plants were most visited plants by pollinators that may alter native plant-pollinator interaction in long term. Dependency of pollinators in exotic flowers is probably less important for stable

ecosystem than dependency on native flower. Hence, management of these exotic plants are required. However, to describe further properties of the plant-pollinator interaction network of SNNP, intensive work is required to be carried out.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Taxonomy, diversity, and community structure of insect pollinators is the subject of interest globally. Although many studies on different aspect of pollinators in different landscape were done, research on pollinators of protected area is very limited. The present research shows that SNNP harbored much interesting fauna of bees and hoverflies. The new country records of bees and hoverflies in this study showed the probability of finding many more bee and hoverfly species, if explore in other areas of the park.

Community composition of three major pollinator groups is assembled to show their relationship with different habitats and environmental conditions. In the present study, pollinators are abundantly present in the flowering herbs and shrubs of the OT indicating the importance of OT. To conserve the community structure of pollinators, the diversity of flowering herbs and shrubs of OT need to protect. Environmental variables like humidity and atmospheric temperature of OT are suitable for thick growth of flower resources compared to FT. Though MH is open area like OT, the diversity and species richness of pollinators are comparatively low. This could be due to human activities and disturbances.

The habitat distribution maps projected for *Nomada mutabilis*, *Thyreus decorus*, *Thyreus himalayensis*, *Megachile femorata*, and *Xylocopa violacea* show that bee species in SNNP are spread out across a broad region. Their distributions are determined by annual precipitation, average temperatures, agricultural land, grassland, and forest.

Plant-pollinator interaction is heterogeneous and stable networks in the park. The high species turnover of bees and hoverflies between seasons shows the different phenology of flowering plants. Common pollinators like *Eristalis tenax*, *E. cerealis*, and *Pieris canidia* were observed, as key pollinators showing their dominance in SNNP. *Ageratina adenophora*, *Bidens pilosa*, and *Trifolium repens* are exotic plants and can proliferate massively compared to native flowers. Furthermore, this work also presented the maximum association of common native pollinators with exotic plants of OT. This

could be due to dominance of exotic plants hence management of exotic plants are important to conserve native plant-pollinator interactions.

6.2 Recommendations for Further work

This thesis enlists the pollinator species along with its distribution in different habitats of SNNP that can provide a headstart for future researchers seeking to explore and edify under this topic. This thesis will lay the groundlook for raising awareness over the declining number of pollinators providing idea to generate tools and plan to conserve them well within national park.

Based on the present findings, following recommendations are made for further research.

1. The faunal exploration of bees and hoverflies as well as community structure of pollinators were focused on the walking trails of the forest, managed habitat, and grassland of the park, while other areas like inner forest can also serve as refugia for pollinators. These areas differ in availability of nesting and foraging habitat leading to expect different composition of pollinators and some bee species are found positively associated with forest (Winfree *et al.*, 2007). Therefore, the further study should focus on the values of inner forest areas for pollinators and pollination.
2. The plant-pollinator interaction was carried only in OT of SNNP. However, there could be interesting plant-pollinator interactions in other habitats of the park. So network interaction with other habitats of the park would be explore. Additionally, to gain insight role of interacted flowers as foraging resources for pollinators, the analysis of pollen grains and nectar carried by pollinators could be examine. This may provide the information on types of plants visited by pollinators.
3. During this study, some genera of hoverfly like *Graptomyza* and *Lycastris* were found confined to a particular habitat, plants or active in a particular period of time. These species are rarely recorded in literature. The biology and ecology of these genera need to understand in detail to conserve them.

CHAPTER 7

SUMMARY

A protected area is a home to many insect pollinators due to its undisturbed nature. The present research showed that SNNP harbored much interesting fauna of bees and hoverflies (Chapter 2). The survey done in 2018 to enlist bees and hoverflies fauna shows exciting result with 42 bee species and 34 hoverfly. List of bees added 11 species: *Amegilla candida*, *Amegilla fallax*, *Amegilla insularis*, *Amegilla quadrifasciata*, *Elaphropoda impatiens*, *Ceratina perforatrix*, *Colletes similis*, *Megachile conjuncta*, *Nomia iridescens*, *Xylocopa collaris*, and *Xylocopa violacea* as new records for Nepal. Both social and solitary wild bee's species were collected in SNNP. There were four species of cuckoo bees among solitary species.

Likewise, list of hoverfly added, *Graptomyza nigripes*, *Lycastris albipe*, and *Volucella trifasciata* as new records for the country. This is the primary work carried out in the small portion of SNNP, a little is known about the bees and hoverflies. This result shows that new findings are possible in SNNP, adding to the list that makes the study of bees and hoverflies appealing, important, and exciting.

Habitat types and vegetation composition determines the distribution of pollinators and enhance pollination (Pan *et al.*, 2022). Chapter 3 presented two years of data on insect pollinators from different habitats of SNNP. All three major pollinator groups were assembled to show their relationship with different habitats and environmental conditions. A total of 167 different species were captured. About 48.50% were butterfly, 29.94% were bees, and 21.56% were hoverflies. OT was comparatively more diverse and maximum movement of pollinators was observed between OT and MH. There was high species turnover between FT and MH, whereas low species turnover between MH and OT. Elevation, humidity, atmospheric temperature, and the presence of flower resources are the important variables for pollinating insects. Flowering herbs and shrubs of the OT have been found harboring pollinators. The other study also found that more insect pollinator occurs in those habitats, which are rich with herbs or shrubs coverage, and not in an area with large trees (Pan *et al.*, 2022). Therefore, retention of this vegetation coverage in OT is important for pollinator management of SNNP.

Wild bee declination is an issue of the present decade. Yet research addressing the status of wild bees in natural habitats is lacking despite natural areas homed with diverse bee communities (Meiners *et al.*, 2019). SNNP is found to be a potential area for wild bees. The survey of pollinators carried out for two years showed 96% was wild bee (Chapter 3) in the study area. This data is exciting to explore the distribution of wild bees in SNNP. Chapter 4 developed the mapping of least observed wild bees of SNNP: *Nomada mutabilis*, *Thyreus decorus*, *Thyreus himalayensis*, *Megachile femorata*, and *Xylocopa violacea*. SDMs tool was used to generate the potential distribution of wild bees invading different parts of SNNP. According to the findings, bee species in SNNP are present throughout the park. The accuracy of model predictions and projected maps varied depending on the species and their habitats. However, in general, bioclimatic variables like annual precipitation and average temperatures were key factors influencing their distribution while agricultural land, grassland, and forest are important determinants of these bees. Although the validation of presence of these wild bees is not carried out in this study, one can predict their presence in the area shown by the modeling. In a further study, validation needs to be done to confirm the result. Also, to maintain sustainable wild bees, it may therefore be important to improve the agricultural areas of MH, and provide guidelines to manage the grassland of SNNP.

Pollinator interactions are assumed to have contributed significantly to the enormous biodiversity found in flowering plants. A large portion of it is undoubtedly maintained by pollinators' flower-visiting behaviors that culminate in the development of seeds (Inouye & Ogilvie, 2001). Plant-pollinator interaction alters highly within small spatial and temporal differences. In all networks, investigations at a finer scale revealed that generalist plant and pollinator species with long phenologies were the most important and helped establish a cohesive network system (Fisogni *et al.*, 2022). Chapter VII presented the plant-pollinator interaction of two different seasons. This is first-hand information on plant-pollinator interaction networks across different seasons in SNNP. The study revealed a stable interaction network, which is a characteristic of many ecosystems. Stable and heterogenous networks were found showing many pollinator species depend on few plants. Seasonal comparisons showed the high species turnover of bees and hoverflies between seasons. *Eristalis tenax*, *E. cerealis*, and *Pieris canidia* are key pollinators highly associated with *Ageratina adenophora*, *Bidens pilosa*, and *Trifolium repens*. Though plant-pollinator networks are important to document the

connection between pollinators and plants, knowledge about particular properties of this interaction that could be the subject for beneficial for conservation planning is rarely understood (Tylianakis *et al.*, 2010). Therefore, further research to find out which specific features infer robustness and define the stability of the network could be helpful. Exotic plant species if becoming invasive could erode the community structure of pollinators (Aizen *et al.*, 2008). Maximum invasive plants compete with native plants for pollinating insects. Therefore, invasive plants can bring change to the pollination network. However, *Ageratina adenophora*, *Bidens pilosa*, and *Trifolium repens* in SNNP are yet not invasive. There are a couple of studies revealing the positive role of invasive species in plant-pollinator interactions. For instance, the introduction of invasive species had no change in the connectance and robustness of the plant-pollinator network (Vila *et al.*, 2009). Invasive plants may well merge and play network hub to preserve the network system by sharing pollinators with native plants or receiving equal or higher visitation rates than natives (Seitz *et al.*, 2020). Moreover, an interaction was more resilient to invasive species (Bartomeus *et al.*, 2008). Invasive species contributed equally to the network system (ParraTabla *et al.*, 2018). However, in all these described examples; the authors have also suggested that though invasive plants provided positive platform to pollinators, they could have detrimental impacts in long term. Therefore, the primary drivers of ecological conservation are the control of invasive species and the protection of native species populations. This could be achieved by a further integrative investigation that considers not only the visitation pattern of pollinators on invasive plants but also adds estimates of pollinator efficiency and species reproductive success of native plants.

REFERENCES

- Abdi, A. M. (2020). Land cover and land use classification performance of machine learning algorithms in a boreal landscape using Sentinel-2 data. *GIScience & Remote Sensing*, **57**(1): 1-20. <https://doi.org/10.1080/15481603.2019.1650447>
- Adedoja, O., Kehinde, T. & Samways, M. J. (2020). Asynchrony among insect pollinator groups and flowering plants with elevation. *Scientific reports*, **10**(1):1–12. <https://doi.org/10.1038/s41598-020-70055-5>
- Adler, L. S. & Irwin, R. E. (2006). Comparison of pollen transfer dynamics by multiple floral visitors: Experiments with pollen and Fluorescent Dye. *Annals of Botany*, **97**:141-150. <https://doi.org/10.1093/aob/mcj012>
- Aguilar, R. Ashworth L, Galetto L. & Aizen, M. A. (2006). Plant reproductive susceptibility to habitat fragmentation: review and synthesis through a meta-analysis. *Ecology Letters*, **8**:968-80. <https://doi.org/10.1111/j.1461-0248.2006.00927.x>
- Ahrne, K., Bengtsson, J., & Elmqvist, T. (2009). Bumble bees (*Bombus* spp) along a gradient of increasing urbanization. *PloS one*, **4**(5): e5574. <https://doi.org/10.1371/journal.pone.0005574>
- Aizen, M. A. and Harder, L. D. (2009). The global stock of Domesticated Honey Bees is growing slower than Agricultural Demand for Pollination. *Current Biology*, **19**: 915-918. <https://doi.org/10.1016/j.cub.2009.03.071>
- Aizen, M. A., Morales, C. L., & Morales, J. M. (2008). Invasive mutualists erode native pollination webs. *PLoS biology*, **6**(2): e31. <https://doi.org/10.1371/journal.pbio.0060031>
- Alison, J., Botham, M., Maskell, L. C., Garbutt, A., Seaton, F. M., Skates, J., ... & Emmett, B. A. (2022). Woodland, cropland and hedgerows promote pollinator abundance in intensive grassland landscapes, with saturating benefits of flower cover. *Journal of Applied Ecology*, **59**(1): 342-354. <https://doi.org/10.1111/1365-2664.14058>
- Arnold, S. E., Le Comber, C. S., & Chittka, L. (2009). Flower color phenology in European grassland and woodland habitats, through the eyes of

- pollinators. *Israel Journal of Plant Sciences*, **57**(3): 211-230. DOI: 10.1560/IJPS.57.3.211
- Arya, M. K., Verma, A., & Tamta, P. (2020). Diversity of Butterflies (Lepidoptera: Papilionoidea) in a Temperate Forest Ecosystem, Binsar Wildlife Sanctuary, Indian Himalayan Region. *Nature Environment & Pollution Technology*, **19**(3).
- Ascher, J. S., & Pickering, J. (2021). Discover Life Bee species guide and world checklist (Hymenoptera: Apoidea: Anthophila). Retrieved from: <http://www.discoverlife.org/> Accessed on (19/ 07/ 2021)
- Aslam, S., Rafi, M. A., & Zia, A. (2017). Non-Apis bees of family Apidae (Hymenoptera) from Potohar region of Pakistan. *J. Entomol. Zool. Stud*, **5**(2): 6-12.
- Attiwilli, S., Karmakar, T., Isvaran, K., & Kunte, K. (2022). Habitat preference and functional traits influence responses of tropical butterflies to varied habitat disturbance. *International Journal of Tropical Insect Science*, **42**(1): 855-864.
- Badoni, A., & Arya, M. K. (2022). Insects visiting the medicinal plants from genus *Berberis* L. in the Western Himalaya. *Oriental Insects*, **56**(1): 1-13. <https://doi.org/10.1080/00305316.2020.1860148>
- Bailey, S., Requier, F., Nusillard, B., Roberts, S. P., Potts, S. G., & Bouget, C. (2014). Distance from forest edge affects bee pollinators in oilseed rape fields. *Ecology and Evolution*, **4**(4): 370-380. <https://doi.org/10.1002/ece3.924>
- Baldock, K. C., Goddard, M. A., Hicks, D. M., Kunin, W. E., Mitschunas, N., Osgathorpe, L. M., ... & Memmott, J. (2015). Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. *Proceedings of the Royal Society B: Biological Sciences*, **282**(1803): 20142849. <https://doi.org/10.1098/rspb.2014.2849>
- Ballantyne, G., Baldock, K. C. R., Rendell, L., & Willmer, P. G. (2017). Pollinator importance networks illustrate crucial value of bees in a highly speciose plant community. *Scientific Report*, **7**(1):8389. DOI:10.1038/s41598-017-08798-x
- Balogun, I., Eluyeba, O., Adedaja, O., Samways, M. J., Polašek, O., & Kehinde, T. (2022). Open habitats in a tropical biodiversity hotspot support pollinator

- diversity in both protected and unprotected areas. *Biotropica*. **54**(4): 947-957.
<https://doi.org/10.1111/btp.13118>
- Barkalov AV, Ståhls G. (2022). Cheilosia (Diptera, Syrphidae: Rhingiini) of Nepal with descriptions of 29 new species. *European Journal of Taxonomy*. **829**:1–27.
<https://doi.org/10.5852/ejt.2022.829.1863>
- Barrios, B., Pena, S. R., Salas, A., & Koptur, S. (2016). Butterflies visit more frequently, but bees are better pollinators: the importance of mouthpart dimensions in effective pollen removal and deposition. *AoB Plants*, **8**.
<https://doi.org/10.1093/aobpla/plw001>
- Bartomeus, I., Vilà, M., & Santamaría, L. (2008). Contrasting effects of invasive plants in plant–pollinator networks. *Oecologia*, **155**(4): 761-770.
- Bascompte, J., & Jordano, P. (2007). Plant-animal mutualistic networks: the architecture of biodiversity. *The Annual Review of Ecology and Evolution, and Systematics*. **38**: 567-593.
- Bascompte, J., Jordano, P., Melián, C. J., & Olesen, J. M. (2003). The nested assembly of plant–animal mutualistic networks. *Proceedings of the National Academy of Sciences*, **100**(16): 9383-9387. <https://doi.org/10.1073/pnas.1633576100>
- Bashir, M. A., Saeed, S., Sajjad, A., Khan, K. A., Ghramh, H. A., Shehzad, M. A., Mubarak, H., Mirza, N., Mahpara, S., Rehmani, M. I. A. & Ansari, M. J. (2019). Insect pollinator diversity in four forested ecosystems of southern Punjab, Pakistan. *Saudi journal of biological sciences*, **26**(7):1835-1842.
<https://doi.org/10.1016/j.sjbs.2018.02.007>
- Bashir, M.A.m Saeed, S. & Sajjad, A. (2013). Monitoring Hymenoptera and Diptera pollinators in a subtropical Forest of Southern Punajb, Pakistan. *Pakistan Journal of Agricultural Science*. **50**(3): 359-366.
- Bastolla, U., Fortuna, M. A., Pascual-García, A., Ferrera, A., Luque, B., & Bascompte, J. (2009). The architecture of mutualistic networks minimizes competition and increases biodiversity. *Nature*, **458**(7241): 1018-1020.
- Bates, A. J., Sadler, J. P., Fairbrass, A. J., Falk, S. J., Hale, J. D. & Matthews, T. J. (2011). Changing bee and hoverfly pollinator assemblages along an urban–rural

gradient. *PloS one*, **6**(8): p.e23459.
<https://doi.org/10.1371/journal.pone.0023459>

- Beckham, J. L., & Atkinson, S. (2017). An updated understanding of Texas bumble bee (Hymenoptera: Apidae) species presence and potential distributions in Texas, USA. *PeerJ*, **5**: e3612. <http://dx.doi.org/10.7717/peerj.3612>
- Beekman, M., & Ratnieks, F. L. W. (2000). Long-range foraging by the honey-bee, *Apis mellifera* L. *Functional Ecology*, **14**(4): 490-496. <https://doi.org/10.1046/j.1365-2435.2000.00443.x>
- Benton, T. G., Vickery, J. A. & Wilson, J. D. (2003). Farmland biodiversity: is habitat heterogeneity the key? *Trends in Ecology and Evolution*, **18**: 182-188. [https://doi.org/10.1016/S0169-5347\(03\)00011-9](https://doi.org/10.1016/S0169-5347(03)00011-9)
- Bentrup, G., Hopwood, J., Adamson, N. L. & Vaughan, M. (2019). Temperate Agroforestry Systems and Insect Pollinators: A Review. *Forests*, **10**(11): 981. <https://doi.org/10.3390/f10110981>
- Bergholz, K., Sittel, L. P., Ristow, M., Jeltsch, F., & Weiss, L. (2022). Pollinator guilds respond contrastingly at different scales to landscape parameters of land-use intensity. *Ecology and Evolution*, **12**(3): e8708. <https://doi.org/10.1002/ece3.8708>
- Bergman, P., Molau, U., & Holmgren, B. (1996). Micrometeorological impacts on insect activity and plant reproductive success in an alpine environment, Swedish Lapland. *Arctic and Alpine Research*, **28**(2): 196-202. <https://doi.org/10.1080/00040851.1996.12003166>
- Bhalchandra, W., & Baviskar, R. K. (2017). Diversity of pollinator bees from Paithan taluka of Aurangabad district (MS) India. *Journal of Entomology and Zoology Studies*, **5**: 697-700.
- Bhatia, H. L., & Shaffi, M. (1933). Life histories of some Indian Syrphidae. *Indian Journal of Agricultural Science*, **2**: 543-570.
- Bian, F. H., Chen, P., & Yu, W. Y. (2018). Breeding system of *Anemone shikokiana* and the influential factors of fruit-setting ratio in different habitats. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology*, **152**(3): 445-452. <https://doi.org/10.1080/11263504.2017.1297336>

- Biesmeijer, J. C., Roberts, S. P., Reemer, M., Ohlemuller, R., Edwards, M., Peeters, T., & Kunin, W. E. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*, **313**(5785): 351-354.
- Bigot, J. M. F. (1884). Dipteres nouveaux ou peu connus. 24 partie, XXXII: Syrphidi (2 partie). Espèces nouvelles, no. III. In *Annales de la Société entomologique de France* (Vol. 6, No. 4, pp. 73-80).
- Bingham, C. T. (1897). *The Fauna of British India, including Ceylon and Burma*. Vol. I. Taylor and Francis, London. <https://doi.org/10.5962/bhl.title.100738>.
- Bingham, C. T. (1903). The Fauna of British India, including Ceylon and Burma. Hymenoptera, Vol. II. Ants and Cuckoo-wasps. *The Fauna of British India, including Ceylon and Burma. Hymenoptera, Vol. II. Ants and Cuckoo-wasps*.
- Blüthgen, N., Menzel, F., & Blüthgen, N. (2006). Measuring specialization in species interaction networks. *BMC ecology*, **6**(1): 1-12. doi:10.1186/1472-6785-6-9
- Blüthgen, N., Menzel, F., Hovestadt, T., Fiala, B., & Blüthgen, N. (2007). Specialization, constraints, and conflicting interests in mutualistic networks. *Current Biology*, **17**(4): 341-346. <https://doi.org/10.1016/j.cub.2006.12.039>
- Bodlah, I., Amjad, M., Bodlah, M.A. & Qayyum, A. (2016). First record of two genera of Anthophorini and one genus of Melectini (Apinae: Apidae: Hymenoptera) from Pothwar Punjab, Pakistan. *Journal of Entomology and Zoology Studies*, **4**:1031–1035.
- Branquart, E., & Hemptinne, J. L. (2000). Selectivity in the exploitation of floral resources by hoverflies (Diptera: Syrphinae). *Ecography*, **23**(6): 732-742. <https://doi.org/10.1111/j.1600-0587.2000.tb00316.x>
- Brown, J. L. (2014). SDM toolbox: a python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. *Methods in Ecology and Evolution*, **5**(7): 694-700. <https://doi.org/10.1111/2041-210X.12200>
- Brown, M. J., & Paxton, R. J. (2009). The conservation of bees: a global perspective. *Apidologie*, **40**(3): 410-416. DOI: 10.1051/apido/2009019
- Brown, S. (2021). Plant-Pollinator Network Dynamics of the Little Fork Shale Barren.

- Brunetti, E. (1907). Notes on the Oriental Syrphidae. *Records of the Zoological Survey of India*, **1**(4): 0379-0380.
- Brunetti, E. (1908). Notes on Oriental Syrphidae with Descriptions of new Species I. *Records of the Zoological Survey of India*, **2**(1): 49-96.
- Brunetti, E. (1913). Zoological results of the Arbor Expedition, 1911–12. XI. Diptera. *Records of the Indian Museum* **8**: 149–190.
- Brunetti, E. (1915). Notes on Oriental Syrphidae with descriptions of new species. Part II. *Records of the Indian Museum*, **11**: 201–256.
- Brunetti, E. (1923). Pipunculidae, Syrphidae, Conopidae, Oestridae. Diptera. Vol. 3, xi + 424 pp., 6 pis. In [Shiple, A. E.] (Eds.), *The Fauna of British India, including Ceylon and Burma*. Taylor & Francis, London.
- Brunetti, E. (1925). Some notes on Indian Syrphidae, Conopidae and Oestridae. *Records of the Indian Museum*, **27**: 75–79.
- Burger, F., Creutzburg, F., Hartmann, J., & Hartmann, M. (2009). Die Hummeln von Nepal (Insecta: Hymenoptera: Apidae: Bombus). Biodiversität und Naturausstattung im Himalaya. III. Verein der Freunde und Förderer des Naturkundemuseums Erfurt eV, Erfurt, 455-462.
- Burke, M. J., & Grime, J. P. (1996). An experimental study of plant community invasibility. *Ecology*, **77**(3), 776-790. <https://doi.org/10.2307/2265501>
- Cameron, S. A., Lozier, J. D., Strange, J. P. Koch, J. B. Cordes, N., Solter, L. F. *et al.* (2011). Patterns of widespread decline in North American bumble bee. *Proceedings of the National Academy of sciences of the United States of America*, **108**: 662-667. <https://doi.org/10.1073/pnas.1014743108>
- Cane, J. H. (2008). A native ground-nesting bee (*Nomia melanderi*) sustainably managed to pollinate alfalfa across an intensively agricultural landscape. *Apidologie*, **39**(3): 315-323.
- Cane, J. H., Griswold, T. & Parker, F. D. (2007). Substrates and Materials Used for Nesting by North American Osmia Bees (Hymenoptera: Apiformes: Megachilidae). *Annals of the Entomological Society of America*, **100**(3): 350-358. [https://doi.org/10.1603/0013-8746\(2007\)100\[350:SAMUFN\]2.0.CO;2](https://doi.org/10.1603/0013-8746(2007)100[350:SAMUFN]2.0.CO;2)
- Cannings, R. A., Kelly-McArthur, B., Skevington, J. H., Higgins, R. J., & Gibson, J. F. (2021). *Microdon tristis* (Diptera: Syrphidae): notes on biology with a new ant

- host record from British Columbia. *Journal of the Entomological Society of British Columbia*, **118**: 76-81.
- CaraDonna, P. J., Petry, W. K., Brennan, R. M., Cunningham, J. L., Bronstein, J. L., Waser, N. M., & Sanders, N. J. (2017). Interaction rewiring and the rapid turnover of plant–pollinator networks. *Ecology letters*, **20**(3), 385-394. <https://doi.org/10.1111/ele.12740>
- Carreck, N. L., & Williams, I. H. (2002). Food for insect pollinators on farmland: insect visits to flowers of annual seed mixtures. *Journal of Insect Conservation*, **6**(1): 13-23.
- Carrié, R., Lopes, M., Ouin, A., & Andrieu, E. (2018). Bee diversity in crop fields is influenced by remotely-sensed nesting resources in surrounding permanent grasslands. *Ecological Indicators*, **90**: 606-614. <https://doi.org/10.1016/j.ecolind.2018.03.054>
- Carstensen, D. W., Sabatino, M., Trøjelsgaard, K., & Morellato, L. P. C. (2014). Beta diversity of plant-pollinator networks and the spatial turnover of pairwise interactions. *PLoS One*, **9**(11): e112903. <https://doi.org/10.1371/journal.pone.0112903>
- Carthew, S. M., & Goldingay, R. L. (1997). Non-flying mammals as pollinators. *Trends in Ecology & Evolution*, **12**(3): 104-108. [https://doi.org/10.1016/S0169-5347\(96\)10067-7](https://doi.org/10.1016/S0169-5347(96)10067-7)
- Carvalho, L. G., Barbosa, E. R. M., & Memmott, J. (2008). Pollinator networks, alien species and the conservation of rare plants: *Trinia glauca* as a case study. *Journal of Applied Ecology*, **45**(5): 1419-1427. <https://doi.org/10.1111/j.1365-2664.2008.01518.x>
- Carvalho, L. G., Kunin, W. E., Keil, P., Aguirre-Gutiérrez, J., Ellis, W. N., Fox, R., ... & Biesmeijer, J. C. (2013). Species richness declines and biotic homogenisation have slowed down for NW-European pollinators and plants. *Ecology Letters*, **16**(7): 870-878. doi: 10.1111/ele.12121
- Carvalho, L. G., Seymour, C. L., Veldtman, R. & Nicolson, S. W. (2010). Pollination services decline with distance from natural habitat even in biodiversity-rich

areas. *Journal of Applied Ecology*, **47**: 810-820. <https://doi.org/10.1111/j.1365-2664.2010.01829.x>

- Carvell, C., Westrich, P., Meek, W. R., Pywell, R. F. & Nowakowski, M. (2006). Assessing the value of annual and perennial forage mixtures for bumble bees by direct observation and pollen analysis. *Apidologie*, **37**: 326-340. DOI: 10.1051/apido:2006002
- Chaguthi, G., & Dyola, U. (2018). Insect Visitors of White Clover (*Trifolium Repens* L) and Their Relation With Environmental Variables in the Premises of Bhaktapur Multiple Campus, Nepal. *Journal of Institute of Science and Technology*, **22**(2): 86-91.
- Chen, R. Q., & Cheng, S. T. (2022). Detecting Nestedness in City Parks for Urban Biodiversity Conservation. *Research Square*, 1-16. <https://doi.org/10.21203/rs.3.rs-1041980/v1>
- Cheng, W., & Ashton, L. (2021). Ecology: What Affects the Distribution of Global Bee Diversity. *Current Biology*, **31**(3): R127-R128. <https://doi.org/10.1016/j.cub.2020.11.044>
- Clarke, K. R. & Gorley, R. N. (2001). *Primer V5 (Plymouth routines in multivariate ecological research): user manual/tutorial*. Primer–e.
- Claussen, C. J., & Weipert, J. (2003). Zur Schwebfliegenfauna Nepals (Insecta: Diptera: Syrphidae) unter besonderer Berücksichtigung Westnepals. *Biodiversität und Naturlausstattung im Himalaya. Verein der Freunde und Förderer des Naturkundemuseums Erfurt ev, Erfurt*, 343-380.
- Claussen, C., & Weipert, J. (2004). Notes on the subgenus *Paragus* (*Pandasyopthalmus*) (Diptera, Syrphidae) from Nepal, with the description of a new species. *Volucella*, **7**: 75-88.
- Coe, R. L. (1964). Diptera from Nepal. *Bulletin of the British Museum of Natural History, Entomology* **15**: 255–290.
- Collado, M. Á., Sol, D., & Bartomeus, I. (2019). Bees use anthropogenic habitats despite strong natural habitat preferences. *Diversity and Distributions*, **25**(6): 924-935.

- Cook, J. M., & Rasplus, J. Y. (2003). Mutualists with attitude: coevolving fig wasps and figs. *Trends in Ecology & Evolution*, **18**(5): 241-248.
- Coquillett, D.W. (1898). *Report on a collection of Japanese Diptera, presented to the U.S. National Museum by the Imperial University of Tokyo. Proceedings of the United States National Museum*, **21**(1146): 301–340.
- Corbet, S. A., Williams, I. H & Osbrone, I. L. (1991). Bees and the pollinators of crops and wild flowers in the European community. *Bee World*, **72**(2): 47-59.
- Cussan, J., Goulson, D., Sanderson, R., Goffe, L., Darvill, B. & Osborne, J. L. (2010). Two bee-pollinated plant species show higher seed production when grown in gardens compared to arable farmland. *PLoS ONE*, **5**(7):11753. <https://doi.org/10.1371/journal.pone.0011753>
- Cusser, S., & Goodell, K. (2013). Diversity and distribution of floral resources influence the restoration of plant–pollinator networks on a reclaimed strip mine. *Restoration Ecology*, **21**(6): 713-721. <https://doi.org/10.1111/rec.12003>
- Danforth, B. N., Cardinal, S., Praz, C., Almeida, E. A., & Michez, D. (2013). The impact of molecular data on our understanding of bee phylogeny and evolution. *Annual Review of Entomology*, **58**: 57-78.
- Dar, S. A., & Sofi, K. A. (2022) Ecology of Alkali bees (Genus: *Nomia*) with Respect to Conservation (Pathogens, Parasites and Predators) and their Behavioral Characteristics.
- Dartnell, S., Hamlett, N., & Meyer, W. M. (2022). Monitoring butterfly assemblages in southern California to assess the impact of habitat and climate modifications. *Journal of Insect Conservation*, 1-14.
- Dawah, H. A., Abdullah, M. A., Ahmad, S. K., Al-Dhafer, H., & Turner, J. (2020). An overview of the Syrphidae (Diptera) of Saudi Arabia. *Zootaxa*, **4855**(1): 1-69. DOI: 10.11646/ZOOTAXA.4855.1.1
- De Araújo, L. D. A., Quirino, Z. G. M., & Machado, I. C. (2014). High specialisation in the pollination system of *Mandevilla tenuifolia* (JCM ikan) Woodson (Apocynaceae) drives the effectiveness of butterflies as pollinators. *Plant Biology*, **16**(5): 947-955. <https://doi.org/10.1111/plb.12152>

- De Geer, C. (1776). Mémoires pour servir à l'histoire des insectes. Tome Sixième. *Stockholm: P Hesselberg*.
- De Groot, R.S., Alkemade, R., Braat, L., Hein, L. & Willemsen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, **7**(3): 260–272. <https://doi.org/10.1016/j.ecocom.2009.10.006>
- de Portugal-Araújo, V. (1958). A contribution to the bionomics of *Lestrimelitta cubiceps* (Hymenoptera, Apidae). *Journal of the Kansas Entomological Society*, **31**(3): 203-211.
- Deserres, J. M., Girard, M.m Chagnon, M. and Fournier, V. (2014). Pollen loads and specificity of native pollinators of lowbush berry. *Journal of Economic Entomology*, **107**(3): 1156-1162. <https://doi.org/10.1603/EC13229>
- Devkota, K. (2020). Beekeeping: Sustainable livelihoods and agriculture production in Nepal. *Modern Beekeeping-Bases for Sustainable Production*, 1-11.
- Devkota, K., Dhakal, S. C. & Thapa, R. B. (2016). Economics of beekeeping as pollination management practices adopted by farmers in Chitwan district of Nepal. *Agriculture & food Security*, **5**:6. DOI 10.1186/s40066-016-0053-9
- Dew, R. M., Silva, D. P., & Rehan, S. M. (2019). Range expansion of an already widespread bee under climate change. *Global Ecology and Conservation*, **17**: e00584. <https://doi.org/10.1016/j.gecco.2019.e00584>
- Dicks, L. V., Corbet, S. A., & Pywell, R. F. (2002). Compartmentalization in plant-insect flower visitor webs. *Journal of Animal Ecology*, 32-43.
- Dirzo, R., Young, H. S., Galetti, M., Ceballos, G., Isaac, N. J., & Collen, B. (2014). Defaunation in the Anthropocene. *Science*, **345**(6195): 401-406. DOI: 10.1126/science.1251817
- Dormann, C. F., Fründ, J., Blüthgen, N., & Gruber, B. (2009). Indices, graphs and null models: analyzing bipartite ecological networks. *The Open Ecology Journal*, **2**(1). <http://dx.doi.org/10.2174/1874213000902010007>
- Dormann, C. F., Gruber, B., & Fründ, J. (2008). Introducing the bipartite package: analysing ecological networks. *Interaction*, **1**(0.2413793).

- Dover, J., & Sparks, T. (2000). A review of the ecology of butterflies in British hedgerows. *Journal of Environmental Management*, **60**(1): 51-63. <https://doi.org/10.1006/jema.2000.0361>
- Doyle, T., Hawkes, W. L. S., Massy, R., Powney, G. D., Menz, M. H. M. & Wotton, K. R. (2020) Pollination by hoverflies in the Anthropocene. *Proceedings. Biological Sciences*, **287**: 20200508. DOI: <https://doi.org/10.1098/rspb.2020.0508>, PMID: 32429807
- Dramstad, W. & Fry, G. (1995). Foraging activity of bumble bees (*Bombus*) in relation to flower resources on arable land. *Agriculture, Ecosystems and Environment*, **53**: 123-135. [https://doi.org/10.1016/0167-8809\(94\)00561-R](https://doi.org/10.1016/0167-8809(94)00561-R)
- Drossart, M., & Gérard, M. (2020). Beyond the decline of wild bees: Optimizing conservation measures and bringing together the actors. *Insects*, **11**(9): 649. <https://doi.org/10.3390/insects11090649>
- Duchenne, F., Thébault, E., Michez, D., Gérard, M., Devaux, C., Rasmont, P., & Fontaine, C. (2020). Long-term effects of global change on occupancy and flight period of wild bees in Belgium. *Global Change Biology*, **26**(12): 6753-6766. <https://doi.org/10.1111/gcb.15379>
- Dunne, J. A., Williams, R. J., & Martinez, N. D. (2002). Network structure and biodiversity loss in food webs: robustness increases with connectance. *Ecology Letters*, **5**(4): 558-567. <https://doi.org/10.1046/j.1461-0248.2002.00354.x>
- Dunning, J. B., Danielson, B. J., & Pulliam, H. R. (1992). Ecological Processes That Affect Populations in Complex Landscapes. *Oikos*, **65**(1): 169–175. <https://doi.org/10.2307/3544901>
- Dyola, U., Baniya, C. B., Acharya, P. R., Pandey, A., & Sapkota, K. (2022a). Bee (Hymenoptera: Apoidea) Fauna of Shivapuri-Nagarjun National Park, Nepal. *Journal of Asia-Pacific Biodiversity*, **15**(2022):231–240. <https://doi.org/10.1016/j.japb.2022.01.007>
- Dyola, U., Baniya, C. B., Acharya, P. R., Subedi, P., Pandey, A., & Sapkota, K. (2022b). Community structure of pollinating insects and its driving factors in different habitats of Shivapuri-Nagarjun National Park, Nepal. *Ecology and Evolution*, **12**(3): e8653. <https://doi.org/10.1002/ece3.8653>

- Eken, G., Bennun, L., Brooks, T. M., Darwall, W., Fishpool, L. D., Foster, M., ... & Tordoff, A. (2004). Key biodiversity areas as site conservation targets. *BioScience*, **54**(12): 1110-1118. [https://doi.org/10.1641/0006-3568\(2004\)054\[1110:KBAASC\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2004)054[1110:KBAASC]2.0.CO;2)
- Elith, J., & Leathwick, J. R. (2009). Species distribution models: ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution and Systematics*, **40**(1): 677-697.
- Enderlein, G. (1938) Beiträge zur Kenntnis der Syrphiden. *Sitzungsberichte der Gesellschaft Naturforschender Freunde Berlin*, 1937: 192–237.
- Erbar, C., & Leins, P. (2013). Nectar production in the pollen flower of *Anemone nemorosa* in comparison with other Ranunculaceae and Magnolia (Magnoliaceae). *Organisms Diversity & Evolution*, **13**(3): 287-300. DOI 10.1007/s13127-013-0131-9
- Evans, L. C., Sibly, R. M., Thorbek, P., Sims, I., Oliver, T. H., & Walters, R. J. (2020). The importance of including habitat-specific behaviour in models of butterfly movement. *Oecologia*, **193**(2): 249-259. <https://doi.org/10.1007/s00442-020-04638-4>
- Everaars, J., Strohbach, M. W., Gruber, B., & Dormann, C. F. (2011). Microsite conditions dominate habitat selection of the red mason bee (*Osmia bicornis*, Hymenoptera: Megachilidae) in an urban environment: A case study from Leipzig, Germany. *Landscape and Urban Planning*, **103**(1): 15-23. <https://doi.org/10.1016/j.landurbplan.2011.05.008>
- Fabricius, J. C. (1775) *Systema entomologiae, sistens insectorum classes, ordines, genera, species, adiectis synonymis, locis, descriptionibus, observationibus*. Kortii, Flensbvr̄gi et Lipsiae [= Flensburg and Leipzig], [30] + 832 pp.
- Fabricius, J. C. (1787) *Mantissa Insectorum sistens species nuper detectas*. Vol. 2. C.G. Proft, Hafniae [= Copenhagen], 382 pp.
- Fabricius, J. C. (1794) *Entomologia systematica emendata et aucta. Secundum classes, ordines, genera, species adjectis synonymis, locis, observationibus, descriptionibus*. Tom. IV. C.G. Proft, Fil. et Soc., Hafniae [= Copenhagen], 472 pp.

- Fabricius, J. C. (1805) *Systema antliatorum secundum ordines, genera, species adiecta synonymis, locis, observationibus, descriptionibus*. C. Reichard, Brunsvigae [= Brunswick], xiv + [15]–372 + [1] + 30 pp.
- Fazlullah, M. S., Hassan, M. A., Mastoi, I., & Arshad, A. (2018). A preliminary list of hover flies (Diptera: Syrphidae) with a new locality records from swat, Khyber Pakhtunkhwa, Northern Pakistan. *Genus*, **15**(19): 20.
- Fisogni, A., Hautekèete, N., Piquot, Y., Brun, M., Vanappelghem, C., Ohlmann, M., ... & Massol, F. (2022). Seasonal trajectories of plant-pollinator interaction networks differ following phenological mismatches along an urbanization gradient. *Landscape and Urban Planning*, **226**: 104512. <https://doi.org/10.1016/j.landurbplan.2022.104512>
- Fitzpatrick, U., Murray, T. E., Paxton, R. J., Breen, J., Cotton, D., Santorum, V. *et al.* (2007). Rarity and decline in bumblebee- A test of causes and correlates in the Irish fauna. *Biological Conservation*, **136**: 185-194. <https://doi.org/10.1016/j.biocon.2006.11.012>
- Fontaine, C., Dajoz, I., Meriguet, J., & Loreau, M. (2006). Functional diversity of plant–pollinator interaction webs enhances the persistence of plant communities. *PLoS biology*, **4**(1): e1. <https://doi.org/10.1371/journal.pbio.0040001>
- Forister, M. L, Mc Call, A. C, Sanders, N. J., Fordyce, J. A., Thorne, J. H., O' Brien, J. *et al.* (2010). Compounded effects of climate change and habitat alteration shift patterns of butterfly diversity. *PNAS*, **107**: 2088-2092. <https://doi.org/10.1073/pnas.0909686107>
- Franzén, M., Larsson, M., & Nilsson, S. G. (2009). Small local population sizes and high habitat patch fidelity in a specialised solitary bee. *Journal of Insect Conservation*, **13**(1): 89-95.
- Frey, R. (1946) Übersicht der Gattungen der Syrphiden–Unterfamilie Syrphinae (Syrphinae + Bacchinae). *Notulae Entomologicae*, **25**, 152–172.
- Fründ, J., Linsenmair, K. E., & Blüthgen, N. (2010). Pollinator diversity and specialization in relation to flower diversity. *Oikos*, **119**(10): 1581-1590. <https://doi.org/10.1111/j.1600-0706.2010.18450.x>

- Fussell, M. & Corbet S. A. (1992). Flower usage by bumblebees-a basis for forage plant management. *Journal of Applied Ecology*, **29**: 451-465. <https://doi.org/10.2307/2404513>
- Gallai, N., Salles, J. M., Settele, J., & Vaissière, B. E. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological economics*, **68**(3): 810-821. <https://doi.org/10.1016/j.ecolecon.2008.06.014>
- Garibaldi, L. A., Steffan-Dewenter, I., Kremen, C., Morales, J. M., Bommarco, R., Cunningham, S. A., ... & Klein, A. M. (2011). Stability of pollination services decreases with isolation from natural areas despite honey bee visits. *Ecology letters*, **14**(10): 1062-1072. <https://doi.org/10.1111/j.1461-0248.2011.01669.x>
- Gathmann, A., & Tschardt, T. (2002). Foraging ranges of solitary bees. *Journal of Animal Ecology*, **71**(5): 757-764. <https://doi.org/10.1046/j.1365-2656.2002.00641.x>
- Gautam, S., & Kunte, K. (2020). Adaptive plasticity in wing melanisation of a montane butterfly across a Himalayan elevational gradient. *Ecological Entomology*, **45**(6): 1272-1283. <https://doi.org/10.1111/een.12911>
- Geoffroy, E. L. (1762) *Histoire abrégée des insectes qui se trouvent aux environs de Paris; dans laquelle ces animaux sont rangés suivant un ordre méthodique*. Tome second. Durand, Paris. 690 pp.
- Gezon, Z. J., Wyman, E. S., Ascher, J. S., Inouye, D. W., & Irwin, R. E. (2015). The effect of repeated, lethal sampling on wild bee abundance and diversity. *Methods in Ecology and Evolution*, **6**(9): 1044-1054. <https://doi.org/10.1111/2041-210X.12375>
- Ghimire, K. C., & Bhusal, D. R. (2021). Distribution of *Bombus haemorrhoidalis* Smith and its Interrelationship with Host Plants in Chitwan Annapurna Landscape of Central Nepal. *BMC Journal of Scientific Research*, **4**(1): 22-30.
- Ghorpadé, K. (1994). Diagnostic keys to new and known genera and species of Indian subcontinent Syrphini (Diptera: Syrphidae). *Colemania: Insect Biosystematics*, **3**: 1-15.

- Ghorpadé, K. (2015a). A summary, updated account of the Hoverflies (Diptera–Syrphidae) of the Nepal Himalaya. *Colemania*, **49**: 1–11.
- Ghorpadé, K. (2015b). Hover-flies (Diptera—Syrphidae) documented from the Northwest Frontier of the Indian sub-continent: a circumstantial history and inclusive bibliography. *Colemania*, **50**: 1–151.
- Ghorpadé, K. (2019). Hover-Flies (Diptera: Syrphidae) Recorded from “Dravidia,” or Central and Peninsular India and Sri Lanka: An Annotated Checklist and Bibliography 1. In *Indian Insects* (pp. 325-388). CRC Press. <https://doi.org/10.1201/9780429061400-18>
- Gibson, R. H., Nelson, I. L., Hopkins, G. W., Hamlett, B. J. & Memmott, J. (2006). Pollinator of rare plants: arable weeds as a case study. *Journal of Applied Ecology*, **43**: 246-257. <https://doi.org/10.1111/j.1365-2664.2006.01130.x>
- Gilbert, L. E. (1972). Pollen Feeding and Reproductive Biology of Heliconius Butterflies. *Proceedings of the National Academy of Sciences*, **69**(6): 1402–1407. <https://doi.org/10.1073/pnas.69.6.1403>
- Gill, R. J., Baldock, K. C., Brown, M. J., Cresswell, J. E., Dicks, L. V., Fountain, M. T., Garratt, M. P., Gough, L. A., Heard, M. S., Holland, J. M. & Ollerton, J. (2016). Protecting an ecosystem service: approaches to understanding and mitigating threats to wild insect pollinators. *Advances in Ecological Research*, **54**: 135–206. <https://doi.org/10.1016/bs.aecr.2015.10.007>
- Gittings, T., O’Halloran, J., Kelly, T. & Giller, P. S. (2006). The contribution of open spaces to the maintenance of hoverfly (Diptera, Syrphidae) biodiversity in Irish plantation forests. *Forest ecology and management*, **237**(1–3): 290–300. <https://doi.org/10.1016/j.foreco.2006.09.052>
- Goldblatt, P., & Manning, J. C. (2007). Pollination of *Romulea syringodeoflora* (Iridaceae: Crocoideae) by a long-proboscid fly, *Prosoeca* sp. (Diptera: Nemestrinidae). *South African Journal of Botany*, **73**(1): 56-59. <https://doi.org/10.1016/j.sajb.2006.07.002>
- Gomes, V. G. N., Quirino, Z. G. M., & Machado, I. C. (2014). Pollination and seed dispersal of *Melocactus ernestii* Vaupelet subsp. *ernestii* (Cactaceae) by lizards: an example of double mutualism. *Plant Biology*, **16**(2): 315-322. <https://doi.org/10.1111/plb.12063>

- Gómez, J. M., Perfectti, F., & Jordano, P. (2011). The functional consequences of mutualistic network architecture. *PLoS One*, **6**(1): e16143. <https://doi.org/10.1371/journal.pone.0016143>
- Goulson, D., Nicholls, E., Botías, C., & Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Scienceexpress*, **347**(6229): 1255957.
- Grab, H., Branstetter, M. G., Amon, N., Urban-Mead, K. R., Park, M. G., Gibbs, J., ... & Danforth, B. N. (2019). Agriculturally dominated landscapes reduce bee phylogenetic diversity and pollination services. *Science*, **363**(6424): 282-284.
- Grass, I., Berens, D. G., Peter, F., & Farwig, N. (2013). Additive effects of exotic plant abundance and land-use intensity on plant–pollinator interactions. *Oecologia*, **173**(3): 913-923. doi:10.1007/s00442-013-2688-6
- Greco, C. F. & Kevan, P. G. (1994). Contrasting patch choosing by anthophilous ambush predator: vegetation and floral cues for decisions by a crab spider (*Misumera vantia*) and males and females of ambush bug (*Phymata americana*). *Canadian Journal of Zoology*, **72**: 1580-1588. <https://doi.org/10.1139/z94-210>
- Greenleaf, S. S., Williams, N. M., Winfree, R., & Kremen, C. (2007). Bee foraging ranges and their relationship to body size. *Oecologia*, **153**(3): 589-596.
- Gregorc, A. (2020). Monitoring of honey bee colony losses: a special issue. *Diversity*, **12**(10): 403. <https://doi.org/10.3390/d12100403>
- Guérin–Méneville, F.E. (1833) Insectes. In: Bélanger, C., *Voyage aux Indes–Orientales, par le nord de l’Europe, les provinces de Caucase, la Géorgie, l’Arménie et la Perse, suivi de détails topographiques, statistiques et autres sur le Pégou, les îles de Java, de Maurice et de Bourbon, sur le Cap–de–Bonne Espérance et Saint–Hélène, pendant les années 1825, 1826, 1827, 1828 et 1829, publié sous les auspices de LL. EE. MM. les Ministres de la Marine et de l’Intérieur.* (Zool.). H. Bertrand, Paris, p. 441–512.
- Guisan, A., & Thuiller, W. (2005). Predicting species distribution: offering more than simple habitat models. *Ecology Letters*, **8**(9): 993-1009. <https://doi.org/10.1111/j.1461-0248.2005.00792.x>

- Güler, Y., & Sorkun, K. (2010). Analysis of pollen collected by *Andrena flavipes* Panzer (Hymenoptera: Andrenidae) in sweet cherry orchards, Afyonkarahisar province of Turkey. *Psyche*, 2010. <https://doi.org/10.1155/2010/160789>
- Guo, Y., Zhang, X., Shan, Y & Li, J. (2017). Evolution of Diversity and abundance of pollinating insects on oilseed rape in major planting area of China. *International Journal of Agricultural Policy and Research*, **5**(6): 117-124. <https://doi.org/10.15739/IJAPR.17.013>
- Gurung, S., Koju, N. K., & Koju, N. P. (2020). Diversity of pollinators in marigold (*Tagetes erecta* L.) in a core area of Kathmandu Valley, Nepal. *Nepal Journal of Environmental Science*, **8**:29-38.
- Guzman, L. M., Chamberlain, S. A., & Elle, E. (2021). Network robustness and structure depend on the phenological characteristics of plants and pollinators. *Ecology and Evolution*, **11**(19): 13321-13334. <https://doi.org/10.1002/ece3.8055>
- Hammer, Ø., Harper, D.A. & Ryan, P.D. (2001). PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, **4**(1): 9.
- Hanula, J. L., Ulyshen, M. D., & Horn, S. (2016). Conserving pollinators in North American forests: a review. *Natural Areas Journal*, **36**(4): 427-439. <https://doi.org/10.3375/043.036.0409>
- Haslett, J. R. (1989). Adult feeding by holometabolous insects: pollen and nectar as complementary nutrient sources for *Rhingia campestris* (Diptera: Syrphidae). *Oecologia*, **81**(3): 361-363.
- Hassan, M. A., Bodlah, I., Ahmad, M., Kayani, A. R., & Mahmood, K. (2020). First record of the genus *Graptomyza* Wiedemann, 1830 (Diptera: Syrphidae) from Pakistan. *The Journal of Animal and Plant Sciences*, **30**(2): 512-516.
- Hassan, M. A., Bodlah, I., Aihetasham, A., Bodlah, M. A. & Hussain, K. (2019) First Record of *Baccha maculata* Walker, 1852 (Diptera: Syrphidae) from the Pothwar Punjab, Pakistan. *Punjab University Journal of Zoology*, **34**(2): 133–135.

- Hassan, M. A., Bodlah, I., Shehzad, A., Fatima, N. & Fazal, S. (2021) First record of the genus *Myolepta* Newman, 1838 (Diptera: Syrphidae) for Pakistan, with description of a new species. *Oriental Insects*, **55**: 564–573. <https://doi.org/10.1080/00305316.2020.1848656>
- Hassan, M. A., Ghorpadé, K., Mahmood, K., Shehzad, A., Nazir, N. & Fatima, N. (2018a) Preliminary studies on the Syrphidae (Diptera) of Poonch District, Azad Kashmir, Pakistan. *Oriental Insects*, **52**(2): 190–209. <https://doi.org/10.1080/00305316.2017.1394924>
- Hassan, M. A., Mahmood, K., Nazir, K. & Fatima, N. (2017) Faunistic work on the Hover flies (Diptera: Syrphidae) of District Narowal, Pakistan. *Journal of Entomology and Zoology Studies*, **5**: 626–630.
- Hellwig, N., Schubert, L. F., Kirmer, A., Tischew, S., & Dieker, P. (2022). Effects of wildflower strips, landscape structure and agricultural practices on wild bee assemblages—A matter of data resolution and spatial scale?. *Agriculture, Ecosystems & Environment*, **326**: 107764. <https://doi.org/10.1016/j.agee.2021.107764>
- Herrera, C. M. (1987). Components of pollinator "quality": comparative analysis of a diverse insect assemblage. *Oikos*, **50**(1):79-90. <https://doi.org/10.2307/3565403>
- Hicks, D. M., Ouvrard, P., Baldock, K. C., Baude, M., Goddard, M. A., Kunin, W. E., Mitschunas, N., Memmott, J., Morse, H., Nikolitsi, M. & Osgathorpe, L. M. (2016). Food for pollinators: quantifying the nectar and pollen resources of urban flower meadows. *PloS one*, **11**(6): e0158117. <https://doi.org/10.1371/journal.pone.0158177>
- Hippa, H., & Ståhls, G. (2005). Morphological characters of adult Syrphidae: descriptions and phylogenetic utility. *Acta Zoologica Fennica*, **2005**(215), 1-72.
- Holloway, B. A. (1976). Pollen-feeding in hover-flies (Diptera: Syrphidae). *New Zealand Journal of Zoology*, **3**:339-350. <https://doi.org/10.1080/03014223.1976.9517924>
- Horiuchi, Y., Ishii, C., Kamijo, T., & Tanaka, N. (2022). Generalist flower-visiting hoverflies as non-negligible actors in pollen transport network in a botanical garden: verification of a hoverfly pollen transport network using pollen DNA barcoding. *Arthropod-Plant Interactions*, 1-11.

- Howlett, B. G., & Gee, M. (2019). The potential management of the drone fly (*Eristalis tenax*) as a crop pollinator in New Zealand. *New Zealand Plant Protection*, **72**: 221-230. <https://doi.org/10.30843/nzpp.2019.72.304>
- Howlett, B. G., Todd, J. H., Willcox, B. K., Rader, R., Nelson, W. R., Gee, M., ... & Davidson, M. M. (2021). Using non-bee and bee pollinator-plant species interactions to design diverse plantings benefiting crop pollination services. In *Advances in Ecological Research* (Vol. 64, pp. 45-103). Academic Press. <https://doi.org/10.33307/entomon.v45i3.550>
- Hudewenz, A., Klein, A.M., Scherber, C., Stanke, L., Tschardt, T., Vogel, A., Weigelt, A., Weisser, W.W. & Ebeling, A. (2012). Herbivore and pollinator responses to grassland management intensity along experimental changes in plant species richness. *Biological Conservation*, **150**(1), 42–52. <https://doi.org/10.1016/j.biocon.2012.02.024>
- Hülsmann, M., von Wehrden, H., Klein, A. M. & Leonhardt, S. D. (2015). Plant diversity and composition compensate for negative effects of urbanization on foraging bumble bees. *Apidologie*, **46**(6): 760-770. DOI: 10.1007/s13592-015-0366-x
- Inouye, D. W., & Ogilvie, J. E. (2001). Pollinators, role of. *Encyclopedia of Biodiversity*, 723-730.
- Irungbam, J. S., Huidrom, H. & Soibam, B. S. (2017). Range extension of the Indian Tortoiseshell *Aglais caschmirensis aesis* (Fruhstorfer, 1912) (Lepidoptera: Nymphalidae) into the hills of Manipur, India. *Journal of Threatened Taxa*, **9**(10): 10860–10864. DOI: <http://doi.org/10.11609/jott.2983.9.10.10860-10864>
- Jacobs, J. H., Clark, S. J., Denholm, I., Goulson, D., Stoate, C. & Osborne, J. L. (2009). Pollination biology of fruit-bearing hedgerow plants and the role of flower-visiting insects in fruits set. *Annals of Botany*, **104**:1394-1404. <https://doi.org/10.1093/aob/mcp236>
- Jalilian, F. (2015). Biology and larval feeding rate of *Episyrphus balteatus* (Dip.: Syrphidae) on *Aphis pomi* (Hom.: Aphididae) at laboratory conditions. In *Biological Forum* (Vol. 7, No. 1, pp. 1395-1399). Satya Prakashan.

- James, C. C., Sánchez, D., Cruz-López, L., & Nieh, J. (2022). Fighting ability and the toxicity of raiding pheromone in an obligate kleptoparasite, the stingless bee *Lestrimelitta niitkib*. *Behavioral Ecology and Sociobiology*, **76**(3): 1-12. <https://doi.org/10.1007/s00265-022-03129-1>
- Janz, N. (2005). The relationship between habitat selection and preference for adult and larval food resources in the polyphagous butterfly *Vanessa cardui* (Lepidoptera: Nymphalidae). *Journal of Insect Behavior*, **18**(6): 767-780.
- Jauker, F., Bondarenko, B., Becker, H. C., & Steffan-Dewenter, I. (2012). Pollination efficiency of wild bees and hoverflies provided to oilseed rape. *Agricultural and Forest Entomology*, **14**(1): 81-87. <https://doi.org/10.1111/j.1461-9563.2011.00541.x>
- Jauker, F., Diekoetter, T., Schwarzbach, F., & Wolters, V. (2009). Pollinator dispersal in an agricultural matrix: opposing responses of wild bees and hoverflies to landscape structure and distance from main habitat. *Landscape Ecology*, **24**(4): 547-555.
- Jauker, F., Jauker, B., Grass, I., Steffan-Dewenter, I., & Wolters, V. (2019). Partitioning wild bee and hoverfly contributions to plant–pollinator network structure in fragmented habitats. *Ecology*, **100**(2): 1–8. <https://www.jstor.org/stable/26627500>.
- Jennersten, O. (1984). Flower visitation and pollination efficiency of some North European butterflies. *Oecologia*, **63**(1): 80-89.
- Jha, P. K. (2020). Seasonal Diversity of Birds in Nagarjun Forest of Shivapuri Nagarjun National Park, Kathmandu, Nepal. *Tribhuvan University Journal*, **35**(1): 33-43.
- Jin, B., Zhang, L., Lu, Y., Wang, D., Jiang, X. X., Zhang, M. & Wang, L. (2012). The mechanism of pollination drop withdrawal in *Ginkgo biloba* L. *BMC Plant Biology*, **12**(59).
- Johnson, N., Triplehorn, C. & Borror, D. (2004). *Introduction to the study of insects*. Thompson Brooks Cole, Belmont, 888pp.
- Johnson, S. D., & Bond, W. J. (1994). *Red flowers and butterfly pollination in the fynbos of South Africa*. In *Plant-animal interactions in Mediterranean-type*

ecosystems (pp. 137-148). Springer, Dordrecht. DOI: 10.1007/978-94-011-0908-6_13

- Jones, E. L., Rendell, L., Pirotta, E., & Long, J. A. (2016). Novel application of a quantitative spatial comparison tool to species distribution data. *Ecological Indicators*, **70**: 67-76.
- Jones, M., Bertola, L. D., & Razgour, O. (2016). Predicting the effect of interspecific competition on habitat suitability for the endangered African wild dog under future climate and land cover changes. *Hystrix, the Italian Journal of Mammalogy*, **27**(1). <https://doi.org/10.1016/j.ecolind.2016.05.051>
- Jordano, P., Bascompte, J., & Olesen, J. M. (2003). Invariant properties in coevolutionary networks of plant–animal interactions. *Ecology Letters*, **6**(1): 69-81. <https://doi.org/10.1046/j.1461-0248.2003.00403.x>
- Kambach, S., Guerra, F., Beck, S. G., Hensen, I., & Schleuning, M. (2012). Human-induced disturbance alters pollinator communities in tropical mountain forests. *Diversity*, **5**(1): 1-14. <https://doi.org/10.3390/d5010001>
- Kammerer, M., Goslee, S. C., Douglas, M. R., Tooker, J. F., & Grozinger, C. M. (2021). Wild bees as winners and losers: Relative impacts of landscape composition, quality, and climate. *Global Change Biology*, **27**(6): 1250-1265. <https://doi.org/10.1111/gcb.15485>
- Kanervo, E. (1938) Zur Systematic und Phylogenie der westpalaarktischen Eristalis-Arten (Dipt. Syrphidae) mit einer Revision derjenigen Finnlands. *Annales Universitatis Turkuensis* (A), **6**(4): 1-54.
- Kapoor V. C., Malla Y. K. & Rajbhandari Y. (1979) Syrphid flies (Diptera: Syrphidae) from Kathmandu Valley, Nepal with a Check List of Syrphids of Nepal. *Journal of Natural History Museum, Kathmandu*, **3**(1–4): 51–68.
- Kato, M. (2000). Anthophilous insect community and plant-pollinator interactions on Amami Islands in the Ryukyu Archipelago, Japan. *Contributions from the Biological Laboratory, Kyoto University*, **29**(2): 157-254.
- Kato, M., Kosaka, Y., Kawakita, A., Okuyama, Y., Kobayashi, C., Phimminith, T., & Thongphan, D. (2008). Plant–pollinator interactions in tropical monsoon forests

- in Southeast Asia. *American Journal of Botany*, **95**(11): 1375-1394.
<https://doi.org/10.3732/ajb.0800114>
- Kato, M., Makutani, T., Inoue, T., & Itino, T. (1990). Insect–flower relationship in the primary beech forest of Ashu. Kyoto: an.
- Kazerani, F., Talebi, A. A., & Gilasian, E. (2013). An annotated checklist of the subfamily Syrphinae (Diptera: Syrphidae) of Iran. *Entomofauna*, **34**(33): 409-448.
- Kearns, C. A. (1992). Anthophilous fly distribution across an elevation gradient. *American Midland Naturalist*, 172–182.
<https://doi.org/10.2307/2426332>
- Kearns, C. A., Inouye, D. W. & Waser, N. M. (1998). Endangered mutualisms. The conservation of plant-pollinators interactions. *Annual Review of ecology and Systemic*, **29**(1): 83-112.
- Kelber, A., & Somanathan, H. (2019). Spatial vision and visually guided behavior in apidae. *Insects*, **10**(12): 418. <https://doi.org/10.3390/insects10120418>
- Kells, A. R. & Goulson, D. (2003). Preferred nesting sites of bumblebee queens (Hymenoptera: Apidae) in agroecosystems in the UK. *Biological Conservation*, **109**:165-174. [https://doi.org/10.1016/S0006-3207\(02\)00131-3](https://doi.org/10.1016/S0006-3207(02)00131-3)
- Kendall, D. A. (1973). The viability and compatibility of pollen on insects visiting apple blossom. *Journal of Applied Ecology*, 847-853.
<https://doi.org/10.2307/2401873>
- Kennedy, C. M., Lonsdorf, E., Neel, M. C., Williams, N. M., Ricketts, T. H., Winfree, R., & Kremen, C. (2013). A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. *Ecology letters*, **16**(5): 584-599. <https://doi.org/10.1111/ele.12082>
- Kevan, P. G., Clark, E. A. & Thomas, V. G. (1990). Insect pollinators and sustainable agriculture. *American Journal of Alternative Agriculture*, **5**(1): 13–22.
<https://doi.org/10.1017/S0889189300003179>
- Khatriwada, S., Paudel, P. K., Chalise, M. K., & Ogawa, H. (2020). Comparative ecological and behavioral study of *Macaca assamensis* and *M. mulatta* in

- Shivapuri Nagarjun National Park, Nepal. *Primates*, **61**(4), 603-621.
<https://doi.org/10.1007/s10329-020-00810-9>
- Kitnya, N., Prabhudev, M. V., Bhatta, C. P., Pham, T. H., Nidup, T., Megu, K., ... & Otis, G. W. (2020). Geographical distribution of the giant honey bee *Apis laboriosa* Smith, 1871 (Hymenoptera, Apidae). *Zookeys*, 951: 67.
<https://doi.org/10.3897/zookeys.951.49855>
- Kjellsson, G., Rasmussen, F. N., & Dupuy, D. (1985). Pollination of *Dendrobium infundibulum*, *Cymbidium insigne* (Orchidaceae) and *Rhododendron lyi* (Ericaceae) by *Bombus eximius* (Apidae) in Thailand: a possible case of floral mimicry. *Journal of Tropical Ecology*, **1**(4): 289-302.
<https://doi.org/10.1017/S0266467400000389>
- Klein, A. M., Brittain, C., Hendrix, S. D., Throp, R., Williams, N. & Kremen, C. (2012). Wild pollination services to California almond rely on semi-natural habitat. *Journal of Applied Ecology*, **49**: 723-732. <https://doi.org/10.1111/j.1365-2664.2012.02144.x>
- Klein, A. M., Vaissiere, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the royal society B: biological sciences*, **274**(1608): 303-313. <https://doi.org/10.1098/rspb.2006.3721>
- Kline, O., & Joshi, N. K. (2020). Mitigating the effects of habitat loss on solitary bees in agricultural ecosystems. *Agriculture*, **10**(4): 115.
<https://doi.org/10.3390/agriculture10040115>
- Kluser, S., & Peduzzi, P. (2007). Global pollinator decline: a literature review.
- Knutson, L. V., Thompson, F. C. & Vockeroth, J. R. (1975). Family Syrphidae. In: Delfinado, M.D. & Hardy, D.E. (Eds.), *A catalog of the Diptera of the Oriental Region. Vol. II. Suborder Brachycera through division Aschiza, suborder Cyclorrhapha*. University of Hawaii Press, Honolulu, pp. 307–374.
- Koh, I., Lonsdorf, E. V., Williams, N. M., Brittain, C., Isaacs, R., Gibbs, J., & Ricketts, T. H. (2016). Modeling the status, trends, and impacts of wild bee abundance in the United States. *Proceedings of the National Academy of Sciences*, **113**(1): 140-145. <https://doi.org/10.1073/pnas.1517685113>

- Koirala, S., Chalise, M. K., Katuwal, H. B., Gaire, R., Pandey, B., & Ogawa, H. (2017). Diet and activity of *Macaca assamensis* in wild and semi-provisioned groups in Shivapuri Nagarjun National Park, Nepal. *Folia Primatologica*, **88**(2): 57-74. DOI: 10.1159/000477581
- Koneri, R., Nangoy, M., & Wakhid, W. (2021). Richness and diversity of insect pollinators in various habitats around Bogani Nani Wartabone National Park, North Sulawesi, Indonesia. *Biodiversitas Journal of Biological Diversity*, **22**(1). <https://doi.org/10.13057/biodiv/d220135>
- Konvicka, M., Hula, V., & Fric, Z. (2003). Habitat of pre-hibernating larvae of the endangered butterfly *Euphydryas aurinia* (Lepidoptera: Nymphalidae): What can be learned from vegetation composition and architecture?. *European Journal of Entomology*, **100**(3): 313-322.
- Kopit, A. M., & Pitts-Singer, T. L. (2018). Routes of pesticide exposure in solitary, cavity-nesting bees. *Environmental Entomology*, **47**(3), 499-510. <https://doi.org/10.1093/ee/nvy034>
- Kovács-Hostyánszki, A., Espíndola, A., Vanbergen, A.J., Settele, J., Kremen, C. & Dicks, L.V., (2017). Ecological intensification to mitigate impacts of conventional intensive land use on pollinators and pollination. *Ecology Letters*, **20**(5): 673–689. <https://doi.org/10.1111/ele.12762>
- Kremen C. (2005). Managing ecosystem services: what do we need to know about their ecology? *Ecology Letters*. **8**:468–79. <https://doi.org/10.1111/j.1461-0248.2005.00751.x>
- Kremen, C., Williams, N. H., Aizen, M. A., Gemmill-Herren, B., LeBuhn, G., Minckley, R. *et al.* (2007). Pollination and other ecosystem services produced by mobile organisms: a conceptual frame work for the effects of land-use change. *Ecology Letters*, **10**: 299-314. <https://doi.org/10.1111/j.1461-0248.2007.01018.x>
- Kudo, G., & Cooper, E. J. (2019). When spring ephemerals fail to meet pollinators: mechanism of phenological mismatch and its impact on plant reproduction. *Proceedings of the Royal Society B*, **286**(1904): 20190573. <https://doi.org/10.1098/rspb.2019.0573>

- Kühnel, S. & Blüthgen, N. (2015). High diversity stabilizes the thermal resilience of pollinator communities in intensively managed grasslands. *nature communications*, **6**(1): 1–10. DOI: 10.1038/ncomms8989
- Kumari, P., & Sidhu, A.K. (2020). Diversity of apoidea (Hymenoptera) from Grassland ecosystem of Jammu (UT of Jammu and Kashmir). *Journal of Entomology and Zoology Studies*, **8**:424–427.
- Kumari, P., Kumar, N. R., Sidhu, A. K., & Chandra, K. (2018). Taxonomical and behavioural studies on *Megachile conjuncta* (Fabricius) (Hymenoptera: Megachilidae: Cressoniella). *Journal of Entomology and Zoology Studies*, **6**:2198–2201.
- Kunin, W. E. (1993). Sex and the single mustard: population density and pollinator behaviour effects on seed-set. *Ecology*, **74**: 2145±2160. <https://doi.org/10.2307/1940859>
- Kunz, T. H., Braun de Torrez, E., Bauer, D., Lobo, T., & Fleming, T. H. (2011). Ecosystem services provided by bats. *Annals of the New York Academy of Sciences*, **1223**(1): 1-38. <https://doi.org/10.1111/j.1749-6632.2011.06004.x>
- Kwaiser, K. S., & Hendrix, S. D. (2008). Diversity and abundance of bees (Hymenoptera: Apiformes) in native and ruderal grasslands of agriculturally dominated landscapes. *Agriculture, Ecosystems & Environment*, **124**(3-4): 200-204. <https://doi.org/10.1016/j.agee.2007.09.012>
- Lambeck, H.J.P. & Kiauta, B. (1973) On a small collection of syrphid flies (Diptera: Syrphidae) from the Kathmandu Valley and the Khumbu Himal region (Nepal). *Entomologische Berichten, Deel*, **33** : 72–78.
- Landry, C. (2010). Mighty Mutualisms: The Nature of Plant-pollinator Interactions. *Nature Education Knowledge*, **3**(10): 37.
- Larson, B. M. H; Kevan, P. G.; Inouye, D. W. (2001). "Flies and flowers: taxonomic diversity of anthophiles and pollinators.". *Canadian Entomologist*, **133**(4): 439–465. <https://doi.org/10.4039/Ent133439-4>
- Latreille, P. A. (1804) Tableau méthodique des insectes. *In: Société de Naturalistes et d'Agriculteurs (Ed.), Nouvelle dictionnaire d'Histoire naturelle. Vol. 24. F. Dufart, Paris, pp. 129–200.*

- Lautenbach, S., Seppelt, R., Liebscher, J., & Dormann, C. F. (2012). Spatial and temporal trends of global pollination benefit. *PLoS one*, **7**(4): e35954. <https://doi.org/10.1371/journal.pone.0035954>
- Laverty, T. M., & Plowright, R. C. (1988). Flower handling by bumblebees: A comparison of specialists and generalists. *Animal Behavior*, **36**(3): 733–740. [https://doi.org/10.1016/S0003-3472\(88\)80156-8](https://doi.org/10.1016/S0003-3472(88)80156-8)
- Le Féon, V., Schermann-Legionnet, A., Delettre, Y., Aviron, S., Billeter, R., Bugter, R., & Burel, F. (2010). Intensification of agriculture, landscape composition and wild bee communities: a large scale study in four European countries. *Agriculture, Ecosystems & Environment*, **137**(1-2): 143-150. <https://doi.org/10.1016/j.agee.2010.01.015>
- Le Van Tho, D. V. S.(2021). Species diversity and distribution of wild bees (Hymenoptera: Apoidea) in Binh Chanh District, Ho Chi Minh City. *Thu Dau Mot University Journal of Science*, **3** (1): 25-35. <https://doi.org/10.37550/tdmu.EJS/2021.01.146>
- LeBuhn, G., Droege, S., & Carboni, M. (2007). Monitoring methods for solitary bee species using bee bowls in North America. *State of the World's Pollinators Report* (2007): 1-007.
- LeBuhn, G., Griswold, T., Minckley, R., Droege, S., Roulston, T. A., Cane, J. *et al.* (2003). A standardized method for monitoring bee populations—the bee inventory (BI) plot, **16**: 15.
- Lepš, J., & Šmilauer, P. (2003). *Multivariate analysis of ecological data using CANOCO*. Cambridge university press.
- Lesica, P., & Kittelson, P. M. (2010). Precipitation and temperature are associated with advanced flowering phenology in a semi-arid grassland. *Journal of Arid Environments*, **74**(9): 1013-1017. <https://doi.org/10.1016/j.jaridenv.2010.02.002>
- Li, T., Liu, X., Li, Z., Ma, H., Wan, Y., Liu, X., & Fu, L. (2018). Study on reproductive biology of *Rhododendron longipedicellatum*: A newly discovered and special threatened plant surviving in limestone habitat in Southeast Yunnan, China. *Frontiers in Plant Science*, **9**: 33. <https://doi.org/10.3389/fpls.2018.00033>

- Liang, C., Ding, G., Huang, J., Zhang, X., Miao, C., & An, J. (2020). Characteristics of the two Asian bumblebee species *Bombus friseanus* and *Bombus breviceps* (Hymenoptera: Apidae). *Insects*, **11**(3): 163. <https://doi.org/10.3390/insects11030163>
- Lieftinck, M. A. (1966). Notes on some anthophorine bees, mainly from the Old World (Apoidea). *Tijdschrift voor Entomologie*, **109**(6): 125-161.
- Linnaeus, C. (1758) *Systema Naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis. Editio decima, reformata. Tomus I. Laurentii Salvii, Holmiae*, 828 pp.
- Liow, L. H., Sodhi, N. S., & Elmqvist, T. (2001). Bee diversity along a disturbance gradient in tropical lowland forests of south-east Asia. *Journal of Applied Ecology*, 180-192.
- Losey, J. E. & Vaughan, M. (2006). The economic value of ecological services provided by insects. *Bioscience*, **56**(4): 311–323. [https://doi.org/10.1641/0006-3568\(2006\)56\[311:TEVOES\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2006)56[311:TEVOES]2.0.CO;2)
- Lucas, A., Bodger, O., Brosi, B. J., Ford, C. R., Forman, D. W., Greig, C., ... & de Vere, N. (2018). Generalisation and specialisation in hoverfly (Syrphidae) grassland pollen transport networks revealed by DNA metabarcoding. *Journal of Animal Ecology*, **87**(4): 1008-1021. <https://doi.org/10.1111/1365-2656.12828>
- Lucas, A., Bull, J. C., de Vere, N., Neyland, P. J., & Forman, D. W. (2017). Flower resource and land management drives hoverfly communities and bee abundance in seminatural and agricultural grasslands. *Ecology and Evolution*, **7**(19), 8073-8086. <https://doi.org/10.1002/ece3.3303>
- Macquart, P. J. M. (1842) *Dipteres exotiques nouveaux ou peu connus. Tome deuxieme. -2e partie*. Roret, Paris. 5–140 pp.
- Macquart, P. J. M. (1855) *Diptères exotiques nouveaux ou peu connus. 5.e supplément. Mémoires de la Société des Sciences, Agriculture et des Arts, de Lille, Series 2*(1): 25–156.
- Maharjan, B., Shah Nawaz, T. B., & Shrestha, P. M. (2017). Geo-spatial analysis of habitat suitability for common leopard (*Panthera pardus* Linnaeus, 1758) in Shivapuri Nagarjun National Park, Nepal. *Environment and Ecology Research*, **5**(2): 117-128. DOI: 10.13189/eer.2017.050206

- Mallinger, R. E., Gaines-Day, H. R., & Gratton, C. (2017). Do managed bees have negative effects on wild bees?: A systematic review of the literature. *PloS one*, **12**(12): e0189268. <https://doi.org/10.1371/journal.pone.0189268>
- Mani, M. S. (1962). Introduction to high altitude Entomology insect life above the timber–line in the north–west Himalaya. **31**(1): 48.
- Marín, A. J. C. (1969) Nota sobre las larvas de *Mesograpta polita* (Say) (Syrphidae, Diptera) en espigas de maíz (*Zea mays* L.) en El Limón, Aragua, Venezuela [Note on the larvae of *Mesograpta polita* (Say) (Syrphidae, Diptera) on the staminate flowers of corn (*Zea mays* L.) in El Limón, Aragua, Venezuela]. *Agronomía Tropical*, **19**: 335–339.
- Masters, J. A., & Emery, S. M. (2015). The showy invasive plant *Ranunculus ficaria* facilitates pollinator activity, pollen deposition, but not always seed production for two native spring ephemeral plants. *Biological Invasions*, **17**(8): 2329-2337.
- Matsumura, S. & Adachi, J. (1917) Synopsis of the economic Syrphidae of Japan (pt. III). *The Entomological Magazine*, Kyoto, **3**: 14–46.
- Matsumura, T. (1970). Bees from Nepal I. *Thyreus* Panzer (Hymenoptera, Apoidea). *Kontyu*, 38:314–317.
- Matteson, K. C. & Langellotto, G. A. (2010). Determinates of inner city butterfly and bee species richness. *Urban Ecosystems*, **13**(3): 333–347. DOI 10.1007/s11252-010-0122-y
- McKinney, A. M., & Goodell, K. (2010). Shading by invasive shrub reduces seed production and pollinator services in a native herb. *Biological Invasions*, **12**(8): 2751-2763.
- Meeus, I., Pisman, M., Smagghe, G., & Piot, N. (2018). Interaction effects of different drivers of wild bee decline and their influence on host–pathogen dynamics. *Current Opinion in Insect Science*, **26**: 136-141. <https://doi.org/10.1016/j.cois.2018.02.007>
- Meiners, J. M., Griswold, T. L., & Carril, O. M. (2019). Decades of native bee biodiversity surveys at Pinnacles National Park highlight the importance of monitoring natural areas over time. *PloS one*, **14**(1): e0207566. <https://doi.org/10.1371/journal.pone.0207566>

- Memmott, J., Waser, N. M., & Price, M. V. (2004). Tolerance of pollination networks to species extinctions. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, **271**(1557): 2605-2611. <https://doi.org/10.1098/rspb.2004.2909>
- Mengual, X., Bot, S., Chkhartishvili, T., Reimann, A., Thormann, J. & von der Mark, L. (2020) Checklist of hover flies (Diptera, Syrphidae) of the Republic of Georgia. *ZooKeys*, 916: 1–123. <https://doi.org/10.3897/zookeys.916.47824>
- Mengual, X., Mayer, C., Burt, T. O., Moran, K. M., Dietz, L., Nottebrock, G., ... & Skevington, J. H. (2022). Systematics and evolution of predatory flower flies (Diptera: Syrphidae) based on exon-capture sequencing. *Systematic Entomology*; 1-28. DOI: 10.1111/syen.12573
- Mengual, X., Ståhls, G. & Rojo, S. (2015) Phylogenetic relationships and taxonomic ranking of pipizine flower flies (Diptera: Syrphidae) with implications for the evolution of aphidophagy. *Cladistics*, **31**(5) : 491–508. <https://doi.org/10.1111/cla.12105>
- Meyer, B., Jauker, F. & Steffan–Dewenter, I. (2009). Contrasting resource–dependent responses of hoverfly richness and density to landscape structure. *Basic and Applied Ecology*, **10**(2), 178–186. <https://doi.org/10.1016/j.baae.2008.01.001>
- Michener, C. D. (1982). A new interpretation of fossil social bees from the Dominican Republic. *Sociobiology*, **7**(1): 37.
- Michener, C. D. (2007). *The Bees of the World*. 2nd edition. Johns Hopkins University Press: Baltimore.
- Michener, C. D. (2013). The meliponini. In Pot-honey (pp. 3-17). Springer, New York, NY. DOI: 10.1007/978-1-4614-4960-7_1
- Mitchell, R. J., Irwin, R. E., Flanagan, R. J., & Karron, J. D. (2009). Ecology and evolution of plant–pollinator interactions. *Annals of Botany*, **103**(9): 1355-1363. <https://doi.org/10.1093/aob/mcp122>
- Momose, K., Yumoto, T., Nagamitsu, T., Kato, M., Nagamasu, H., Sakai, S. *et al.* (1998). Pollination biology in a lowland dipterocarp forest in Sarawak, Malaysia. I. Characteristics of the plant-pollinator community in a lowland dipterocarp forest. *American Journal of Botany*, **85**(10): 1477-1501. <https://doi.org/10.2307/2446404>

- Moquet, L., Laurent, E., Bacchetta, R. & Jacquemart, A. L. (2018). Conservation of hoverflies (Diptera, Syrphidae) requires complementary resources at the landscape and local scales. *Insect Conservation and Diversity*, **11**(1): 72–87. <https://doi.org/10.1111/icad.12245>
- Moran, K. M., Skevington, J. H., Kelso, S., Mengual, X., Jordaens, K., Young, A. D., ... & Van Steenis, W. (2022). A multigene phylogeny of the eristaline flower flies (Diptera: Syrphidae), with emphasis on the subtribe Criorhinina. *Zoological Journal of the Linnean Society*, **194**(1), 120-135. <https://doi.org/10.1093/zoolinnean/zlab006>
- Morandin, L. A., & Kremen, C. (2013). Hedgerow restoration promotes pollinator populations and exports native bees to adjacent fields. *Ecological Applications*, **23**(4): 829-839. <https://doi.org/10.1890/12-1051.1>
- Morse, R. A., & Calderone, N. W. (2000). The value of honey bees as pollinators of US crops in 2000. *Bee Culture*, **128**(3): 1-15.
- Mudri-Stojnić, S., Andrić, A., Jozan, Z., & Vujić, A. (2012). Pollinator diversity (Hymenoptera and Diptera) in semi-natural habitats in Serbia during summer. *Archives of Biological Sciences*, **64**(2): 777-786. <https://doi.org/10.2298/ABS1202777S>
- Murao, R., & Matsumura, T. (2012). Occurrence of *Lipotriches ceratina* and *Nomia incerta* (Hymenoptera, Halictidae) in Nepal. *Japanese Journal of Systematic Entomology*, **18**(2): 421-423.
- Murao, R., & Tadauchi, O., (2013). Notes on the distribution of the genus *Seladonia* (Hymenoptera, Halictidae). *Japanese Society of Systematic Entomology*, **19**: 77–81.
- Murao, R., Tadauchi, O., Miyanaga, R., & Matsumura, T. (2015). New Records of the Bee Genus *Nomia* (Hymenoptera: Halictidae) in Nepal. *Japanese Journal of Systematic Entomology*, **21**(1): 5–6.
- Murray, E. T., Fitzpatrick, U., Brown, M. J. F. & Paxton, R. J. (2008). Cryptic species diversity in a widespread bumble bee complex revealed using mitochondrial DNA RFLPs. *Conserv Genet*, **9**:653–666.

- Nayar, J. L. (1968) A contribution to our knowledge of high altitude Syrphidae (Cyclorrhapha: Diptera) from NW Himalaya. Part II—Subfamily Eristalinae. *Agra University Journal of Research, Science*, **16**(3): 27–31.
- Nemésio, A., Silva, D. P., Nabout, J. C., & Varela, S. (2016). Effects of climate change and habitat loss on a forest-dependent bee species in a tropical fragmented landscape. *Insect Conservation and Diversity*, **9**(2): 149-160. <https://doi.org/10.1111/icad.12154>
- Neumüller, U., Burger, H., Krausch, S., Blüthgen, N. & Ayasse, M. (2020). Interactions of local habitat type, landscape composition and flower availability moderate wild bee communities. *Landscape Ecology*, **35**(10): 2209–2224. <https://doi.org/10.1007/s10980-020-01096-4>
- Ngat, T. T., Minh, N. P., Lam, T. X., Thi, N., & Lien, P. (2017). Studies of the genus *Thyreus panzer* (Hymenoptera: Apidae: Apinae) with six new records from Vietnam. In *Biological Forum—an International Journal*, **9**(2): 227-236.
- Nielsen, A., & Totland, Ø. (2013). Structural properties of mutualistic networks withstand habitat degradation while species functional roles might change. *Oikos*, **123**(3): 323-333. <https://doi.org/10.1111/j.1600-0706.2013.00644.x>
- Nielsen, A., Steffan- Dewenter, I., Westphal, C., Messinger, O., Potts, S. G., Roberts, S. P. M., *et al.* (2011). Assessing bee species richness in two Mediterranean communities: importance of habitat type and sampling techniques. *Ecological Research*, **26**: 969-983.
- Nielsen, T. R. (2016). Records and notes on some Oriental *Platycheirus* species and description of the female *P. himalayensis* Brunetti, 1915 (Diptera, Syrphidae). *Norwegian Journal of Entomology*, **63**: 169–174.
- Nuriyah, S., Husodo, T., Hermawan, W., Yusuf, A. A., Kasmara, H., Kusmoro, J., ... & Shanida, S. S. (2021). Floral diversity of honey bee-collected pollen (*Apis cerana*) colonies in the Ir. H. Djuanda Forest Park, West Java, Indonesia. *Nusantara Bioscience*, **13**(2). <https://doi.org/10.13057/nusbiosci/n130208>
- Oksanen, J., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O'hara, R. B., ... & Oksanen, M. J. (2013). Package ‘vegan’. *Community Ecology Package, Version*, **2**(9): 1-295.

- Okuyama, T., & Holland, J. N. (2008). Network structural properties mediate the stability of mutualistic communities. *Ecology Letters*, **11**(3): 208-216. <https://doi.org/10.1111/j.1461-0248.2007.01137.x>
- Olesen, J. M., Bascompte, J., Elberling, H., & Jordano, P. (2008). Temporal dynamics in a pollination network. *Ecology*, **89**(6): 1573-1582. <https://doi.org/10.1890/07-0451.1>
- Oliver, T., Roy, D. B., Hill, J. K., Brereton, T. & Thomas, C. D. (2010). Heterogeneous landscapes promote population stability. *Ecology letters*, **13**(4): 473-484. <https://doi.org/10.1111/j.1461-0248.2010.01441.x>
- Ollerton, J., Winfree, R., & Tarrant, S. (2011). How many flowering plants are pollinated by animals?. *Oikos*, **120**(3): 321-326. doi: 10.1111/j.1600-0706.2010.18644.x
- Orr, M. C., Hughes, A. C., Chesters, D., Pickering, J., Zhu, C. D., & Ascher, J. S. (2021). Global patterns and drivers of bee distribution. *Current Biology*, **31**(3): 451-458. <https://doi.org/10.1016/j.cub.2020.10.053>
- Osten Sacken, C. R. (1875) A list of the North American Syrphidae. *Bulletin of the Buffalo Society of Natural Science*, **3**: 38-71.
- Osten Sacken, C. R. (1877) Western Diptera: Descriptions of new genera and species of Diptera from the region west of the Mississippi and especially from California. *Bulletin of the United States Geological and Geographic Survey of the Territories*, **3**: 189-354.
- Quin, A., Sarthou, J. P., Bouyjou, B., Deconchat, M., Lacombe, J. P., & Monteil, C. (2006). The species-area relationship in the hoverfly (Diptera, Syrphidae) communities of forest fragments in southern France. *Ecography*, **29**(2): 183-190. <https://doi.org/10.1111/j.2006.0906-7590.04135.x>
- Pan, K., Marshall, L., Biesmeijer, K., & de Snoo, G. R. (2022). The distributions of insect, wind and self-pollination of plants in the Netherlands in relation to habitat types and 3D vegetation structure. *Journal of Pollination Ecology*, **31**: 16-28. [https://doi.org/10.26786/1920-7603\(2022\)684](https://doi.org/10.26786/1920-7603(2022)684)

- Pape, T., Blagoderov, V. & Mostovski, M. B. (2011) Order Diptera Linnaeus, 1758. *In*: Zhang, Z.Q. (Ed.), Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness. *Zootaxa*, **3148**: 222–229.
- Pape, T., & Evenhuis, N. (2019) Systema Dipterorum. The biosystematics database of world, Diptera, version 1.5. Available at: <http://sd.zoobank.org/> [Accessed 30th January 2020]
- Parra-Tabla, V., Albor-Pinto, C., Tun-Garrido, J., Angulo-Pérez, D., Barajas, C., Silveira, R., ... & Arceo-Gómez, G. (2018). Spatial patterns of species diversity in sand dune plant communities in Yucatan, Mexico: importance of invasive species for species dominance patterns. *Plant Ecology & Diversity*, **11**(2), 157-172. <https://doi.org/10.1080/17550874.2018.1455232>
- Partap, T. (2001). Mountain agriculture, marginal land and sustainable livelihoods: Challenges and opportunities. International Symposium on Mountain Agriculture in HKH Region (21-24 May 2001). ICIMOD, Kathmandu, Nepal
- Pasquet R. S, Peltier A, Hufford M. B, Oudin, E. & Saulnier, J. (2008). Longdistance pollen flow assessment through evaluation of pollinator foraging range suggests transgene escape distance. *PNAS*, **105**(36): 13456-13461. <https://doi.org/10.1073/pnas.0806040105>
- Pathak, H. N., Shrestha, B. B., Bhujju, D. R., & Bhandari, P. (2020). Floristic Diversity in the Lake Cluster of Pokhara Valley, Central Nepal. *Journal of Natural History Museum*, **31**(1): 1-32.
- Patrício-Roberto, G. B., & Campos, M. J. (2014). Aspects of landscape and pollinators—what is important to bee conservation?. *Diversity*, **6**(1): 158-175. <https://doi.org/10.3390/d6010158>
- Pauli, T., Burt, T. O., Meusemann, K., Bayless, K., Donath, A., Podsiadlowski, L. A. R. S., ... & Mengual, X. (2018). New data, same story: phylogenomics does not support Syrphoidea (Diptera: Syrphidae, Pipunculidae). *Systematic Entomology*, **43**(3), 447-459. <https://doi.org/10.1111/syen.12283>
- Pellissier, L., Pottier, J., Vittoz, P., Dubuis, A. & Guisan, A. (2010). Spatial pattern of floral morphology: possible insight into the effects of pollinators on plant distributions. *Oikos*, **119**(11): 1805–1813. <https://doi.org/10.1111/j.1600-0706.2010.18560.x>

- Pellmyr, O. (2003). Yuccas, yucca moths, and coevolution: a review. *Annals of the Missouri Botanical Garden*, 35-55. <https://doi.org/10.2307/3298524>
- Pereira, K. D. S., Meeus, I., & Smagghe, G. (2019). Honey bee-collected pollen is a potential source of *Ascospaera apis* infection in managed bumble bees. *Scientific Reports*, **9**(1), 1-9.
- Peterson, A. T., & Nakazawa, Y. 2008. Environmental data sets matter in ecological niche modelling: an example with *Solenopsis invicta* and *Solenopsis richteri*. *Global Ecology and Biogeography*, **17**: 135–144. <https://doi.org/10.1111/j.1466-8238.2007.00347.x>
- Phillips, S. J., Dudík, M., & Schapire, R. E. (2004). A maximum entropy approach to species distribution modeling. In *Proceedings of the twenty-first international conference on Machine learning* (p. 83).
- Pinheiro, L. A., Torres, L. M., Raimundo, J. & Santos, S. A. (2015). Effects of pollen, sugars and honeydew on lifespan and nutrient levels of *Episyrphus balteatus*. *BioControl*, **60**(1): 47–57. <https://doi.org/10.1007/s10526-014-9621-8>
- Pitts-Singer, T. L., & Cane, J. H. (2011). The alfalfa leafcutting bee, *Megachile rotundata*: the world's most intensively managed solitary bee. *Annual Review of Entomology*, 56:221–237
- Plowright, C. M. S., & Plowright, R. C. (1997). The advantage of short tongues in bumblebees (*Bombus*)—analyses of species distributions according to flower corolla depth, and of working speeds on white clover. *The Canadian Entomologist*, **129**(1): 51-59. <https://doi.org/10.4039/Ent12951-1>
- Poisot, T., Canard, E., Mouillot, D., Mouquet, N., & Gravel, D. (2012). The dissimilarity of species interaction networks. *Ecology Letters*, **15**(12): 1353-1361. <https://doi.org/10.1111/ele.12002>
- Pokhrel, S. (2006). Prospect, challenges, and opportunity of organic honey production in Nepal. In *Proceedings of a First National Workshop on Organic Farming* (pp. 12-14).
- Pokhrel, S. (2009). Comparative benefits of beekeeping enterprise in Chitwan, Nepal. *Journal of Agriculture and Environment*, **10**: 46-59.

- Policarová, J., Cardinal, S., Martins, A. C., & Straka, J. (2019). The role of floral oils in the evolution of apid bees (Hymenoptera: Apidae). *Biological Journal of the Linnean Society*, **128**(2): 486-497. <https://doi.org/10.1093/biolinnean/blz099>
- Pollard, E., & Yates, T. J. (1994). *Monitoring butterflies for ecology and conservation: the British butterfly monitoring scheme*. Springer Science & Business Media.
- Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution*, **25**(6): 345-353. <https://doi.org/10.1016/j.tree.2010.01.007>
- Potts, S. G., Imperatriz-Fonseca, V., Ngo, H. T., Aizen, M. A., Biesmeijer, J. C., Breeze, T. D., ... Vanbergen, A. J. (2016). Safeguarding pollinators and their values to human well-being. *Nature*, **540**(7632): 220–229. <https://doi.org/10.1038/nature20588>
- Potts, S. G., Vulliamy, B., Dafni, A., Ne'eman, G. & Willmer, P. (2003). Linking bees and flowers: how do floral communities structure pollinator communities? *Ecology*, **84**(10): 2628–2642. <https://doi.org/10.1890/02-0136>
- Potts, S. G., Vulliamy, B., Roberts, S., O. Too le, C., Dafni, A., Ne'Eman, G. *et al.* (2005). Role of nesting resources in organizing diverse bee communities in a mediterranean landscape. *Ecological Entomology*, **30**: 78-85. <https://doi.org/10.1111/j.0307-6946.2005.00662.x>
- Power, E. F & Stout, J. C. (2011). Organic dairy farming: impacts on insect-flower interaction networks and pollination. *Journal of Applied Ecology*, **48**: 561-569. <https://doi.org/10.1111/j.1365-2664.2010.01949.x>
- Prakash, A. S., Jobiraj, T., & Bijoy, C. (2020). A checklist of bees (Insecta: Hymenoptera: Apoidea) of Kerala. *Entomon*, **45**(3), 189-200. <https://doi.org/10.33307/entomon.v45i3.550>
- Primack, R. (1978). Variability in New Zealand montane and alpine pollinator assemblages. *New Zealand Journal of Ecology* 1: 66±73.
- Proesmans, W. (2019). *The importance of small forest fragments for pollination services in agricultural landscapes* (Doctoral dissertation, Ghent University).

- Proesmans, W., Bonte, D., Smaghe, G., Meeus, I., & Verheyen, K. (2019). Importance of forest fragments as pollinator habitat varies with season and guild. *Basic and Applied Ecology*, **34**: 95-107. <https://doi.org/10.1016/j.baae.2018.08.004>
- Proshchalykin, M. Y., & Schwarz, M. (2017). The genus *Nomada* (Hymenoptera: Apidae) in Siberia. *Linzer Biologische Beiträge*, *49*(1), 985-1006.
- R Core Team, (2021). R: A language and environment for statistical computing. *R Foundation for statistical computing, Vienna, Austria*. URL <https://www.R-project.org/>
- Rader, R., Bartomeus, I., Garibaldi, L. A., Garratt, M. P., Howlett, B. G., Winfree, R., ... & Woyciechowski, M. (2016). Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences*, **113**(1): 146-151. <https://doi.org/10.1073/pnas.1517092112>
- Rader, R., Cunningham, S. A., Howlett, B. G., & Inouye, D. W. (2020). Non-bee insects as visitors and pollinators of crops: Biology, ecology, and management. *Annual Review of Entomology*, **65**: 391-407. <https://doi.org/10.1146/annurev-ento-011019-025055>
- Rader, R., Howlett, B. G., Cunningham, S. A., Westcott, D. A., Newstrom-Lloyd, L. E., Walker, M. K., ... & Edwards, W. (2009). Alternative pollinator taxa are equally efficient but not as effective as the honeybee in a mass flowering crop. *Journal of Applied Ecology*, **46**(5): 1080-1087. <https://doi.org/10.1111/j.1365-2664.2009.01700.x>
- Radosavljevic, A., & Anderson, R. P. (2014). Making better Maxent models of species distributions: complexity, overfitting and evaluation. *Journal of Biogeography*, **41**(4): 629-643. <https://doi.org/10.1111/jbi.12227>
- Raguso, R. A. (2020). Don't forget the flies: Dipteran diversity and its consequences for floral ecology and evolution. *Applied Entomology and Zoology*, **55**(1): 1-7. <https://doi.org/10.1007/s13355-020-00668-9>
- Ramirez, C. S., Martinez, P., Nunez, M., Gonzalez, C. & Armesto, J. J. (2005). Diversity, Flower visitation frequency and generalism of pollinators in temperate rainforest of Chiloe Island, Chile. *Botanical Journal of the Linnean Society*, **147**: 399-416. <https://doi.org/10.1111/j.1095-8339.2005.00388.x>

- Ramos-Jiliberto, R., Valdovinos, F. S., Moisset de Espanés, P., & Flores, J. D. (2012). Topological plasticity increases robustness of mutualistic networks. *Journal of Animal Ecology*, **81**(4): 896-904. <https://doi.org/10.1111/j.1365-2656.2012.01960.x>
- Reemer, M. (2005). Saproxyllic hoverflies benefit by modern forest management (Diptera: Syrphidae). *Journal of Insect Conservation*, **9**(1): 49-59. DOI: 10.1007/s10841-004-6059-9
- Reemer, M. (2012). *Natural history of Microdontinae (Diptera: Syrphidae): a review. Unravelling a hotchpotch: phylogeny and classification of the Microdontinae (Diptera: Syrphidae)*. PhD dissertation, Universiteit Leiden, Leiden.
- Reemer, M. (2016). Syrphidae (Diptera) of Surinam: Eristalinae and synthesis. *Tijdschrift voor Entomologie*, **159**(2): 97-142.
- Reemer, M., & Rotheray, G. E. (2009). Pollen feeding larvae in the presumed predatory syrphine genus *Toxomerus* Macquart (Diptera, Syrphidae). *Journal of Natural History*, **43**(15-16): 939-949. <https://doi.org/10.1080/00222930802610576>
- Riley, C. V., & Howard, L. O. (1888). The Corn-feeding *Syrphus*-fly (*Mesograpta polita* Say)(Order Diptera; family Syrphidae). *Insect life*, **1**: 5-8.
- Roberts, M. R. (2004). Response of the herbaceous layer to natural disturbance in North America. *Canadian Journal of Botany*, **82**: 1273-1283. <https://doi.org/10.1139/b04-091>
- Rodríguez-Gasol, N., Alins, G., Veronesi, E. R., & Wratten, S. (2020). The ecology of predatory hoverflies as ecosystem-service providers in agricultural systems. *Biological Control*, **151**: 104405. <https://doi.org/10.1016/j.biocontrol.2020.104405>
- Rohde, A. T., & Pilliod, D. S. (2021). Spatiotemporal dynamics of insect pollinator communities in sagebrush steppe associated with weather and vegetation. *Global Ecology and Conservation*, **29**: e01691. <https://doi.org/10.1016/j.gecco.2021.e01691>
- Rojo, S., Gilbert, F., Marcos-García, M. A., Nieto, J. M., & Mier, M. P. (2003). *A world review of predatory hoverflies (Diptera, Syrphidae: Syrphinae) and their prey* (No. DC).

- Rondani, C. (1845) Ordinamento sistematico dei generi italiani degli insetti ditteri. *Nuovi Annali delle Scienze Naturali e Rendiconto delle Sessioni della Società Agraria e dell'Accademia delle Scienze dell'Istituto di Bologna*, Series, **2**(2) : 443–459.
- Rondani, C. (1857) *Dipterologiae Italicae prodromus. Vol. II. Species Italicae ordinis dipterorum in genera characteribus definita, ordinatim collectae, methodo analitica distinctae, et novis vel minus cognitis descriptis. Pars prima. Oestridae: Syrphidae: Conopidae*. A. Stocche, Parmae [= Parma], 264 pp.
- Rotheray, G. E., & Gilbert, F. (2008). Phylogenetic relationships and the larval head of the lower Cyclorrhapha (Diptera). *Zoological Journal of the Linnean Society*, **153**(2): 287-323. <https://doi.org/10.1111/j.1096-3642.2008.00395.x>
- Roubik, D. (2006). Stingless bee nesting biology. *Apidologie*, **37**: 124-143. DOI: 10.1051/apido:2006026
- Roulston, T. A. H., & Goodell, K. (2011). The role of resources and risks in regulating wild bee populations. *Annual Review of Entomology*, **56**: 293-312.
- Rundlöf, M., Nilsson, H., & Smith, H. G. (2008). Interacting effects of farming practice and landscape context on bumble bees. *Biological Conservation*, **141**(2): 417-426. <https://doi.org/10.1016/j.biocon.2007.10.011>
- Sakagami, S. F., Roubik, D. W., & Zucchi, R. (1993). Ethology of the robber stingless bee, *Lestrimelitta limao* (Hymenoptera: Apidae). *Sociobiology*, **21**(2):237-277.
- Sankararaman, H., Daniel, J. A., Manickavasagam, S. & Pennards, G. (2020). First record of two interesting genera of hover flies (Diptera: Syrphidae) in South India. *Journal of Insect Biodiversity*, **14**(2): 54–63. <https://doi.org/10.12976/jib/2020.14.2.4>
- Sapkota, S., Gurung, D. B., Nepal, A., & Shah, K. B. (2021). Ecological Niche Modelling of King Cobra, *Ophiophagus hannah* (Cantor, 1836) in Nepal. *Indonesian Journal of Social and Environmental Issues (IJSEI)*, **2**(2): 163-175. <https://doi.org/10.47540/ijsei.v2i2.259>
- Schiner, I. R. (1860) Vorläufiger Commentar zum dipterologischen Theile der 'Fauna Austriaca', mit einer naheren Begründung der in derselben aufgenommenen

- neuen Dipteren–Gattungen. II. *Wiener Entomologische Monatschrift*, 4: 208–216.
- Schweiger, O., Musche, M., Bailey, D., Billeter, R., Diekötter, T., Hendrickx, F., ... & Dziöck, F. (2007). Functional richness of local hoverfly communities (Diptera, Syrphidae) in response to land use across temperate Europe. *Oikos*, **116**(3): 461-472. <https://doi.org/10.1111/j.2007.0030-1299.15372.x>
- Scopoli, J. A. (1763) *Entomologia carniolica exhibens insecta carnioliae indigena et distribute in ordines, genera, species, varietates. Methodo Linnaeana*. Trattner, Vindobonae [=Vienna], 420 pp.
- Seitz, N., vanEngelsdorp, D., & Leonhardt, S. D. (2020). Are native and non-native pollinator friendly plants equally valuable for native wild bee communities? *Ecology and Evolution*, **10**(23): 12838-12850. <https://doi.org/10.1002/ece3.6826>
- Senapathi, D., Biesmeijer, J. C., Breeze, T. D., Kleijn, D., Potts, S. G. & Carvalheiro, L. G. (2015). Pollinator conservation- the differences between managing for pollination services and preserving pollinator diversity. *Current Opinion in Insect Science*, **12**:93-101. <https://doi.org/10.1016/j.cois.2015.11.002>
- Senapathi, D., Goddard, M. A., Kunin, W. E. & Baldock, K. C. (2017). Landscape impacts on pollinator communities in temperate systems: evidence and knowledge gaps. *Functional Ecology*, **31**(1): 26–37. <https://doi.org/10.1111/1365-2435.12809>
- Sengupta, J., Naskar, A., Maity, A., Hazra, S., Sarkar, N. K. & Banerjee, D. (2017). Hover Flies (Diptera: Syrphidae) from Darjeeling Himalaya—A Part of Indo–Burmese Hotspot. *Indian Journal of Entomology*, **79**(3): 336–353. <http://dx.doi.org/10.5958/0974-8172.2017.00065.7>
- Sharp, M. A., Parks, D. R. & Ehrlich, P. R., 1974. Plant resources and butterfly habitat selection. *Ecology*, **55**(4): 870–875. <https://doi.org/10.2307/1934423>
- Shehzad, A., Ghorpadé, K., Rafi, M. A., Zia, A., Bhatti, A. R., Ilyas, M., & Shah, S. W. (2017) Faunistic study of Hover flies (Diptera: Syrphidae) of Pakistan. *Oriental Insects*, **51**(3): 197–220. <https://doi.org/10.1080/00305316.2016.1274275>

- Shiokawa, M. (2008). Synopsis of the bee genus *Ceratina* (Insecta: Hymenoptera: Apidae) in Nepal, with descriptions of five new species and one new subspecies. *Species Diversity*, **13**(4): 201-220. <https://doi.org/10.12782/specdiv.13.201>
- Shrestha, B. B. (2019). Management of invasive alien plants in Nepal: Current practices and future prospects. In *Tropical ecosystems: Structure, functions and challenges in the face of global change* (pp. 45-68). Springer, Singapore DOI: 10.1007/978-981-13-8249-9_4
- Shrestha, M., Garcia, J. E., Bukovac, Z., Dorin, A., & Dyer, A. G. (2018). Pollination in a new climate: assessing the potential influence of flower temperature variation on insect pollinator behaviour. *PLoS One*, **13**(8): e0200549. <https://doi.org/10.1371/journal.pone.0200549>
- Simanonok, M. P., & Burkle, L. A. (2014). Partitioning interaction turnover among alpine pollination networks: spatial, temporal, and environmental patterns. *Ecosphere*, **5**(11): 1-17. <https://doi.org/10.1890/ES14-00323.1>
- Siregar, E. H., Atmowidi, T. & Kahono, S. (2016). Diversity and Abundance of Insect Pollinators in Different agricultural land in Jambi, Sumatera. *Hayati Journal of Bioscience*, **23**: 13-17. <https://doi.org/10.1016/j.hjb.2015.11.002>
- Sjödin, N. E., Bengtsson, J. & Ekbom, B. (2008). The influence of grazing intensity and landscape composition on the diversity and abundance of flower-visiting insects. *Journal of Applied Ecology*, **45**(3): 763–772. <https://doi.org/10.1111/j.1365-2664.2007.01443.x>
- Slaa, E. J., Chaves, L. A. S., Malagodi-Braga, K. S., & Hofstede, F. E. (2006). Stingless bees in applied pollination: practice and perspectives. *Apidologie*, **37**(2): 293-315. <https://doi.org/10.1051/apido:2006022>
- Smith, C. (2010). Butterflies of Nepal, Himalayan Nature.
- Smith, C. (2011). Illustrated checklists of Nepal's butterflies. Mujpuria Publication, Craftman Press, Bangkok, Thailand.
- SNNP. (2017). *Shivapuri Nagarjun National Park and buffer zone management plan Fiscal Year 074/075-078/079 (2017/018- 2021/022)*. Shivapuri Nagarjun National Park office.

- Soares, R. G. S., Ferreira, P. A., & Lopes, L. E. (2017). Can plant-pollinator network metrics indicate environmental quality? *Ecological Indicators*, **78**: 361-370. <https://doi.org/10.1016/j.ecolind.2017.03.037>
- Soh, E. J., Soh, Z. W., Ascher, J. S., & Tan, H. T. (2019). Diversity of plants with leaves cut by bees of the genus *Megachile* in Singapore. *Nature in Singapore*, **12**: 63-74. DOI: 10.26107/NIS-2019-0007
- Soh, Z. W. W., & Ngiam, R. W. J. (2013). Flower-visiting bees and wasps in Singapore parks (Insecta: Hymenoptera). *Nature in Singapore*, **6**: 153-172.
- Sotomayor, A. I. T. (2002). A spatial analysis of different forest cover types using GIS and remote sensing techniques. A case study in Shivapuri area, Nepal. Master's degree thesis. Forest Science Division International Institute for Geo information Science and Earth observation Enschede, The Netherlands
- Speight, M. C. D. (2017) Species accounts of European Syrphidae (Diptera). In: Speight, M.C.D., Castella, E., Sarthou, J.-P. & Vanappelghem, C. (Eds.), *Syrph the Net, the database of European Syrphidae*, 97. Syrph the Net Publication, Dublin, 294 pp.
- Speight, M. C. D. (2020). StN key for the identification of the genera of European Syrphidae 2020. *Syrph the Net, the database of European Syrphidae (Diptera)*, **105**, 1-46.
- Speight, M.C.D., Monteil, C., Castella, E. & Sarthou, J.-P. (2006) StN Ferrara 2006. Syrph the Net on CD, Issue 5. The database of European Syrphidae (eds M. C. D. Speight, E. Castella, J.-P. Sarthou, & C. Monteil), Syrph the Net Publications, Dublin.
- Ssymank, A., & Jordaens, K. (2021). Description of the female of *Syrittosyrphus opacea* Hull, 1944 (Diptera, Syrphidae, Eristalinae) with additional notes on the genus. *African Invertebrates*, **62**(1), 339-353. doi: 10.3897/AfrInvertebr.62.61504
- Staab, M., Pereira-Peixoto, M. H., & Klein, A. M. (2020). Exotic garden plants partly substitute for native plants as resources for pollinators when native plants become seasonally scarce. *Oecologia*, **194**(3): 465-480. <https://doi.org/10.1007/s00442-020-04785-8>

- Stang, M., Klinkhamer, P. G., Waser, N. M., Stang, I., & van der Meijden, E. (2009). Size-specific interaction patterns and size matching in a plant–pollinator interaction web. *Annals of Botany*, **103**(9): 1459-1469. <https://doi.org/10.1093/aob/mcp027>
- Stanley, D. A. & Stout, J. C. (2014). Pollinator sharing between mass-flowering oilseed rape and co-flowering wild plants: implications for wild plant pollination. *plant Ecol.* DOI 10.1007/511258-014-0301-7.
- Stanley, D. A. (2013). *Pollinators and pollination in changing agricultural landscapes; investigating the impact of bioenergy crops*. Department of Botany, School of Natural Sciences. Trinity College Dublin, USA.
- Stanley, D. A., & Stout, J. C. (2013). Quantifying the impacts of bioenergy crops on pollinating insect abundance and diversity: a field-scale evaluation reveals taxon-specific responses. *Journal of Applied Ecology*, **50**(2): 335-344. <https://doi.org/10.1111/1365-2664.12060>
- Stanley, D. A., Gunning, D., & Stout, J. C. (2013b). Pollinators and pollination of oilseed rape crops (*Brassica napus* L.) in Ireland: ecological and economic incentives for pollinator conservation. *Journal of Insect Conservation*, **17**(6): 1181-1189. DOI: 10.1007/s10841-013-9599-z
- Stavert, J. R., Pattemore, D. E., Bartomeus, I., Gaskett, A. C., & Beggs, J. R. (2018). Exotic flies maintain pollination services as native pollinators decline with agricultural expansion. *Journal of Applied Ecology*, **55**(4): 1737-1746. <https://doi.org/10.1111/1365-2664.13103>
- Steenis, J. van, & Hippa, H. (2012) Revision and phylogeny of the Oriental hoverfly genus *Korinchia* Edwards (Diptera: Syrphidae). *Tijdschrift voor Entomologie*, **155**(2–3): 209–268.
- Steenis, J. van, Hippa, H., & Mutin, V. A. (2018) Revision of the oriental species of the genus *Sphagina* Meigen, 1822 (Diptera: Syrphidae). *European Journal of Taxonomy*, 489. 1–198. <https://doi.org/10.5852/ejt.2018.489>
- Steenis, J. van., Wu, T. H., Ssymank, A. M., Steenis, W. van., J. H. Skevington., Young, A. D., Palmer, C. J., Zuijlen, M. P. van., Lechner-Ssymank, B. & Shiao, S. F. (2021) Preliminary Results of the 2016 International Taiwan Expedition on SYRPHIDAE (DIPTERA). *Formosan Entomologist*, **41**: 78–134.

- Stewart, A. B., Sritongchuay, T., Teartisup, P., Kaewsomboon, S., & Bumrungsri, S. (2018). Habitat and landscape factors influence pollinators in a tropical megacity, Bangkok, Thailand. *PeerJ*, **6**, e5335. <https://doi.org/10.7717/peerj.5335>
- Stouffer, D. B., Cirtwill, A. R., & Bascompte, J. (2014). How exotic plants integrate into pollination networks. *Journal of Ecology*, **102**(6): 1442-1450. doi: 10.1111/1365-2745.12310
- Straka, J., & Engel, M. S. (2012). The apid cuckoo bees of the Cape Verde Islands (Hymenoptera, Apidae). *ZooKeys*, (218): 77.
- Subedi, A., Chaudhary, R. P., Achterberg, C. Heijerman, T., Lens, F., Dooren, Tom J. M. V *et al.* (2011). Pollination and protection against herbivory of nepalese coelogyninae (orchidaceae). *American Journal of Botany*, **98**(7): 1095–1103. <https://doi.org/10.3732/ajb.1000306>
- Subedi, C. K., Rokaya, M. B., Münzbergová, Z., Timsina, B., Gurung, J., Chettri, N., ... & Chaudhary, R. P. (2020). Vascular plant diversity along an elevational gradient in the Central Himalayas, western Nepal. *Folia Geobotanica*, **55**(2): 127-140.
- Svensson, B., Lagerlof, J. & Sevensson, B. G. (2000). Habitat preferences of nest-seeking bumble bees (Hymenoptera: Apidae) in an agricultural landscape. *Agriculture, Ecosystem and Environment*, **77**:247-255. [https://doi.org/10.1016/S0167-8809\(99\)00106-1](https://doi.org/10.1016/S0167-8809(99)00106-1)
- Sydenham, M. A., Eldegard, K., Venter, Z. S., Evju, M., Åström, J., & Rusch, G. M. (2022). Priority maps for pollinator habitat enhancement schemes in semi-natural grasslands. *Landscape and Urban Planning*, **220**: 104354. <https://doi.org/10.1016/j.landurbplan.2022.104354>
- Sydenham, M. A., Häusler, L. D., Moe, S. R. & Eldegard, K. (2016). Inter-assembly facilitation: The functional diversity of cavity-producing beetles drives the size diversity of cavity-nesting bees. *Ecology and evolution*, **6**(2): 412–425. <https://doi.org/10.1002/ece3.1871>
- Szigeti, V., Körösi, Á., Harnos, A., Nagy, J. & Kis, J. (2016). Comparing two methods for estimating floral resource availability for insect pollinators in semi-natural

- habitats. *In Annales de la Société entomologique de France*, **52**(5): 289–299.
<https://doi.org/10.1080/00379271.2016.1261003>
- Tadauchi, O., & Matsumura, T. (2007). The genus *Andrena* collected from Nepal (Hymenoptera, Andrenidae) with redescrptions of some types of *Andrena* described from North India. *Esakia*, **47**: 1-20. <http://hdl.handle.net/2324/8322>.
- Tadey, M. (2015). Indirect effects of grazing intensity on pollinators and floral visitation. *Ecological Entomology*, **40**(4): 451-460.
<https://doi.org/10.1111/een.12209>
- Thakur, S., Bahrdwaj, S., & Singh, A. P. (2021). Diversity pattern of butterfly communities (Lepidoptera) in different habitat types of Nahan, Himachal Pradesh, India. *Journal of Threatened Taxa*, **13**(8): 19137-19143.
<https://doi.org/10.11609/jott.7095.13.8.19137-19143>
- Thapa, R. B. (2006). Honeybees and other insect pollinators of cultivated plants: a review. *Journal of the Institute of Agriculture and Animal Science*, **27**: 1-23.
- Thapa, V. K. (1997). *An inventory of Nepal's insects* (Vol. 1). IUCN-The World Conservation Union, Nepal.
- Thapa, V. K. (2000). *An inventory of Nepal's insects*, vol. III. IUCN Nepal, Kathmandu,[xi+].
- Thapa, V. K. (2015). *Insect diversity in Nepal*. VK Thapa Publication, Kathmandu, Nepal, 1097pp.
- Thinley, U., Banterng, P., Katawatin, R., & Gonkhamdee, S. (2022). Spatial surveillance of invasion by alien species in a heterogeneous ecological landscape. *Research Anthology on Ecosystem Conservation and Preserving Biodiversity* (pp. 575-593). IGI Global.
- Thompson F. C. (2019) Syrphidae. Systema Dipteroorum, version 2.4, 13,431 records.
<http://sd.zoobank.org/Nomenclator>.
- Thompson, F. C. (1966). A new *Sphegina* from Nepal (Diptera: Syrphidae). *Bulletin of the Brooklyn Entomological Society*, 59+60: 42–45.
- Thompson, F. C. (1974). The genus *Spheginobaccha* de Meijere (Diptera: Syrphidae). *Transactions of the American Entomological Society*, 100: 255–287.

- Thompson, F. C. (2012). Fabulous flower flies for famous fly fanatics (Diptera: Syrphidae). A tribute to the dipterists of the Canadian National Collection. *The Canadian Entomologist*, **144**: 1–16. [2012.03.06].
- Thompson, F. C., & Ghorpade, K. (1992). A new coffee aphid predator, with notes on other Oriental species of *Paragus* (Diptera: Syrphidae). *Colemania*, **5**: 1-24.
- Thompson, F. C., & Vockeroth, J. R. (1989). 51. Family Syrphidae. *Catalog of the Diptera of the Australasian and Oceanian Regions*, 437-458.
- Tiple, A. D., Deshmukh, V. P., & Dennis, R. L. (2005). Factors influencing nectar plant resource visits by butterflies on a university campus: implications for conservation. *Nota Lepidopterologica*, **28**(3/4): 213.
- Tkalcu, B. (1974). Eine Hummel-Ausbeute aus dem Nepal-Himalaya (Insecta,-Hymenoptera, Apoidea, Bombinae). *Senckenbergiana Biologica*, 311:349.
- Totland, Ø., Nielsen, A., Bjerknes, A. L., & Ohlson, M. (2006). Effects of an exotic plant and habitat disturbance on pollinator visitation and reproduction in a boreal forest herb. *American Journal of Botany*, **93**(6), 868-873. <https://doi.org/10.3732/ajb.93.6.868>
- Tylianakis, J. M., Laliberté, E., Nielsen, A., & Bascompte, J. (2010). Conservation of species interaction networks. *Biological Conservation*, **143**(10): 2270-2279. <https://doi.org/10.1016/j.biocon.2009.12.004>
- Urbina-Cardona, N., Blair, M. E., Londono, M. C., Loyola, R., Velásquez-Tibatá, J., & Morales-Devia, H. (2020). Species distribution modeling in Latin America: a 25-year retrospective review. *Tropical Conservation Science*, **12**(1): 1-19. <https://doi.org/10.1177/1940082919854058>
- Ushimaru, A., Ishida, C., Sakai, S., Shibata, M., Tanaka, H., Niiyama, K., & Nakashizuka, T. (2008). The effects of human management on spatial distribution of two bumble bee species in a traditional agro-forestry Satoyama landscape. *Journal of Apicultural Research*, **47**(4): 296-303. <http://dx.doi.org/10.1080/00218839.2008.11101478>
- van der Sluijs, J. P. (2020). Insect decline, an emerging global environmental risk. *Current Opinion in Environmental Sustainability*, **46**: 39-42. <https://doi.org/10.1016/j.cosust.2020.08.012>

- Van Swaay, C., Cuttelod, A., Collins, S., Maes, D., Munguira, M. L., Sasic, M. *et al.* (2010). European Red List of Butterflies Publication office of the European Union. Luxembourg. doi:10.2779/83897.
- van Veen M. P. (2010) *Hoverflies of Northwest Europe: identification keys to the Syrphidae*. Utrecht: KNNV Publishing, 248 pp.
- Vanbergen, A. J., & Initiative, T. I. P. (2013). Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and the Environment*, **11**(5): 251-259. <https://doi.org/10.1890/120126>
- Vanbergen, A. J., Espíndola, A., & Aizen, M. A. (2018). Risks to pollinators and pollination from invasive alien species. *nature ecology & evolution*, **2**(1):16-25.
- Vanbergen, A. J., Woodcock, B. A., Heard, M. S., & Chapman, D. S. (2017). Network size, structure and mutualism dependence affect the propensity for plant–pollinator extinction cascades. *Functional Ecology*, **31**(6): 1285-1293. <https://doi.org/10.1111/1365-2435.12823>
- Vanengelsdrop, D., Hayes, J., Underwood, R. M. & Pettis, J. (2008). A survey of honey bee colony losses in the US, Fall 2007 to spring 2008. *PLoS One*, **3**(12). <https://doi.org/10.1371/journal.pone.0004071>
- Vasiliev, D., & Greenwood, S. (2021). The role of climate change in pollinator decline across the Northern Hemisphere is underestimated. *Science of the Total Environment*, **775**: 145788. <https://doi.org/10.1016/j.scitotenv.2021.145788>
- Verma, L. R., & Partap, U. (1993). *The Asian hive bee, Apis cerana, as a pollinator in vegetable seed production: an awareness handbook*.
- Vila, M., Bartomeus, I., Dietzsch, A. C., Petanidou, T., Steffan-Dewenter, I., Stout, J. C., & Tscheulin, T. (2009). Invasive plant integration into native plant–pollinator networks across Europe. *Proceedings of the Royal Society B: Biological Sciences*, **276**(1674): 3887-3893. <https://doi.org/10.1098/rspb.2009.1076>
- Vockeroth, J. R. (1971) The identity of some holarctic and Old World species of *Sphaerophoria* (Diptera: Syrphidae). *The Canadian Entomologist*, **103**(11): 1627–1635.
- Vosteen, I., Gershenzon, J. & Kunert, G. (2018), Dealing with food shortage: larval dispersal behaviour and survival on non-prey food of the hoverfly *Episyrphus*

balteatus. *Ecological Entomology*, **43**: 578-590. <https://doi.org/10.1111/een.12636>

Vulliamy, B., G. Potts, S., & G. Willmer, P. (2006). The effects of cattle grazing on plant-pollinator communities in a fragmented Mediterranean landscape. *Oikos*, **114**(3): 529-543. <https://doi.org/10.1111/j.2006.00301299.14004.x>

Wagner, D. L. (2020). Insect declines in the Anthropocene. *Annual Review of Entomology*, **65**: 457-480.

Walker, F. (1852) Diptera. Part III, pp. 157–252. In: Saunders, W.W. (Ed.), *Insecta Saundersiana: or characters of undescribed insects in the collection of William Wilson Saunders, Esq., F.R.S., F.L.S., & c. Vol. 1*. Van Voorst, London, 474 pp.

Walker, F. (1857) Characters of undescribed Diptera in the collection of W. W. Saunders, Esq., F.R.S., & c. *Transactions of the Entomological Society*, London, (n.s.) 4, 119–158.

Warren, M. S., Hill, J. K., Thomas, J. A., Asher, J., Fox, R., Huntley, B., ... & Thomas, C. D. (2001). Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature*, **414**(6859): 65-69. <https://doi.org/10.1038/35102054>

Warren, M. S., Maes, D., van Swaay, C. A., Goffart, P., Van Dyck, H., Bourn, N. A., ... & Ellis, S. (2021). The decline of butterflies in Europe: Problems, significance, and possible solutions. *Proceedings of the National Academy of Sciences*, **118**(2).

Warren, S. D., Harper, K. T., & Booth, G. M. (1988). Elevational distribution of insect pollinators. *American Midland Naturalist*, 325-330. <https://doi.org/10.2307/2426004>

Weibull, A.C., Bengtsson, J. & Nohlgren, E. (2000). Diversity of butterflies in the agricultural landscape: the role of farming system and landscape heterogeneity. *Ecography*, **23**(6): 743–750. <https://doi.org/10.1111/j.1600-0587.2000.tb00317.x>

Weiner, C. N., Werner, M., Linsenmair, K. E., & Blüthgen, N. (2014). Land-use impacts on plant–pollinator networks: interaction strength and specialization

- predict pollinator declines. *Ecology*, **95**(2): 466-474.
<https://doi.org/10.1890/13-0436.1>
- Westphal, C., Bommarco, R., Carré, G., Lamborn, E., Morison, N., Petanidou, T., ... & Steffan-Dewenter, I. (2008). Measuring bee diversity in different European habitats and biogeographical regions. *Ecological Monographs*, **78**(4): 653-671.
<https://doi.org/10.1890/07-1292.1>
- Westrich, P. (1996). Habitat requirements of central European bees and the problems of partial habitats. In *Linnean Society Symposium Series* (Vol. 18, pp. 1-16). Academic Press Limited.
- Whelan, C. J., Şekercioğlu, Ç. H., & Wenny, D. G. (2015). Why birds matter: from economic ornithology to ecosystem services. *Journal of Ornithology*, **156**(1): 227-238. <https://doi.org/10.1007/s10336-015-1229-y>
- Wickham, H., Chang, W., & Wickham, M. H. (2016). Package ‘ggplot2’. *Create elegant data visualisations using the grammar of graphics. Version*, **2**(1): 1-189.
- Widhiono, I., Sudiana, E., & Suciarto, E. T. (2016). Insect pollinator diversity along a habitat quality gradient on Mount Slamet, Central Java, Indonesia. *Biodiversitas Journal of Biological Diversity*, **17**(2). <https://doi.org/10.13057/biodiv/d170250>
- Wiedemann, C. R. (1819) Beschreibung neuer Zweiflügler aus Ostindien und Afrika. *Zoologisches Magazin*, Kiel, **1**(3): 1–39.
- Wiedemann, C. R. W. (1818) Neue Insecten vom Vorgebirge der guten Hoffnung. *Zoologisches Magazin*, **1**(2): 40–48.
- Wiedemann, C. R. W. (1820) *Munus rectoris in Academia Chrisiano–Albertina iterum aditurus nova dipterorum genera offert iconibusque illustrat*. Christiana Friderici Mohr, Kiliae, i–viii + 1–23.
- Wiedemann, C. R. W. (1824) *Munus rectoris in Academia Christiana Albertina aditurus analecta entomologica ex Museo Regio Havniensi maximw congesta profert iconibusque illustrat. Eregio typographeo scholarum*, Kiliae [= Kiel], 60 pp.
- Wiedemann, C. R. W. (1830) *Aussereuropäische zweiflügelige Insekten. Zweiter Theil*. Schulz, Hamm. xii + 684 pp.

- Wiegmann, B. M. (1986) A new species of *Myolepta* (Diptera: Syrphidae) from Nepal, with its phylogenetic placement and a key to oriental species. *Journal of the New York Entomological Society*, **94**(3): 377–382.
- Wijesekara, A. (2001). An annotated list of bees (Hymenoptera: Apoidea: Apiformis) of Sri Lanka. *Tijdschrift voor Entomologie*, **144**(1): 145-158.
- Willcox, B. K., Howlett, B. G., Robson, A. J., Cutting, B., Evans, L., Jesson, L., ... & Rader, R. (2019). Evaluating the taxa that provide shared pollination services across multiple crops and regions. *Scientific reports*, **9**(1): 1-10. <https://doi.org/10.1038/s41598-019-49535-w>
- Willemstein, S. C. (1987). An Evolutionary Basis for pollination Ecology. *Reiden Botanical Series*, **10**: 425.
- Williams, P. H., Ito, M., Matsumura, T., & Kudo, I. (2010). The bumblebees of the Nepal Himalaya (Hymenoptera: Apidae). *Insecta matsumurana. New series: journal of the Faculty of Agriculture Hokkaido University, series entomology*, **66**: 115-151.
- Willmer, P. G. (1983). Thermal constraints on activity patterns in nectar-feeding insects. *Ecological Entomology*, **8**(4): 455-469. <https://doi.org/10.1111/j.1365-2311.1983.tb00524.x>
- Winfree, R. (2010). The conservation and restoration of wild bees. *Annals of the New York academy of sciences*, **1195**(1): 169-197. <https://doi.org/10.1111/j.1749-6632.2010.05449.x>
- Winfree, R., Bartomeus, I., & Cariveau, D. P. (2011). Native pollinators in anthropogenic habitats. *Annual Review of Ecology, Evolution, and Systematics*, **42**: 1-22.
- Winfree, R., Griswold, T., & Kremen, C. (2007). Effect of human disturbance on bee communities in a forested ecosystem. *Conservation Biology*, **21**(1): 213-223. <https://doi.org/10.1111/j.1523-1739.2006.00574.x>
- Wittmann, D., Radtke, R., Zeil, J., Lübke, G., & Francke, W. (1990). Robber bees (*Lestrimelitta limao*) and their host chemical and visual cues in nest defense by *Trigona* (*Tetragonisca*) *angustula* (Apidae: Meliponinae). *Journal of Chemical Ecology*, **16**(2): 631-641.

- Wojcik, V. (2021). Pollinators: Their Evolution, Ecology, Management, and Conservation. *Arthropods: Are They Beneficial for Mankind?*, 33. DOI: 10.5772/intechopen.97153.
- Wood, T. J., Michez, D., Paxton, R. J., Drossart, M., Neumann, P., Gerard, M., ... & Vereecken, N. J. (2020). Managed honey bees as a radar for wild bee decline? *Apidologie*, **51**(6): 1100-1116. <http://dx.doi.org/10.1007/s13592-020-00788-9>
- Woyke, J. (1999). Orientation flight of *Apis dorsata* worker bees. Dabur Apicultural Center, Chitwan, Nepal. WRI/IUCN/UNEP. 1989. Gift to the nature. WRI, USA.
- Woyke, J., Wilde, J., & Wilde, M. (2012). Swarming and migration of *Apis dorsata* and *Apis laboriosa* honey bees in India, Nepal and Bhutan. *Journal of Apicultural Science*, **56**(1): 81. DOI: 10.2478/v10289-012-0009-7
- Yackulic, C. B., Chandler, R., Zipkin, E. F., Royle, J. A., Nichols, J. D., Campbell Grant, E. H., & Veran, S. (2013). Presence-only modelling using MAXENT: when can we trust the inferences? *Methods in Ecology and Evolution*, **4**(3): 236-243. <https://doi.org/10.1111/2041-210x.12004>
- Yang D, Wang MQ, Li WL. 2020. Species Catalog of China. Volume 2. *Animals, Insecta* (VII), Diptera (3), Brachycera Cyclorrhaphous. Science Press, Beijing; p. 1312.
- Young, A. D., Lemmon, A. R., Skevington, J. H., Mengual, X., Ståhls, G., Reemer, M., ... & Wiegmann, B. M. (2016). Anchored enrichment dataset for true flies (order Diptera) reveals insights into the phylogeny of flower flies (family Syrphidae). *BMC Evolutionary Biology*, **16**(1), 1-13. DOI 10.1186/s12862-016-0714-0
- Young, N., Carter, L., & Evangelista, P. (2011). A MaxEnt model v3. 3.3 e tutorial (ArcGIS v10). *Natural Resource Ecology Laboratory, Colorado State University and the National Institute of Invasive Species Science*, 1-30.
- Yuan, B., Hu, G. X., Zhang, X. X., Yuan, J. K., Fan, X. M., & Yuan, D. Y. (2022). What Are the Best Pollinator Candidates for *Camelia oleifera*: Do Not Forget Hoverflies and Flies. *Insects*, **13**(6): 539. <https://doi.org/10.3390/insects13060539>

Zattara, E. E., & Aizen, M. A. (2021). Worldwide occurrence records suggest a global decline in bee species richness. *One Earth*, **4**(1): 114-123.
<https://doi.org/10.1016/j.oneear.2020.12.005>

Zetterstedt, J. W. (1843) *Diptera Scandinaviae. Disposita et descripta. Vol. 2.* Officina Lundbergiana, Lundae [=Lund], 409 pp. [pp. 441–894]

APPENDICES

Appendix I: Families, genera, and species of superfamily Apoidea (Hymenoptera), recorded from SNNP

Families	Genera	Species
Andrenidae (1 Genus, 3 species)	<i>Andrena</i>	3
Apidae (8 Genus, 27 species)	<i>Amegilla</i>	7
	<i>Apis</i>	2
	<i>Bombus</i>	4
	<i>Ceratina</i>	3
	<i>Elaphropoda</i>	1
	<i>Nomada</i>	1
	<i>Thyreus</i>	3
	<i>Xylocopa</i>	6
Colletidae (1 Genus, 1 species)	<i>Colletes</i>	1
Halictidae (3 Genus, 8 species)	<i>Halictus</i>	2
	<i>Lasioglossum</i>	3
	<i>Nomia</i>	3
Megachilidae (1 Genus, 3 species)	<i>Megachile</i>	3
Five Families	14 genera	42 species

Appendix II : List of hoverflies collected in 2018 from SNNP with three new country records (*). Manichud (MN), Nagarjun (NG), Shivapuri (SI), Sundarijal (SN), and Gurje Bhanjyang (GR)

Species name	Altitude (m)	Material Examined	Collecting sites	Collecting dates
<i>Eristalis (Eoseristalis) cerealis</i>	1,400–2,300	31♀, 20♂	MN, NG, SI, SN, GR	15–28.iii; 2–20.iv; 03– 28.x; 01–05.xi
<i>Eristalis (Eoseristalis) himalayensis</i>	1,700–2,300	3♀	SI, GR	12–20.iv
<i>Eristalis (Eristalis) tenax</i>	1,400–2,300	26♀, 14♂	MN, NG, SI, SN, GR	20–30.iii; 02–20.iv; 28–30.ix; 07–28.x; 01–03.xi
<i>Eristalinus (Eristalinus) aeneus</i>	1,600–2,000	4♀, 2♂	MN, SN, GR	15.iii; 05–08.iv; 05.xi
<i>Eristalinus (Eristalinus) arvorum</i>	2,000	1♀	SN	05.iv
<i>Eristalinus (Eristalinus) taeniops</i>	1,800	2♀	MN	15.iii
* <i>Graptomyza nigripes</i>	2,000	1♀	SN	12.x
* <i>Lycastris albipes</i>	1,500–2,300	2♂	SI, SN	02– 20.iv
<i>Lycastris flavohirta</i>	1,500–1,700	2♀	SI, SN	02 –15.iv
<i>Mesembrius bengalensis</i>	1,500–1,900	2♀	SI, SN	30.ix; 07.x
<i>Phytomia errans</i>	1,600–1,900	2♀	SI, GR	30.ix; 01.xi
<i>Phytomia zonata</i>	1,500–2,300	3♀	MN, SI, SN	20.iv; 07–14.x
<i>Rhingia siwalikensis</i>	2,000	1♀	GR	12.iv
<i>Syritta indica</i>	1,400–2,300	15♀, 7♂	MN, NG, SI, SN, GR	28.iii; 05–20.v; 28–30.ix; 03–28.x; 01–05.xi
<i>Syritta orientalis</i>	1,400–2,300	11♀, 8♂	MN, NG, SI, SN, GR	26.iii; 15–17.iv; 28–30.ix; 12–28.x; 01–05.xi
<i>Syritta pipiens</i>	1,400–2,300	17♀, 9♂	MN, NG, SI, SN, GR	26–28.iii; 02–20.iv; 28–30.ix; 03–24.x; 01–05.xi
* <i>Volucella trifasciata</i>	1,500	1♀	SN	12.x
<i>Asarkina incisuralis</i>	1,600	1♂	GR	08. iv
<i>Asarkina porcina</i>	1,500–1,600	4♀	NA, SN, GR	02–28. iv
<i>Baccha maculate</i>	1,400	1♂	NA	24.x

<i>Betasyrphus serarius</i>	1,500	1♀	SN	02.iv
<i>Dasyrphus orsua</i>	1,400– 2,300	12♀, 7♂	MN, NG, SI, SN, GR	15–30.iii; 02– 17.iv
<i>Episyrrhus balteatus</i>	1,400– 2,300	37♀, 27♂	MN, NG, SI, SN, GR	15–30.iii; 02–20.iv; 28–30.ix; 03– 28.x; 01–05.xi
<i>Episyrrhus viridaureus</i>	1,400– 2,300	34♀, 27♂	MN, NG, SI, SN, GR	15–30.iii; 02–20.iv; 28–30.ix; 14– 28.x; 01–05.xi
<i>Eupeodes bucculatus</i>	1,400– 1,800	3♂	MN, NG, SI	15–26.iii; 15.iv
<i>Melanostoma orientale</i>	1,400– 2,300	11♀, 8♂	MN, NG, SI, SN, GR	15–30.iii; 02–20.iv; 03–24.x; 05.xi
<i>Melanostoma scalare</i>	1,400– 2,300	14♀, 9♂	MN, NG, SI, SN, GR	15–30.iii; 04–20.iv
<i>Melanostoma univittatum</i>	1,400– 2,300	15♀, 11♂	MN, NG, SI, SN, GR	15–28.iii; 02– 20.iv
<i>Meliscaeva cinctella</i>	1,400– 1,500	2♂	NG, SN	26.iii; 02.iv
<i>Scaeva pyrastris</i>	1,800	1♀	SN	03.iv
<i>Sphaerophoria bengalensis</i>	1,500– 2,300	8♀, 5♂	MN, NG, SI, SN, GR	15–30.iii; 02– 20.iv
<i>Sphaerophoria indiana</i>	1,400– 2,300	11♀, 3♂	MN, NG, SI, SN, GR	15–30.iii; 02–20.iv
<i>Sphaerophoria scripta</i>	1,900– 2,100	5♀	MN, NG, SI, SN, GR	20–30.iii; 05–17.iv
<i>Syrphus torvus</i>	2,000– 2,300	4♀	MN, NG, SI, SN	22–30.iii; 05–20.iv

Appendix III: Family, scientific name and number of each species of insect pollinators collected from SNNP, Nepal

Family	Genus	species	Number	Author	Date	
Order Lepidoptera						
Hesperiidae	<i>Parnara</i>	<i>naso</i>	26	Moore	1878	
		<i>guttata</i>	42	Bremer & Grey	1852	
Lycaenidae	<i>Pelopidas</i>	<i>agna</i>	36	Moore	1865	
		<i>mathias</i>	40	Fabricius	1798	
	<i>Chrysozephyrus</i>	<i>birupa</i>	23	Moore	1877	
	<i>Cyrestis</i>	<i>thyodamas</i>	18	Boisduval	1836	
	<i>Lampides</i>	<i>boeticus</i>	64	Linnaeus	1767	
	<i>Lestranicus</i>	<i>transpectus</i>	71	Moore	1879	
	<i>Rapala</i>	<i>manea</i>	28	Hewitson	1863	
Nymphalidae	<i>Udara</i>	<i>dilectus</i>	45	Moore	1879	
	<i>Zizeeria</i>	<i>maha</i>	93	Kollar	1844	
	<i>Aglais</i>	<i>caschmirensis</i>	296	Kollar	1844	
	<i>Appias</i>	<i>lyncida</i>	11	Cramer	1777	
	<i>Argyreus</i>	<i>hyperbius</i>	50	Linnaeus	1763	
	<i>Athyma</i>	<i>cama</i>	14	Moore	1858	
		<i>Jina</i>	27	Moore	1858	
		<i>opalina</i>	42	Kollar	1844	
		<i>Childrena</i>	<i>childreni</i>	23	Gray	1831
		<i>Danaus</i>	<i>chrysippus</i>	48	Linnaeus	1758
		<i>Danaus</i>	<i>genutia</i>	47	Cramer	1779
		<i>Dichorragia</i>	<i>nesimachus</i>	3	Doyère	1840
		<i>Euploea</i>	<i>core</i>	69	Cramer	1780
			<i>mulciber</i>	64	Cramer	1777
		<i>Fabriciana</i>	<i>kamala</i>	24	Moore	1857
		<i>Hypolimnas</i>	<i>misippus</i>	8	Linnaeus	1764
		<i>Lethe</i>	<i>confusa</i>	13	Aurivillius	1897
			<i>insana</i>	31	Kollar	1844
			<i>kansa</i>	54	Moore	1857
			<i>serbonis</i>	23	Hewitson	1876
			<i>verma</i>	108	Kollar	1844
			<i>vindhya</i>	10	Felder	1859
		<i>Melanitis</i>	<i>phedima</i>	32	Cramer	1780
		<i>Mycalesis</i>	<i>francisca</i>	18	Stoll	1780
			<i>mineus</i>	20	Linnaeus	1758
			<i>perseus</i>	32	Fabricius	1775
		<i>Neptis</i>	<i>ananta</i>	29	Moore	1857
			<i>hylas</i>	58	Linnaeus	1758
		<i>mahendra</i>	98	Moore	1872	
		<i>manasa</i>	13	Moore	1857	
	<i>Orsotriaena</i>	<i>medus</i>	31	Fabricius	1775	
	<i>Parantica</i>	<i>aglea</i>	31	Stoll	1782	
		<i>pedonga</i>	20	Fujioka	1970	
	<i>Phaedyma</i>	<i>columella</i>	49	Cramer	1782	
		<i>almana</i>	14	Linnaeus	1758	

	<i>Precis</i>	<i>iphita</i>	53	Cramer	1779
	<i>Vanessa</i>	<i>cardui</i>	170	Linnaeus	1758
		<i>indica</i>	70	Herbst	1794
	<i>Ypthima</i>	<i>avanta</i>	20	Moore	1874
		<i>baldus</i>	128	Fabricius	1775
		<i>confusa</i>	12	Shirozu & Shima	1977
		<i>hannynghoni</i>	13	Eliot	1967
		<i>indica</i>	27	Hewitson	1865
	<i>Zophoessa</i>	<i>goalpara</i>	13	Moore	1866
		<i>sidonis</i>	22	Hewitson	1863
Papilionidae	<i>Graphium</i>	<i>agamemnon</i>	22	Linnaeus	1758
		<i>sarpedon</i>	43	Linnaeus	1758
	<i>Papilio</i>	<i>castor</i>	71	Westwood	1842
		<i>helenus</i>	85	Linnaeus	1758
		<i>krishna</i>	3	Moore	1857
		<i>memnon</i>	66	Linnaeus	1758
		<i>polytes</i>	52	Linnaeus	1758
		<i>protenor</i>	50	Cramer	1775
		<i>rhetenor</i>	47	Westwood	1842
Pieridae	<i>Cepora</i>	<i>nadina</i>	44	Lucas	1852
	<i>Colias</i>	<i>erate</i>	86	Esper	1805
		<i>fieldii</i>	87	Menetries	1855
	<i>Delias</i>	<i>belladonna</i>	14	Fabricius	1793
	<i>Eurema</i>	<i>hecabe</i>	83	Linnaeus	1758
	<i>Gonepteryx</i>	<i>rhamni</i>	45	Linnaeus	1758
	<i>Hebomoia</i>	<i>glaucippe</i>	7	Linnaeus	1758
	<i>Metaporia</i>	<i>agathon</i>	22	Gray	1831
	<i>Pieris</i>	<i>brassicae</i>	58	Linnaeus	1758
		<i>canidia</i>	255	Linnaeus	1768
	<i>Catopsilia</i>	<i>pomona</i>	64	Fabricius	1775
Riodinidae	<i>Abisara</i>	<i>fylla</i>	72	Westwood	1851
	<i>Dodona</i>	<i>dipoea</i>	115	Hewitson	1865
		<i>durga</i>	7	Kollar & Redtenbacher	1844
		<i>egeon</i>	46	Westwood	1851
		<i>eugenes</i>	169	Bates	1868
	<i>Zemeris</i>	<i>flegyas</i>	38	Cramer	1780
Satyridae	<i>Dallacha</i>	<i>hyagriva</i>	21	Moore	1858
Order Diptera					
Syrphidae	<i>Eristalinus</i>	<i>aeneus</i>	21	Scopoli	1763
		<i>arvorum</i>	22	Fabricius	1787
		<i>taeniops</i>	44	Wiedemann	1818
	<i>Eristalis</i>	<i>cerealis</i>	292	Fabricius	1805
		<i>himalayensis</i>	29	Brunetti	1908
		<i>tenax</i>	260	Linnaeus	1758
	<i>Graptomyza</i>	<i>nigripes</i>	21	Brunetti	1913
	<i>Lycastris</i>	<i>albipes</i>	19	Walker	1857
		<i>flavohirta</i>	16	Brunetti	1907
	<i>Mesembrius</i>	<i>bengalensis</i>	28	Rondani	1857

	<i>Phytomia</i>	<i>errans</i>	22	Fabricius	1787
		<i>zonata</i>	6	Fabricius	1787
	<i>Rhingia</i>	<i>siwalikensis</i>	1	Nayar	1968
	<i>Syritta</i>	<i>indica</i>	61	Wiedemann	1824
		<i>orientalis</i>	61	Macquart	1842
		<i>pipiens</i>	65	Linnaeus	1758
	<i>Volucella</i>	<i>trifasciata</i>	1	Wiedemann	1830
	<i>Asarkina</i>	<i>porcina</i>	22	Coquillett	1898
		<i>incisuralis</i>	17	Macquart	1855
	<i>Baccha</i>	<i>maculata</i>	5	Walker	1852
	<i>Betasyrphus</i>	<i>serarius</i>	11	Wiedemann	1830
	<i>Dasysyrphus</i>	<i>orsua</i>	55	Walker	1852
	<i>Episyrphus</i>	<i>balteatus</i>	222	De Geer	1776
		<i>viridaureus</i>	248	Wiedemann	1824
	<i>Eupeodes</i>	<i>bucculatus</i>	84	Rondani	1857
	<i>Melanostoma</i>	<i>orientale</i>	44	Wiedemann	1824
		<i>scalare</i>	87	Fabricius	1794
		<i>univittatum</i>	93	Wiedemann	1824
	<i>Meliscaeva</i>	<i>cinctella</i>	50	Zetterstedt	1843
	<i>Paragus</i>	<i>crenulatus</i>	37	Thomson	1869
	<i>Parasyrphus</i>	sp.1	58		
	<i>Scaeva</i>	<i>pyrastris</i>	14	Linnaeus	1758
	<i>Sphaerophoria</i>	<i>bengalensis</i>	59	Macquart	1842
		<i>indiana</i>	71	Bigot	1884
		<i>scripta</i>	35	Linnaeus	1758
	<i>Syrphus</i>	<i>torvus</i>	47	Osten Sacken	1875
Order Hymenoptera					
Andrenidae	<i>Andrena</i>	<i>flavipes</i>	77	Panzer	1799
		<i>gorkhana</i>	58	Tadauchi & Matsumura	2007
		<i>kathmanduensis</i>	34	Tadauchi & Matsumura	2007
Apidae	<i>Ceratina</i>	<i>bryanti</i>	63	Cockerell	1919
		<i>dentipes</i>	36	Friese	1914
		<i>perforatrix</i>	58	Smith	1879
	<i>Nomada</i>	<i>mutabilis</i>	4	Morawitz	1871
		sp.1	3		
	<i>Thyreus</i>	<i>decorus</i>	16	Smith	1852
		<i>himalayensis</i>	14	Radoszkowski	1893
		<i>histrion</i>	19	Fabricius	1775
	<i>Xylocopa</i>	<i>acutipennis</i>	25	Smith	1854
		<i>aestuans</i>	51	Linnaeus	1758
		<i>collaris</i>	39	Lepeletier	1841
		<i>fenestrata</i>	47	Fabricius	1798
		<i>tenuiscapa</i>	48	Westwood	1840
		<i>violacea</i>	11	Linnaeus	1758
	<i>Amegilla</i>	<i>candida</i>	26	Smith	1879
		<i>cingulifera</i>	42	Cockerell	1910

		<i>confusa</i>	20	Smith	1854
		<i>fallax</i>	32	Smith	1879
		<i>insularis</i>	33	Smith	1857
		<i>quadrifasciata</i>	37	de Villers	1789
		<i>zonata</i>	37	Linnaeus	1758
	<i>Elaphropoda</i>	<i>impatiens</i>	35	Lieftinck	1944
	<i>Apis</i>	<i>cerana</i>	386	Fabricius	1793
		<i>mellifera</i>	146	Linnaeus	1761
	<i>Bombus</i>	<i>breviceps</i>	5	Smith	1852
		<i>eximius</i>	95	Smith	1852
		<i>flavescens</i>	102	Smith	1852
		<i>haemorrhoidalis</i>	128	Smith	1852
Colletidae	<i>Colletes</i>	<i>similis</i>	55	Schenck	1853
		sp.1	29		
		sp.2	22		
Halictidae	<i>Halictus</i>	<i>intricatus</i>	27	Vachal	1894
		<i>propinquus</i>	19	Smith	1853
		<i>senescens</i>	54	Smith	1879
		<i>subopacus</i>	40	Smith	1853
		<i>vicinus</i>	34	Vachal	1895
	<i>Lasioglossum</i>	<i>albescens</i>	51	Smith	1853
		<i>albipes</i>	50	Fabricius	1781
		sp.1	49		
		<i>marginatum</i>	54	Brullé	1853
		<i>villosulum</i>	34	Kirby	1802
	<i>Nomia</i>	<i>formosa</i>	33	Smith	1858
		<i>incerta</i>	39	Gribodo	1894
		<i>iridescens</i>	30	Smith	1858
Megachilidae	<i>Megachile</i>	<i>conjuncta</i>	17	Smith	1853
		<i>femorata</i>	13	Smith	1853
		<i>umbripennis</i>	19	Smith	1853

Appendix IV: Herbs and shrubs present in the sampling transects of SNNP, Nepal

Flower	Flower
<i>Ageratina adenophora</i>	<i>Taraxacum officinale</i>
<i>Ageratum conyzoides</i>	<i>Trifolium repens</i>
<i>Ageratum houstonianum</i>	<i>Viburnum cylindricum</i>
<i>Astragalus khasianus</i>	<i>Viola serpens</i>
<i>Bidens pilosa</i>	<i>Achyranthes aspera</i>
<i>Campanula argyrottrica</i>	<i>Aconogonum molle</i>
<i>Porana racemosa</i>	<i>Alternanthera sessilis</i>
<i>Crepis</i> sp.	<i>Anaphalis busua</i>
<i>Drymaria cordata</i>	<i>Artemisia dubia</i>
<i>Eclipta prostrate</i>	<i>Tridax procumbens</i>
<i>Galinsoga ciliate</i>	<i>Bupleurum hamiltonii</i>
<i>Galinsoga parviflora</i>	<i>Carex felicina</i>
<i>Gaultheria fragrantissima</i>	<i>Cerastium holosteoides</i>
<i>Geranium nepalense</i>	<i>Coriaria nepalensis</i>
<i>Gnaphalium hypoleucum</i>	<i>Daphne bholua</i>
<i>Hypericum japonicum</i>	<i>Elsholtzia strobilifera</i>
<i>Indigofera</i> sp.	<i>Fagopyrum esculentum</i>
<i>Lantana camara</i>	<i>Fagopyrum tataricum</i>
<i>Leucas cephalotes</i>	<i>Guizotia abyssinica</i>
<i>Myrsine capitellata</i>	<i>Hedychium spicatum</i>
<i>Osbeckia stellate</i>	<i>Justicia simplex</i>
<i>Oxalis corniculata</i>	<i>Luculia gratissima</i>
<i>Oxyspora paniculata</i>	<i>Plectranthus barbatus</i>
<i>Parthenium hysterophorus</i>	<i>Polygonum hydropiper</i>
<i>Persicaria capitata</i>	<i>Reinwardtia indica</i>
<i>Persicaria</i> sp.	<i>Sarcococca wallichii</i>
<i>Ranunculus</i> sp.	<i>Scutellaria</i> sp.
<i>Rubus ellipticus</i>	<i>Strobilanthes atropurpureus</i>
<i>Senna alexandrina</i>	<i>Swertia angustifolia</i>
<i>Sida rhombifolia</i>	<i>Urena lobate</i>

Appendix V: Range of flower resource abundance in different habitats in two seasons along the elevation gradient of SNNP, Nepal

Habitats	Elevation (meter)	Flower resource abundance range	
		Autumn	Spring
	1500 – 1700	26–33	27–38
Forest trail	1800 – 1900	20–32	25–29
	2000 – 2700	8–24	14–28
Grass land	1500 – 1700	17–21	13–16
	1800 – 1900	16–21	12–16
	2000 – 2700	18–20	14–16
Open trail	1500 – 1700	72–88	84–87
	1800 – 1900	71–88	84–88
	2000 – 2700	26–88	29–88
	1500 – 1700	72–84	71–74
Managed habitat	1800 – 1900	75–81	72–73
	2000 – 2700	69–83	64–74

Appendix VI: Habitat suitability of wild bees in different village of SNNP

SN	Village Name	<i>Xylocopa violacea</i>	<i>Thyreus himalayensis</i>	<i>Thyreus decorus</i>	<i>Nomada mutabilis</i>	<i>Megachile femorata</i>
1	Adhikarigaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Suitable
2	Allegaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
3	Arkhaule		Least Suitable	Least Suitable	Least Suitable	Least Suitable
4	Aryaltar			Least Suitable		Least Suitable
5	Ath Mail				Least Suitable	Least Suitable
6	Babrang	Least Suitable	Suitable	Least Suitable	Least Suitable	Suitable
7	Bade Pakha			Least Suitable		Least Suitable
8	Badridanda	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
9	Baingkhu			Least Suitable	Least Suitable	Least Suitable
10	Bala Mahadev			Least Suitable	Least Suitable	Least Suitable
11	Banepakha	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
12	Bansgode			Least Suitable		Least Suitable
13	Baralgaun			Least Suitable	Least Suitable	Least Suitable
14	Batase	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
15	Baundu			Least Suitable	Least Suitable	Least Suitable
16	Bhandarigaun			Least Suitable	Least Suitable	Least Suitable
17	Bhange		Least Suitable	Least Suitable	Least Suitable	Least Suitable
18	Bhasanthali			Least Suitable	Least Suitable	Least Suitable
19	Bhattarigaun			Least Suitable		Least Suitable
20	Bhiltar			Least Suitable		Least Suitable
21	Bhirkot	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
22	Bhorletar	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
23	Bhotechaur	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
24	Bhotechaur	Least Suitable	Moderately Suitable	Least Suitable	Least Suitable	Least Suitable
25	Bicharithok			Least Suitable	Least Suitable	Least Suitable
26	Biradigaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
27	Bisnumatigaun			Least Suitable	Least Suitable	Least Suitable
28	Bohratar			Least Suitable		Least Suitable

29	Budhanilakantha			Least Suitable	Least Suitable	Least Suitable
30	Chagaun			Least Suitable	Least Suitable	Least Suitable
31	Chaiju			Least Suitable		Least Suitable
32	Chandeshwarigaun			Least Suitable	Least Suitable	Least Suitable
33	Chapali			Least Suitable		Least Suitable
34	Chauki Bhanjyang	Moderately Suitable	Suitable	Moderately Suitable	Least Suitable	Moderately Suitable
35	Chaukibhanjyang	Suitable	Suitable	Suitable	Suitable	Suitable
36	Chhabeli	Suitable	Suitable	Least Suitable	Suitable	Moderately Suitable
37	Chilanthok			Least Suitable		Least Suitable
38	Chilaunegaun			Least Suitable	Least Suitable	Least Suitable
39	Chilaunegaun	Least Suitable	More Suitable	More Suitable	Moderately Suitable	Suitable
40	Chipalibot			Least Suitable	Least Suitable	Least Suitable
41	Chisenigaun	Least Suitable	Least Suitable	Moderately Suitable	Least Suitable	Moderately Suitable
42	Chogaun			Least Suitable	Least Suitable	Least Suitable
43	Dalkap			Least Suitable	Least Suitable	Least Suitable
44	Damdame			Least Suitable	Least Suitable	Least Suitable
45	Dandagaun	Least Suitable	Least Suitable	Suitable	Moderately Suitable	Suitable
46	Dandakateri	Suitable	Suitable	Suitable	Suitable	Suitable
47	Dandathok	Least Suitable	Moderately Suitable	Moderately Suitable	Least Suitable	Suitable
48	Devasthan	Least Suitable	Moderately Suitable	Moderately Suitable	Suitable	Moderately Suitable
49	Devkotatol	Least Suitable	Suitable	Suitable	Least Suitable	Suitable
50	Dhakaalchaur	Least Suitable	Moderately Suitable	Suitable	Moderately Suitable	Moderately Suitable
51	Dhakaalgaun	Least Suitable	Least Suitable	Moderately Suitable	Least Suitable	More Suitable
52	Dhand	Suitable	Suitable	Suitable	Least Suitable	Suitable
53	Dharapani	Moderately Suitable	Moderately Suitable	Least Suitable	Moderately Suitable	Least Suitable
54	Dharapani			Least Suitable		Least Suitable
55	Dharapanichok	Moderately Suitable	Moderately Suitable	Least Suitable	Moderately Suitable	Moderately Suitable
56	Dhitalgaun		Least Suitable	Least Suitable	Least Suitable	Least Suitable
57	Dobhangaun			Suitable	Least Suitable	Suitable
58	Dulalgaun	Least Suitable	Least Suitable	Moderately Suitable	Least Suitable	Moderately Suitable

59	Dulalgaun			Least Suitable	Least Suitable	Least Suitable
60	Dumrichaur			Least Suitable	Least Suitable	Least Suitable
61	Gagalphedi	Moderately Suitable	Suitable	Suitable	Moderately Suitable	More Suitable
62	Gairigaun			Least Suitable	Least Suitable	Least Suitable
63	Gairigaun			Least Suitable	Least Suitable	Least Suitable
64	Gairigaun	Least Suitable	Least Suitable	Moderately Suitable	Least Suitable	Suitable
65	Gairigaun		Suitable	Least Suitable	Least Suitable	Least Suitable
66	Galmati			Least Suitable		Least Suitable
67	Ganko			Least Suitable	Least Suitable	Moderately Suitable
68	Garhadol	Moderately Suitable	Least Suitable	Suitable	Least Suitable	More Suitable
69	Gelalbarigaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
70	Ghattekholaun			Least Suitable		Least Suitable
71	Ghimiregaun			Least Suitable	Least Suitable	Least Suitable
72	Ghumarichok	More Suitable	Moderately Suitable	Suitable	Least Suitable	Suitable
73	Ghumarithok	Suitable	More Suitable	More Suitable	Suitable	More Suitable
74	Ghyejet	Least Suitable	Least Suitable	Moderately Suitable	Least Suitable	Moderately Suitable
75	Golbhitta	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
76	Goldhunga			Least Suitable		Least Suitable
77	Gumba	Least Suitable	Moderately Suitable	Moderately Suitable	Moderately Suitable	Moderately Suitable
78	Gurje		Suitable	Least Suitable	Least Suitable	Least Suitable
79	Gurunggaun			Least Suitable	Least Suitable	Least Suitable
80	Gurunggaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
81	Gurunggaun		Suitable	Least Suitable	Least Suitable	Least Suitable
82	Gurungtol	More Suitable	More Suitable	More Suitable	Suitable	More Suitable
83	Halchok	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
84	Harkatol	Suitable	More Suitable	More Suitable	Moderately Suitable	More Suitable
85	Hattigaunda				Least Suitable	Least Suitable
86	Hattigaunda	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
87	Ichangu	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
88	Jagatgaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable

89	Jaingaun			Least Suitable	Least Suitable	Least Suitable
90	Jaisigaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
91	Jalukeni	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
92	Jamacho	Moderately Suitable	More Suitable	More Suitable	More Suitable	Moderately Suitable
93	Jhorgaun	Least Suitable	Least Suitable	Moderately Suitable	Moderately Suitable	Suitable
94	Jhule		Least Suitable	Least Suitable	Least Suitable	Least Suitable
95	Jitpurphedi			Least Suitable		Least Suitable
96	Kabregaun			Least Suitable	Least Suitable	Least Suitable
97	Kagatigaun			Least Suitable		Least Suitable
98	Kakani	Least Suitable	Least Suitable	Least Suitable	Suitable	Suitable
99	Kakaregaun			Least Suitable	Least Suitable	Least Suitable
100	Kallabari	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
101	Kamigaun				Least Suitable	Least Suitable
102	Kamitar			Least Suitable		Least Suitable
103	Karanglung				Least Suitable	Least Suitable
104	Karkigaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
105	Katheri	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
106	Kattike			Least Suitable	Least Suitable	Least Suitable
107	Kaudol			Least Suitable	Least Suitable	Least Suitable
108	Kaule	Least Suitable	Least Suitable	Moderately Suitable	Least Suitable	Moderately Suitable
109	Khadkagaun			Least Suitable		Moderately Suitable
110	Khadwal			Least Suitable	Least Suitable	Least Suitable
111	Khalle		Least Suitable	Least Suitable	Least Suitable	Least Suitable
112	Khanigaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
113	Kharibhanjyang			Least Suitable	Least Suitable	Least Suitable
114	Khatrigaun			Least Suitable	Least Suitable	Least Suitable
115	Kisandol			Least Suitable	Least Suitable	Least Suitable
116	Kotgaun				Least Suitable	Least Suitable
117	Kuatwal			Least Suitable		Least Suitable
118	Kuchipakhel	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable

119	Kuinkelgaun	More Suitable	More Suitable	More Suitable	Least Suitable	More Suitable
120	Kulabanjh		Least Suitable	Least Suitable	Least Suitable	Least Suitable
121	Kunegaun		Least Suitable	Least Suitable	Least Suitable	Least Suitable
122	Kuwapani	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
123	Lakure	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
124	Lamabagar			Least Suitable		Least Suitable
125	Lamichhanegaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
126	Lamichhanegaun			Least Suitable	Least Suitable	Least Suitable
127	Lamichhanegaun			Least Suitable	Least Suitable	Least Suitable
128	Lapse	More Suitable	More Suitable	More Suitable	Moderately Suitable	More Suitable
129	Lasuntol	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
130	Lipikot			Least Suitable	Least Suitable	Least Suitable
131	Lolung			Least Suitable		Least Suitable
132	Mahadev Danda			Least Suitable	Least Suitable	Least Suitable
133	Mahankal	Least Suitable	Least Suitable	Suitable	Suitable	More Suitable
134	Mahantagaun			Least Suitable		Least Suitable
135	Maidan				Least Suitable	Least Suitable
136	Majuwa	Least Suitable	Suitable	Least Suitable	Least Suitable	Suitable
137	Majuwa	Moderately Suitable	More Suitable	Suitable	Least Suitable	Suitable
138	Mathillo Paundi Mudkhu			Least Suitable	Least Suitable	Least Suitable
139	Bhanjyang			Least Suitable	Least Suitable	Least Suitable
140	Mudkhu Dhoka			Least Suitable	Least Suitable	Least Suitable
141	Mulkharka	More Suitable	More Suitable	More Suitable	Suitable	More Suitable
142	Naghighyang	Least Suitable	Moderately Suitable	Moderately Suitable	Moderately Suitable	Suitable
143	Nakhandol			Least Suitable	Least Suitable	Least Suitable
144	Nanedandagaun			Least Suitable	Least Suitable	Least Suitable
145	Naphunche	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
146	Narayansthan			Least Suitable	Least Suitable	Least Suitable
147	Narayanthan	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
148	Nayanbasti			Least Suitable	Least Suitable	Least Suitable

149	Nayangaun		Least Suitable	Least Suitable	Moderately Suitable	Least Suitable
150	Nayangaun				Least Suitable	Least Suitable
151	Nayangaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
152	Nepalthok	Least Suitable	Moderately Suitable	Suitable	Moderately Suitable	Moderately Suitable
153	Nepane		Least Suitable	Least Suitable	Least Suitable	Least Suitable
154	Nibugaun			Least Suitable	Least Suitable	Least Suitable
155	Odare			Least Suitable	Least Suitable	Least Suitable
156	Okhreni	Least Suitable	Suitable	Suitable	Moderately Suitable	Moderately Suitable
157	Padali	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
158	Paiyupani	Least Suitable	Moderately Suitable	Least Suitable	Moderately Suitable	Suitable
159	Pakhathok			Moderately Suitable	Least Suitable	Moderately Suitable
160	Panchmane	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
161	Pargang			Least Suitable	Least Suitable	Least Suitable
162	Parigaun			Least Suitable	Least Suitable	Least Suitable
163	Pasikot			Least Suitable	Least Suitable	Least Suitable
164	Patesaura	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
165	Pathibhara			Moderately Suitable		Suitable
166	Patigaun			Least Suitable	Least Suitable	Least Suitable
167	Patikhet			Least Suitable	Least Suitable	Least Suitable
168	Phedigaun	Least Suitable	Moderately Suitable	Suitable	Moderately Suitable	Suitable
169	Phuyalthok			Least Suitable	Least Suitable	Least Suitable
170	Piplephedi			Least Suitable	Least Suitable	Least Suitable
171	Punwargaun	More Suitable	More Suitable	Suitable	Least Suitable	More Suitable
172	Raitar	Moderately Suitable	Least Suitable	Suitable	Least Suitable	More Suitable
173	Raitar			Least Suitable		Least Suitable
174	Rangmen	Least Suitable	Moderately Suitable	Least Suitable	Least Suitable	Moderately Suitable
175	Raniban	Least Suitable	Suitable	Moderately Suitable	More Suitable	Least Suitable
176	Rupsetar			Least Suitable		Moderately Suitable
177	Ryale	Least Suitable	Suitable	Suitable	Suitable	Moderately Suitable
178	Salle			Least Suitable	Least Suitable	Least Suitable

179	Sangla	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
180	Sanogaun			Least Suitable	Least Suitable	Least Suitable
181	Sanyasitar			Least Suitable		Least Suitable
182	Sapantirthagaun			Least Suitable		Least Suitable
183	Sapkotagaun			Least Suitable	Least Suitable	Least Suitable
184	Sarkigaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
185	Sikre				Least Suitable	Least Suitable
186	Simle			Least Suitable		Least Suitable
187	Simle	Least Suitable	Least Suitable	Moderately Suitable	Least Suitable	Suitable
188	Simtar			Least Suitable	Least Suitable	Least Suitable
189	Sinche		Least Suitable	Least Suitable	Moderately Suitable	Least Suitable
190	Sundarijal	Least Suitable	Least Suitable	Suitable	Least Suitable	Suitable
191	Suntakhan			Least Suitable	Least Suitable	Least Suitable
192	Swarthok			Least Suitable		Least Suitable
193	Talakhu	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
194	Tarebhir	Least Suitable	Moderately Suitable	More Suitable	Moderately Suitable	Suitable
195	Targaun	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
196	Taulung			Least Suitable	Least Suitable	Least Suitable
197	Thana Bhanjyang				Least Suitable	Least Suitable
198	Thaple	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Least Suitable
199	Thatipipal			Least Suitable	Least Suitable	Least Suitable
200	Thulagaun	Least Suitable	Least Suitable	Moderately Suitable	Least Suitable	Moderately Suitable
201	Thulogaun			Least Suitable	Least Suitable	Least Suitable
202	Thumki			Least Suitable	Least Suitable	Least Suitable
203	Thumki			Least Suitable	Least Suitable	Least Suitable
204	Tikhe Pakha			Least Suitable	Least Suitable	Least Suitable
205	Tinghare			Least Suitable	Least Suitable	Least Suitable
206	Tinpane	More Suitable	More Suitable	More Suitable	Moderately Suitable	Suitable
207	Tinpiple			Least Suitable	Least Suitable	Least Suitable
208	Tusal			Least Suitable		Least Suitable

209	Tusal	Least Suitable	Least Suitable	Least Suitable	Least Suitable	Moderately Suitable
210	Tusalgaun			Least Suitable		Least Suitable
211	Upallogaun	Least Suitable	Moderately Suitable	Suitable	Moderately Suitable	Moderately Suitable
212	Washigaun			Least Suitable	Least Suitable	Least Suitable

Appendix VII: Scientific name of plants, family, color, shape, and their type (Cluster; C and Single; S), code (used for bipartite analysis), rank of plants, and number of plant network in SNNP during spring and autumn

Spring	Family	Color	Shape	Type	Origin	Code	Rank	Number of plant network
<i>Ageratina adenophora</i>	Asteraceae	White	Open	C	E	II	4-5	46
<i>Bidens pilosa</i>	Asteraceae	White	Open	S	E	VIII	2-5	35
<i>Campanula argyrotricha</i>	Campanulaceae	Blue	Close	S	N	VIII	3-4	5
<i>Oxalis latifolia</i>	Oxalidaceae	Purple	Open	S	E	XXVI	2-3	10
<i>Drymaria cordata</i>	Caryophyllaceae	White	Open	S	E	X	2-5	4
<i>Eclipta prostrata</i>	Asteraceae	White	Open	S	E	XI	4-5	2
<i>Gaultheria fragrantissima</i>	Ericaceae	White	Close	C	N	XIII	3-4	16
<i>Geranium nepalense</i>	Geraniaceae	White	Open	S	N	XIV	2	1
<i>Gnaphalium hypoleucum</i>	Asteraceae	Yellow	Close	C	N	XV	1-4	4
<i>Hypericum japonicum</i>	Hypericaceae	Yellow	Open	S	N	VXII	1-2	4
<i>Indigofera atropurpurea</i>	Fabaceae	Indigo	Close	C	N	XVIII	2-3	10
<i>Lantana camara</i>	Verbenaceae	Pink, yellow	Open	C	E	XX	2-4	22
<i>Viburnum cylindricum</i>	Viburnaceae	White	Close	C	N	XLI	1-3	6
<i>Leucas cephalotes</i>	Lamiaceae	White	close	C	N	XXI	2-3	2
<i>Osbeckia stellata</i>	Melastomataceae	Purple	Open	S	N	XXIV	1-4	2
<i>Oxalis corniculata</i>	Oxalidaceae	Yellow	Open	S	E	XXV	2-4	17
<i>Oxyspora paniculata</i>	Melastomataceae	Pinkish purple	Close	C	N	XXVII	1-2	2

<i>Parthenium hysterophorus</i>	Asteraceae	White	Open	C	E	XXVIII	3-4	9
<i>Persicaria capitata</i>	Polygonaceae	Pink	Close	??	N	XXIX	3-4	7
<i>Ranunculus sceleratus</i>	Ranunculaceae	Yellow	Open	S	N	XXXI	2-3	19
<i>Rubus ellipticus</i>	Rosaceae	White	Open	S	N	XXXIII	1-2	6
<i>Ageratum conyzoides</i>	Asteraceae	white	Open	C	E	III	1-2	2
<i>Sida rhombifolia</i>	Malvaceae	Yellow	Open	S	N	XXXV	1-3	6
<i>Taraxacum officinale</i>	Asteraceae	Yellow	Open	S	E	XXXVII	3-4	16
<i>Trifolium repens</i>	Fabaceae	White	Close	C	E	XXXIX	3-4	37
<i>Viola serpens</i>	Violaceae	White	Open	S	N	XLII	1-2	2
Autumn								
<i>Aconogonum molle</i>	Polygonaceae	White	close	C	N	I		2
<i>Ageratum houstonianum</i>	Asteraceae	Blue	Open	C	E	IV	3-5	26
<i>Anaphalis busua</i>	Asteraceae	White	Open	C	N	VI	2-5	15
<i>Lindenbergia indica</i>	Orobanchaceae	Yellow	Open	S	N	XXII	1-2	2
<i>Daphne bholua</i>	Thymelaeaceae	Pink	Open	C	N	IX	1-2	4
<i>Drymaria cordata</i>	Caryophyllaceae	White	Open	S	E	X	2-5	2
<i>Elsholtzia strobilifera</i>	Lamiaceae	Light blue	Close	C	N	XII	3-5	25
<i>Geranium nepalense</i>	Geraniaceae	White	Open	S	N	XIV	1-2	4
<i>Gnaphalium hypoleucum</i>	Asteraceae	Yellow	Close	C	N	XV	1-4	4
<i>Guizotia abyssinica</i>	Asteraceae	Yellow	Open	S	E	XVI	1-2	16
<i>Indigofera atropurpurea</i>	Fabaceae	Indigo	Close	C	N	XVIII	1-3	4

<i>Justicia simplex</i>	Acanthaceae	Blue	Open	C	N	XIX	1-3	3
<i>Luculia gratissima</i>	Rubiaceae	Pink	Open	C	N	XXIII	1-4	9
<i>Osbeckia stellata</i>	Melastomataceae	Purple	Open	S	N	XXIV	1-3	4
<i>Plectranthus mollis</i>	Lamiaceae	blue	Close	C	N	XXX	1-2	4
<i>Reinwardtia indica</i>	Linaceae	yellow	Open	S	N	XXXII	1-2	20
<i>Scutellaria discolor</i>	Lamiaceae	Blue	Close	C	N	XXXIV	2-4	2
<i>Strobilanthes atropurpureus</i>	Acanthaceae	Blue/purple	Close	C	N	XXXVI	1-4	10
<i>Tridax procumbens</i>	Asteraceae	White	Open	S	E	XXXVIII	1-2	19
<i>Urena lobata</i>	Malvaceae	Pink	Open	S	N	XL	1-2	3
<i>Lantana camara</i>	Verbenaceae	Pink, yellow	Open	C	E	XX	2-4	25
<i>Bidens pilosa</i>	Asteraceae	White	Open	S	E	VII	3-5	49
<i>Alternanthera sessilis</i>	Amaranthaceae	White	Open	S	E	V	3-5	9
<i>Viburnum cylindricum</i>	Viburnaceae	White	Close	C	N	XLI	1-3	5

Appendix VIII: Study information of vegetation analysis of SNNP

Feature	Explanation
Exotic plant in total (%)	36
Native plant in total (%)	64
Exotic plant in spring (%)	42
Exotic plant in autumn (%)	29
Number of flower species visited by pollinators	26 (spring), 24 (autumn)
Number of Flower visitor species	67(spring), 84(autumn)
Number of Flower visitor species Full	93

Appendix IX: Pollinator species, abundance, network number visitor and their corresponding numerical codes for the bipartite graphics

Pollinator species	Abundance	Network number visitor	Code
<i>Dasysyrphus orsua</i>	21	11	X1
<i>Sphaerophoria indiana</i>	14	13	X2
<i>Episyrphus balteatus</i>	136	28	X3
<i>Eristalis cerealis</i>	291	17	X4
<i>Eristalis himalayensis</i>	1	1	X5
<i>Eristalis tenax</i>	323	29	X6
<i>Eristalinus taeniops</i>	16	13	X7
<i>Eupeodes bucculatus</i>	7	6	X8
<i>Asarkina sp.1</i>	1	1	X9
<i>Lycastris flavohirta</i>	2	2	X10
<i>Phytomia zonata</i>	2	2	X11
<i>Melanostoma univittatum</i>	20	7	X12
<i>Melanostoma scalare</i>	24	13	X13
<i>Syrphus torvus</i>	5	4	X14
<i>Episyrphus viridaureus</i>	127	21	X15
<i>Sphaerophoria bengalensis</i>	18	11	X16
<i>Scaeva pyrastris</i>	2	2	X17
<i>Asarkina porcina</i>	10	8	X18
<i>Meliscaeva cinctella</i>	2	2	X19
<i>Phytomia errans</i>	1	1	X20
<i>Mesembrius bengalensis</i>	7	6	X21
<i>Melanostoma orientale</i>	25	11	X22
<i>Syritta pipiens</i>	18	9	X23
<i>Syritta indica</i>	13	6	X24
<i>Eristalinus aeneus</i>	16	6	X25
<i>Paragus crenulatus</i>	2	1	X26
<i>Syritta orientalis</i>	12	9	X27
<i>Sphaerophoria scripta</i>	10	5	X28
<i>Betasyrphus serarius</i>	1	1	X29
<i>Bombus breviceps</i>	1	1	X30
<i>Lasioglossum albescens</i>	6	5	X31
<i>Ceratina dentipes</i>	5	4	X32

<i>Nomia formosa</i>	7	4	X33
<i>Thyreus decorus</i>	1	1	X34
<i>Andrena flavipes</i>	11	7	X35
<i>Andrena gorkhana</i>	5	4	X36
<i>Andrena kathmanduensis</i>	7	6	X37
<i>Amegilla zonata</i>	7	5	X38
<i>Amegilla cingulifera</i>	5	3	X39
<i>Apis mellifera</i>	39	15	X40
<i>Apis cerana</i>	94	15	X41
<i>Bombus eximius</i>	14	7	X42
<i>Bombus flavescens</i>	27	9	X43
<i>Bombus haemorrhoidalis</i>	39	19	X44
<i>Amegilla confusa</i>	15	6	X45
<i>Thyreus histrio</i>	1	1	X46
<i>Colletes</i> sp.	2	2	X47
<i>Halictus vicinus</i>	2	2	X48
<i>Lasioglossum marginatum</i>	12	8	X49
<i>Ceratina bryanti</i>	15	9	X50
<i>Nomada mutabilis</i>	1	1	X51
<i>Megachile umbripennis</i>	1	1	X52
<i>Thyreus himalayensis</i>	2	1	X53
<i>Halictus</i> sp.	1	1	X54
<i>Nomia incerta</i>	4	1	X55
<i>Lasioglossum</i> sp.	1	1	X56
<i>Xylocopa tenuiscapa</i>	1	1	X57
<i>Xylocopa fenestrata</i>	2	2	X58
<i>Lasioglossum villosulum</i>	2	2	X59
<i>Megachile femorata</i>	1	1	X60
<i>Abisara fylla</i>	12	7	X61
<i>Aglais caschmirensis</i>	42	14	X62
<i>Cepora nadina</i>	3	2	X63
<i>Delias belladonna</i>	2	2	X64
<i>Colias erate</i>	12	9	X65
<i>Colias fieldii</i>	10	8	X66
<i>Danaus genutia</i>	9	6	X67
<i>Dodona dipoea</i>	2	2	X68
<i>Dodona egeon</i>	7	5	X69
<i>Dodona eugenes</i>	4	1	X70
<i>Graphium sarpedon</i>	2	1	X71
<i>Euploea core</i>	5	4	X72
<i>Lampides boeticus</i>	6	3	X73
<i>Lestranicus transpectus</i>	3	3	X74
<i>Orsotriaena medus</i>	4	3	X75
<i>Lethe kansa</i>	5	5	X76
<i>Graphium agamemnon</i>	2	1	X77
<i>Lethe verma</i>	2	2	X78

<i>Gonepteryx rhamni</i>	3	3	X79
<i>Catopsilia pomona</i>	4	4	X80
<i>Cyrestis thyodamas</i>	3	2	X81
<i>Appias lyncida</i>	11	6	X82
<i>Neptis mahendra</i>	4	3	X83
<i>Neptis manasa</i>	1	1	X84
<i>Papilio castor</i>	3	3	X85
<i>Papilio polytes</i>	3	3	X86
<i>Parantica aglea</i>	3	3	X87
<i>Parnara guttata</i>	3	3	X88
<i>Eurema hecabe</i>	8	5	X89
<i>Zizeeria maha</i>	7	5	X90
<i>Pieris brassicae</i>	3	2	X91
<i>Pieris canidia</i>	151	28	X92
<i>Vanessa cardui</i>	40	18	X93

Appendix X: Species richness and abundance of interacting pollinators of SNNP.

Group	Species	Frequency
Bee	31	331
Hoverfly	29	1127
Butterfly	44	379

Appendix XI: Frequency and species richness of pollinators visiting two topmost flowers in two different seasons

Plant	Season	Species richness of pollinators	Frequency
<i>Ageratina adenophora</i>	Spring	46	682
<i>Bidens pilosa</i>	Autumn	49	231

Appendix XII: Definitions of network indices, based on Dormann *et al.* (2009)

Qualitative indices

L; Total links in an interaction

I; Total lower trophic level (plant) species

J; Total higher trophic level (insect) species

Network size; $I \times J$

Connectance; The proportion of links; $C = L / (IJ)$

Nestedness; Likelihood of specialist species to interact with subsets of more generalist species (Bascompte *et al.* 2003)

Quantitative indices

Number of interactions (L); the total links in a network

Generality; Mean number of plants per pollinating insects. For unweighted link, Generality is L/J (Dormman *et al.*, 2009).

H2; measurement of specialization (Bluthgen *et al.*, 2006)

Interaction evenness; Shannons evenness of interactions

Linkage density; Mean number of links per species (Tylianakis *et al.*, 2007)

Specialisation asymmetry; Assymetry of specialization in higher versus lower trophic levels. Positive values means a higher specialization of the pollinators (Bluthgen *et al.*, 2007).

Vulnerability; Mean number of higher trophic species per lower trophic species (Bersier, Banasek-Richter & Cattin, 2002)

Web asymmetry; Balance between numbers of pollinating insects and plant species. Positive values show high insect pollinating species, negative values mean more plant species.

$W = (I - J) / (I + J)$ ((Dormman *et al.*, 2009)

Appendix XIII: Conference attended and papers presented

1. Participation and oral presentation

5th International conference on mountains in the changing world, 08–09 , October 2020, Kathmandu, Nepal. Title: “Species composition of insect pollinators in different habitats of Shivapuri-Nagarjun National Park, Nepal.”

2. Participation and oral presentation

First National Conference on zoology 2020. Title: “Diversity and abundance of bee (Hymenoptera: Apoidea) in Shivapuri- Nagarjun National Park, Nepal.”

3. Participation and oral presentation

International conference on zoology 2021. Title: “Species distribution modelling of wild bee species: a case study in Shivapuri-Nagarjun National Park, Nepal.”

Appendix XIV: Scientific publications

The following are papers based on chapters of this Ph.D. work.

1. Dyola, U., Baniya, C. B., Acharya, P. R., Pandey, A., & Sapkota, K. (2022). Bee (Hymenoptera: Apoidea) Fauna of Shivapuri-Nagarjun National Park, Nepal. *Journal of Asia-Pacific Biodiversity*, **15**(2022):231–240.<https://doi.org/10.1016/j.japb.2022.01.007>
2. Dyola, U., Baniya, C. B., Acharya, P. R., Subedi, P., Pandey, A., & Sapkota, K. (2022). Community structure of pollinating insects and its driving factors in different habitats of Shivapuri-Nagarjun National Park, Nepal. *Ecology and evolution*, **12**(3): e8653. <https://doi.org/10.1002/ece3.8653>
3. Dyola, U., Baniya, C. B., Acharya, P. R., Pandey, Hassan, A.M., Anjeela Pandey, A., & Sapkota, K. (2023). A faunistic study on the hoverflies (Diptera:Syrphidae) of Shivapuri Nagarjun National Park, Central Nepal. *Oriental Insects*, <https://doi.org/10.1080/00305316.2023.2171497>



Original Article

Bee (Hymenoptera: Apoidea) Fauna of Shivapuri-Nagarjun National Park, Nepal

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ABSTRACT

The present study was carried out in Shivapuri-Nagarjun National Park to document the baseline data of bee fauna. The study was regulated at elevations of 1,500–2,732 m. The specimens were collected using the sweeping net and colored pan traps. The collection was done from March to October 2018. Total 42 species, 14 genera, 12 tribes, and five families of bees were recorded. Of these, 41 species are the first record from the park and 11 species, viz., *Amegilla candida* (Smith, 1879), *Amegilla fallax* (Smith, 1879), *Amegilla insularis* (Smith, 1857), *Amegilla quadrifasciata* (de Villiers, 1789), *Elaphropoda impatiens* (Lief-tinck, 1944), *Ceratina perforatrix* Smith, 1879, *Colletes similis* Schenck, 1853, *Megachile conjuncta* Smith, 1879, *Nomia iridescens* Smith, 1858, *Xylocopa collaris* Lepeletier, 1841, and *Xylocopa violacea* (Linnaeus, 1758) are new records for Nepal.

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Introduction

Bees (Hymenoptera: Apoidea) are vital pollinators of flowering plants in natural and agricultural ecosystems (Grab et al. 2019). Michener (2007) further classified the superfamily Apoidea into seven families namely, Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae, Melittidae, and Stenotritidae. There are 20,507 known species of bees globally (Ascher and Pickering 2021), about 173 species of bees have been reported (Ascher and Pickering 2021) from Nepal. They differ from sphecoid wasps, their closest relatives, having branched hairs on the body and enlarged hind basitarsus (Wijesekaran 2001). They exhibit a wide range of lifestyles from solitary to social. Honey bees, bumblebees, and stingless bees are social bees. They live in colonies where the members follow the division of labor. However, carpenter bees and cuckoo bees are solitary, and cleptoparasitic species (Danforth et al. 2013). Recent shreds of evidence show a

decline in the number of bee specimens in the world (Potts et al. 2010; Wood et al. 2020). Various reasons have been reported such as quality food shortage (Biesmeijer et al. 2006), habitat loss and pathogen (Potts et al. 2010), climate change and deforestation (Nemésio et al. 2016; Dew et al. 2019), and the use of pesticides in agriculture (Goulson et al. 2015).

There have been very few attempts to study bee fauna in Nepal. Most of the studies on the bees of Nepal have been executed by foreign researchers: Matsumura 1970; Tkalcu 1974; Tadauchi and Matsumura 2007; Shiokawa 2008; Burger et al. 2009; Williams et al. 2010; Murao and Tadauchi 2013; Murao et al. 2015. A very few Nepalese researchers include Thapa (2015) who was the first person to summarize the dissipated data on the bee's fauna of Nepal. Hence, it is fair enough to conclude that research in the bees of Nepal is a very less explored and least understood area. Therefore, the work on bee fauna in Shivapuri-Nagarjun National Park (SNNP) could be an important contribution to this very less spoken area and field of study as SNNP is a good landscape for biodiversity in Nepal. Thus, this study aims to document the bee fauna of SNNP that may provide baseline data for future research on bee biodiversity, ecology, and conservation from SNNP.

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Material and methods

Study area

The SNNP (Figure 1), covers an area of 159 km² and elevation ranges of 960–2,732 m above sea level. It is located in central Nepal (Shivapuri 27.75° to 27.87° N and 85.27° to 85.75° E, Nagarjun 27.72° to 27.77° N and 85.22° to 85.30° E). It is the only protected area that falls entirely within the mid–mountain range with 1,114 species of flowering plants (SNNP 2017). Our study sites covered the area from the lowest point (1,500 m above sea level) to the peak of SNNP (2,732 m above sea level).

Collection methods

The fieldwork was carried out from March to October 2018 including two seasons: spring and autumn. We selected five sites: Sundarijal, Shivapuri, Gurje Bhanjyang, Nagarjun, and Manichud. Each site was sampled in three different elevations and each elevation was divided into five sampling plots with a 100 by 5 m area. The bees were collected using two standard protocols; hand sweeping and colored pans traps (white, yellow, and blue). The pan traps method is suitable for sampling bees in multiple locations and covering a large area (Westphal et al. 2008). Rainy and cloudy days were avoided. Garmin eTriX Hc Global Positioning System was used to record the altitude, latitude, and longitude of each site. The collected bee specimens were stored in airtight containers and kept

in the icebox for the laboratory process. Specimens were subsequently dry mounted using standard insect pins. The map of study sites was created with ArcGIS (Geographic Information System) 10.5 version.

Identifications and deposition

The adult specimens of the bee were observed under a stereoscopic microscope. Bee specimens were identified using published identification keys mostly from adjacent regions: Bingham 1897; Tadauchi and Matsumura 2007; Williams et al. 2010; Bodlah et al. 2016; Aslam et al. 2017; Ngat et al. 2017; Kumari et al. 2018. The studied specimens were deposited in the Central Department Zoology Museum of Tribhuvan University, Kirtipur, Kathmandu, Nepal.

Nomenclature

The nomenclature of bees is based on Michener (2007) and the latest published literature.

Classification and arrangement of taxa

The complete listing of bees of SNNP is organized alphabetically by family and subfamily, followed by tribe, genus, and finally species name.

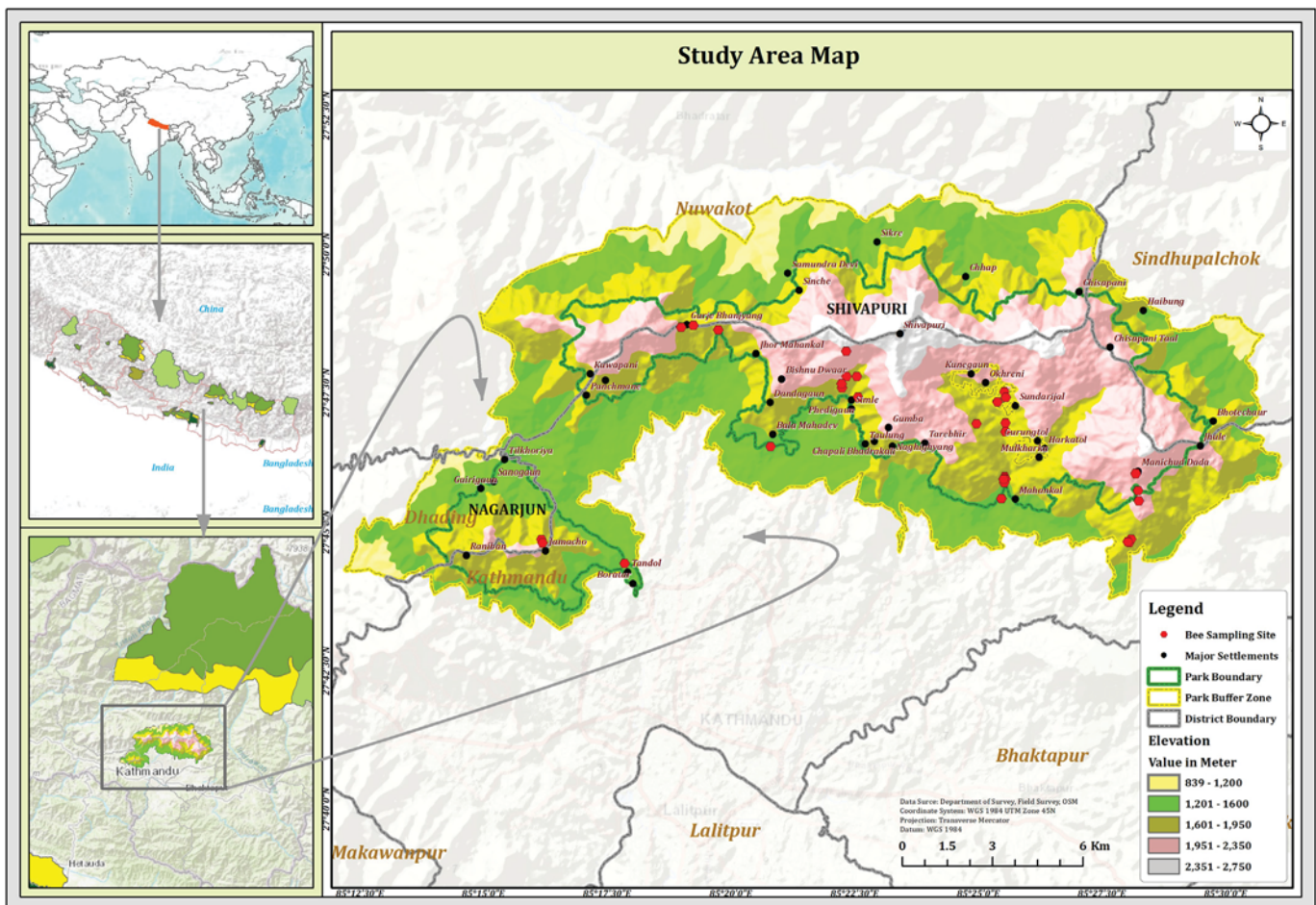


Figure 1. Map showing sampling sites in Shivapuri-Nagarjun National Park.

Distribution data

The article also provides the distribution of species within Nepal and the neighboring countries. The distribution data are arranged in the list “Nepal” followed by the countries: China, India, and Pakistan, respectively.

Endemic species. The species reported only from Nepal are treated as endemic.

New records for the country. They are marked by Asterisk (*).

Results

During the field study, 42 species of bees belonging to 14 genera, 12 tribes, and five families (Table 1) were reported. Except *Bombus (Pyrobombus) eximius* other 41 species are the first records from SNNP. Among these documented bees, 11 species: *Amegilla candida* (Smith, 1879) (Figure 2A–C), *Amegilla fallax* (Smith, 1879) (Figure 2D–F), *Amegilla insularis* (Smith, 1857) (Figure 2G–I), *Amegilla quadrifasciata* (de Villiers, 1789) (Figure 3A–C), *Elaphropoda impatiens* (Lieftinck, 1944) (Figure 3D–F), *Ceratina perforatrix* Smith, 1879 (Figure 3G–I), *Colletes similis* Schenck, 1853 (Figure 4A–C), *Megachile conjuncta* Smith, 1879 (Figure 4D–F), *Nomia iridescens* Smith, 1858 (Figure 4G–I), *Xylocopa collaris* Lepelletier, 1841 (Figure 5A–C), and *Xylocopa violacea* (Linnaeus, 1758) (Figure 5D–F) are new records for Nepal.

Taxonomic accounts

Family Andrenidae Latreille, 1802

Subfamily Andreninae

Tribe Andrenini

Genus *Andrena* Fabricius, 1775

Andrena (Zonandrena) flavipes Panzer, 1799

Material examined. 1♂, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 15 iii 2018(U. Dyola), from 1,800 m; 1♂, Shivapuri, 27.79217°N, 85.37602°E, 15 iv 2018(U. Dyola)1, from 1,700 m; 2♀1♂, Sundarikal, 27.76453°N, 85.42340°E, 04 iv 2018(U. Dyola), from 1,500 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81170°N, 85.31319°E, 12 iv 2018 (U. Dyola), from 2,000 m.

Distribution. Nepal. Sindhupalchok: Pati Bhanjyang at 1,500 m and Barhabise at 1,300 m; Kathmandu: Balaju and Godawari at 1,400 m; Parsa: Birgunj at 100 m; Syangja: at 2,700 m; Palpa: at 750 m; Myagdi: Ghodepani at 1,900 m; Mustang: Marpha at 2,670 m,

Tukuche at 2,600 m, and Lete at 2,440 m (Tadauchi and Matsumura 2007); China and India (Ascher and Pickering 2021).

Floral association. *Ageratina adenophora*.

Andrena (Simandrena) gorkhana Tadauchi & Matsumura, 2007

Material examined. 2♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 15 iii 2018(U. Dyola), from 1,800 m; 1♀, Shivapuri, 27.79217°N, 85.37602°E, 15 iv 2018, from 1,700 m; 1♀, Sundarikal, 27.764531°N, 85.4234°E, 4 iv 2018 (U.Dyola), from 1,500 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81170°N, 85.31319°E, 12 iv 2018(U. Dyola), from 2,000 m.

Distribution. Nepal. Kathmandu at 1,340 m; Parsa: Birgunj at 100 m; Gorkha: Arughat at 300–600 m, Bhanjyang at 1,200–1,500 m, and Kanchok at 900 m (Tadauchi and Matsumura 2007; Ascher and Pickering 2021).

Endemic to Nepal.

Floral association. *Ageratina adenophora*.

Andrena (Euandrena) kathmanduensis Tadauchi & Matsumura, 2007

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 15 iii 2018 (U. Dyola), from 1,800 m; 1♀, Sundarikal, 27.764531°N, 85.4234°E, 02 iv 2018(U. Dyola), from 1,500 m.

Distribution. Nepal. Sindhupalchok: Pati Bhanjyang at 1,500 m and Helambu at 2,400 m; Kathmandu Godawari and Balaju at 1,400 m; Palpa; Kaski: Ulleri at 2,200 m; Myagdi: Ghodepani at 2,750 m; Mustang: Lete at 2,400 m (Tadauchi and Matsumura 2007; Ascher and Pickering 2021).

Endemic to Nepal.

Floral association. *Ageratina adenophora*.

Family Apidae Linnaeus, 1758

Subfamily Apinae

Tribe Anthophorini

Genus *Amegilla* Friese, 1897

****Amegilla candida*** (Smith, 1879)

(Figure 2A–C)

Material examined. 1♀, Kathmandu, Sundarikal, 27.79172°N, 85.4211°E, 12 x 2018, (U. Dyola) from 2,000 m.

Distribution. India and Pakistan (Ascher and Pickering 2021).

Floral association. *Ageratum houstonianum*.

Amegilla (Zonamegilla) cingulifera (Cockerell, 1910)

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018(U. Dyola), from 1,800 m; Nagarjun, 1♀, 27.68304°N, 85.28741°E, 24 x 2018 (U. Dyola), from 1,500 m; 1♀, Sundarikal, 27.764531°N, 85.4234°E, 07 x 2018 (U. Dyola), from 1,500 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81219°N, 85.3265°E, 03. xi 2018 (U. Dyola), from 1,900 m.

Distribution. Nepal. China and India (Ascher and Pickering 2021).

Floral association. *Ageratum houstonianum* and *Biden pilosa*.

Amegilla (Zonamegilla) confusa (Smith, 1854)

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018 (U. Dyola), from 1,800 m; 1♀, Nagarjun, 27.68304°N, 85.28741°E, 24 x 2018 (U. Dyola), from 1,500 m; 2♀, Shivapuri, 27.79519°N, 85.38848°E, 17 iv 2018 (U. Dyola), from 1,900 m; 1♀, Sundarikal, 27.79172°N, 85.4211 °E, 07 x 2018 (U. Dyola), from 2,000 m.

Table 1. Families, genera, and species of superfamily Apoidea (Hymenoptera), recorded from SNNP.

Families	Genera	Species
Andrenidae (1 genus, 3 species)	<i>Andrena</i>	3
Apidae (8 genus, 27 species)	<i>Amegilla</i>	7
	<i>Apis</i>	2
	<i>Bombus</i>	4
	<i>Ceratina</i>	3
	<i>Elaphropoda</i>	1
	<i>Nomada</i>	1
	<i>Thyreus</i>	3
	<i>Xylocopa</i>	6
Colletidae (1 genus, 1 species)	<i>Colletes</i>	1
Halictidae (3 genus, 8 species)	<i>Halictus</i>	2
	<i>Lasioglossum</i>	3
	<i>Nomia</i>	3
Megachilidae (1 genus, 3 species)	<i>Megachile</i>	3
Five families	14 genera	42 species

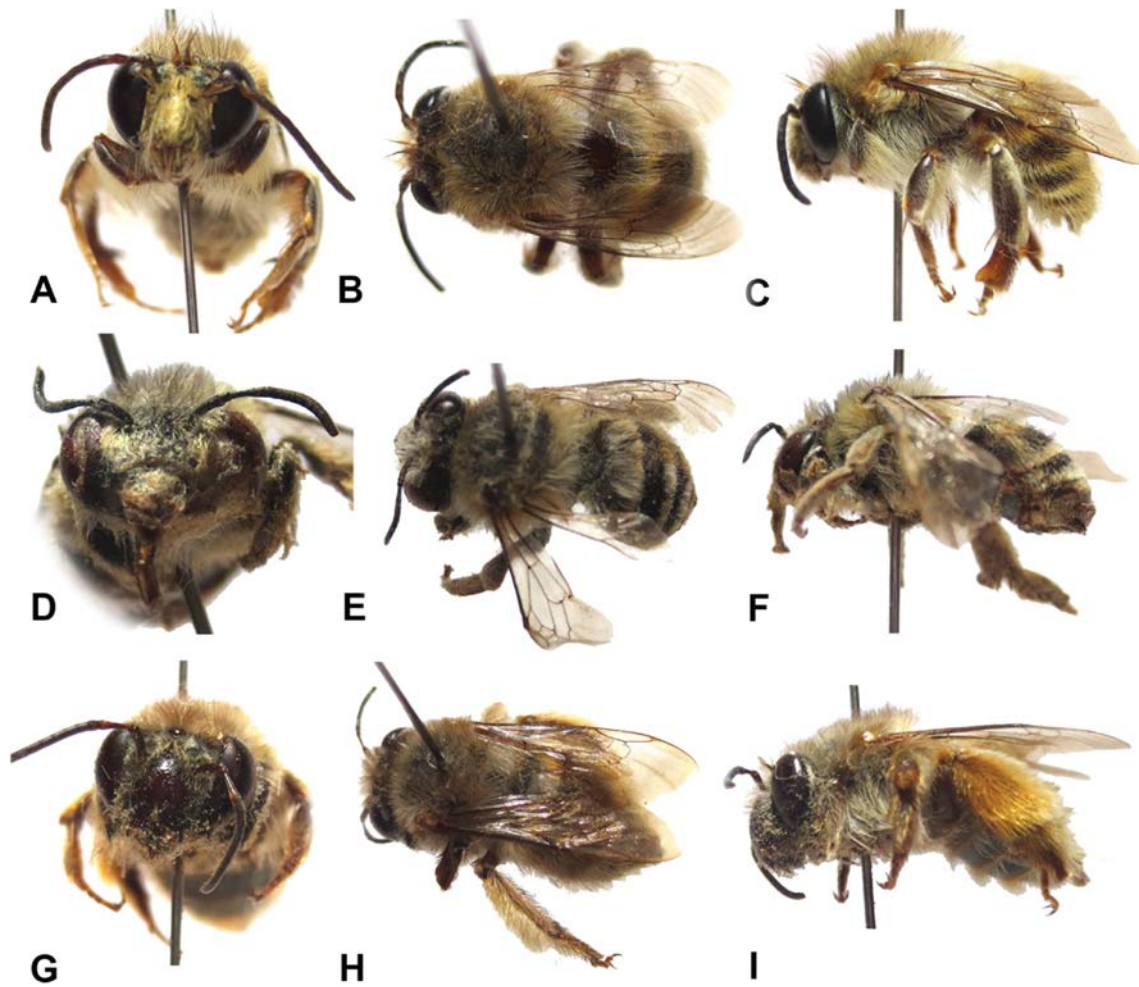


Figure 2. *Amegilla candida* female: A, Frontal habitus; B, Dorsal habitus; C, Lateral habitus; *Amegilla fallax* female: D, Frontal habitus; E, Dorsal habitus; F, Lateral habitus; *Amegilla insularis* female: G, Frontal habitus; H, Dorsal habitus; I, Lateral habitus.

Distribution. Nepal, China, India (Ascher and Pickering 2021), and Pakistan (Bodlah et al. 2016).

Floral association. *Ageratum houstonianum* and *Biden pilosa*.

**Amegilla (Zebamegilla) fallax* (Smith, 1879)
(Figure 2D–F)

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018 (U. Dyola), from 1,800 m.

Distribution. India (Saini et al. 2016).

Floral association. *Ageratum houstonianum*.

**Amegilla (Glossamegilla) insularis* (Smith, 1857)
(Figure 2G–I)

Material examined. 1♀, Nuwakot, Gurjebhanjyang, 27.80197°N, 85.32268°E, 01 xi 2018 (U. Dyola), from 1,600 m.

Distribution. Pakistan (Aslam et al. 2017).

Floral association. *Biden pilosa*.

**Amegilla (Amegilla) quadrifasciata* (de Villiers, 1789)
(Figure 3A–C)

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018 (U. Dyola), from 1,800 m; 1♀, Sundarikal, 27.79172°N, 085.4211°E, 12 x 2018 (U. Dyola), from 2,000 m.

Distribution. India and Pakistan (Ascher and Pickering 2021).

Floral association. *Ageratum houstonianum* and *Biden pilosa*.

Amegilla (Zonamegilla) zonata (Linnaeus, 1758)

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018 (U. Dyola), from 1,800 m; 1♀, Shivapuri, 27.79519°N, 85.38848°E, 30 ix 2018 (U. Dyola), from 1,900 m; 1♀, Sundarikal, 27.79172°N, 085.4211°E, 12 x 2018 (U. Dyola), from 2,000 m.

Distribution. Nepal, China and India (Kumari and Sidhu 2020).

Floral association. *Ageratum houstonianum* and *Biden pilosa*.

Genus *Elaphropoda* Lieftinck, 1966

**Elaphropoda impatiens* (Lieftinck, 1944)
(Figure 3D–F)

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018 (U. Dyola), from 1,800 m; 1♀, Sundarikal, 27.79172°N, 085.4211°E, 12 x 2018 (U. Dyola), from 2,000 m.

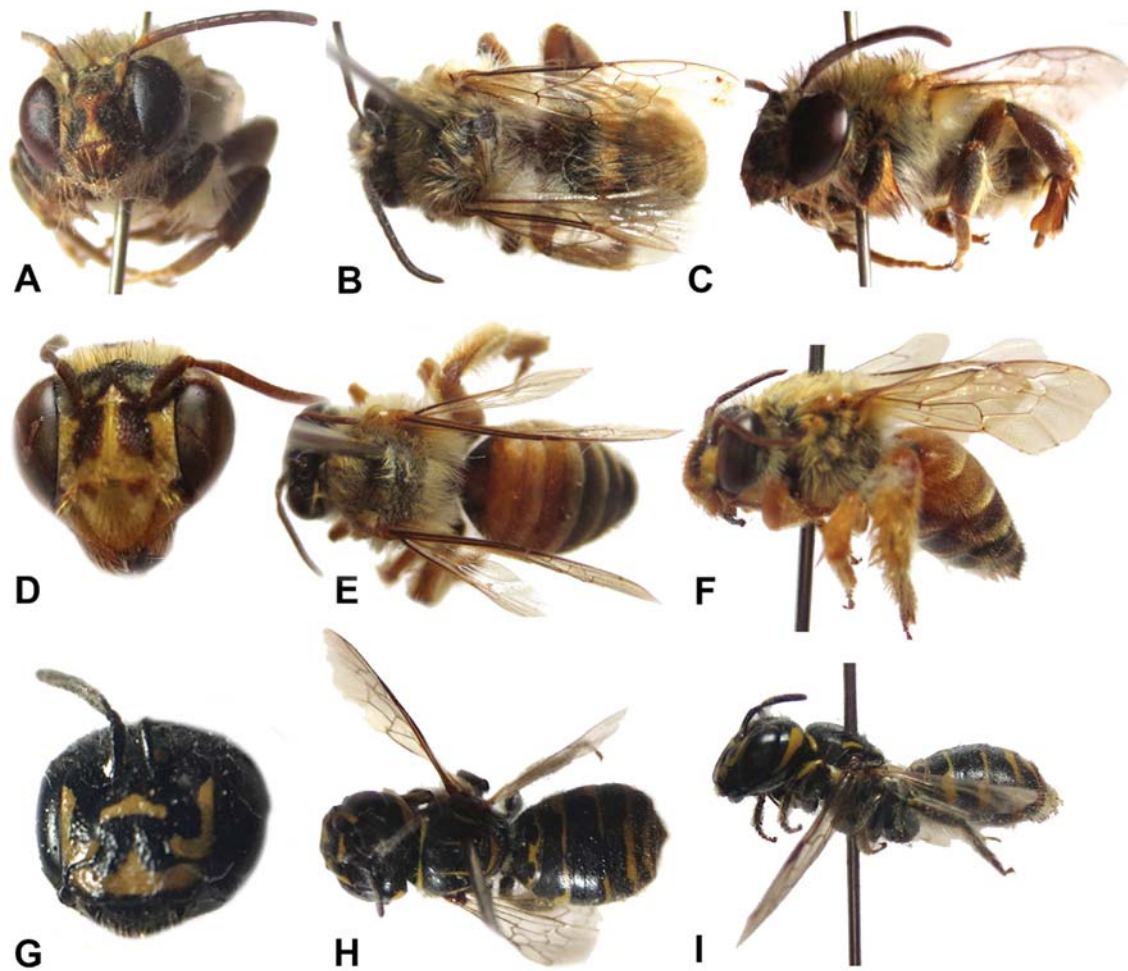


Figure 3. *Amegilla quadrifasciata* female: A, Frontal habitus; B, Dorsal habitus; C, Lateral habitus; *Elaphropoda impatiens* female: D, Head in frontal view; E, Dorsal habitus; F, Lateral habitus; *Ceratina perforatrix* female: G, Head in frontal view; H, Dorsal habitus; I, Lateral habitus.

Distribution. No records from neighboring countries (China, India, and Pakistan).

Floral association. *Lantana camara*.

Tribe Apini

Genus *Apis* Linnaeus, 1758

Apis cerana Fabricius, 1793

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 15 iii 2018 (U. Dyola), from 1,800m; 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018 (U. Dyola), from 1,800m; 2♀, Nagarjun, 27.68304°N, 85.28741°E, 26 iii 2018 (U. Dyola), from 1,500m; 1♀, Nagarjun, 27.68304°N, 85.28741°E, 24 x 2018 (U. Dyola), from 1,500m; 1♀, Nagarjun, 27.74415°N, 85.29023°E, 28 iii 2018 (U. Dyola), from 1,600m; 2♀, Shivapuri, 27.79217°N, 85.37602°E, 15 iv 2018 (U. Dyola), from 1,700m; 1♀, Shivapuri, 27.79217°N, 85.37602°E, 28 ix 2018 (U. Dyola), from 1,700m; 2♀, Shivapuri, 27.79519°N, 85.38848°E, 17 iv 2018 (U. Dyola), from 1,900m; 1♀, Shivapuri, 27.79519°N, 85.38848°E, 30 ix 2018 (U. Dyola), from 1,900m; 2♀, Sundarijal, 27.764531°N, 85.4234°E, 02 iv 2018 (U. Dyola), from 1,500m; 2♀, Sundarijal, 27.764531°N, 85.4234°E, 07 x 2018 (U. Dyola), from 1,500m; 1♀, Sundarijal, 27.79172°N, 85.4211°E, 05 iv 2018 (U. Dyola), from 2,000m; 1♀, Sundarijal, 27.79172°N, 85.4211°E, 12 x 2018 (U. Dyola), from 2,000m; 2♀, Nuwakot, Gurjebhanjyang, 27.80197°N,

85.32268°E, 08 iv 2018 (U. Dyola), from 1,600m; 2♀, Nuwakot, Gurjebhanjyang, 27.80197°N, 85.32268°E, 01 xi 2018 (U. Dyola), from 1,600m.

Distribution. Nepal. From Terai–3,500m. Kathmandu (Thapa 2015); China, India, and Pakistan (Saini et al. 2018).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, and *Biden pilosa*.

Apis mellifera Linnaeus, 1761

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 15 iii 2018 (U. Dyola), from 1,800m; 2♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018 (U. Dyola), from 1,800m; 2♀, Nagarjun, 27.68304°N, 85.28741°E, 26 iii 2018 (U. Dyola), from 1,500m; 1♀, Nagarjun, 27.68304°N, 85.28741°E, 24 x 2018 (U. Dyola), from 1,500m; 1♀, Nagarjun, 27.74415°N, 85.29023°E, 28 iii 2018 (U. Dyola), from 1,600m; 1♀, Shivapuri, 27.79217°N, 85.37602°E, 28 ix 2018 (U. Dyola), from 1,700m; 2♀, Shivapuri, 27.79519°N, 85.38848°E, 17 iv 2018 (U. Dyola), from 1,900m; 2♀, Sundarijal, 27.764531°N, 85.4234°E, 02 iv 2018 (U. Dyola), from 1,500m; 2♀, Sundarijal, 27.764531°N, 85.4234°E, 07 x 2018 (U. Dyola), from 1,500m; 1♀, Sundarijal, 27.79172°N, 85.4211°E, 02 iv 2018 (U. Dyola), from 2,000m; 1♀, Sundarijal, 27.79172°N, 85.4211°E, 12 x 2018 (U. Dyola), from 2,000m; 2♀, Nuwakot, Gurjebhanjyang, 27.80197°N, 85.32268°E, 08 iv 2018 (U. Dyola), from 1,600m; 2♀, Nuwakot, Gurjebhanjyang, 27.80197°N, 85.32268°E, 01 xi 2018 (U. Dyola), from 1,600m.

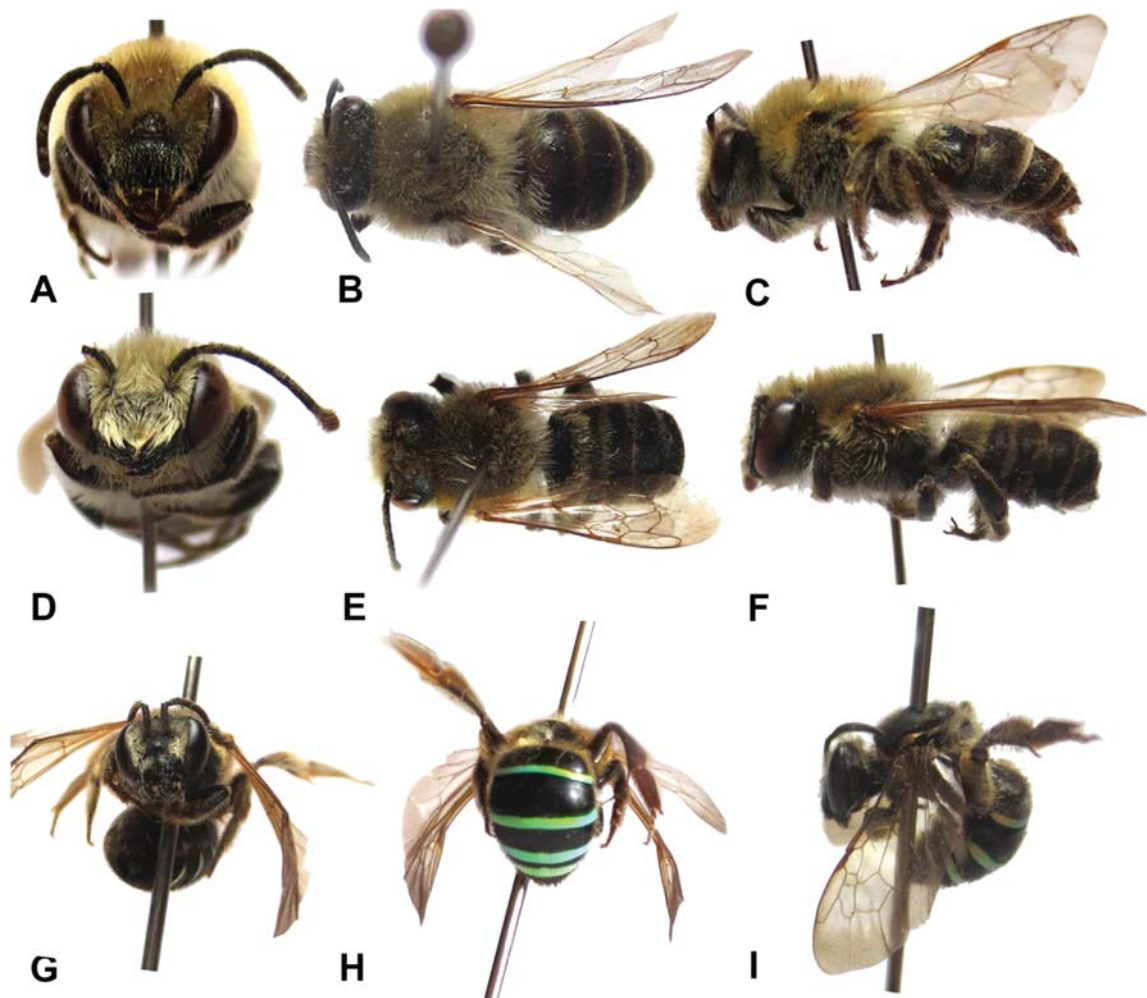


Figure 4. *Colletes similis* female. A. Frontal habitus; B. Dorsal habitus; C. Lateral habitus; *Megachile conjuncta* male. D. Frontal habitus; E. Dorsal habitus; F. Lateral habitus; *Nomia iridescens* female. G. Frontal habitus; H. Dorsal abdomen; I. Lateral habitus.

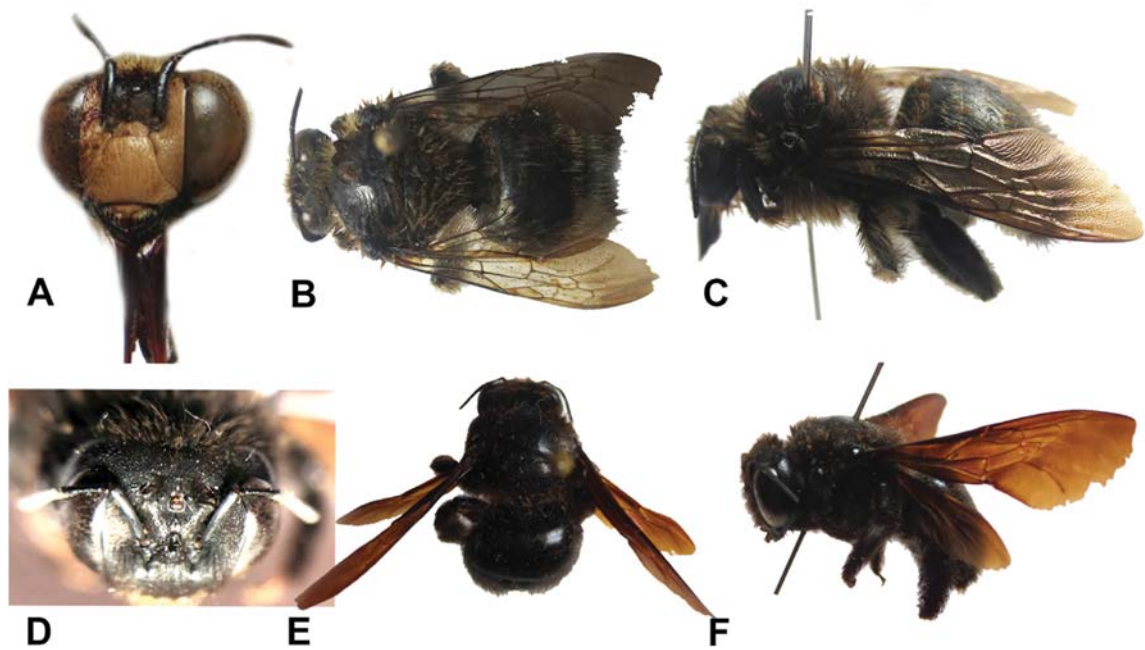


Figure 5. *Xylocopa collaris* female: A. Head in frontal view; B. Dorsal habitus; C. Lateral habitus; *Xylocopa violacea* female: D. Head in frontal view; E. Dorsal habitus; F. Lateral habitus.

Distribution. Nepal. Terai—3,000 m (Thapa 2015); China, India, and Pakistan (Ascher and Pickering 2021).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, and *Biden pilosa*.

Tribe Bombini

Genus *Bombus* Latreille, 1802

Bombus (Alpigenobombus) breviceps Smith, 1852

Material examined. 1♀, Sundarimal, 27.79172°N, 85.4211°E, 12 x 2018 (U. Dyola), from 2,000m.

Distribution. Nepal. From 980–3,000 m. Kathmandu: Gokarna Safari; China and India (Burger et al. 2009; Williams et al 2010; Thapa 2015).

Floral association. *Plectranthus barbatus*.

Bombus (Pyrobombus) eximius Smith, 1852

Material examined. 1♀, Kathmandu Manichud, 27.77076°N, 85.46804°E, 22 iii 2018 (U. Dyola), from 2,300m; 1♀, Nagarjun, 27.68304°N, 85.28741°E, 26 iii 2018 (U. Dyola), from 1,500m; 1♀ Shivapuri, 27.79217°N, 85.37602°E, 28 ix 2018 (U. Dyola), from 1,700m; 2♀, Sundarimal, 27.764531°N, 85.4234°E, 02 iv 2018] (U. Dyola), from 1,500m; 1♀, Nuwakot, Gurjebhanjyang, 27.81219°N, 85.3265°E, 10 iv 2018 (U. Dyola), from 1,900m; 1♀, Nuwakot, Gurjebhanjyang, 27.81170°N, 85.31319°E, 12 iv 2018 (U. Dyola), from 2,000m.

Distribution. Nepal. From 914–2,700 m. Sankhuwasabha: Arun valley Uwa at 1,600 m; Solukhumbu: above Gudel at 2,000–2,500 m; Kathmandu: Shivapuri at 1,600 m, Nagarjun forest, Sundarimal, and Lalitpur: Phulchoki at 1,800–2,000m; Kaski: Pothana at 2,000m; Myagdi: Thulo Khola Rakhori at 1,700–2,100 m, Bega to Bega Deurali at 1,700–2,400 m; Dailekh: Bharin at 2,400 m (Burger et al. 2009; Williams et al 2010; Thapa 2015); –China and India (Ascher and Pickering 2021).

Floral association. *Lantana camara*, *Rubus ellipticus*, *Strobilanthes atropurpureus*, and *Viola serpens*.

Bombus (Pyrobombus) flavescens Smith, 1852

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 15 iii 2018 (U. Dyola), from 1,800m; 1♀, Kathmandu, Manichud, 27.77076°N, 85.46804°E, 22 x 2018 (U. Dyola), from 2,300m; 1♀, Nagarjun, 27.68304°N, 85.28741°E, 26 iii 2018 (U. Dyola), from 1,500m; 1♀, Shivapuri, 27.60567°N, 85.36913°E, 03 x 2018] (U. Dyola), from 2,300m; 1♀, Sundarimal, 27.764531°N, 85.4234°E, 02 iv 2018 (U. Dyola), from 1,500m; 1♀, Sundarimal, 27.79172°N, 85.4211°E, 12 x 2018 (U. Dyola), from 2,000m; 1♀, Nuwakot, Gurjebhanjyang, 27.81170°N, 85.31319°E, 05 xi 2018 (U. Dyola), from 2,000m.

Distribution. Nepal. From 1,400–2,950m. Kaski: Ulleri at 2,000m (Burger et al. 2009; Williams et al. 2010; Thapa 2015); China and India (Williams et al. 2010).

Floral association. *Lantana camara* and *Strobilanthes atropurpureus*.

Bombus (Orientalibombus) haemorrhoidalis Smith, 1852

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 15 iii 2018 (U. Dyola), from 1,800m; 1♀, Kathmandu, Manichud, 27.77076°N, 85.46804°E, 22 iii 2018 (U. Dyola), from 2,300m; 1♀, Nagarjun, 27.74415°N, 85.29023°E, 28 iii 2018 (U.

Dyola), from 1,600m; 1♀, Shivapuri, 27.79519°N, 85.38848°E, 17 iv 2018 (U. Dyola), from 1,900m; 2♀ Shivapuri, 27.60567°N, 85.36913°E, 20 iv 2018 (U. Dyola), from 2,300m; 1♀ Sundarimal, 27.764531°N, 85.4234°E, 02 iv 2018 (U. Dyola), from 1,500m; 1♀, Sundarimal, 27.79172°N, 85.4211°E, 05 iv 2018 (U. Dyola), from 2,000m; 1♀, Nuwakot, Gurjebhanjyang, 27.80197°N, 85.32268°E, 08 iv 2018 (U. Dyola), from 1,600m.

Distribution. Nepal. From 830–recorded up to 4,000 m. Dailekh Bharin at 2,400 m; Kalikot: Gamkhet at 1,850 m; Mugu: Rara at 2,990 m; Jumla: Tatopani at 200 m; Surkhet at 1,700 m; Humla: Simikot at 2,200 m (Burger et al. 2009; Thapa 2015); China, India, and Pakistan (Williams et al. 2010).

Floral association. *Plectranthus barbatus*, *Rubus ellipticus*, *Strobilanthes atropurpureus*, and *Viola serpens*.

Tribe Melectini

Genus *Thyreus* Panzer, 1806

Thyreus decorus (Smith, 1852)

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018 (U. Dyola), from 1,800m; 1♀, Shivapuri, 27.79519°N, 85.38848°E, 30 ix 2018 (U. Dyola), from 1,900m; 1♀, Sundarimal, 27.764531°N, 85.4234°E, 07 x 2018 (U. Dyola), from 1500m.

Distribution. Nepal. Chembu at 1,650 m (Thapa 2015); China and India (Ngat et al. 2017).

Floral association. *Lantana camara*.

Thyreus himalayensis (Radoszkowski, 1893)

Material examined. 1♀, Kathmandu, Shivapuri, 27.79519°N, 85.38848°E, 30 ix 2018 (U. Dyola), from 1,900m; 1♀, Nuwakot, Gurjebhanjyang, 27.81219°N, 85.3265°E, 03 xi 2018 (U. Dyola), from 1,900m.

Distribution. Nepal. From 750–1,600 m. Kathmandu: Godawari at 1,450 m; Kaski: Rupakot at 750 m; Sanopakha at 1,600 m, Namoto at 1,400 m (Thapa 2015); China, India (Ascher and Pickering 2021), and Pakistan (Bodlah et al. 2016).

Floral association. *Lantana camara*.

Thyreus histrio (Fabricius, 1775)

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018 (U. Dyola), from 1,800m; 1♀, Shivapuri, 27.79519°N, 85.38848°E, 30 ix 2018 (U. Dyola), from 1,900m; 1♀, Sundarimal, 27.764531°N, 85.4234°E, 07 x 2018 (U. Dyola), from 1,500m.

Distribution. Nepal. Kathmandu at 1,340 m (Thapa 2015); India (Ascher and Pickering 2021).

Floral association. *Lantana camara*.

Subfamily Nomadinae

Tribe Nomadini

Genus *Nomada* Scopoli, 1770

Nomada mutabilis Morawitz, 1871

Material examined. 1♀, Kathmandu, Nagarjun, 27.74415°N, 85.29023°E, 24 x 2018 (U. Dyola), from 1,600m.

Distribution. Nepal (Proshchalykin and Schwarz 2017). India (Proshchalykin and Schwarz 2017; Ascher and Pickering 2021).

Floral association. *Biden pilosa*.

Subfamily Xylocopinae
Tribe Ceratinini

Genus *Ceratina* Latreille, 1802

Ceratina (Ceratinidia) bryanti Cockerell, 1919

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 15 iii 2018 (U. Dyola), from 1,800m; 1♀, Shivapuri, 27.79217°N, 85.37602°E, 15 iv 2018 (U. Dyola), from 1,700m; 1♀, Sundarrijal, 27.764531°N, 85.4234°E, 04 iv 2018 (U. Dyola), from 1,500m; 1♀, Nuwakot, Gurjebhanjyang, 27.81170°N, 85.31319°E, 12 iv 2018 (U. Dyola), from 2,000m.

Distribution. Nepal. Lower warm–temperate zone from 1,300–1,400 m. Kathmandu (Shiokawa 2008); China (Ascher and Pickering 2021).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, and *Biden pilosa*.

Ceratina (Neoceratina) dentipes Friese, 1914

Material examined. 1♀, Kathmandu, Sundarrijal, 27.764531°N, 85.4234°E, 02 iv 2018 (U. Dyola), from 1,500m.

Distribution. Nepal. Warm–temperate zone at an altitude of about 1,500 m. Naudanda, Central Nepal (Shiokawa 2008); China (Shiokawa 2008; Ascher and Pickering 2021).

Floral association. *Ageratina adenophora*.

****Ceratina (Catoceratina) perforatrix*** Smith, 1879
(Figure 3G–I)

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 15 iii 2018 (U. Dyola), from 1,800m; 1♀, Nagarjun, 27.74508°N, 85.26694°E, 30 iii 2018 (U. Dyola), from 2,100m; 1♀, Sundarrijal, 27.79172°N, 85.4211°E, 05 iv 2018 (U. Dyola), from 2,000m.

Distribution. China and India (Ascher and Pickering 2021).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, and *Biden pilosa*.

Tribe Xylocopini

Genus *Xylocopa* Latreille, 1802

Xylocopa (Mesotrichia) acutipennis Smith, 1854

Material examined. 1♀, Kathmandu, Shivapuri, 27.79519°N, 85.38848°E, 17 iv 2018 (U. Dyola), from 1,900m.

Distribution. Nepal. From Terai–2,200m. Kathmandu; Nuwakot: Nagarkot at 2,200m;

Rupandehi: Bhairahawa (Thapa 2015); China, India, and Pakistan (Maryam et al. 2020; Ascher and Pickering 2021).

Floral association. *Lantana camara*.

Xylocopa (Koptortosoma) aestuans Linnaeus, 1758

Material examined. 1♀, Kathmandu, Shivapuri, 27.79217°N, 85.37602°E, 15 iv 2018 (U. Dyola), from 1,700m.

Distribution. Nepal. Kathmandu (Thapa 2015); India and Pakistan (Aslam et al. 2017).

Floral association. *Lantana camara*.

****Xylocopa (Zonohirsuta) collaris*** Lepeletier, 1841
(Figure 5 A–C)

Material examined. 1♀, Kathmandu, Sundarrijal, 27.764531°N, 85.4234°E, 02 iv 2018 (U. Dyola), from 1,500m.

Distribution. Pakistan (Aslam et al. 2017).

Floral association. *Lantana camara*.

Xylocopa (Ctenoxylocopa) fenestrata (Fabricius, 1798)

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 15 iii 2018 (U. Dyola), from 1,800m; 1♀, Nagarjun, 27.74415°N, 85.29023°E, 28 iii 2018 (U. Dyola), from 1,600m; 1♀, Sundarrijal, 27.79172°N, 85.4211°E, 05 iv 2018 (U. Dyola), from 2,000m; 1♀, Nuwakot, Gurjebhanjyang, 27.81170°N, 85.31319°E, 12 iv 2018 (U. Dyola), from 2,000m.

Distribution. Nepal. Kathmandu, also in Terai: Pipal Hali (Thapa 2015); India and Pakistan (Aslam et al. 2017; Ascher and Pickering 2021).

Floral association. *Lantana camara*.

Xylocopa (Mesotrichia) tenuiscapa Westwood, 1840

Material examined. 1♀, Kathmandu, Nagarjun, 27.74415°N, 85.29023°E, 28 iii 2018 (U. Dyola), from 1,600m; 1♀, Sundarrijal, 27.79172°N, 85.4211°E, 05 iv 2018 (U. Dyola), from 2,000m.

Distribution. Nepal. Kathmandu (Thapa 2015); India (Thapa 2015).

Floral association. *Lantana camara*.

****Xylocopa (Xylocopa) violacea*** (Linnaeus, 1758)
(Figure 5 D–F)

Material examined. 1♀, Kathmandu, Manichud, 27.7657°N, 85.4688°E, 20 iii 2018 (U. Dyola), from 2,000m.

Distribution. India (Bhalchandra and Baviskar 2017).

Floral association. *Lantana camara*.

Family Colletidae Lepeletier, 1841

Subfamily Colletinae

Tribe Colletini

Genus *Colletes* Latreille, 1802

****Colletes similis*** Schenck, 1853
(Figure 4 A–C)

Material examined. 1♀, Kathmandu, Nagarjun, 27.74415°N, 85.29023°E, 28 iii 2018 (U. Dyola), from 1,600m; 1♀, Sundarrijal, 27.79172°N, 85.4211°E, 05 iv 2018 (U. Dyola), from 2,000m.

Distribution. China (Ascher and Pickering 2021).

Floral association. *Ageratina adenophora*.

Family Halictidae Thomson, 1869

Subfamily Halictinae

Tribe Halictini

Genus *Halictus* Latreille, 1804

Halictus (Seladonia) propinquus Smith, 1853

Material examined. 1♀, Kathmandu, Nagarjun, 27.68304°N, 85.28741°E, 24 x 2018 (U. Dyola), from 1,500m.

Distribution. Nepal. From 1,350–2,050 m. Kathmandu: Kalimati, Swayambhu, Gokarna Safari and Godawari Botanical Garden; Dolpa: Tripurakot at 2,050 m (Murao and Tadauchi 2013; Thapa 2015); China and India (Murao and Tadauchi 2013).

Floral association. *Biden pilosa*.

Halictus (Seladonia) vicinus Vachal, 1894

Material examined. 1♀, Kathmandu, Nagarjun, 27.68304°N, 85.28741°E, 24 x 2018 (U. Dyola), from 1,500m.

Distribution. Nepal. From 2,450–3,115 m. Solukhumbu: Ringmo at 2,900 m and Junbesi at 2,700–2,780 m; Jumla at 2,450 m and Talpi at 3,115 m (Murao and Tadauchi 2013; Thapa 2015); India (Ascher and Pickering 2021).

Floral association. *Ageratum houstonianum*.

Genus Lasioglossum Curtis, 1833**Lasioglossum (Ctenonomia) albescens** (Smith, 1853)

Material examined. 1♀, Kathmandu, Shivapuri, 27.79519°N, 85.38848°E, 17 iv 2018 (U. Dyola), from 1,900m.

Distribution. Nepal. From Terai–1,600 m. 1,500 m; Bara: Adhabar at 183 m; Parsa: Birgunj at 100 m; Chitwan: Sauraha at 180 m; Banke: Hotel Batika at 170 m. Nepalgunj; Kaski: Pokhara at 830 m; Sanopakha at 1,600 m (Thapa 2015); China, India and Pakistan (Ascher and Pickering 2021).

Floral association. *Lantana camara*.

Lasioglossum (Evylaeus) marginatum (Brullé, 1832)

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018 (U. Dyola), from 1,800m; 1♀, Sundarijal, 27.79172°N, 85.4211°E, 12 x 2018 (U. Dyola), from 2,000m.

Distribution. Nepal. Jumla: Churta at 3,800 m and Gothichaur at 2,800 m and at 2,900–3,050 m (Thapa 2015); India (Ascher and Pickering 2021).

Floral association. *Ageratum houstonianum* and *Biden pilosa*.

Lasioglossum (Evylaeus) villosulum (Kirby, 1802)

Material examined. 1♀, Nuwakot, Gurjebhanjyang, 27.81219°N, 85.3265°E, 03 xi 2018 (U. Dyola), from 1,900m.

Distribution. Nepal. Jumla: Gothichour at 2,650 m and 2,850 m (Thapa 2015); China, India, and Pakistan (Ascher and Pickering 2021).

Floral association. *Ageratum houstonianum* and *Biden pilosa*.

Subfamily Nomiinae

Tribe Nomiini

Genus Nomia Latreille, 1804**Nomia (Acunomia) formosa** Smith, 1858

Material examined. 1♀, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018 (U. Dyola), from 1,800m; 1♀, Sundarijal, 27.79172°N, 85.4211°E, 12 x 2018 (U. Dyola), from 2,000m.

Distribution. Nepal (Murao et al. 2015).

Floral association. *Ageratum houstonianum* and *Lantana camara*.

Nomia (Hoplonomia) incerta Gribodo, 1894

Material examined. 1♀, Kathmandu, Shivapuri, 27.79519°N, 85.38848°E, 30 ix 2018 (U. Dyola), from 1,900m.

Distribution. Nepal. Godawari, Kathmandu valley (Murao and Matsumra 2012); China and India (Murao and Matsumra 2012).

Floral association. *Alternanthera sessilis*.

***Nomia (Acunomia) iridescens** Smith, 1858

(Figure 4G–I)

Material examined. 1♀, Kathmandu, Sundarijal, 27.79172°N, 85.4211°E, 12 x 2018 (U. Dyola), from 2,000m.

Distribution. India (Prakash et al. 2020).

Floral association. *Ageratum houstonianum*.

Family Megachilidae Latreille, 1802

Subfamily Megachilinae

Tribe Megachilini

Genus Megachile Latreille, 1802***Megachile (Aethomegachile) conjuncta** Smith, 1853

(Figure 4 D–F)

Material examined. 1♂, Kathmandu, Manichud, 27.75114°N, 85.46680°E, 14 x 2018 (U. Dyola), from 1,800m.

Distribution. India (Saini et al. 2018).

Floral association. *Biden pilosa*.

Megachile femorata Smith, 1853

Material examined. 1♀, Kathmandu, Shivapuri, 27.79519°N, 85.38848°E, 30 ix 2018 (U. Dyola), from 1,900m.

Distribution. Nepal. China and India (Kumari and Sidhu 2020).

Floral association. *Alternanthera sessilis*.

Megachile (Callomegachile) umbripennis Smith, 1853

Material examined. 1♀, Kathmandu, Sundarijal, 27.764531°N, 85.4234°E, 12 x 2018 (U. Dyola), from 1,500m.

Distribution. Nepal (Thapa 2015); China and India (Saini et al. 2018).

Floral association. *Cuphea hyssopifolia*.

Discussion

In our present collection from SNNP, we recorded 42 species under 14 genera, and five families (Table 1). Except, *Apis* spp. all other species were wild bees. These wild bees included two categories: social bees and solitary bees with four and 36 species, respectively. Among solitary bees, four species were cuckoo bees.

Social bees

Out of 42 documented species, six species of social bee belong to two genera; *Apis* Linnaeus, 1767 and *Bombus* Latreille, 1802. In Nepal, four species of *Apis* Linnaeus, 1767 were recorded (Ascher and Pickering 2021) so far while we have found only two species; *Apis cerana* Fabricius, 1793 and *Apis mellifera* Linnaeus, 1761 from SNNP. Similarly, there are 37 *Bombus* Latreille, 1802 species documented from the country (Ascher and Pickering 2021) whereas we listed only four species; *Bombus (Alpigenobombus) breviceps* Smith, 1852, *Bombus (Pyrobombus) eximius* Smith, 1852, *Bombus (Orientalibombus) haemorrhoidalis* Smith, 1852, and *Bombus (Pyrobombus) flavescens* Smith, 1852 from our study area.

Solitary bees

The genus *Andrena* Fabricius, 1775, commonly called the mining bee, is a nearly cosmopolitan genus of solitary, ground nesting bees. Worldwide, a total of 1,552 species of them were recorded (Ascher and Pickering 2021) and from Nepal, 12 species of *Andrena* Fabricius, 1775 have been reported (Ascher and Pickering 2021). However, we collected only three species: *Andrena flavipes* Panzer, 1799, *Andrena gorkhana* Tadauchi & Matsumura, 2007, *Andrena*

kathmanduensis Tadauchi & Matsumura, 2007. Among these three species, *Andrena gorkhana* and *Andrena kathmanduensis* have not been recorded in any other part of the world, hence, is possibly endemic to the country. *Andrena kathmanduensis* Tadauchi & Matsumura, 2007 is considered as the "Least concern" according to the IUCN Red List Criteria.

Genus *Amegilla* Friese, 1897 is named a blue-banded bee with a blue and metallic green coloration. Globally, about 225 species have been reported (Ascher and Pickering 2021) and only four species were recorded from the country previously. However, we collected seven species from SNNP of this genus with four new records for Nepal. Similarly, there were 376 species of *Xylocopa* worldwide (Ascher and Pickering 2021) and only six species were documented from Nepal to date. We presented six species from SNNP with *Xylocopa collaris* and *X. violacea* as a new addition for the country. Moreover, *Megachile* is a leafcutter mason bee, a majority of them make nests in existing wooden cavities. The total species of *Megachile* were listed 1,489 globally (Ascher and Pickering 2021) while only four species listed from Nepal. From our fieldwork, *Megachile conjuncta* is found to be a new one for Nepal out of three collected species.

Finally, the genus *Nomia* Latreille, 1804 is mainly distributed in Africa, south to southeastern Asia, and contains 138 species in the world (Ascher and Pickering 2021). From Nepal, five species of genus *Nomia* have been reported (Ascher and Pickering 2021). We recorded three species and *Nomia iridescens* Smith, 1858 among them is a new record for Nepal.

Cuckoo bees

All melectini species are cleptoparasitic i.e. cuckoo bees that lay their eggs in nests of other bees. The worldwide record presents about 106 species in Genus *Thyreus* Panzer, 1806 (Ascher and Pickering 2021) whereas we reported three species: *Thyreus decorus* (Smith, 1852), *T. himalayensis* (Radoszkowski, 1893), and *T. histrio* (Fabricius, 1775) from SNNP. They especially parasitize *Amegilla* species. Concerning the Genus *Nomada* Scopoli, 1770, about 716 species have been reported (Ascher and Pickering 2021) globally and eight species from Nepal. We identified only one species *Nomada mutabilis* Morawitz, 1871 from SNNP.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Ascher JS, Pickering J. 2021. *Discover Life Bee species guide and world checklist (Hymenoptera: Apoidea: Anthophila)*. Available at: <http://www.discoverlife.org/> [Date Accessed: 19 July 2021].
 Aslam A, Rafi MA, Zia A. 2017. Non-*Apis* bees of family Apidae (Hymenoptera) from Potohar region of Pakistan. *Journal of Entomology and Zoology Studies* 5:6–12.

Bhalchandra W, Baviskar RK. 2017. Diversity of pollinator bees from Paithan taluka of Aurangabad district (MS) India. *Journal of Entomology and Zoology Studies* 5: 697–700.
 Biesmeijer JC, Roberts SP, Reemer M, et al. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science* 313:351–354.
 Bingham CT. 1897. *The fauna of British India, including Ceylon and Burma*, vol. 1. London: Taylor and Francis.
 Bodlah I, Amjad M, Bodlah MA, et al. 2016. First record of two genera of Anthophorini and one genus of Melectini (Apinae: Apidae: Hymenoptera) from Pothwar Punjab, Pakistan. *Journal of Entomology and Zoology Studies* 4:1031–1035.
 Burger F, Creutzburg F, Hartmann J, et al. 2009. Die Hummeln von Nepal (Insecta: Hymenoptera: Apidae: *Bombus*). *Biodiversität und Naturlandschaft im Himalaya. III. Verein der Freunde und Förderer des Naturkundemuseums Erfurt eV, Erfurt*:455–462.
 Danforth BN, Cardinal S, Praz C, et al. 2013. The impact of molecular data on our understanding of bee phylogeny and evolution. *Annual review of Entomology* 58: 57–78.
 Dew RM, Silva DP, Rehan SM. 2019. Range expansion of an already widespread bee under climate change. *Global Ecology and Conservation* 17:e00584.
 Goulson D, Nicholls E, Botias C, et al. 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science* 347: 6229–1255957.
 Grab H, Branstetter MG, Amon N, et al. 2019. Agriculturally dominated landscapes reduce bee phylogenetic diversity and pollination services. *Science* 363:282–284. <https://doi.org/10.1126/science.aat6016>.
 Kumari P, Kumar NR, Sidhu AK, et al. 2018. Taxonomical and behavioural studies on *Megachile conjuncta* (Fabricius) (Hymenoptera: Megachilidae: Cressoniella). *Journal of Entomology and Zoology Studies* 6:2198–2201.
 Kumari P, Sidhu AK. 2020. Diversity of apoidea (Hymenoptera) from Grassland ecosystem of Jammu (UT of Jammu and Kashmir). *Journal of Entomology and Zoology Studies* 8:424–427.
 Matsumura T. 1970. Bees from Nepal I. *Thyreus* Panzer (Hymenoptera, Apoidea). *Kontyu* 38:314–317.
 Maryam H, Rafi MA, Zia A, et al. 2020. Insect pollinator fauna of apricot from Gilgit–Baltistan, Pakistan. *Pakistan Journal of Agricultural Research* 33:202.
 Michener CD. 2007. *The Bees of the World*. 2nd edition. Baltimore: Johns Hopkins University Press.
 Murao R, Matsumura T. 2012. Occurrence of *Lipotriches ceratina* and *Nomia incerta* (Hymenoptera, Halictidae) in Nepal. *Japanese Journal of Systematic Entomology* 18:421–423.
 Murao R, Tadauchi O, Miyayama R, et al. 2015. New Records of the Bee Genus *Nomia* (Hymenoptera: Halictidae) in Nepal. *Japanese Journal of Systematic Entomology* 21:5–6.
 Murao R, Tadauchi O. 2013. *Notes on the distribution of the genus Seladonia* (Hymenoptera, Halictidae), vol. 19. Japanese Society of Systematic Entomology. pp. 77–81.
 Nemésio A, Silva DP, Nabout JC, et al. 2016. Effects of climate change and habitat loss on a forest-dependent bee species in a tropical fragmented landscape. *Insect Conservation and Diversity* 9:149–160.
 Ngat TT, Minh NP, Lam TX, et al. 2017. Studies of the Genus *Thyreus* Panzer (Hymenoptera: Apidae: Apinae) with Six New Records from Vietnam. *Biological Forum* 9:227–236.
 Potts SG, Biesmeijer JC, Kremen C, et al. 2010. Global pollinator declines: Trends, impacts and drivers. *Trends in Ecology and Evolution* 25:345–353.
 Prakash AS, Jobiraj T, Bijoy C. 2020. A checklist of bees (Insecta: Hymenoptera: Apoidea) of Kerala. *Entomo* 45:189–200.
 Proshchalykin MY, Schwarz M. 2017. The genus *Nomada* (Hymenoptera: Apidae) in Siberia. *Linzer Biologische Beiträge* 49:985–1006.
 Saini J, Chandra K, Kumar H, et al. 2018. Diversity of bees (Hymenoptera: Apoidea) in and around Namdapha national park, with an updated checklist from Arunachal Pradesh, India. *Records of the Zoological Survey of India* 118:413–425.
 Saini J, Sharma SL, Gupta RK. 2016. Taxonomy of the bee genus *Amegilla* Friese (Apoidea, Apidae: Anthophorini) with eight species first recorded from Rajasthan, India with a dichotomous key and a complete distribution record. *Journal of environment and bio-sciences* 30:567–572.
 Shiokawa M. 2008. Synopsis of the bee genus *Ceratina* (Insecta: Hymenoptera: Apidae) in Nepal, with descriptions of five new species and one new subspecies. *Species Diversity* 13:201–220.
 SNNP. 2017. *Shivapuri–Nagarjun National Park and Buffer Zone, Management Plan*. Panimuhan, Kathmandu, Nepal: Shivapuri–Nagarjun Park Office.
 Tadauchi O, Matsumura T. 2007. The Genus *Andrena* Collected from Nepal (Hymenoptera, Andrenidae) with Redescriptions of Some Types of *Andrena* Described from North India. *Esakia* 47:1–20.
 Thapa VK. 2015. *Insect diversity in Nepal*. Kathmandu, Nepal: VK Thapa Publication.
 Tkalcu B. 1974. Eine Hummel–Ausbeute aus dem Nepal–Himalaya (Insecta, –Hymenoptera, Apoidea, Bombinae). *Senckenbergiana biologica* 311:349.
 Westphal C, Bommarco R, Carré G, et al. 2008. Measuring bee diversity in different European habitats and biogeographical regions. *Ecological monographs* 78:653–671.
 Wijesekara A. 2001. An annotated list of bees (Hymenoptera: Apoidea: Apiformis) of Sri Lanka. *Tijdschrift voor Entomologie* 144:145–158.
 Williams PH, Ito M, Matsumura T, et al. 2010. The bumblebees of the Nepal Himalaya (Hymenoptera: Apidae). *Insecta matsumurana. New series: journal of the Faculty of Agriculture Hokkaido University, series entomology* 66:115–151.
 Wood TJ, Michez D, Paxton RJ, et al. 2020. Managed honey bees as a radar for wild bee decline? *Apidologie* 51:1100–1116.

RESEARCH ARTICLE

Community structure of pollinating insects and its driving factors in different habitats of Shivapuri-Nagarjun National Park, Nepal

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Abstract

Insect pollinators are important means for a stable ecosystem. The habitat types play a crucial role in the community composition, abundance, diversity, and species richness of the pollinators. The present study in Shivapuri-Nagarjun National Park explored the species richness and abundances of insect pollinators in four different habitats and different environmental variables in determining the community composition of the pollinators. Data were collected from 1,500 m to 2,700 m using color pan traps and hand sweeping methods. Non-Metric Multidimensional Scaling (NMDS) and Redundancy Analysis (RDA) were conducted to show the association between insect pollinators and environmental variables. The results firmly demonstrated that species richness and abundances were higher (158) in Open trail compared to other habitats. The distribution of the pollinator species was more uniform in the Open trail followed by the Grassland. Similarly, a strong positive correlation between flower resources and pollinators' abundance ($R^2 = .63$, $P < .001$) was found. In conclusion, the Open trail harbors rich insect pollinators in lower elevation. The community structure of the pollinators was strongly influenced by the presence of flowers in the trails.

KEYWORDS

community composition, open trail, pollinators, Shivapuri-Nagarjun National Park, species richness

TAXONOMY CLASSIFICATION

Entomology

1 | INTRODUCTION

Pollinators are important agents for a stable ecosystem (De Groot et al., 2010; Kremen, 2008). They enhance pollination for both wild and cultivated flowering plants and help humans to increase agricultural

production (Corbet et al., 1991; Kevan et al., 1990; Widhiono et al., 2016). These insects also benefit the economic, aesthetic, and cultural aspects of mankind (Gill et al., 2016). In general, social and solitary bees, butterflies and moths, beetle and flies account as dominant pollinators (Vanbergen & Initiative, 2013; Wojcik, 2021).

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Most of the cultivated plants around the world are pollinated by bees (56.5%), flies (19%), and butterflies (4%) (Bashir et al., 2019). Honeybees are better-known bees for pollination in comparison with wild pollen bees (Losey & Vaughan, 2006; Potts et al., 2010) while flies and butterflies are the least known as pollinating insects (Jennersten, 1984; Larson et al., 2001). Several studies show that there is decline in pollinators globally (Carvalho et al., 2013; Dirzo et al., 2014). Especially, the population of bumblebees (Cameron et al., 2011; Fitzpatrick et al., 2007) and butterflies (Van Swaay et al., 2010; Warren et al., 2001) is shrinking in the world due to natural as well as anthropogenic threats. The major drivers of pollinator loss are recognized as habitat loss, landscape modification, intensification in agriculture, and even climate change (Kearns et al., 1998; Kovács-Hostyánszki et al., 2017; Potts et al., 2010). Hence, maintaining pollinator diversity in the given landscape requires an understanding of a clear pattern of pollinator diversity along with the habitat types.

The species richness, diversity, distribution, and community structure of pollinators depend upon the local environment (Neumüller et al., 2020; Williams et al., 2010). Availability of flower resources, humidity, and temperature need to be taken into account especially while comparing the pollinators among habitats (Neumüller et al., 2020). The activity of pollinators is strongly correlated with air temperature, plant species richness (Hudewenz et al., 2012), and humidity (Pellissier et al., 2010). Bees and butterflies prefer warmer temperatures than flies (Kühnel & Blüthgen, 2015). Furthermore, elevation also determines the abundance and community structure of insect pollinators (Adedjoja et al., 2020). There is an interesting distribution pattern among different groups of insect pollinators. Hymenoptera is the dominant pollinator in the lowland while Lepidoptera and Diptera dominate the high land (Warren et al., 1988). This kind of distribution in a range of habitats is probably for fulfilling their ecological requirements and these ecological necessities are mostly species or guild specific (Proesmans et al., 2019). For instance, bees prefer to forage the flowering plants close to their nesting area (Gathmann & Tscharnke, 2002; Greenleaf et al., 2007). They also construct the nest in deadwood (Sydenham et al., 2016) and the sun-exposed soil ground (Everaars et al., 2011). However, hoverflies and butterflies fly away from the egg-laying areas for foraging and do not construct the nest. Aphidophagous hoverflies such as *Episyrphus*, *Sphaerophoria* depend on agricultural habitat (Jauker et al., 2009; Pinheiro et al., 2015), while saproxylic hoverflies (*Xylota*) are benefitted from the forest (Reemer, 2005). Similarly, butterflies can make a flight over greater distances (Herrera, 1987). They make such range of flight in search of different kinds of flowers for pollen (Gilbert, 1972) and nectar (Tiple et al., 2005). Additionally, oviposition-plant's location signifies habitat selection for smaller and less mobile butterflies, such as the 'blues' while the larger butterflies like *Erebia epispodea* and *Colias* probably have large ranges of the search for their widespread ovipositing plants (Sharp et al., 1974). The above examples show that pollinators share different habitats and hence the habitat types potentially impact the community

composition, abundance, diversity, and species richness of the pollinators.

Many studies have evaluated how environmental factors influence pollinator composition. However, the effects of many environmental factors on pollinator composition can be very different among climate/vegetation zones (Neumüller et al., 2020; Senapathi et al., 2017). Shivapuri-Nagarjun National Park (SNNP) lies in the southern foot of the Himalayas, a mountainous area with a complex landscape. The unique landscape of the park could harbor interesting pollinator fauna and number of environmental factors may differently influence their composition. So, it is necessary to test the roles of these factors on pollinators in SNNP. The general understanding about natural habitat is, if freed from pesticides, it probably possesses more diversity than the managed habitat. However, the habitat heterogeneity would also affect the pollinator community as the interaction between plant-pollinator is specific (Oliver et al., 2010; Rundlöf et al., 2008; Weibull et al., 2000).

We examined species richness, abundance, and the community composition of insect pollinators in different habitats along the elevation gradient. We hypothesized that there is an effect of habitat types in the diversity, distribution, and composition of pollinating insects. Our research questions were as follows: 'What is the distribution pattern of pollinating insects? Which environmental factors significantly influence this distribution pattern, diversity, and community composition of pollinators?'

2 | MATERIALS AND METHODS

2.1 | Study area

Shivapuri-Nagarjun National Park (Figure 1) is the only protected area in the mid-hill region of Nepal. The Park covers an area of 159 square kilometers with a buffer area of around 118.61 square km. It lies within 27°45' to 27°52'N Latitude and 85°16' to 85°45'E Longitude. It has an altitude ranging from 1,360 m to 2,732 m above sea level. The Park is rich in freshwater resources with abundant biodiversity and cultural heritage (SNNP, 2017). The Park possesses a subtropical to warm temperate weather with an average maximum and minimum temperature of 19.9°C and 11.15°C, respectively, and the mean annual precipitation of 236.5 mm (Climatic data from 1985 to 2017 AD, Department of Hydrology and Meteorology/DHM).

The mountainous topography of SNNP with steep slopes of >30% uses a pattern that constitutes 74.45% forest, 20.45% shrubland, 3.22% grassland, 1.80% cultivated area, and 0.055% other features (SNNP, 2017). Different forest types are present under different altitudes of the Park: Lower Mixed Hardwood, Chir pine Forest, Oak Forest, and Upper Mixed Hardwood Forest (Amatya, 1993). The major tree species are *Schima wallichii*, *Alnus nepalensis*, *Castanopsis* spp., *Myrica esculanata*, *Madhuca indica*, *Pinus roxburghii*, *Pyrus pashia*, *Aesculus* sp., *Acer* sp., *Salix* sp., *Lithocarpus* sp., *Ilex diprena*, etc.

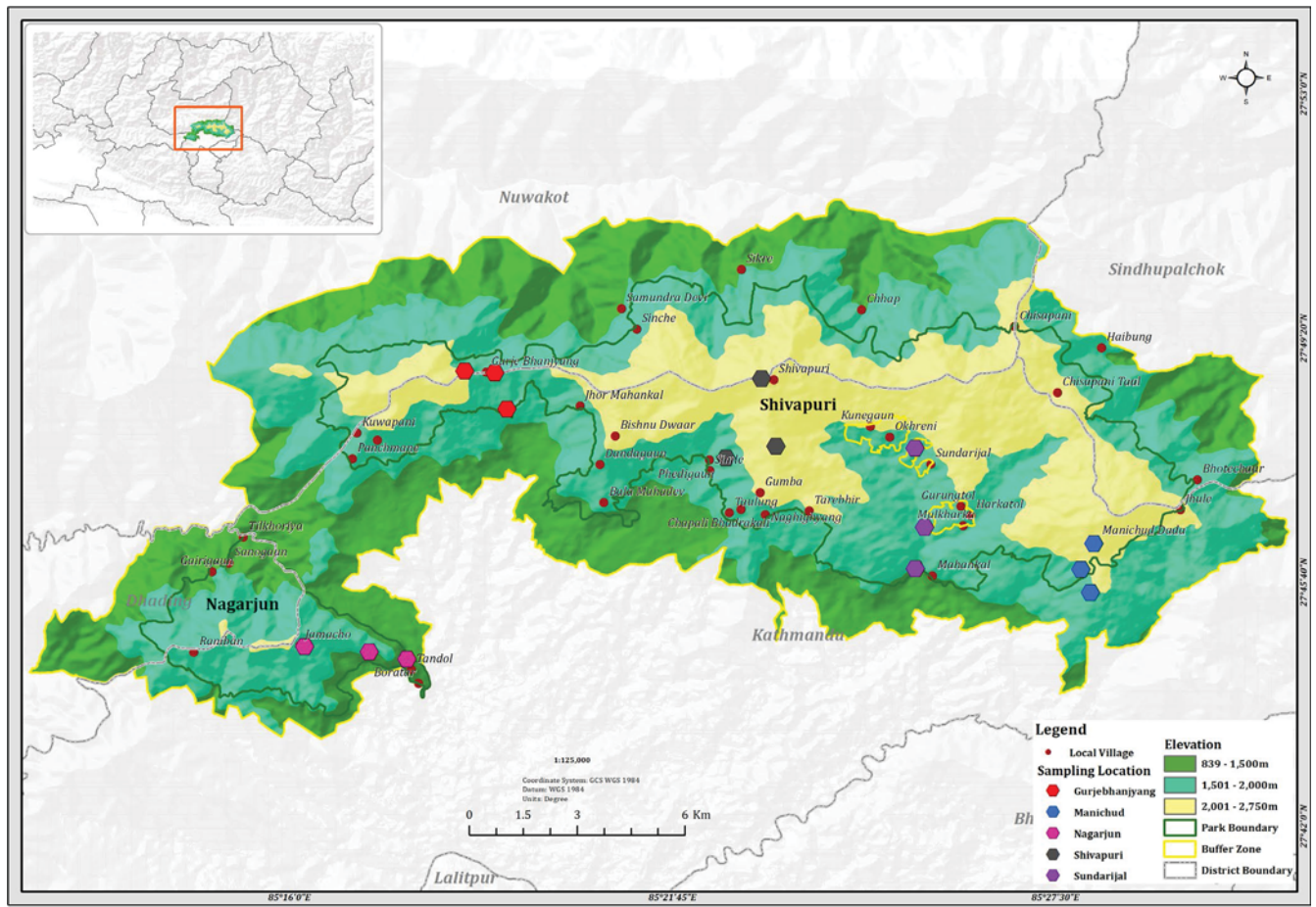


FIGURE 1 Map of study area showing the location of sampling sites

TABLE 1 Number of sampling transects in four different habitats along the elevation gradient of Shivapuri-Nagarjun National Park, Nepal

Habitat	Elevation (meter)	Number of transects	Description
Forest trail	1,500–1,700	11	Forest trail is denoted as the forest with canopy coverage of more than 70% with a walking trail of 15 m width
	1,800–1,900	12	
	2,000–2,700	10	
Grassland	1,500–1,700	3	Grassland habitat is herb-dominated in the transect with sparsely located trees
	1,800–1,900	6	
	2,000–2,700	5	
Open trail	1,500–1,700	4	Open trail habitat of the forest means an area with no tree coverage within 15 m width on either side of the survey transect
	1,800–1,900	5	
	2,000–2,700	6	
Managed habitat	1,500–1,700	7	The Open trail of managed habitat is the transect along the walking trail of the managed habitat with no canopy tree within 15 m width of the trail that incorporates the buffer zone area of the National Park. The area is a human settlement with cultivated lands. The major crops cultivated during spring are mustard and coriander while mustard, buckwheat, balsam apple, and squash are in autumn
	1,800–1,900	2	
	2,000–2,700	4	

Note: The fourth column of the table describes the characteristics of each habitat.

2.2 | Sampling sites

We identified five representative study sites across the SNNP, namely, Sundaridal (27°77'N Latitude and 85°42'E Longitude), Shivapuri (27°79'N Latitude and 85°37'E Longitude), Gurjebhanjyang (27°81'N Latitude and 85°31'E Longitude), Nagarjun (27°74'N Latitude and 85°27'E Longitude), and Manichud (27°77'N Latitude and 85°46'E Longitude). We selected these five sites as they represent the chosen habitat and elevation for survey. We sampled all five sites in three different elevations; a lower transect occurred between 1,500 m and 1,700 m, middle transect at 1,800 m–1,900 m, and upper transect at 2,000 m–2,700 m. These elevations included four different habitats: Forest trail (FT), Grassland (GL), the trail of the Managed habitat (MH), and the Open trail of the forest (OT). In each elevation, five transects, each of 100 m × 5 m with 100 m inter-transect distance, were fixed. So, a total of 75 transects were surveyed in the study sites. The number of transects in FT, GL, OT, and MH were 33, 14, 15, and 13, respectively (Table 1).

2.3 | Pollinators' sampling

Pollinators here mean flower-visiting and nectar-feeding insects. The transect line was fixed in walking trail of Forest, Open forest, and Managed habitat, while in the Grassland transects were drawn at the edge and the middle of the Grassland with 20-m inter-transect distance (Stanley, 2013). The survey was performed in the spring and autumn seasons for the consecutive years 2018 and 2019. In each season, the pollinators were sampled for 3 consecutive days in sunny weather between 9 am and 4 pm (Pollard & Yates, 1994). The pollinators were collected using hand sweeping and color pan traps. White, yellow, and blue color pans were used for insect sampling. During each sampling day, a transect walk of 30 min was made along the 100 m of the trail in the Open trail of the forest, Forest trail, and trail of the Managed habitat, while in Grassland the transect walk was made at the edge and the middle (Stanley et al., 2013). The transect walk method was used to sample butterflies (Pollard & Yates, 1994), bumblebees (Fussell & Corbet, 1992), hoverflies, and other bees (Proesmans et al., 2019). During the walk, all insect pollinators, which fed on flowers within 2 m of the observer, were captured, except for those that could be identified to a species level in the field (Neumüller et al., 2020). Unidentified insect pollinators were collected in separate vials, transferred in the icebox, and brought to the laboratory for identification.

Similarly, colored pan traps were deployed in each transect. This method aids in the simultaneous sampling of multiple locations, coverage of a large number of sites, and is the efficient method of bee sampling (Nielsen et al., 2011; Westphal et al., 2008). The pans were plastic bowls of about 15 cm in diameter and painted with non-toxic three different colors; white, yellow, and blue (LeBuhn et al., 2003). Each pan was attached to a post using a metal clamp adjusting the bowl in the rim. The pan was filled with 400 ml of detergent water. Three posts were deployed at a 100-m distance, 20 m apart from

each other. The traps were visited for collecting the fallen insects after 24 h and were transferred in labelled vials with 70% ethanol.

2.4 | Survey of flower resources

The survey of flower resources was carried out in the spring and autumn season during the pollinator survey in the same transect. We made five quadrats of 10 m × 5 m in each sampling transect. For an estimation of abundance flower resources, we scanned insect pollinating herbs and shrubs in each quadrat and identified the genus and species. The cover of flower resources in each quadrat was ranked between 1 and 6 (Szigeti et al., 2016). Rank: very scarcely = 1, scarce = 2, more or less scarce = 3, more or less abundance = 4, abundance = 5, and extremely abundance = 6. The abundance of flower resources for each sampling transect was calculated as $FLOWER = \sum_{t=1}^N t \cdot taxon_t$ (t = mean of the rank of flowering plant of each transect).

2.5 | Humidity and temperature

The humidity and temperature during each sampling time were measured with a digital Thermo-hygrometer (HTC-2).

2.6 | Identification of insect pollinators

Unidentified insect pollinators in the field were identified to species level in the laboratory using relevant keys. Bingham (1897), Tadauchi and Matsumura (2007), Williams et al. (2010), Bodlah et al. (2016), Aslam et al. (2017), Ngat et al. (2017), and Kumari et al. (2018) for bee specimens. Brunetti (1923), Thompson and Ghorpade (1992), Ghorpadé (1994), Ghorpadé (2019), Claussen and Weipert (2003), Sengupta et al. (2017), Hassan et al. (2019), Hassan et al. (2020), Sankararaman et al. (2020) for hoverflies, and Smith (2011) for butterfly specimens' identification.

2.7 | Statistical analysis

For each habitat type, we decided the cumulative species richness and species abundance across all samplings and assembled the community matrix. The species accumulation curves were plotted by using the package 'vegan', function `specaccum` to test the adequacy of sampling effort. Pollinator's richness and abundance were compared between different habitats, using linear mixed-effect models with habitats as predictor variables and pollinators as response variables. The statistical analysis was performed in Program R (R Core Team, 2021). Kruskal–Wallis test was carried out to find significance because data were not normal and different in the number of habitat types.

PAST: Paleontological Statistics (Hammer et al., 2001) Version 3.17 computed the diversity indices. Random matrices with two

samples were generated, each with the same row and column totals as in the original data matrix, which provided the significance of diversity between groups.

Pollinator's community compositions of different habitats (FT, GL, OT, and MH) were analyzed by Non-metric Multidimensional Scaling (NMDS) of the abundance data employing the function 'metaMDS' which is incorporated in the statistical package 'vegan' (Oksanen et al., 2013) and NMDS result with sample plots of different abundance scores were fitted with different habitats using the package 'ggplot2' (Wickham et al., 2016).

NMDS was followed by statistical analyses: Adonis (Permutational Multivariate Analysis of variance), ANOSIM (Analysis of Similarities), and SIMPER (Similarity Percentage Analysis).

Adonis was carried out following NMDS to analyze statistically if the pollinator's community differs between the habitats. It provides the *p*-value to determine the statistical significance. ANOSIM, on the other hand, was used to determine if the differences of pollinator's community between the habitats are significant. In addition to the significant difference tests, SIMPER analysis was used to identify those species that contributed the most to the observed pollinator's community differences (Clarke & Gorley, 2001).

To find relations between the environmental variables and the species composition, ordinations were performed on insect pollinators. For the pollinator's community of 15 most abundance species, five from each group; bee, butterfly, and hoverfly (Supplementary 1), a Detrended Correspondence Analysis (DCA) was carried out to decide whether unimodal or linear ordination methods were appropriate (Lepš & Šmilauer, 2003). DCA analysis projected a gradient length of 2.5 indicating Redundancy Analysis (RDA) ordination as an appropriate process. Environmental variables were backward selected (*p* < .05) and a Monte Carlo permutation test with 999 iterations was used to assess the significance of the ordination.

NMDS, RDA, and all of the three procedures (Adonis, ANOSIM, and SIMPER) were carried out in Program R (R Core Team, 2021) using the package 'vegan' (Oksanen et al., 2013). Venn diagrams showing the species distribution between the habitats were performed in Program R (R Core Team, 2021) by using the package 'VennDiagram' employing the function draw.quad.venn.

3 | RESULTS

3.1 | Insect pollinators in Shivapuri-Nagarjun National Park

During the total sampling period, 8720 insect pollinators were caught, belonging to 167 different species (see Supplementary 1) from both pan traps (1,339) and sweeping net (7,381); the butterfly with the most dominant species (48.50%) followed by a bee (29.94%) and hoverfly (21.56%). Representative 12 insect pollinators collected from different habitats of SNNP are shown in Figure 2. Sixty flower herbs and shrubs were recorded from both sampling seasons in both years (Supplementary 2). The abundance of flower resources varied

between habitats, elevations, and seasons (see Supplementary 3). Species accumulation curves for pollinators showed saturation in all habitat types indicating adequate sampling effort (Figure 3).

3.2 | Abundance and species richness of insect pollinators in different habitats

Species richness and abundances were higher in Open trail than in other habitats (Figure 4). There is a significant difference in species richness (Kruskal-Wallis test, $\chi^2 = 104.96$, *df* = 3, *p* < .001) and abundance among habitats (Kruskal-Wallis test, $\chi^2 = 110.16$, *df* = 3, *p* < .001).

3.3 | Diversity and Distribution pattern of insect pollinators

Diversity indices in alpha level (Species richness, Shannon index) show that the Open trail was comparatively more diverse, followed by the Managed habitat. The distribution of the pollinator species was much even in the Open trail followed by Grassland. The species richness and Shannon index were significant (*t*-test, *p* < .05) in all of the habitat types. Similarly, similar evenness was observed in Forest trail and Grassland (Table 2).

Among 167 species, the highest number of species was found in the Open trail (158), followed by the Managed habitat (124), Forest trail (103), and Grassland (92). Sixty-one species were common in all of the habitats while the number of species exclusively found in one of the habitats was 12 for OT, 6 for FT, and 3 for MH (Figure 5). While comparing two types of habitats, the high number of habitats sharing of species was found between Open trail and Managed habitat (121) followed by Open trail and Forest trail (97), Grassland and Open trail (92), and Grassland and Managed habitat (82).

Whittaker Beta diversity showed the high species turnover between Forest trail and Managed habitat, whereas accounted for low species turnover between Managed habitat and Open trail (Table 3). Overall, Shannon Diversity of pollinators in SNNP (Gamma diversity) was 4.683 with 167 species (Supplementary 1).

3.4 | Community composition of insect pollinators

3.4.1 | NMDS

The distance matrix of Bray-Curtis dissimilarity was calculated to plot Non-metric Multidimensional Scaling (NMDS) to analyze insect pollinator's communities in four studied habitats (Forest trail, Grassland, Managed habitat, and Open trail). A stress value of 0.15 cleared convergence of NMDS ordination. Vector fitting of environmental variables showed that elevation, humidity, atmospheric temperature, and presence of flower resources have a significant association with pollinating insects (Table 4; Figure 6). Flower



(a) *Andrena gorkhana* Tadauchi & Matsumura, 2007



(b) *Amegilla zonata* Linnaeus, 1758



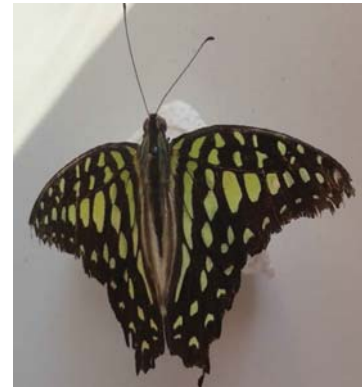
(c) *Nomia incerta* Gribodo, 1894



(d) *Thyreus histrio* (Fabricius, 1775)



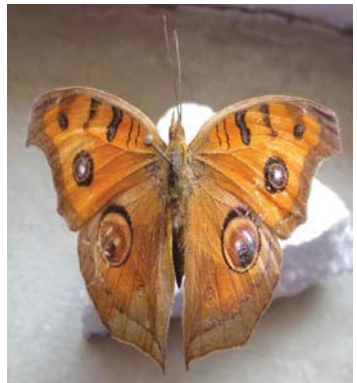
(e) *Argyreus hyperbius* Linnaeus, 1763



(f) *Graphium agamemnon* (Linnaeus, 1758)



(g) *Cyrestis thyodamas* Boisduval, 1836



(h) *Precis almana* Linnaeus, 1758



(i) *Eristalis himalayensis* Brunetti, 1908



(j) *Eristalinus aeneus* (Scopoli, 1763)



(k) *Phytomia errans* (Fabricius, 1787)



(l) *Asarkina porcina* (Coquillett, 1898)

FIGURE 2 A range of insect pollinators collected from four different habitats of Shivapuri-Nagarjun National Park (Bees: a–d, Butterflies: e–h, and Hoverflies: i–l). (a) *Andrena gorkhana* Tadauchi and Matsumura, 2007; (b) *Amegilla zonata* (Linnaeus, 1758); (c) *Nomia incerta* Gribodo, 1894; (d) *Thyreus histrio* (Fabricius, 1775); (e) *Argyreus hyperbius* Linnaeus, 1763; (f) *Graphium agamemnon* (Linnaeus, 1758); (g) *Cyrestis thyodamas* Boisduval, 1836; (h) *Precis almana* Linnaeus, 1758; (i) *Eristalis himalayensis* Brunetti, 1908 (j) *Eristalinus aeneus* (Scopoli, 1763); (k) *Phytomia errans* (Fabricius, 1787); (l) *Asarkina porcina* (Coquillett, 1898)

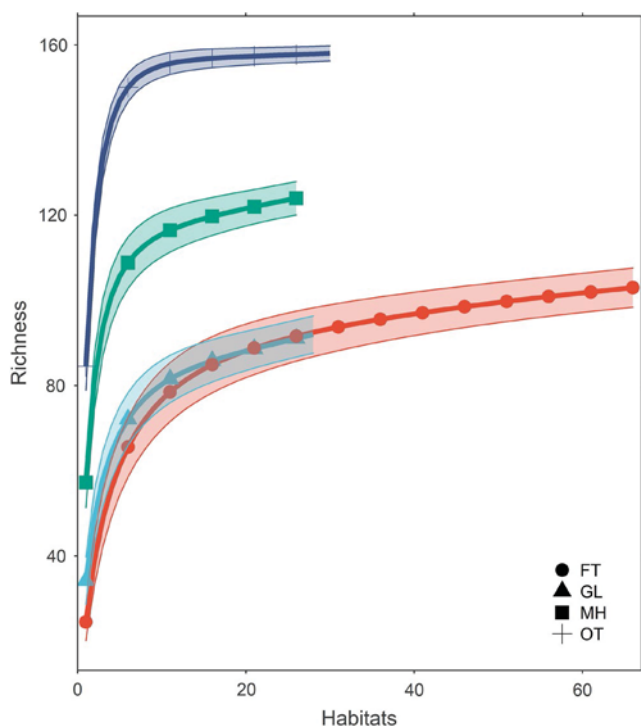


FIGURE 3 Species accumulation curve for pollinator's community in four different habitats of Shivapuri-Nagarjun National Park. Each line represents a different habitat. Habitat: FT- Forest trail with canopy, GL- Grassland, MH- Managed habitat, and OT- Open trail of the forest without canopy

possessed significantly high NMDS1 score value of 0.62 ($p < .001$, $R^2 = .63$). Elevation and humidity were significantly negative with NMDS1 score value -0.51 ($p = .009$, $R^2 = .07$) and -1.00 ($p < .001$, $R^2 = .10$), respectively (Table 4). The highest compositional abundances of species were found associated with the flower resources which was at lower elevation (Positive end of NMDS1). Similarly, high species compositional abundance was seen in the Managed habitat and Open trail (Positive end of NMDS1) which were again at low elevation.

Pollinators composition in four habitats is significantly different (Adonis, $p < .001$) with a significantly strong strength (ANOSIM, $R = 0.62$, $p < .001$). SIMPER analysis showed that *Xylocopa tenuiscapa* (0.70), *Danaus genutia* (0.70), and *Pelopidas agna* (0.69) were three species for different compositions between Forest trail and Managed habitat. Similarly, *Ceratina dentipes* (0.70), *Xylocopa tenuiscapa* (0.69), and *Graphium sarpedon* (0.69) were three species for the difference in composition between Forest trail and Open trail. Furthermore, *Syricta orientalis* (0.70), *Eristalis himalayensis* (0.70), and *Lasioglossum albipes* (0.69) were three species to contribute to the difference in the composition between Forest trail and Grassland.

In Managed habitat and Open trail, *Andrena kathmanduensis* (0.70), *Neptis hylas* (0.70), and *Andrena gorkhana* (0.69) were three species to alter the pollinator's composition, while *Elaphropoda impatiens* (0.70), *Lethe verma* (0.70), and *Precis iphita* (0.69) in Managed habitat and Grassland. In the Open trail and Grassland, *Eristalinus taeniops* (0.70), *Pieris brassica* (0.70), and *Graphium sarpedon* (0.68) were three species indifferent in the composition.

3.4.2 | RDA

The correlation of environmental variables and the top 15 most abundance pollinator's community was shown by RDA ordination method (Figure 7). *Apis mellifera* or *A. cerana* use an active recruitment system (Proesmans et al., 2019; Winfree et al., 2007), which may result in an overabundance at certain spots that do not reflect the actual density of the species and vice versa. Thus, the analyses with *Apis* spp. included and excluded were carried out to estimate the effect of *Apis* spp. on the parameters assessed. The results showed that there were no such differences (Table 5). Hence, the *Apis* spp. were also included in the analysis. Two canonical axes of RDA analysis explained the variance by 12.83% in the pollinator–environmental interaction where the first axis and second axis accounted for 10.71% and 2.12% of the variance, respectively. Environmental factors: elevation and abundance of flower resources were found to be significantly associated with top 15 most abundant pollinators ($p < .05$), whereas humidity and atmospheric temperature did not have a significant impact on them. Managed habitat type represented the higher abundance of flowers associated with the high number of *Apis cerana* and *Apis mellifera*. On the other hand, *Pieris canidia* was found associated with both Open trail and Grassland and *Vanessa cardui* in a Managed habitat. *Bombus eximius*, *Bombus flavescens*, *Eristalis tenax*, and *Ypthima baldus* were more associated with the Forest trail which was a relatively humid area. Likewise, *Melanostoma univittatum* and *Episyrphus viridaureus* were associated with the Open trail, whereas *Episyrphus balteatus* was close to Grassland and Managed habitat.

4 | DISCUSSION

4.1 | Abundance and species richness of pollinators in different habitats

Our present findings show that there are differences in the abundance and species richness of pollinators in the habitat types of SNNP. Such influence of habitat types in pollinators has also been reported in a tropical megacity, Bangkok, Thailand (Stewart et al., 2018). Our

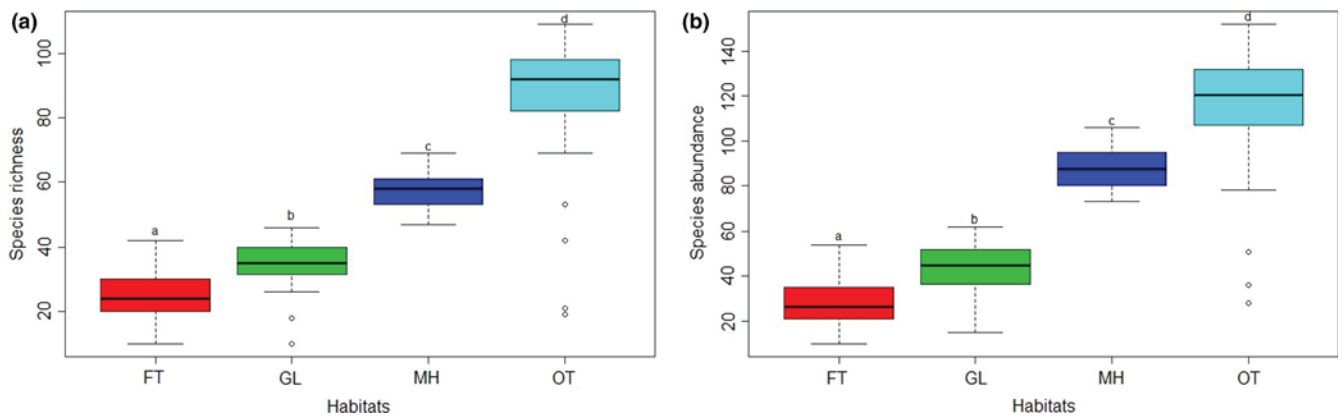


FIGURE 4 Species richness (a) and species abundance (b) of insect pollinators in four different habitats of Shivapuri-Nagarjun National Park. Horizontal line across each box represents median, whiskers show the data range, and circles indicate outliers. Habitat: FT- Forest trail with canopy, GL- Grassland, MH- Managed habitat, and OT- Open trail of the forest without canopy

TABLE 2 S: Species richness, H: Shannon–Weiner, J: Pielou's evenness, D: Dominance

		S	H	J	D
Habitat	MH	124 ^a	4.30 ^a	0.59 ^a	0.024 ^a
	FT	103 ^b	4.19 ^b	0.64 ^b	0.020 ^b
	GL	92 ^c	4.09 ^c	0.65 ^b	0.022 ^a
	OT	158 ^d	4.85 ^d	0.81 ^c	0.010 ^c

Note: On a given column, values followed by the different superscripted letter (a, b, c, d) are significantly different at $p < .05$ by the t-test comparing diversity in PAST software.

TABLE 3 Whittaker Beta Diversity among four different habitats of Shivapuri-Nagarjun National Park, Nepal

	FT	GL	MH	OT
FT	0	0.30	0.34	0.26
GL	0.30	0	0.24	0.26
MH	0.34	0.24	0	0.14
OT	0.26	0.26	0.14	0

Note: Habitat: FT-Forest trail with Canopy, GL-Grassland, MH-Managed habitat, and OT-the open trail of the forest without canopy.

results indicate that the Open trail of the forest possesses the highest abundance and species richness of pollinating insects. The result reflects a direct relation of insects with the presence of flower resources. The Open trails of forest harbor a comparatively thick layer of herbs and shrubs with varieties of wildflowers that suffice pollinators with nectar and pollen sources. The availability of food for insect visitors is measured by flower resources (Baldock et al., 2015; Sjödin et al., 2008) which is one of the consistent and important variables (Ahrne et al., 2009; Hülsmann et al., 2015; Stewart et al., 2018) observed globally. The quality and quantity of nectar and pollen play a major role in the presence of pollinators (Hicks et al., 2016). Trails of open forest were densely proliferated and covered by *Ageratina adenophora* along with other wild herbs providing a good resource

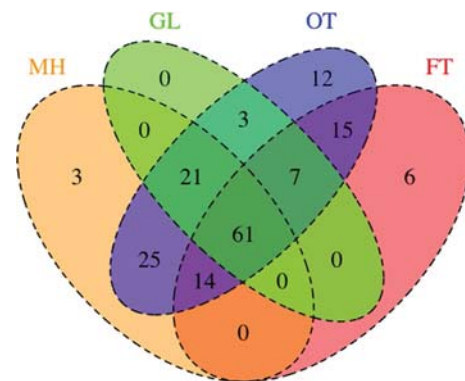


FIGURE 5 The Venn diagram showing the sharing of insect pollinators between four different habitats of Shivapuri-Nagarjun National Park. Habitat: FT- Forest trail with canopy, GL- Grassland, MH- Managed habitat, and OT- Open trail of the forest without canopy. Color-coding: FT (Pink), GL (green), MH (Skin), OT (Blue)

TABLE 4 NMDS scores on the axes of NMDS1 and NMDS2, significance values and coefficients of determination for the assessed environmental variables

	NMDS1	NMDS2	R ²	Pr(>r)
Elevation	-0.51	0.86	.07	.009 ^{**}
Humidity	-1.00	-0.09	.10	.001 ^{***}
Atmospheric Temperature	0.97	-0.25	.05	.036 [*]
Flower	0.62	-0.79	.63	.001 ^{***}

Note: Significant codes: 0^{****} 0.001^{***} 0.01^{**} 0.05^{*} 0.1['] 1.

Permutation: free.

Number of permutations: 999.

platform especially for hoverflies and bees. Furthermore, weeds like *Ranunculus repens* and *Trifolium repens* were comparatively more abundant in the Open trail. These flowers were preferred by both bees and butterflies (Chaguthi & Dyola, 2018; Hicks et al., 2016). These plants provide nectar and pollen for the insects (Erbar &

FIGURE 6 NMDS showing the influence of environmental variables on the community composition of insect pollinators in four different habitats of Shivapuri-Nagarjun National Park. Habitat: FT- Forest trail with canopy, GL- Grassland, MH- Managed habitat, and OT- Open trail of the forest without canopy

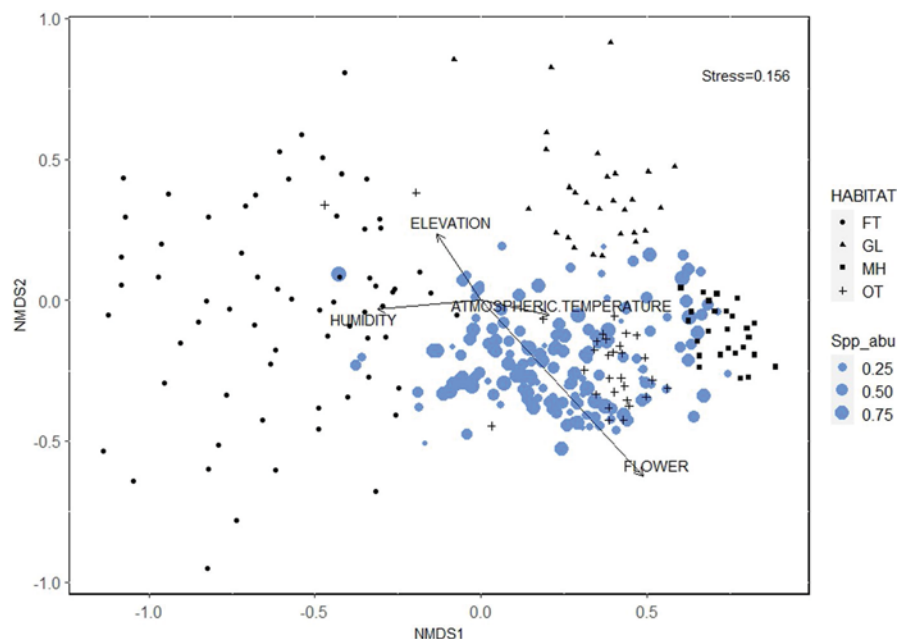
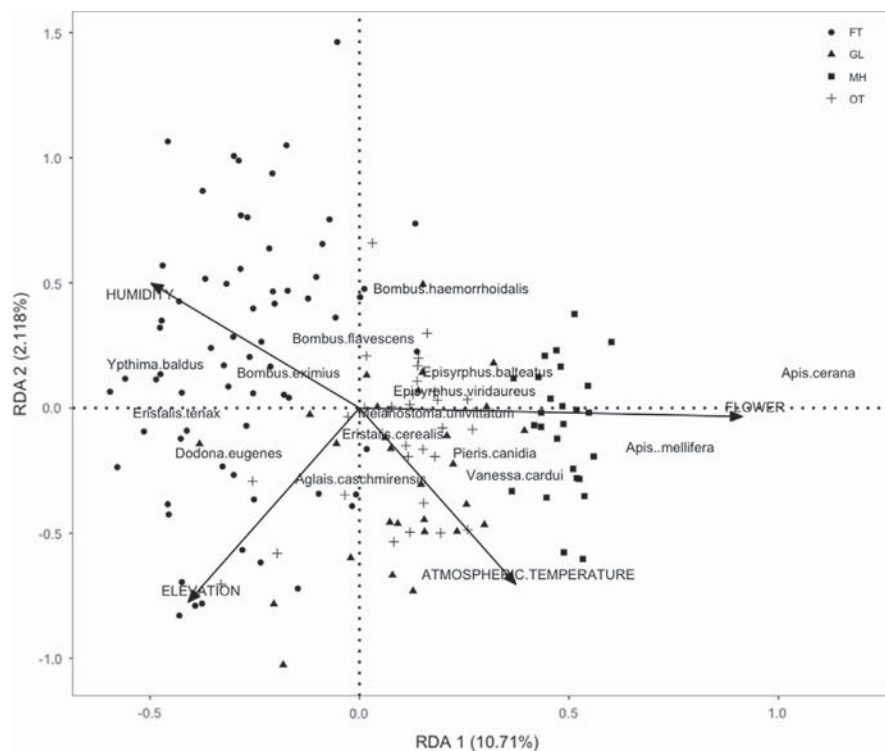


FIGURE 7 Redundancy Analysis (RDA) - biplot showing the correlation between insect pollinator species and the environmental variables. Only top 15 most abundance (five from each group; bee, butterfly, and hoverfly) of the total species are shown on the plot. Habitat: FT-Forest trail with canopy, GL- Grassland, MH-Managed habitat, and OT-Open trail of the forest without canopy



Leins, 2013; Masters & Emery, 2015). Adult hoverflies require high energy for hovering flight that could be obtained from the local landscape with abundant flowers (Haslett, 1989; Meyer et al., 2009; Proesmans et al., 2019). In contrast, the presence of low flower resources also accounts for the decline in pollinator abundance and species richness in Forest trail with canopy. Canopy cover increases shade in the understory herb and shrub of the forest lowering flower blooms and limiting pollinator's movement (Proesmans et al., 2019). Sampled areas of the Managed habitat in SNNP were open, inhabited, and disturbed by some human activities. Some previous study

also shows that the diversity of butterfly is negatively influenced by this factor of human disturbances (Kambach et al., 2013).

4.2 | Diversity and distribution pattern of insect pollinators

Furthermore, our result depicts that Open trail is more diverse followed by Managed habitat. There is low species turnover between these two habitats. This could again be explained by the influence

TABLE 5 RDA presents correlation of environmental variables with the top 15 most abundance insect pollinators with analysis including *Apis* spp. (In.) and excluding *Apis* spp. (Ex.)

	df	Variance		F		Pr(>F)	
		In.	Ex.	In.	Ex.	In.	Ex.
Elevation	1	0.006	0.004	3.248	2.052	0.002**	0.025*
Humidity	1	0.003	0.004	1.588	1.700	0.099	0.070.
Atmospheric Temperature	1	0.003	0.003	1.238	1.533	0.250	0.107
Flower residue	1	0.021	0.011	10.651	5.568	0.001***	0.001***
	145	0.288	0.297				

Note: Significant codes: 0**** ' 0.001 '** ' 0.01 '* ' 0.05 ' ' 0.1 ' ' 1'.

of the local environment between habitats. These two habitat types are open along with the presence of thicker beds of flower resources. Most of the pollinators show a strong preference for the structurally different land-use type that add variety in resources they required (Bates et al., 2011; Matteson & Langellotto, 2010). However, flower resources are comparatively less in the Forest trail and Grassland, which could be the probable reason for less diverse pollinators and similar evenness of pollinators between these two habitats.

The distribution pattern of pollinators is varied among different species in the present study. Among all pollinators, 61 species were common in all the studied habitats. This result reflects the different needs of pollinators for different activities. There is a heterogeneous habitat choice of wild bees and a wider temporal range of activities of flies (Willcox et al., 2019). Many bee groups require different habitats for nesting and foraging (Franzén et al., 2009) and also different spatial foraging distances made by bees like *Bombus* spp. and *Xylocopa* spp. (Greenleaf et al., 2007). This could be a probable reason for the presence of some bees group in all habitats. Likewise, hoverflies feed on varieties of food resources in different stages of their life. For instance, the larva of some hoverfly develops in a close canopy while adults of the same fly hover in open flower-rich biotopes (Gittings et al., 2006). Furthermore, the abundance of hoverflies increases with proximity to the forest (Moquet et al., 2018) and some flies are confined to only one kind of habitat like *Volucella trifasciata* and *Baccha maculata* which were recorded from forest habitats only. The latter species usually prefer the shady area of forest (Coe, 1964; Hassan et al., 2019). Butterflies too, show a different kind of habitats preference in their life cycles (Janz, 2005). Females dwell in grassland for oviposition while forage in flower-rich habitats (Evans et al., 2020).

4.3 | The community composition of insect pollinators

4.3.1 | NMDS

There is an influence of environmental variables in the community composition of pollinators. In our findings, the measured environmental variables (elevation, humidity, air temperature, and flower

resources) are found to have a significant association with the pollinator's community. Species abundance of pollinators was concentrated in the Managed habitat and Open trail which were open to the high amount of solar exposure. Activities of the insect pollinators are highly influenced by such sun exposures (McKinney & Goodell, 2010; Sydenham et al., 2016). Similarly, flower resources were the next positive influencing factor for insect pollinators. The mixture of wildflowers could be a good attraction for all of these pollinators. A similar kind of relation of a different group was reported in the previous study (Carreck & Williams, 2002).

The complex environmental gradient of high altitude affects the abundance of different taxa of pollinators (Warren et al., 1988). As expected, with the elevation, the abundance of pollinators declined. The reason could be either decreasing of bee and fly attracted flowers or their limited number in higher altitude (Arnold et al., 2009). The plant communities at the high altitude limit the vascular plant and thus, availability of insect pollinators (Mani, 1962). The atmospheric temperature and abundance of flower resources have a negative correlation with elevation. Temperature and humidity (two oppositely related variables) are important factors for defining the plant composition at higher altitudes (Subedi et al., 2020) and hence alter pollinator's abundance. Only a few species of hoverflies that do not have specific food choices (Kearns, 1992) and big size bees, for instance, *Bombus* spp. that can thermoregulate and forage at low temperature, were only found in the highest altitude of our study area.

4.3.2 | RDA

The species of pollinators are differently associated with measured environmental variables in this study. *Apis cerana* and *A. mellifera* were mainly determined by the abundance of flower resources of the Managed habitat, while *Bombus eximius* and *B. flavescens* were associated with humid forest. The explanation for the *Apis* spp. could be their preference on floral resources near the nesting area like small size bees (Gathmann & Tscharncke, 2002; Vulliamy et al., 2006) so that they could gather maximum nectar to support the large bee colony (Potts et al., 2003). Large body-sized bees like *Bombus* spp. could travel away from the nesting area for foraging (Greenleaf et al.,

2007) and humid areas to avoid hotter day temperature (Willmer, 1983). *Aglaia caschmirensis* is the most abundant and frequently seen butterfly in all kinds of habitats (Irungbam et al., 2017). This could be the reason for its presence in the forest as well as Managed habitat in our study area. Similarly, the association of *Episyrphus balteatus* in the Managed habitat indicates the preference for flowers of vegetables such as coriander, buckwheat (Pinheiro et al., 2015) as their host plant.

5 | CONCLUSIONS

We studied the diversity, distribution, and community structure of insect pollinators in different habitats of SNNP, Nepal. Overall, habitats, humidity, atmospheric temperature, abundance of flower resources, and elevation played a significant role in the diversity, distribution, and community structure of pollinating insects. Insect pollinators were strongly associated with flower resources which were highly recorded in an Open trail. Shannon Index and evenness were high in an Open trail and similar evenness was found in the Forest trail and Grassland. Conservation of plant diversity in the walking trails of SNNP is important to conserve the community structure of insect pollinators.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

Urmila Dyola: Conceptualization (lead); Data curation (lead); Formal analysis (lead); Funding acquisition (lead); Investigation (lead); Writing – original draft (lead); Writing – review & editing (lead). **Chitra Bahadur Baniya:** Conceptualization (equal); Formal analysis (equal); Investigation (supporting); Supervision (equal); Writing – review & editing (supporting). **Pushpa Raj Acharya:** Conceptualization (equal); Supervision (equal); Writing – review & editing (supporting). **Pradip Subedi:** Data curation (supporting); Formal analysis (supporting); Investigation (supporting). **Anjeela Pandey:** Data curation (supporting); Investigation (supporting). **Kumar Sapkota:** Conceptualization (lead); Investigation (supporting); Supervision (lead); Writing – review & editing (supporting).

DATA AVAILABILITY STATEMENT

The supplementary data associated with this manuscript are available at Dryad: <https://doi.org/10.5061/dryad.9zw3r22g1>.

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REFERENCES

- Adedoja, O., Kehinde, T., & Samways, M. J. (2020). Asynchrony among insect pollinator groups and flowering plants with elevation. *Scientific Reports*, 10(1), 1–12. <https://doi.org/10.1038/s41598-020-70055-5>
- Ahrne, K., Bengtsson, J., & Elmqvist, T. (2009). Bumble bees (*Bombus* spp) along a gradient of increasing urbanization. *PLoS One*, 4(5), e5574. <https://doi.org/10.1371/journal.pone.0005574>
- Amatya, D. (1993). Forest vegetation analysis. Development Project, GCP/NEP/048/NOR. Kathmandu: His Majesty's Government of Nepal and Food and Agriculture Organisation of the United Nations and possible ecological implications. *Brazilian Journal of Biology*, 64, 563–568.
- Arnold, S. E., Le Comber, C. S., & Chittka, L. (2009). Flower color phenology in European grassland and woodland habitats, through the eyes of pollinators. *Israel Journal of Plant Sciences*, 57(3), 211–230. <https://doi.org/10.1560/IJPS.57.3.211>
- Aslam, A., Rafi, M. A., & Zia, A. (2017). Non-Apis bees of family Apidae (Hymenoptera) from Potohar region of Pakistan. *Journal of Entomology and Zoology Studies*, 5(2), 6–12.
- Baldock, K. C. R., Goddard, M. A., Hicks, D. M., Kunin, W. E., Mitschunas, N., Osgathorpe, L. M., Potts, S. G., Robertson, K. M., Scott, A. V., Stone, G. N., Vaughan, I. P., & Memmott, J. (2015). Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. *Proceedings of the Royal Society B: Biological Sciences*, 282(1803), 20142849. <https://doi.org/10.1098/rspb.2014.2849>
- Bashir, M. A., Saeed, S., Sajjad, A., Khan, K. A., Ghramh, H. A., Shehzad, M. A., Mubarak, H., Mirza, N., Mahpara, S., Rehmani, M. I. A., & Ansari, M. J. (2019). Insect pollinator diversity in four forested ecosystems of southern Punjab, Pakistan. *Saudi Journal of Biological Sciences*, 26(7), 1835–1842. <https://doi.org/10.1016/j.sjbs.2018.02.007>
- Bates, A. J., Sadler, J. P., Fairbrass, A. J., Falk, S. J., Hale, J. D., & Matthews, T. J. (2011). Changing bee and hoverfly pollinator assemblages along an urban–rural gradient. *PLoS One*, 6(8), e23459. <https://doi.org/10.1371/journal.pone.0023459>
- Bingham, C. T. (1897). *The Fauna of British India, Including Ceylon and Burma. Hymenoptera, 1. Wasps and Bees*. Taylor & Francis.
- Bodlah, I., Amjad, M., Bodlah, M. A., & Qayyum, A. (2016). First record of two genera of Anthophorini and one genus of Melectini (Apinae: Apidae: Hymenoptera) from Pothwar Punjab, Pakistan. *Journal of Entomology and Zoology Studies*, 4, 1031–1035.
- Brunetti, E. (1923). Pipunculidae, Syrphidae, Conopidae, Oestridae. In A. E. Shipley (Ed.), *The Fauna of British India, Including Ceylon and Burma*. (Diptera. Vol. 3, xi +424 pp., 6 pis). Taylor and Francis.
- Cameron, S. A., Lozier, J. D., Strange, J. P., Koch, J. B., Cordes, N., Solter, L. F., & Griswold, T. L. (2011). Patterns of widespread decline in North American bumble bees. *Proceedings of the National Academy of Sciences*, 108(2), 662–667. <https://doi.org/10.1073/pnas.1014743108>

- Carreck, N. L., & Williams, I. H. (2002). Food for insect pollinators on farmland: Insect visits to flowers of annual seed mixtures. *Journal of Insect Conservation*, 6(1), 13–23.
- Carvalho, L. G., Kunin, W. E., Keil, P., Aguirre-Gutiérrez, J., Ellis, W. N., Fox, R., Groom, Q., Hennekens, S., Van Landuyt, W., Maes, D., & Van de Meutter, F. (2013). Species richness declines and biotic homogenisation have slowed down for NW-European pollinators and plants. *Ecology Letters*, 16(7), 870–878. <https://doi.org/10.1111/ele.12121>
- Chaguthi, G., & Dyola, U. (2018). Insect visitors of white clover (*Trifolium repens* L) and their relation with environmental variables in the premises of bhaktapur multiple campus, Nepal. *Journal of Institute of Science and Technology*, 22(2), 86–91. <https://doi.org/10.3126/jst.v22i2.19598>
- Clarke, K. R., & Gorley, R. N. (2001). *Primer V5 (Plymouth routines in multivariate ecological research): User manual/tutorial*. Primer-e.
- Claussen, C. J., & Weipert, J. (2003). Zur Schwebfliegenfauna Nepals (Insecta: Diptera: Syrphidae) unter besonderer Berücksichtigung Westnepals. In *Biodiversität und Naturlandschaft im Himalaya*. Verein der Freunde und Förderer des Naturkundemuseums Erfurt ev, Erfurt (pp. 343–380).
- Coe, R. L. (1964). Diptera from Nepal. *Bulletin of the British Museum of Natural History, Entomology*, 15, 255–290.
- Corbet, S. A., Williams, I. H., & Osborne, J. L. (1991). Bees and the pollination of crops and wild flowers in the European Community. *Bee World*, 72(2), 47–59. <https://doi.org/10.1080/0005772X.1991.11099079>
- De Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemsen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, 7(3), 260–272. <https://doi.org/10.1016/j.ecocom.2009.10.006>
- Dirzo, R., Young, H. S., Galetti, M., Ceballos, G., Isaac, N. J., & Collen, B. (2014). Defaunation in the anthropocene. *Science*, 345(6195), 401–406. <https://doi.org/10.1126/science.1251817>
- Erbar, C., & Leins, P. (2013). Nectar production in the pollen flower of *Anemone nemorosa* in comparison with other Ranunculaceae and Magnolia (Magnoliaceae). *Organisms Diversity and Evolution*, 13(3), 287–300. <https://doi.org/10.1007/s13127-013-0131-9>
- Evans, L. C., Sibly, R. M., Thorbek, P., Sims, I., Oliver, T. H., & Walters, R. J. (2020). The importance of including habitat-specific behaviour in models of butterfly movement. *Oecologia*, 193(2), 249–259. <https://doi.org/10.1007/s00442-020-04638-4>
- Everaars, J., Strohbach, M. W., Gruber, B., & Dormann, C. F. (2011). Microsite conditions dominate habitat selection of the red mason bee (*Osmia bicornis*, Hymenoptera: Megachilidae) in an urban environment: A case study from Leipzig, Germany. *Landscape and Urban Planning*, 103(1), 15–23. <https://doi.org/10.1016/j.landurbplan.2011.05.008>
- Fitzpatrick, Ú., Murray, T. E., Paxton, R. J., Breen, J., Cotton, D., Santorum, V., & Brown, M. J. (2007). Rarity and decline in bumblebees—a test of causes and correlates in the Irish fauna. *Biological Conservation*, 136(2), 185–194. <https://doi.org/10.1016/j.biocon.2006.11.012>
- Franzén, M., Larsson, M., & Nilsson, S. G. (2009). Small local population sizes and high habitat patch fidelity in a specialised solitary bee. *Journal of Insect Conservation*, 13(1), 89–95. <https://doi.org/10.1007/s10841-007-9123-4>
- Fussell, M., & Corbet, S. A. (1992). Flower usage by bumble-bees: A basis for forage plant management. *Journal of Applied Ecology*, 451–465. <https://doi.org/10.2307/2404513>
- Gathmann, A., & Tscharntke, T. (2002). Foraging ranges of solitary bees. *Journal of Animal Ecology*, 71(5), 757–764. <https://doi.org/10.1046/j.1365-2656.2002.00641.x>
- Ghorpadé, K. (1994). Diagnostic keys to new and known genera and species of Indian subcontinent Syrphini (Diptera: Syrphidae). *Colemania: Insect Biosystematics*, 3, 1–15.
- Ghorpadé, K. (2019). Hover-flies (Diptera: Syrphidae) recorded from “Dravidia,” or Central and Peninsular India and Sri Lanka. An Annotated Checklist and Bibliography. In Ramani, S., Mohanraj, P., & Yeshwanth, H. (Eds.), *Indian insects: Diversity and science* (Vol. 472, pp. 325–388). CRC Press. <https://doi.org/10.1201/9780429061400-18>
- Gilbert, L. E. (1972). Pollen feeding and reproductive biology of Heliconius butterflies. *Proceedings of the National Academy of Sciences*, 69(6), 1403–1407. <https://doi.org/10.1073/pnas.69.6.1403>
- Gill, R. J., Baldock, K. C., Brown, M. J., Cresswell, J. E., Dicks, L. V., Fountain, M. T., Garratt, M. P., Gough, L. A., Heard, M. S., Holland, J. M., & Ollerton, J. (2016). Protecting an ecosystem service: Approaches to understanding and mitigating threats to wild insect pollinators. *Advances in Ecological Research*, 54, 135–206. <https://doi.org/10.1016/bs.aecr.2015.10.007>
- Gittings, T., O'Halloran, J., Kelly, T., & Giller, P. S. (2006). The contribution of open spaces to the maintenance of hoverfly (Diptera, Syrphidae) biodiversity in Irish plantation forests. *Forest Ecology and Management*, 237(1–3), 290–300. <https://doi.org/10.1016/j.foreco.2006.09.052>
- Greenleaf, S. S., Williams, N. M., Winfree, R., & Kremen, C. (2007). Bee foraging ranges and their relationship to body size. *Oecologia*, 153(3), 589–596. <https://doi.org/10.1007/s00442-007-0752-9>
- Hammer, Ø., Harper, D. A., & Ryan, P. D. (2001). PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, 4(1), 9.
- Haslett, J. R. (1989). Adult feeding by holometabolous insects: Pollen and nectar as complementary nutrient sources for *Rhingia campetris* (Diptera: Syrphidae). *Oecologia*, 81(3), 361–363. <https://doi.org/10.1007/BF00377084>
- Hassan, M. A., Bodlah, I., Ahmad, M., Kayani, A. R., & Mahmood, K. (2020). First record of the genus *Graptomyza* Wiedemann, 1830 (Diptera: Syrphidae) from Pakistan. *The Journal of Animal and Plant Sciences*, 30(2), 512–516.
- Hassan, M. A., Bodlah, I., Aihetasham, A., Bodlah, M. A., & Hussain, K. (2019). First Record of *Baccha maculata* Walker, 1852 (Diptera: Syrphidae) from the Pothwar Punjab, Pakistan. *Punjab University Journal of Zoology*, 34(2), 133–135. <https://doi.org/10.17582/journal.pujz/2019.34.2.133.135>
- Herrera, C. M. (1987). Components of pollinator "quality": Comparative analysis of a diverse insect assemblage. *Oikos*, 50, 79–90. <https://doi.org/10.2307/3565403>
- Hicks, D. M., Ouvrard, P., Baldock, K. C. R., Baude, M., Goddard, M. A., Kunin, W. E., Mitschunas, N., Memmott, J., Morse, H., Nikolitsi, M., Osgathorpe, L. M., Potts, S. G., Robertson, K. M., Scott, A. V., Sinclair, F., Westbury, D. B., & Stone, G. N. (2016). Food for pollinators: Quantifying the nectar and pollen resources of urban flower meadows. *PLoS One*, 11(6), e0158117. <https://doi.org/10.1371/journal.pone.0158117>
- Hudewenz, A., Klein, A. M., Scherber, C., Stanke, L., Tscharntke, T., Vogel, A., Weigelt, A., Weisser, W. W., & Ebeling, A. (2012). Herbivore and pollinator responses to grassland management intensity along experimental changes in plant species richness. *Biological Conservation*, 150(1), 42–52. <https://doi.org/10.1016/j.biocon.2012.02.024>
- Hülsmann, M., von Wehrden, H., Klein, A. M., & Leonhardt, S. D. (2015). Plant diversity and composition compensate for negative effects of urbanization on foraging bumble bees. *Apidologie*, 46(6), 760–770. <https://doi.org/10.1007/s13592-015-0366-x>
- Irunbam, J. S., Huidrom, H., & Soibam, B. S. (2017). Range extension of the Indian Tortoiseshell *Aglais caschmirensis aesis* (Fruhstorfer, 1912) (Lepidoptera: Nymphalidae) into the hills of Manipur, India. *Journal of Threatened Taxa*, 9(10), 10860–10864. <https://doi.org/10.11609/jott.2983.9.10.10860-10864>
- Janz, N. (2005). The relationship between habitat selection and preference for adult and larval food resources in the polyphagous butterfly *Vanessa cardui* (Lepidoptera: Nymphalidae). *Journal of*

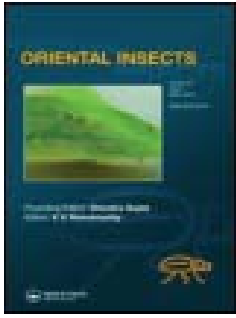
- Insect Behavior*, 18(6), 767–780. <https://doi.org/10.1007/s10905-005-8739-z>
- Jauker, F., Diekoetter, T., Schwarzbach, F., & Wolters, V. (2009). Pollinator dispersal in an agricultural matrix: Opposing responses of wild bees and hoverflies to landscape structure and distance from main habitat. *Landscape Ecology*, 24(4), 547–555. <https://doi.org/10.1007/s10980-009-9331-2>
- Jennersten, O. (1984). Flower visitation and pollination efficiency of some North European butterflies. *Oecologia*, 63(1), 80–89. <https://doi.org/10.1007/BF00379789>
- Kambach, S., Guerra, F., Beck, S. G., Hensen, I., & Schleuning, M. (2013). Human-induced disturbance alters pollinator communities in tropical mountain forests. *Diversity*, 5(1), 1–14. <https://doi.org/10.3390/d5010001>
- Kearns, C. A. (1992). Anthophilous fly distribution across an elevation gradient. *American Midland Naturalist*, 127, 172–182. <https://doi.org/10.2307/2426332>
- Kearns, C. A., Inouye, D. W., & Waser, N. M. (1998). Endangered mutualisms: the conservation of plant–pollinator interactions. *Annual Review of Ecology and Systematics*, 29(1), 83–112. <https://doi.org/10.1146/annurev.ecolsys.29.1.83>
- Kevan, P. G., Clark, E. A., & Thomas, V. G. (1990). Insect pollinators and sustainable agriculture. *American Journal of Alternative Agriculture*, 5(1), 13–22. <https://doi.org/10.1017/S088918930003179>
- Kovács-Hostyánszki, A., Espindola, A., Vanbergen, A. J., Settele, J., Kremen, C., & Dicks, L. V. (2017). Ecological intensification to mitigate impacts of conventional intensive land use on pollinators and pollination. *Ecology Letters*, 20(5), 673–689. <https://doi.org/10.1111/ele.12762>
- Kremen, C. (2008). Crop pollination services from wild bees. In *Bee pollination in agricultural ecosystems* (pp. 10–26).
- Kühnel, S., & Blüthgen, N. (2015). High diversity stabilizes the thermal resilience of pollinator communities in intensively managed grasslands. *Nature Communications*, 6(1), 1–10. <https://doi.org/10.1038/ncomms8989>
- Kumari, P., Kumar, N. R., Sidhu, A. K., & Chandra, K. (2018). *Taxonomical and behavioural studies on Megachile conjuncta (Fabricius) (Hymenoptera: Megachilidae: Cressoniella)*.
- Larson, B. M. H., Kevan, P. G., & Inouye, D. W. (2001). Flies and flowers: Taxonomic diversity of anthophiles and pollinators. *The Canadian Entomologist*, 133(4), 439–465. <https://doi.org/10.4039/Ent133439-4>
- LeBuhn, G., Griswold, T., Minckley, R., Droege, S., Roulston, T. A., Cane, J., Parker, F., Buchmann, S., Tepedino, V., Williams, N., & Kremen, C. (2003). A standardized method for monitoring bee populations—the bee inventory (BI) plot. *Accessed*, 16, 15.
- Lepš, J., & Šmilauer, P. (2003). *Multivariate analysis of ecological data using CANOCO*. Cambridge University Press.
- Losey, J. E., & Vaughan, M. (2006). The economic value of ecological services provided by insects. *BioScience*, 56(4), 311–323. [https://doi.org/10.1641/0006-3568\(2006\)56\[311:TEVOES\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2006)56[311:TEVOES]2.0.CO;2)
- Mani, M. S. (1962). *Introduction to high altitude entomology insect life above the timber-line in the North-west Himalaya* (Vol. 31, pp. 48).
- Masters, J. A., & Emery, S. M. (2015). The showy invasive plant *Ranunculus ficaria* facilitates pollinator activity, pollen deposition, but not always seed production for two native spring ephemeral plants. *Biological Invasions*, 17(8), 2329–2337. <https://doi.org/10.1007/s10530-015-0878-3>
- Matteson, K. C., & Langellotto, G. A. (2010). Determinates of inner city butterfly and bee species richness. *Urban Ecosystems*, 13(3), 333–347. <https://doi.org/10.1007/s11252-010-0122-y>
- McKinney, A. M., & Goodell, K. (2010). Shading by invasive shrub reduces seed production and pollinator services in a native herb. *Biological Invasions*, 12(8), 2751–2763. <https://doi.org/10.1007/s10530-009-9680-4>
- Meyer, B., Jauker, F., & Steffan-Dewenter, I. (2009). Contrasting resource-dependent responses of hoverfly richness and density to landscape structure. *Basic and Applied Ecology*, 10(2), 178–186. <https://doi.org/10.1016/j.baae.2008.01.001>
- Moquet, L., Laurent, E., Bacchetta, R., & Jacquemart, A. L. (2018). Conservation of hoverflies (Diptera, Syrphidae) requires complementary resources at the landscape and local scales. *Insect Conservation and Diversity*, 11(1), 72–87. <https://doi.org/10.1111/icad.12245>
- Neumüller, U., Burger, H., Krausch, S., Blüthgen, N., & Ayasse, M. (2020). Interactions of local habitat type, landscape composition and flower availability moderate wild bee communities. *Landscape Ecology*, 35(10), 2209–2224. <https://doi.org/10.1007/s10980-020-01096-4>
- Ngat, T. T., Minh, N. P., Lam, T. X., Thi, N., & Lien, P. (2017). Studies of the genus *Thyreus* panzer (Hymenoptera : Apidae : Apinae) with six new records from Vietnam. *Biological Forum - an International Journal*, 9(2), 227–236.
- Nielsen, A., Steffan-Dewenter, I., Westphal, C., Messinger, O., Potts, S. G., Roberts, S. P. M., Settele, J., Szentgyörgyi, H., Vaissière, B. E., Vaitis, M., Woyciechowski, M., Bazos, I., Biesmeijer, J. C., Bommarco, R., Kunin, W. E., Tscheulin, T., Lamborn, E., & Petanidou, T. (2011). Assessing bee species richness in two Mediterranean communities: importance of habitat type and sampling techniques. *Ecological Research*, 26(5), 969–983. <https://doi.org/10.1007/s11284-011-0852-1>
- Oksanen, J., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O'Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., Wagner, H., & Oksanen, M. J. (2013). Package 'vegan'. *Community Ecology Package, Version*, 2(9), 1–295.
- Oliver, T., Roy, D. B., Hill, J. K., Brereton, T., & Thomas, C. D. (2010). Heterogeneous landscapes promote population stability. *Ecology Letters*, 13(4), 473–484. <https://doi.org/10.1111/j.1461-0248.2010.01441.x>
- Pellissier, L., Pottier, J., Vittoz, P., Dubuis, A., & Guisan, A. (2010). Spatial pattern of floral morphology: Possible insight into the effects of pollinators on plant distributions. *Oikos*, 119(11), 1805–1813. <https://doi.org/10.1111/j.1600-0706.2010.18560.x>
- Pinheiro, L. A., Torres, L. M., Raimundo, J., & Santos, S. A. (2015). Effects of pollen, sugars and honeydew on lifespan and nutrient levels of *Episyrphus balteatus*. *BioControl*, 60(1), 47–57. <https://doi.org/10.1007/s10526-014-9621-8>
- Pollard, E., & Yates, T. J. (1994). *Monitoring butterflies for ecology and conservation: The British butterfly monitoring scheme*. Springer Science and Business Media.
- Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: Trends, impacts and drivers. *Trends in Ecology and Evolution*, 25(6), 345–353. <https://doi.org/10.1016/j.tree.2010.01.007>
- Potts, S. G., Vulliamy, B., Dafni, A., Ne'eman, G., & Willmer, P. (2003). Linking bees and flowers: How do floral communities structure pollinator communities? *Ecology*, 84(10), 2628–2642. <https://doi.org/10.1890/02-0136>
- Proesmans, W., Bonte, D., Smaghe, G., Meeus, I., & Verheyen, K. (2019). Importance of forest fragments as pollinator habitat varies with season and guild. *Basic and Applied Ecology*, 34, 95–107. <https://doi.org/10.1016/j.baae.2018.08.004>
- R Core Team (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>
- Reemer, M. (2005). Saproxilic hoverflies benefit by modern forest management (Diptera: Syrphidae). *Journal of Insect Conservation*, 9(1), 49–59. <https://doi.org/10.1007/s10841-004-6059-9>
- Rundlöf, M., Nilsson, H., & Smith, H. G. (2008). Interacting effects of farming practice and landscape context on bumble bees. *Biological Conservation*, 141(2), 417–426. <https://doi.org/10.1016/j.biocon.2007.10.011>

- Sankararaman, H., Daniel, J. A., Manickavasagam, S., & Pennards, G. (2020). First record of two interesting genera of hover flies (Diptera: Syrphidae) in South India. *Journal of Insect Biodiversity*, 14(2), 54–63. <https://doi.org/10.12976/jib/2020.14.2.4>
- Senapathi, D., Goddard, M. A., Kunin, W. E., & Baldock, K. C. (2017). Landscape impacts on pollinator communities in temperate systems: Evidence and knowledge gaps. *Functional Ecology*, 31(1), 26–37. <https://doi.org/10.1111/1365-2435.12809>
- Sengupta, J., Naskar, A., Maity, A., Hazra, S., Sarkar, N. K., & Banerjee, D. (2017). Hover flies (Diptera: Syrphidae) from Darjeeling Himalaya—A part of indo-Burmese hotspot. *Indian Journal of Entomology*, 79(3), 336–353. <https://doi.org/10.5958/0974-8172.2017.00065.7>
- Sharp, M. A., Parks, D. R., & Ehrlich, P. R. (1974). Plant resources and butterfly habitat selection. *Ecology*, 55(4), 870–875. <https://doi.org/10.2307/1934423>
- Sjödín, N. E., Bengtsson, J., & Ekbom, B. (2008). The influence of grazing intensity and landscape composition on the diversity and abundance of flower-visiting insects. *Journal of Applied Ecology*, 45(3), 763–772. <https://doi.org/10.1111/j.1365-2664.2007.01443.x>
- Smith, C. (2011). *Illustrated checklists of Nepal's butterflies*. Mujpuria Publication, Craftman Press.
- SNNP (2017). *Shivapuri Nagarjun National Park and buffer zone management plan Fiscal Year*. Shivapuri Nagarjun National Park office.
- Stanley, D. A. (2013). *Pollinators and Pollination in Changing Agricultural Landscapes: Investigating the Impacts of Bioenergy Crops* (Doctoral dissertation, Trinity College Dublin).
- Stanley, D. A., Gunning, D., & Stout, J. C. (2013). Pollinators and pollination of oilseed rape crops (*Brassica napus* L.) in Ireland: ecological and economic incentives for pollinator conservation. *Journal of Insect Conservation*, 17(6), 1181–1189. <https://doi.org/10.1007/s10841-013-9599-z>
- Stewart, A. B., Sritongchuy, T., Teartisup, P., Kaewsomboon, S., & Bumrungsri, S. (2018). Habitat and landscape factors influence pollinators in a tropical megacity, Bangkok. *Thailand. PeerJ*, 6, e5335. <https://doi.org/10.7717/peerj.5335>
- Subedi, C. K., Rokaya, M. B., Münzbergová, Z., Timsina, B., Gurung, J., Chettri, N., Baniya, C. B., Ghimire, S. K., & Chaudhary, R. P. (2020). Vascular plant diversity along an elevational gradient in the Central Himalayas, western Nepal. *Folia Geobotanica*, 55(2), 127–140. <https://doi.org/10.1007/s12224-020-09370-8>
- Sydenham, M. A., Häusler, L. D., Moe, S. R., & Eldegard, K. (2016). Inter-assemblage facilitation: The functional diversity of cavity-producing beetles drives the size diversity of cavity-nesting bees. *Ecology and Evolution*, 6(2), 412–425. <https://doi.org/10.1002/ece3.1871>
- Szigeti, V., Kőrösi, Á., Harnos, A., Nagy, J., & Kis, J. (2016). Comparing two methods for estimating floral resource availability for insect pollinators in semi-natural habitats. *Annales De La Société Entomologique De France (N.S.)*, 52(5), 289–299. <https://doi.org/10.1080/00379271.2016.1261003>
- Tadauchi, O., & Matsumura, T. (2007). The genus *Andrena* collected from Nepal (Hymenoptera, Andrenidae) with redescrptions of some types of *Andrena* described from North India. *Esakia*, 47, 1–20. <https://doi.org/10.5109/8322>
- Thompson, F. C., & Ghorpade, K. (1992). A new coffee aphid predator, with notes on other Oriental species of *Paragus* (Diptera: Syrphidae). *Colemania*, 5, 1–24.
- Tiple, A. D., Deshmukh, V. P., & Dennis, R. L. (2005). Factors influencing nectar plant resource visits by butterflies on a university campus: Implications for conservation. *Nota Lepidopterologica*, 28(3/4), 213.
- Van Swaay, C. C., Cuttelod, A., Collins, S., Maes, D., Munguira, M. L., Šašić, M., Settele, J., Verovnik, R., Verstrael, T., Warren, M., & Wiemers, M. (2010). *European Red List of Butterflies*. <https://doi.org/10.2779/83897>
- Vanbergen, A. J., & Initiative, T. I. P. (2013). Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and the Environment*, 11(5), 251–259. <https://doi.org/10.1890/120126>
- Vulliamy, B., G. Potts, S., & G. Willmer, P. (2006). The effects of cattle grazing on plant-pollinator communities in a fragmented Mediterranean landscape. *Oikos*, 114(3), 529–543. <https://doi.org/10.1111/j.2006.0030-1299.14004.x>
- Warren, M. S., Hill, J. K., Thomas, J. A., Asher, J., Fox, R., Huntley, B., Roy, D. B., Telfer, M. G., Jeffcoate, S., Harding, P., Jeffcoate, G., Willis, S. G., Greatorex-Davies, J. N., Moss, D., & Thomas, C. D. (2001). Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature*, 414(6859), 65–69. <https://doi.org/10.1038/35102054>
- Warren, S. D., Harper, K. T., & Booth, G. M. (1988). Elevational distribution of insect pollinators. *American Midland Naturalist*, 325–330. <https://doi.org/10.2307/2426004>
- Weibull, A. C., Bengtsson, J., & Nohlgren, E. (2000). Diversity of butterflies in the agricultural landscape: The role of farming system and landscape heterogeneity. *Ecography*, 23(6), 743–750. <https://doi.org/10.1111/j.1600-0587.2000.tb00317.x>
- Westphal, C., Bommarco, R., Carré, G., Lamborn, E., Morison, N., Petanidou, T., Potts, S. G., Roberts, S. P. M., Szentgyörgyi, H., Tscheulin, T., Vaissière, B. E., Woyciechowski, M., Biesmeijer, J. C., Kunin, W. E., Settele, J., & Steffan-Dewenter, I. (2008). Measuring bee diversity in different European habitats and biogeographical regions. *Ecological Monographs*, 78(4), 653–671. <https://doi.org/10.1890/07-1292.1>
- Wickham, H., Chang, W., & Wickham, M. H. (2016). Package 'ggplot2'. *Create Elegant Data Visualisations Using the Grammar of Graphics. Version, 2(1)*, 1–189.
- Widhiono, I., Sudiana, E., & Suciarto, E. T. (2016). Insect pollinator diversity along a habitat quality gradient on Mount Slamet, Central Java, Indonesia. *Biodiversitas Journal of Biological Diversity*, 17(2). <https://doi.org/10.13057/biodiv/d170250>
- Willcox, B. K., Howlett, B. G., Robson, A. J., Cutting, B., Evans, L., Jesson, L., Kirkland, L., Jean-Meyzonnier, M., Potdevin, V., Saunders, M. E., & Rader, R. (2019). Evaluating the taxa that provide shared pollination services across multiple crops and regions. *Scientific Reports*, 9(1), 1–10. <https://doi.org/10.1038/s41598-019-49535-w>
- Williams, P. H., Ito, M., Matsumura, T., & Kudo, I. (2010). The bumblebees of the Nepal Himalaya (Hymenoptera: Apidae). *Insecta matsumurana. New Series: Journal of the Faculty of Agriculture Hokkaido University, Series Entomology*, 66, 115–151.
- Willmer, P. G. (1983). Thermal constraints on activity patterns in nectar-feeding insects. *Ecological Entomology*, 8(4), 455–469. <https://doi.org/10.1111/j.1365-2311.1983.tb00524.x>
- Winfree, R., Griswold, T., & Kremen, C. (2007). Effect of human disturbance on bee communities in a forested ecosystem. *Conservation Biology*, 21(1), 213–223. <https://doi.org/10.1111/j.1523-1739.2006.00574.x>
- Wojcik, V. (2021). Pollinators: Their evolution, ecology, management, and conservation. In *Arthropods*. IntechOpen. <https://doi.org/10.5772/intechopen.97153>

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A faunistic study on the hoverflies (Diptera: Syrphidae) of Shivapuri Nagarjun National Park, Central Nepal

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ABSTRACT

Nepal is a mountainous country in the Central Himalayas, well known for its high biodiversity and unique fauna. The vivid habitat of Nepal seems to possess high diversity of hoverflies (Diptera: Syrphidae), however, little investigation has been done on these flies in this country. The present study aims to explore the hoverfly fauna based on present field sampling from the Shivapuri Nagarjun National Park. The field collection includes 454 hoverfly specimens belonging to 34 species from the park with three new country records: *Graptomyza nigripes*, *Lycastris albipes* and *Volucella trifasciata*. The photographs of dorsal and lateral habitus of all 34 collected species are presented. The present collection of hoverfly specimens in the park shows equal number of species in both subfamilies; Eristalinae and Syrphinae while none of the specimen collected from subfamilies Pipizinae and Microdontinae.

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Introduction

Hoverflies (Diptera: Syrphidae) comprise one of the most abundant, speciose, and conspicuous group of true flies, including 209 genera with more than 6,300 species distributed worldwide, except Antarctica and remote oceanic islands (Pape et al. 2011; Skevington et al. 2019; Thompson 2019; Mengual et al. 2022). Mengual et al. (2015) classified hoverfly into four subfamilies: Syrphinae, Pipizinae, Eristalinae, and Microdontinae. All subfamilies are recovered as monophyletic in recent studies except Eristalinae (Hippa and Ståhls 2005; Mengual et al. 2015; Young et al. 2016; Pauli et al. 2018, 2022; Moran et al. 2022; Mullens et al. 2022). The representatives of the three subfamilies are known to occur in Nepal except for Pipizinae. The adult

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hoverflies are smaller to larger in body size, ranging from 4–25 mm long, and greatly diverse in morphology and environmental requirements. They can be easily identified by their hovering behaviour and the presence of a spurious vein between the radial and medial vein branches (Ssymank et al. 2021). They are popular ‘non-bee’ pollinators in the world and visit 72% of global crop plants (Doyle et al. 2020). Besides their vivid colours, amazing hovering behaviour, and flower-visiting habits, they also provide services in ecological, environmental, and economic aspects (Rotheray and Gilbert 2011; Mengual et al. 2022). Adult hoverflies feed on pollen and nectar as a source of energy, but their larvae have diverse modes of feeding habits (Mengual et al. 2022). Eristalinae larvae, for example, can be found near ponds with decaying leaves, wood, and rotting seaweed, as well as marshes and wetlands (Vockeroth and Thompson 1987). Other Eristalines within the genera *Cheilosia* and *Merodon* eat hard plant parts like stem and root tunnelling larvae (Rotheray and Gilbert 2008, 2011), as well as bulbs, leaf miners, stem, and tuber borers (Thompson and Vockeroth 1989). Syrphinae larvae, unlike Eristalinae, are important biocontrol agents that feed on Hemiptera, as well as Acari, Thysanoptera, and Lepidoptera larvae (Rotheray 1993; Rojo et al. 2003), with the exception of two *Toxomerus* species that feed on pollen (Riley and Howard 1888; Marín 1969; Reemer and Rotheray 2009). Some Microdontinae have slug-like larvae that live as inquilines in ant nests (Reemer 2013; Cannings et al. 2021; Ssymank et al. 2021).

Nepal is situated in the central and eastern Himalayas. With varied faunal and floral diversity, the country shares the world’s two major biogeographical regions: the Oriental and Palaearctic. A number of European naturalists have studied Nepal’s flora and fauna during the last 200 years. European and Indian scientists have mostly done previous research on hoverflies of Nepal. Among the series of published articles on the Syrphidae of the Indian Brunetti (1907; 1908, 1913, 1915, 1923, 1925) listed 21 species with three new species from Nepal. Following Brunetti, Bhatia and Shaffi (1933), Coe (1964), Thompson (1966, 1974, 2012), Vockeroth (1971), Lambeck and Kiauta (1973), Knutson et al. (1975), Wiegmann (1986), Claussen and Weipert (2003, 2004), van Steenis and Hippa (2012), Ghorpadé (2015a), and Nielsen (2016) added number of hoverfly species that are new records for Nepal. Then, Kapoor et al. (1979) presented 22 species from their field work in Nepal. Their updated list contained 11 new records for the country. Thereafter, Thapa (2015) and Ghorpadé (2015a) updated the checklist with 134 species under 55 genera and 157 species in 71 genera respectively. van Steenis et al. (2018) reported five new species from Nepal. Recently Barkalov and Ståhls (2022) revised the genus *Cheilosia* from Nepal and recorded 37 species, of which 29 species are described: 26 species have been assigned at subgeneric level while the remaining three new species only described based on female specimens are not included in any generic group. The recent

additions of new hoverfly species to the fauna of Nepal by van Steenis et al. (2018) and Barkalov and Ståhls (2022) show that the country have a great potential of unexplored hoverfly fauna. Present study of hoverflies has been carried out in different habitat types and altitudinal gradient of Shivapuri Nagarjun National Park, which has not yet been done. At a same time, data show the number of known hoverfly species in Nepal is much lower than that in India (Ghorpadé 2015b, p. 357 species) and almost double that of Pakistan (Hassan et al. 2021, p. 82 species). This indicates that there remains a lot to discover in Nepal to fulfill the gap in knowledge of hoverflies.

This work presents 34 species of hoverflies collected from different study sites of Shivapuri Nagarjun National Park with the elevation and associated flower. The current research could provide a better platform for future research in Nepal on several aspects of hoverflies.

Materials and methods

Study sites and collecting techniques

Shivapuri Nagarjun National Park (SNNP) is the only National Park located near the densely populated urban city of Kathmandu, Nepal (Fig. 1). It lies within 27°45' to 27°52' N latitude and 85°16' to 85°45' E longitude. SNNP covers 159 square kilometres that is divided into two different areas; Shivapuri (144 square kilometres) and Nagarjun (15 square kilometres). The buffer zone of

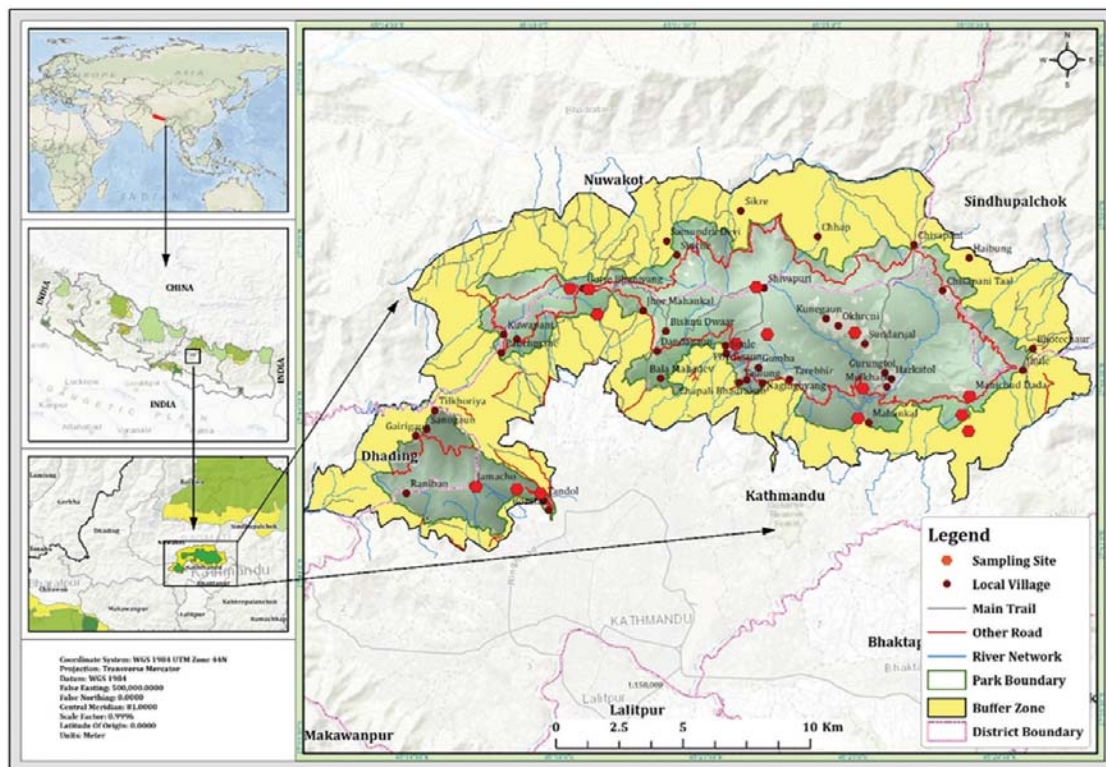


Figure 1. Map of study area showing sampling sites.

SNNP covers an area of 118.61 square kilometres. SNNP is a transitional zone of temperate and subtropical regions and represents the biodiversity of the middle mountain range of Nepal. SNNP has steep mountains which are mostly covered by forest trees, shrubs, grasses, and croplands. The forest trees are dominated by *Schima wallichii*, *Castanopsis indica* and *Alnus nepalensis* (SNNP 2017).

The adult specimens were collected from SNNP in 2018 during two different seasons: spring (March to May) and autumn (September to November). Sundarijal, Shivapuri, Gurjebhanjyang, Nagarjun, and Manichud sites were selected as the study area because they represent different vegetation and habitat types sufficient to collect different species. There are human settlements in some areas of Sundarijal and Manichud with croplands, the easy collection areas for saprophagous and aphidophagous hoverflies. Shivapuri, Nagarjun, and Gurjebhanjyang are dominated by forest habitats. Patches of grassland are present in Sundarijal, Nagarjun, and Manichud in the sampling transects (Fig. 1). The collection was made in different elevation that started from 1400 m a.s.l. to 2700 m a.s.l. (the Shivapuri peak) (Table 1). Each collection site was further divided into three different elevations and for each elevation, five sampling transects of 100 m × 5 m were fixed. In such transect, the hoverflies were collected by using two standard protocols, i.e., by hand sweeping net and coloured pan traps (white, yellow, and blue) for two consecutive days of sweeping. The collected specimens by sweeping net were kept in vials individually. These vials were transferred to an icebox. The pan traps were fixed in the transect for 24 hours. The insects trapped in pans after 24 hours were poured into a white enamel tray. The hoverfly specimens were handled carefully by brush and were put into the vial containing 70% ethanol. A map of the study area was created with the ArcGIS (Geographic Information System) 10.5 version. The photographs of the dorsal and lateral habitus of each representative for 34 species presently collected from SNNP are included. The photographs of pinned specimens were taken by using Canon camera EOS 60D DSLR, attached with a 60 mm EF-Macro lens and flash GODOXTT 685C Speedlight in the specimen holder stage.

Identification

The collected specimens were identified by using the following available literatures: Brunetti (1923), Speight (2017, 2020), Hassan et al. (2018), and van Steenis et al. (2021) for the most common species. Ghorpadé (1994) is used for the genera and species of Syrphini. Sengupta et al. (2017) and Dawah et al. (2020), for the genera and species of Syrphinae and Eristalinae. Claussen and Weipert (2003), for *Rhingia*. Hassan et al. (2019) for *Baccha maculata* and Sankararaman et al. (2020), for *Volucella trifasciata*. The collected specimens (each one of representative species) were deposited in the Central Department

Table 1. List of hoverflies collected in 2018 from SNNP with three new country records (*).

Subfamily	Species name	Elevation (m)	Material examined	
Eristalinae	<i>Eristalis (Eoseristalis) cerealis</i>	1,400–2,300	31 ♀, 20 ♂	
	<i>Eristalis (Eoseristalis) himalayensis</i>	1,700–2,300	3 ♀	
	<i>Eristalis (Eristalis) tenax</i>	1,400–2,300	26 ♀, 14 ♂	
	<i>Eristalinus (Eristalinus) aeneus</i>	1,600–2,000	4 ♀, 2 ♂	
	<i>Eristalinus (Eristalinus) arvorum</i>	2,000	1 ♀	
	<i>Eristalinus (Eristalinus) taeniops</i>	1,800	2 ♀	
	* <i>Graptomyza nigripes</i>	2,000	1 ♀	
	* <i>Lycastris albipes</i>	1,500–2,300	2 ♂	
	<i>Lycastris flavohirta</i>	1,500–1,700	2 ♀	
	<i>Mesembrius bengalensis</i>	1,500–1,900	2 ♀	
	<i>Phytomia errans</i>	1,600–1,900	2 ♀	
	<i>Phytomia zonata</i>	1,500–2,300	3 ♀	
	<i>Rhingia siwalikensis</i>	2,000	1 ♀	
	<i>Syritta indica</i>	1,400–2,300	15 ♀, 7 ♂	
	<i>Syritta orientalis</i>	1,400–2,300	11 ♀, 8 ♂	
	<i>Syritta pipiens</i>	1,400–2,300	17 ♀, 9 ♂	
	* <i>Volucella trifasciata</i>	1,500	1 ♀	
	Syrphinae	<i>Asarkina incisuralis</i>	1,600	1 ♂
		<i>Asarkina porcina</i>	1,500–1,600	4 ♀
		<i>Baccha maculata</i>	1,400	1 ♂
<i>Betasyrphus serarius</i>		1,500	1 ♀	
<i>Dasysyrphus orsua</i>		1,400–2,300	12 ♀, 7 ♂	
<i>Episyrphus balteatus</i>		1,400–2,300	37 ♀, 27 ♂	
<i>Episyrphus viridaureus</i>		1,400–2,300	34 ♀, 27 ♂	
<i>Eupeodes bucculatus</i>		1,400–1,800	3 ♂	
<i>Melanostoma orientale</i>		1,400–2,300	11 ♀, 8 ♂	
<i>Melanostoma scalare</i>		1,400–2,300	14 ♀, 9 ♂	
<i>Melanostoma univittatum</i>		1,400–2,300	15 ♀, 11 ♂	
<i>Meliscaeva cinctella</i>		1,400–1,500	2 ♂	
<i>Scaeva pyrastris</i>		1,800	1 ♀	
<i>Sphaerophoria bengalensis</i>		1,500–2,300	8 ♀, 5 ♂	
<i>Sphaerophoria indiana</i>		1,400–2,300	11 ♀, 3 ♂	
<i>Sphaerophoria scripta</i>		1,900–2,100	5 ♀	
<i>Syrphus torvus</i>	2,000–2,300	4 ♀		

Zoology Museum of Tribhuvan University (CDZMTU), Kirtipur, Kathmandu, Nepal as vouchers.

Nomenclature

The nomenclature follows recent studies: Yang et al. (2020), Dawah et al. (2020), Mengual et al. (2020), and van Steenis et al. (2018, 2021).

Classification and arrangement

The classification of subfamilies is followed of Mengual et al. (2015). Synonyms with type localities are given as far as they have been used in the literature dealing with the Nepalese fauna.

Floral association and local distribution

The flowers from which the specimens were collected are also presented in the paper. The distribution of the species within Nepal is given as District named followed by local area with the elevation as far as they are available.

Results

A total of 454 specimens including 291 females and 163 males were collected from SNNP during 2018 (Table 1). They belong to 34 species representing 20 genera. Among these, three species, *Graptomyza nigripes* Brunetti, 1913 (Fig. 4A-B), *Lycastris albipes* Walker, 1857 (Fig. 4C-D) and *Volucella trifasciata* Wiedemann, 1830 (Fig. 7A-B) are recorded for the first time in Nepal.

Taxonomic Accounts

Family Syrphidae

Subfamily Eristalinae

Genus *Eristalis* Latreille, 1804

Subgenus *Eoseristalis* Kanervo, 1938

1. *Eristalis (Eoseristalis) cerealis* Fabricius, 1805 (Fig. 2A-B)

Eristalis cerealis Fabricius, 1805: 232. Type locality: China.

Eristalis solitus Walker, 1849: 619. Type locality: Nepal.

Material examined. 1♀, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1800 m; 1♂, Kathmandu, Manichud, 27.76°N, 85.47°E, 14.x.2018, 1800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 20.iii.2018, 2000 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 19.x.2018, 2000 m; 2♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2300 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.x.2018, 2300 m; 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1400 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1400 m; 1♀, 1♂, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1600 m; 1♀, 1♂, Nagarjun, 27.74°N, 85.29°E, 26.x.2018, 1600 m; 1♀, Nagarjun, 27.75°N, 85.27°E, 28.x.2018, 2100 m; 1♀, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1700 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 28.ix.2018, 1700 m; 2♀, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1900 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1900 m; 1♀, 2♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2300 m; 1♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 03.x.2018, 2300 m; 2♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1500 m; 2♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1500 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 03.iv.2018, 1800 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 09.x.2018, 1,800 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2000 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.4211°E, 12.x.2018, 2000 m; 2♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1600 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 10.iv.2018, 1900 m; 1♀, Nuwakot,

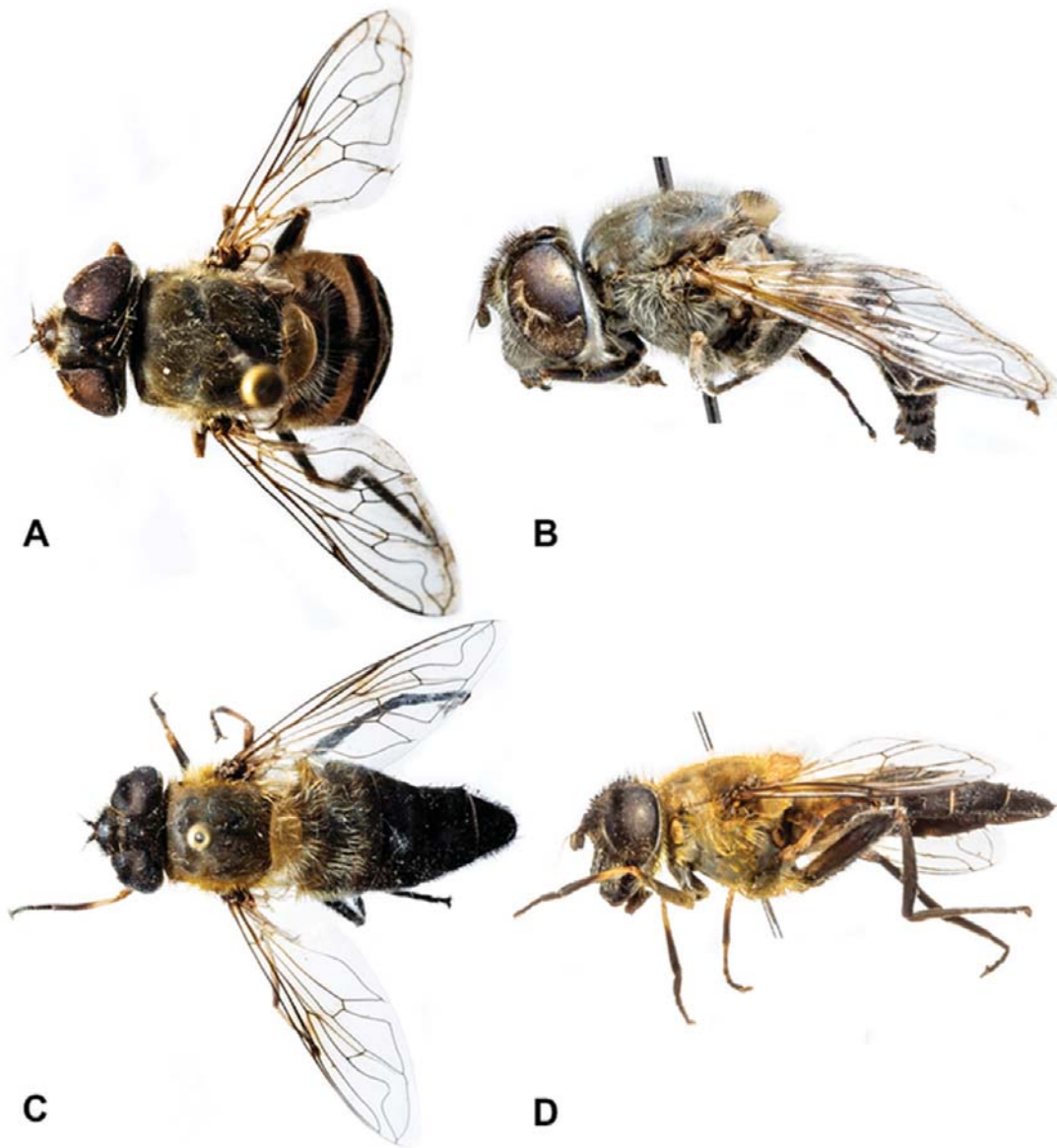


Figure 2A-D. Dorsal and lateral habitus: A–B, *Eristalis (Eoseristalis) cerealis*; C–D, *Eristalis (Eoseristalis) himalayensis*.

Gurjebhanjyang, 27.81°N, 85.33°E, 3.xi.2018, 1900 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2000 m; 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2000 m.

Distribution in Nepal. Taplejung District: Sanghu at Tumlingtar plateau, 609 m; Sankhuwasabha District: Chichila Arun valley; Lalitpur District: Godawari Botanical Garden, 1400 m/Phulchoki, 2300–2500 m, Hotel Norrbu Linka, 1350 m; Kathmandu District: Thamel, Kritipur, Tribubvan, 1400 m; Kaski District: Ulleri, 2070–1800 m, Pokhara, 900 m; Myagdi: Ghodepani, 2855 m, Sikha, 2850–1920 m; Dolpa District: Kaigaon to Rimi, 2800–3100 m; Jumla District, 2400 m, Uthu,

2500 m (Coe 1964; Lambeck and Kiauta 1973; Kapoor et al. 1979; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

2. *Eristalis (Eoseristalis) himalayensis* Brunetti, 1908 (Fig. 2C-D)

Eristalis himalayensis Brunetti, 1908: 70. Type locality: India.

Material examined. 1♀, Kathmandu, Shivapuri, 27.80°N, 85.38°E, 15. iv.2018, 1700 m; 1♀, Kathmandu, Shivapuri, 27.60°N, 85.36913°E, 20. iv.2018, 2300 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12. iv.2018, 2000 m.

Distribution in Nepal. Taplejung District: Sanghu, 1981–2804 m; Sankhuwasabha District: Chichila to Num, 1600–1900 m; Solukhumbu District: Thangboche Gonda, 3850 m; Makawanpur District: Chitlang, 1600 m; Kaski District: Pipar and Ulleri, 2070–1800 m; Myagdi District: Ghodepani, 2855 m, Simikot, 2300 m, Dandaphaya Dharapani; Dolpa District: Gurung valley, Hurikot, 3100–3600 m; Humla District: Simikot, 2200 m, Phunki Drangka, 3400 m (Coe 1964; Lambeck and Kiauta 1973; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

Subgenus *Eristalis* Latreille, 1804

3. *Eristalis (Eristalis) tenax* (Linnaeus, 1758) (Fig. 3A-B)

Musca tenax Linnaeus, 1758: 591. Type locality: Sweden.

Material examined. 1♀, Kathmandu Manichud, 27.75°N, 85.47°E, 14. x.2018, 1800 m; 2♀, Kathmandu Manichud, 27.77°N, 85.47°E, 20.iii.2018, 2000 m; 1♂, Kathmandu Manichud, 27.77°N, 85.47°E, 19.X.2018, 2000 m; 1♀, Kathmandu Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2300 m; 1♀, 1♂, Kathmandu Manichud, 27.77°N, 85.47°E, 22.x.2018, 2,300 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1400 m; 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1400 m; 1♀, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1600 m; 1♀, 1♂, Nagarjun, 27.74415°N, 85.29°E, 26.x.2018, 1600 m; 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2100 m; 1♀, Nagarjun, 27.75°N, 85.27°E, 28. x.2018, 2100 m; 2♀, 1♂, Shivapuri, 27.80°N, 85.38°E, 15.iv.2018, 1700 m; 1♀, 27.79°N, 85.38°E, 28.ix.2018, 1700 m; 1♀, Shivapuri, 27.80°N, 85.39°E,

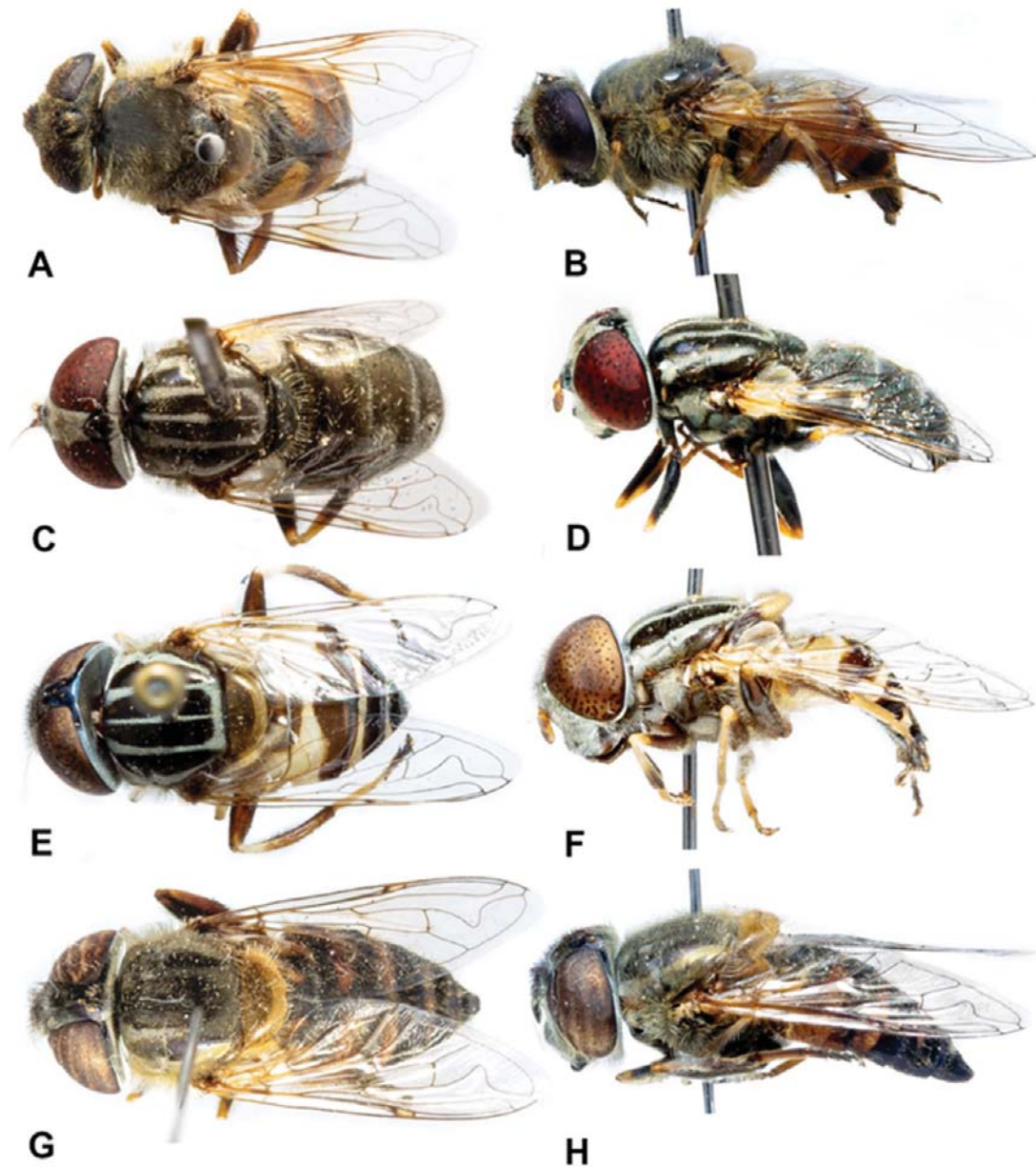


Figure 3A-H. Dorsal and lateral habitus: A–B, *Eristalis (Eristalis) tenax*; C–D, *Eristalinus (Eristalinus) aeneus*; E–F, *Eristalinus (Eristalinus) arvorum*; G–H, *Eristalinus (Eristalinus) taeniops*.

17.iv.2018, 1900 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1,900 m; 1♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2300 m; 2♀, Sundarijal, 27.76°N, 85.4234°E, 02.iv.2018, 1500 m; 1♀, 1♂, 27.76°N, 85.42°E, 07.x.2018, 1500 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 03. iv.2018, 1800 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2000 m; 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1600 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 10.iv.2018, 1900 m; 2♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 03.xi.2018, 1,900 m; 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2000 m.

Distribution in Nepal. Taplejung District: Sanghu, 1890–2134 m; Sankhuwasabha District: Arun Valley, Tumlingtar, 610 m; Dolakha District: Hurikot Garpung valley, 2700–3000 m, Churta, 3400 m; Sindhupalchok District: Helambu, 2400 m; Kathmandu District: Balaju, Kirtipur, Chhauni, 1400 m, Gokarna Safari; Lalitpur District: Godawari Botanical Garden, 1400 m, Phulchoki, 2300–2500 m; Myagdi District: Sikha Ghodepani, 1920–2850 m, Jumla, 2200–2400 m, Uthu, 25,000 m, Kaigaon, 3000 m, Tatopani, 2200 m; Humla District: Simikot, 3100 m, Tuling Kermi, 2300–2700 m; Jumla District: Gothichour, 2700–3200 m (Coe 1964; Lambeck and Kiauta 1973; Kapoor et al. 1979; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

Genus *Eristalinus* Rondani, 1845

Subgenus *Eristalinus* Rondani, 1845

4. *Eristalinus (Eristalinus) aeneus* (Scopoli, 1763) (Fig. 3C-D)

Conops aeneus Scopoli, 1763: 356. Type locality: Slovenia [as ‘Carniola’].

Material examined. 1♀, 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1800 m; 1♀, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2000 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1600 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2000 m.

Distribution in Nepal. NEPAL (Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

5. *Eristalinus (Eristalinus) arvorum* (Fabricius, 1787) (Fig. 4E-F)

Syrphus arvorum Fabricius, 1787: 335. Type locality: India.

Material examined. 1♀, Kathmandu, Sundarijal, 27.79°N, 85.42 °E, 05.iv.2018, 2000 m.

Distribution in Nepal. Taplejung District: Sanghu 1889 m; Sankhuwasabha District: Tumlingtar, 548 m Arun valley; Chitwan District: Sauraha, 180 m; Makawanpur District: Hetauda, 430 m; Kathmandu District: Chhauni, Taudaha, 1350 m, Phulchoki, 2300–2500 m, Hotel Norbu Linka, 1350 m,

Thamel; Jumla District: Gothichour, 2800 m (Coe 1964; Lambeck and Kiauta 1973; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora* (Asteraceae).

6. *Eristalinus (Eristalinus) taeniops* (Wiedemann, 1818) (Fig. 3G-H)

Eristalis taeniops Wiedemann, 1818: 42. Type locality: South Africa.

Material examined. 2♀, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1800 m.

Distribution in Nepal. NEPAL (Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Bidens pilosa* (Asteraceae).

Genus *Graptomyza* Wiedemann, 1820

7. *Graptomyza nigripes* Brunetti, 1913 (Fig. 4A-B)

Graptomyza nigripes Brunetti, 1913a: 167. Type locality: India.

Material examined. 1♀, Kathmandu, Sundarijal, 27.79°N, 85.42 °E, 12.x.2018, 2000 m.

Floral association. *Cuphea hyssopifolia* (Lythraceae).

Remark. New species record for Nepal.

Genus *Lycastris* Walker, 1857

8. *Lycastris albipes* Walker, 1857 (Fig. 4C-D)

Lycastris albipes Walker, 1857: 155. Type locality: India.

Material examined. 1♂, Kathmandu, Shivapuri, 27.61°N, 85.37°E, 20.iv.2018, 2300 m; 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1500 m.

Floral association. *Ageratina adenophora* (Asteraceae).

Remark. New species record for Nepal.

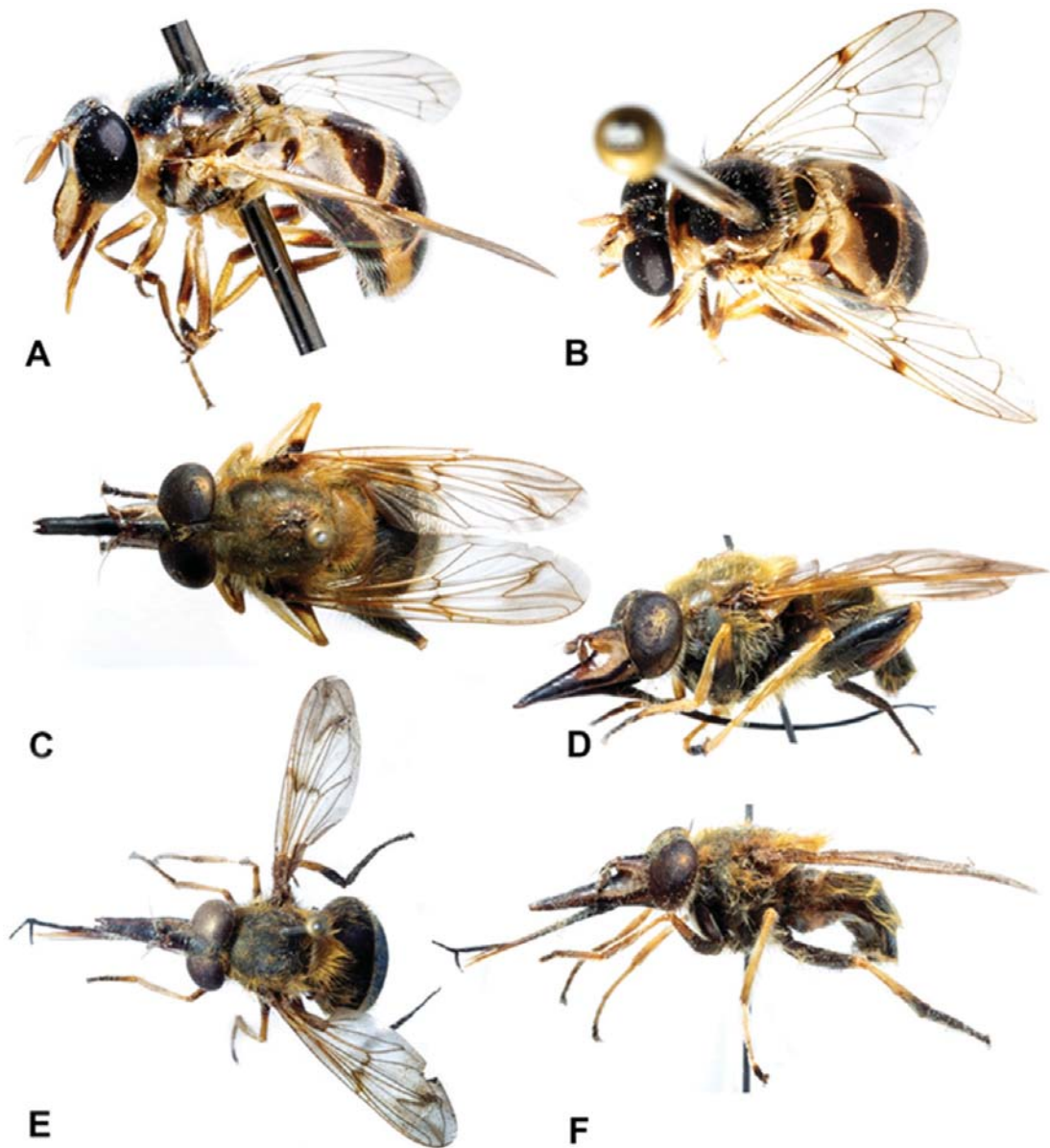


Figure 4A-F. Dorsal and lateral habitus: A–B, *Graptomyza nigripes*; C–D, *Lycastris albipes*; E–F; *Lycastris flavohirta*.

9. *Lycastris flavohirta* Brunetti, 1907 (Fig. 4E-F)

Lycastris flavohirta Brunetti, 1907: 16. Type locality: India.

Material examined. 1♀, Kathmandu, Shivapuri, 27.79°N, 85.38°E, 15. iv.2018, 1700 m; 1♀, Sundarijal, 27.77°N, 85.42°E, 02.iv.2018, 1500 m.

Distribution in Nepal. Taplejung District: Sangu, 2804 m (Coe 1964; Thapa 2015; Ghorpadé 2015a).

Floral association. *Bidens pilosa* (Asteraceae).

Genus *Mesembrius* Rondani, 1857

10. *Mesembrius bengalensis* (Wiedemann, 1819) (Fig. 5A-B)

Eristalis bengalensis Wiedemann, 1819: 16. Type locality: India (Bengal).

Eumerosyrphus indianus Bigot, 1882: 2. Type locality: India.

Material examined. 1♀, Kathmandu, Shivapuri, 27.80°N, 85.39°E, 30. ix.2018, 1900 m; 1♀, Sundarikal, 27.76°N, 85.42°E, 07.x.2018, 1500 m.

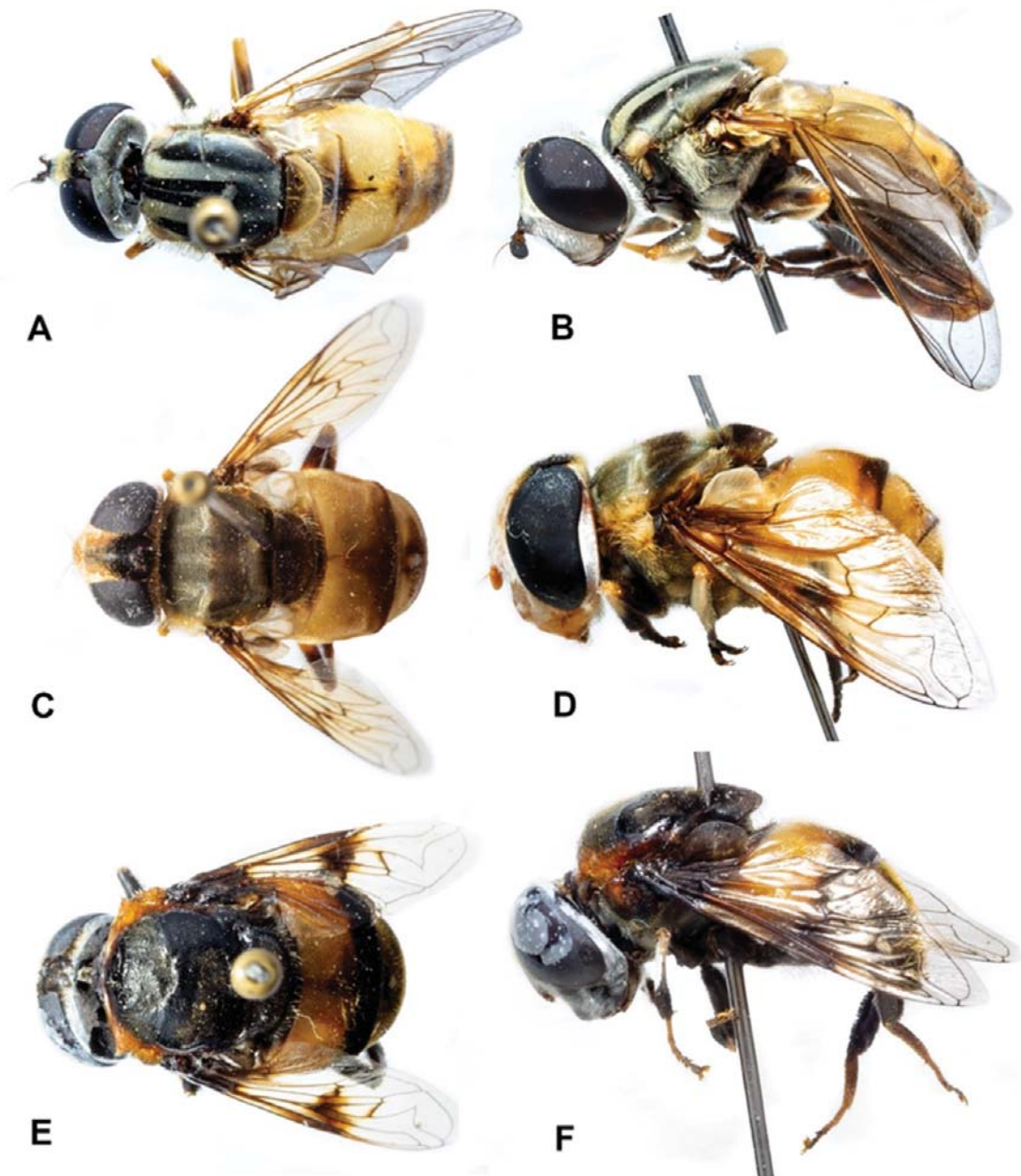


Figure 5A-F. Dorsal and lateral habitus: A–B, *Mesembrius bengalensis*; C–D, *Phytomia errans*; E–F, *Phytomia zonata*.

Distribution in Nepal. Kathmandu District; Banke District: Hotel Batika, 170 m, Nepalgunj (Thapa 2015; Ghorpadé 2015a).

Floral association. *Alternanthera sessilis* (Amaranthaceae), *Lantana camara* (Verbenaceae).

Genus *Phytomia* Guérin-Ménéville, 1833

11. *Phytomia errans* (Fabricius, 1787) (Fig. 5C-D)

Syrphus errans Fabricius, 1787: 337. Type locality: China.

Material examined. 1♀, Kathmandu, Shivapuri, 27.80°N, 85.39°E, 30. ix.2018, 1900 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01. xi.2018, 1600 m.

Distribution in Nepal. Taplejung District: Sanghu, 1850 m, Sankhuwasabha District: Arun Valley, Tumlingtar, 610 m; Kathmandu District: Chhauni, 1400 m (Coe 1964; Lambeck and Kiauta 1973; Thapa 2015; Ghorpadé 2015a).

Floral association. *Alternanthera sessilis* (Amaranthaceae), *Lantana camara* (Verbenaceae).

12. *Phytomia zonata* (Fabricius, 1787) (Fig. 5E-F)

Syrphus zonatus Fabricius, 1787: 337. Type locality: China.

Material examined. 1♀, Kathmandu, Manichud, 27.75°N, 85.467°E, 14. x.2018, 1800 m; 1♀, Shivapuri, 27.60°N, 85.37°E, 20. iv.2018, 2300 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 07. x.2018, 1500 m.

Distribution in Nepal. Taplejung District: Sanghu, 1850 m, Dobhan, 2076 m; Kathmandu District: Chhauni, 1400 m (Coe 1964; Lambeck and Kiauta 1973; Thapa 2015; Ghorpadé 2015a).

Floral association. *Alternanthera sessilis* (Amaranthaceae), *Lantana camara* (Verbenaceae).

Genus *Rhingia* Scopoli, 1763

13. *Rhingia siwalikensis* Nayar, 1968 (Fig. 6A-B)

Rhingia siwalikensis Nayar, 1968: 126. Type locality: India.

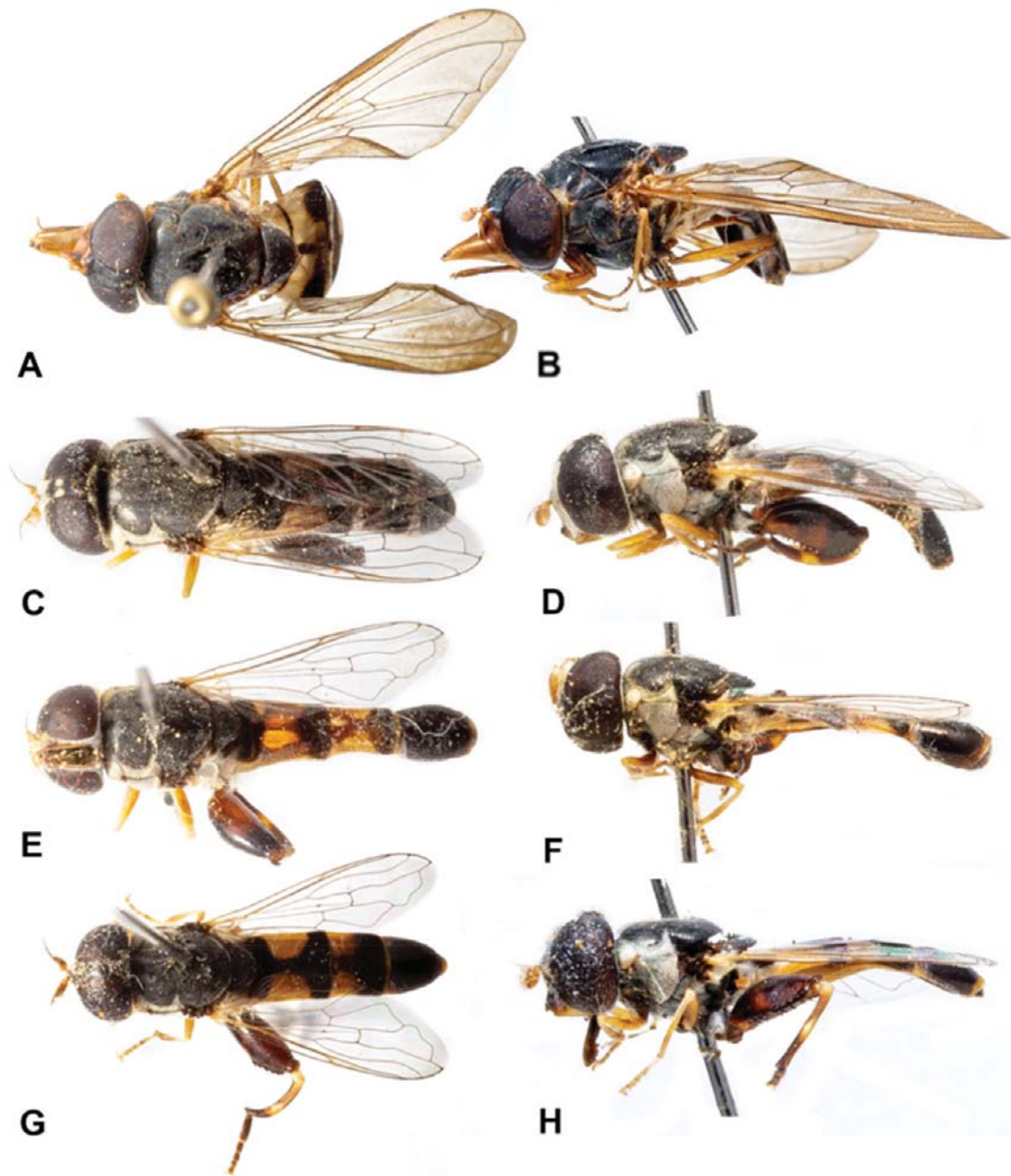


Figure 6A-H. Dorsal and lateral habitus: A–B, *Rhingia siwalikensis*; C–D, *Syritta indica*; E–F, *Syritta orientalis*; G–H, *Syritta pipiens*.

Material examined. 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12. iv.2018, 2000 m.

Distribution in Nepal. Myagdi District: Ghodepani, 2855 m (Claussen and Weipert 2003; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora* (Asteraceae).

Genus *Syritta* Lepeletier & Serville, 1828

14. *Syritta indica* (Wiedemann, 1824) (Fig. 6C-D)

Eumerus indica Wiedemann, 1824: 33. Type locality: India.

Material examined. 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1800 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1400 m; 1♀, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1600 m; 1♀, Nagarjun, 27.74°N, 85.29°E, 26.x.2018, 1600 m; 1♀, Nagarjun, 27.75°N, 85.27°E, 28.x.2018, 2100 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 28.ix.2018, 1700 m; 1♀, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1900 m; 1♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2300 m; 1♂, Shivapuri, 27.60°N, 85.37°E, 03.x.2018, 2300 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1500 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 09.x.2018, 1800 m; 1♀, Sundarijal, 27.79°N, 85.4211°E, 05.iv.2018, 2000 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 12.x.2018, 2000 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1600 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1600 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 10.iv.2018, 1900 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 03.xi.2018, 1900 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2000 m,

Distribution in Nepal. NEPAL (Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

15. *Syritta orientalis* Macquart, 1842 (Fig. 6E-F)

Syritta orientalis Macquart, 1842: 76. Type locality: India.

Material examined. 1♀, Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 19.x.2018, 2000 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.x.2018, 2,300 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1400 m; 1♂, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1400 m; 1♀, Nagarjun, 27.74°N, 85.29°E, 26.x.2018, 1600 m; 1♀, Nagarjun, 27.75°N, 85.27°E, 28.x.2018, 2100 m; 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1700 m; 1♀, Shivapuri, 27.79°N, 85.37°E, 28.ix.2018, 1700 m; 1♂, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1900 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1900 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 12.x.2018, 2000 m; 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 03.

xi.2018, 1900 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2000 m.

Distribution in Nepal. NEPAL (Ghorpadé 2015a, 2015b; Hassan et al. 2017; Shehzad et al. 2017).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

16. *Syritta pipiens* (Linnaeus, 1758) (Fig. 6G-H)

Musca pipiens Linnaeus, 1758: 594. Type locality: Sweden.

Material examined. 1♀, Kathmandu, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1400 m; 2♀, 1♂, Kathmandu, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1400 m; 1♀, Kathmandu, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1600 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 28.ix.2018, 1700 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1900 m; 1♀, 2♂, Shivapuri, 27.60°N, 85.36°E, 20.iv.2018, 2300 m; 1♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 03.x.2018, 2300 m; 1♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1500 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1500 m; 1♂, Sundarijal, 27.769°N, 85.42°E, 09.x.2018, 1800 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2000 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 12.x.2018, 2000 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1600 m; 2♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.33°E, 3.xi.2018, 1900 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2000 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2000 m.

Distribution in Nepal. Kathmandu District: Chauni, 1400 m; Jumla District: Gothichour, 2900–3050 m, Tripurakot, 2500 m; Humla District: Simikot, 3100 m (Lambeck and Kiauta 1973; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

Genus *Volucella* Geoffroy, 1762

17. *Volucella trifasciata* Wiedemann, 1830 (Fig. 7A-B)

Volucella trifasciata Wiedemann, 1830: 196. Type locality: Java.

Material examined. 1♀, Kathmandu, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1500 m.

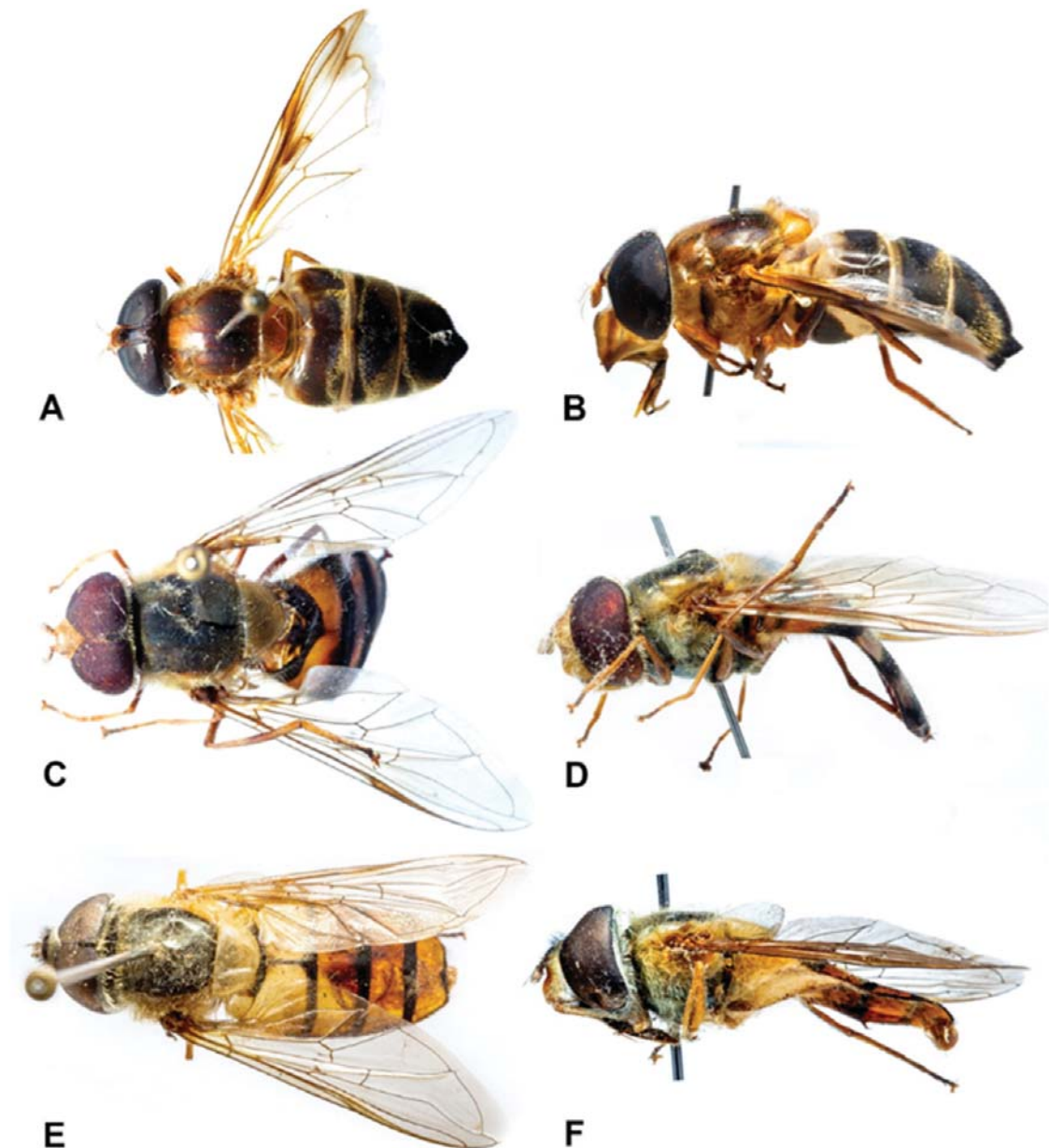


Figure 7A-F. Dorsal and lateral habitus: A–B, *Volucella trifasciata*; C–D, *Asarkina incisuralis*; E–F, *Asarkina porcina*.

Floral association. *Bidens pilosa* (Asteraceae).

Remark. New species record for Nepal.

Subfamily Syrphinae

Genus *Asarkina* Macquart, 1842

18. *Asarkina incisuralis* (Macquart, 1855) (Fig. 7C-D)

Syrphus incisuralis Macquart, 1855: 94. Type locality: India.

Material examined. 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85. 32°E, 08. iv.2018, 1600 m.

Distribution in Nepal. Lothar near Birganj (Ghorpadé 2015a).

Floral association. *Bidens pilosa* (Asteraceae).

19. *Asarkina porcina* (Coquillett, 1898) (Fig. 7E-F)

Syrphus porcina Coquillett, 1898: 322. Type locality: Japan.

Material examined. 2♀, Kathmandu, Nagarjun, 27.74°N, 85.29°E, 28. iv.2018, 1600 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1500 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85. 32°E, 08.iv.2018, 1600 m.

Distribution in Nepal. NEPAL (Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

Genus *Baccha* Fabricius, 1805

20. *Baccha maculata* Walker, 1852 (Fig. 8A-B)

Baccha maculata Walker, 1852: 223. Type locality: India [East Indies].

Baccha tinctipennis Brunetti, 1907: 11. Type locality: India.

Baccha tenera Meijere, 1910: 103. Type locality: Indonesia.

Baccha austeni Meijere, 1908: 325. Type locality: Indonesia.

Material examined. 1♂, Kathmandu, Nagarjun, 27.68°N, 85.29°E, 24. x.2018, 1400 m.

Distribution in Nepal. Taplejung District: Sanghu, 1890 m (Coe 1964; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratum houstonianum* (Asteraceae).

Genus *Betasyrphus* Matsumura & Adachi, 1917

21. *Betasyrphus serarius* (Wiedemann, 1830) (Fig. 8C-D)

Syrphus serarius Wiedemann, 1830: 128. Type locality: China.

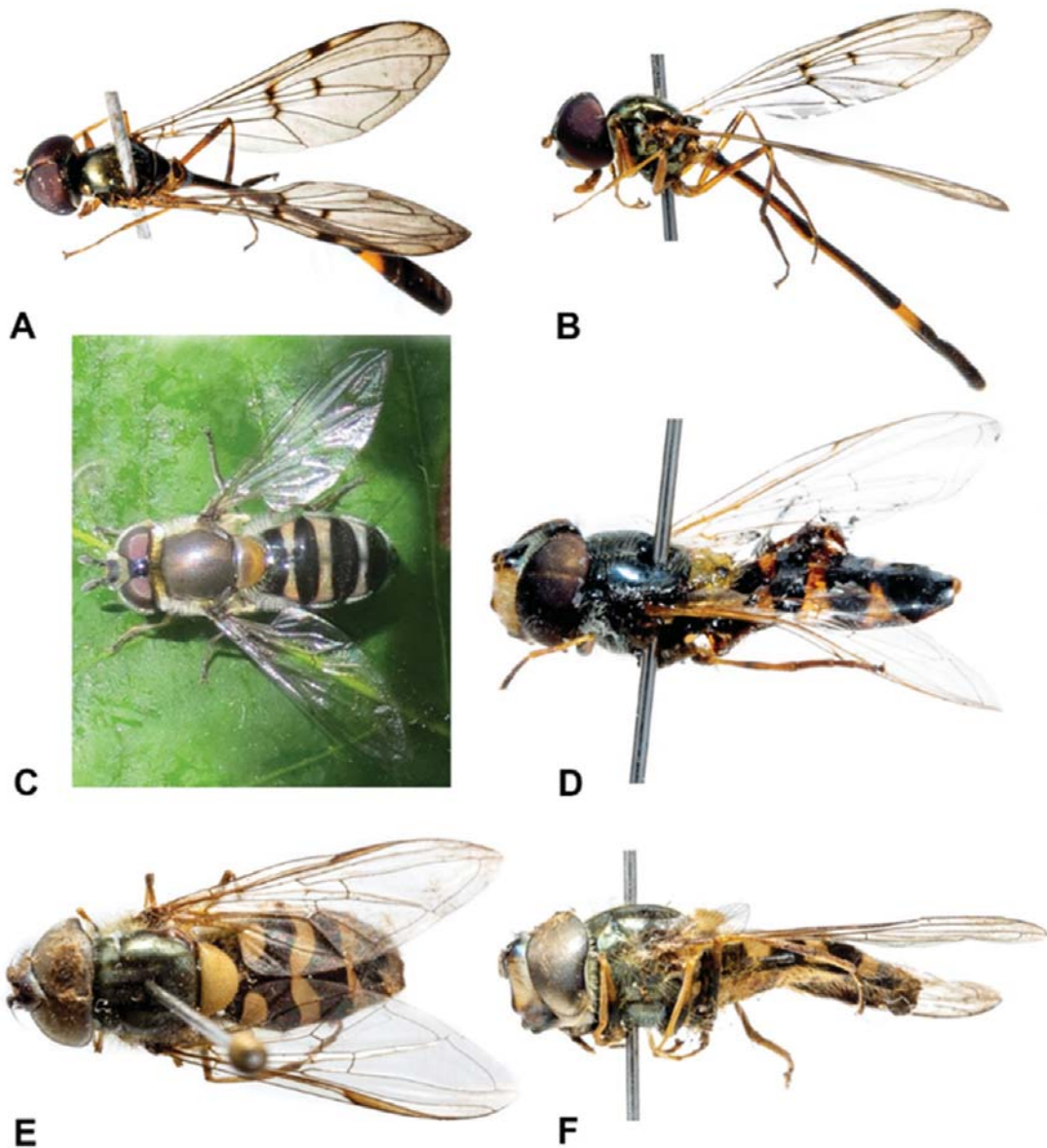


Figure 8A-F. Dorsal and lateral habitus: A–B, *Baccha maculata*; C–D, *Betasyrphus serarius*; E–F, *Dasysyrphus orsua*.

Material examined. 1 ♀, Kathmandu, Sundarijal, 27.76°N, 85.42°E, 02. iv.2018, 1500 m.

Distribution in Nepal. Taplejung District: Sanghu, 1900 m; Bhaktapur District: Nagarkot, 2200 m; Kathmandu District: Sundarijal, 1400–2000 m (Coe 1964; Thapa 2015).

Floral association. *Brassica campestris* (Brassicaceae).

Genus *Dasysyrphus* Enderlein, 1938

22. *Dasysyrphus orsua* (Walker, 1852) (Fig. 8E-F)

Syrphus orsua Walker, 1852: 231. Type locality: India.

Material examined. 1♀, 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2300 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1400 m; 1♂, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1600 m; 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2100 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.38°E, 15.iv.2018, 1700 m; 1♀, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1900 m; 2♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2300 m; 1♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1500 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2000 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2000 m.

Distribution in Nepal. Taplejung District: Sanghu, 1585–1890 m; Myagdi District: Ghodepani 2855 m; Jumla District: Churta, 2900–3500 m; Gothichour, 2900 m, Khari, 3285 m, Maharigaon, 3220 m (Coe 1964; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

Genus *Episyrphus* Matsumura & Adachi, 1917

23. *Episyrphus balteatus* (De Geer, 1776) (Fig. 9A-B)

Musca balteata De Geer, 1776: 116. Type locality: Sweden.

Material examined. 1♀, 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1800 m; 1♀, 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 20.iii.2018, 2000 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 19.x.2018, 2000 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2300 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.x.2018, 2300 m; 1♀, 2♂, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1400 m; 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1400 m; 1♀, 1♂, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1600 m; 1♀, 1♂, Nagarjun, 27.74°N, 85.29°E, 26.x.2018, 1600 m; 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2100 m; 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 28.x.2018,

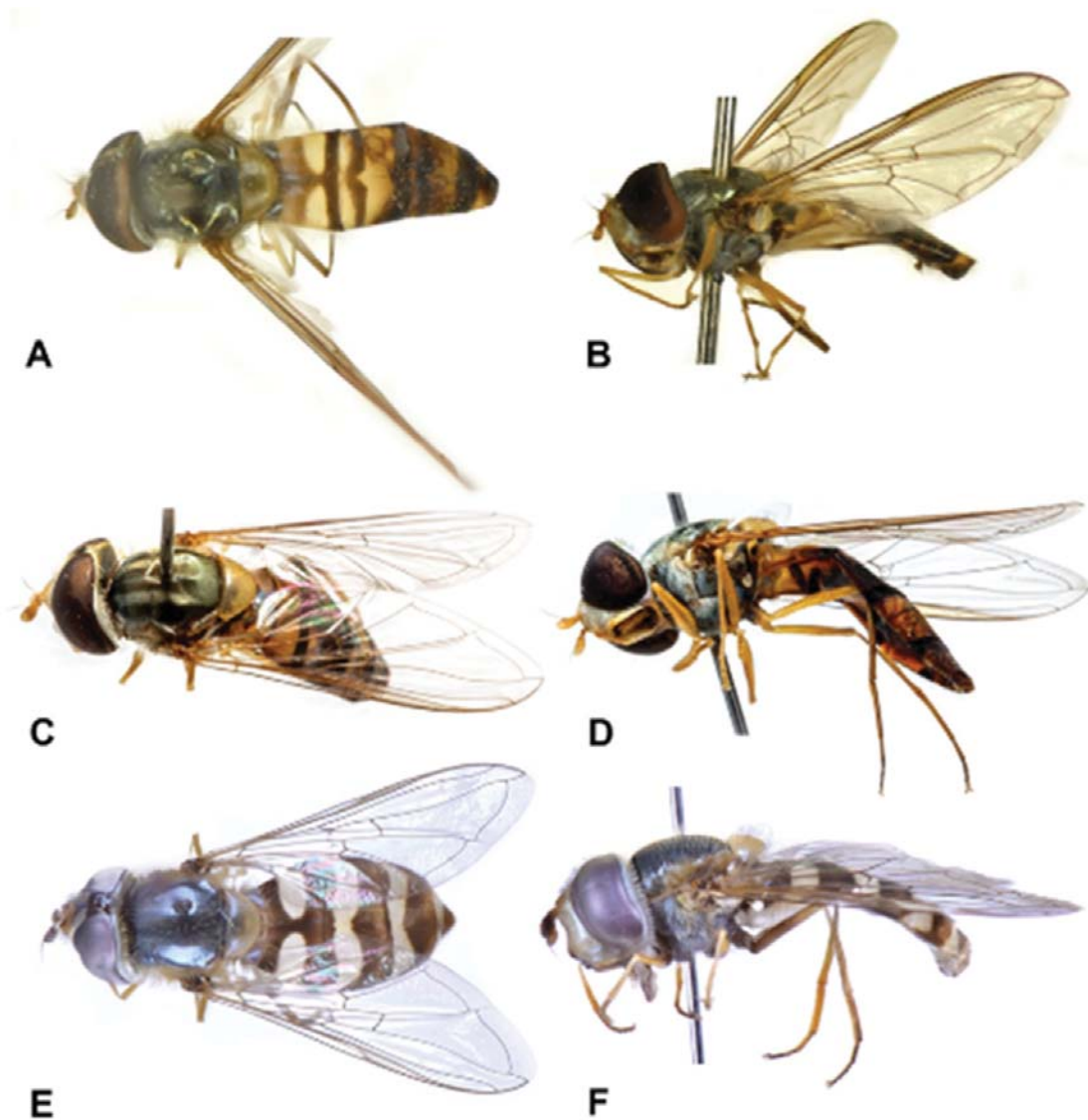


Figure 9A-F. Dorsal and lateral habitus: A–B, *Episyrrhus balteatus*; C–D, *Episyrrhus viridaureus*; E–F, *Eupeodes bucculatus*.

2100 m; 2♀, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1700 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 28.ix.2018, 1700 m; 2♀, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018 1900 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 30. ix.2018, 1900 m; 1♀, 2♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2300 m; 1♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 03.x.2018, 2300 m; 2♀, 2♂, Sundarijal, 27.77°N, 85.42°E, 02.iv.2018, 1500 m; 2♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1500 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42° E, 03.iv.2018, 1800 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 09.x.2018, 1800 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2000 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 12.x.2018, 2,000 m; 2♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1600 m; 2♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 8532°E, 01.xi.2018, 1600 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.32°E, 10.iv.2018, 1900 m; 2♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.32°E, 03.xi.2018, 1900 m; 1♀, Nuwakot,

Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2000 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2000 m.

Distribution in Nepal. Taplejung District: Sanghu, Tamrang, 1585 m; Kathmandu District: Guheswari, 1300 m, Godawari, Chhauni, Kirtipur, Balaju; Sindhupalchok District: Helambu, 2400 m; Manang District: Chame, 2700–3200 m, Pisang; Mugu District: Rara lekeide, 2945 m, Jumla, Gothichour, 2800–3100 m, Maharigaon, 3220 m; Bajura District: Kuwadi Khola, 2900 m (Coe 1964; Lambeck and Kiauta 1973; Kapoor et al. 1979; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

24. *Episyrphus viridaureus* (Wiedemann, 1824) (Fig. 9C-D)

Syrphus viridaureus Wiedemann, 1824: 35. Type locality: Indonesia (Java).

Material examined. 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1800 m; 2♀, 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 20.iii.2018, 2000 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 19.x.2018, 2000 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2300 m; 1♀, 1♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.x.2018, 2300 m; 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1400 m; 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, from 1,400 m; 1♀, 1♂, Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1600 m; 1♀, 1♂, Nagarjun, 27.74°N, 85.29°E, 26.x.2018, 1600 m; 1♀, 1♂, Nagarjun, 27.74°N, 85.27°E, 30.iii.2018, 2100 m; 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 28.x.2018, 2100 m; 2♀, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1700 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 28.ix.2018, 1700 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1900 m; 1♀, 1♂, Shivapuri, 27.80°N, 85.39°E, 30.ix.2018, 1900 m; 1♀, 2♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2300 m; 1♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 03.x.2018, 2300 m; 1♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1500 m; 1♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 07.x.2018, 1500 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 03.iv.2018, 1800 m; 1♀, 1♂, Sundarijal, 27.77°N, 85.42°E, 09.x.2018, 1800 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2,000 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.4211°E, 12.x.2018, 2000 m; 2♀, 1♂, Nuwakot Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1600 m; 2♀, 1♂, Nuwakot Gurjebhanjyang, 27.80°N, 85.32°E, 01.xi.2018, 1600 m; 1♀, 1♂, Nuwakot Gurjebhanjyang, 27.81°N, 85.33°E, 10.iv.2018, 1900 m; 2♀, 1♂, Nuwakot Gurjebhanjyang, 27.81°N, 85.33°E, 03.xi.2018, 1900 m; 1♀, Nuwakot Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2000 m; 1♀, 1♂, Nuwakot Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2000 m.

Distribution in Nepal. Sankhuwasabha District; Kaski District; Dailekh District; Jumla District; Mugu District; Bajura District (Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

Genus *Eupeodes* Osten Sacken, 1877

25. *Eupeodes bucculatus* (Rondani, 1857) (Fig. 9E-F)

Syrphus bucculatus Rondani, 1857: 134. Type locality: Italy.

Material examined. 1♀, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1800 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1400 m; 1♀, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1700 m.

Distribution in Nepal. Jumla District: Gothichour, 2800–3050 m, Maharigaon, 2800–3200 m, Khari La, 3250 m; Humla District: Simikot, 3050 m, Soli Khola, 2900 m, Sankha La, at 4,300 m, Kuwadi Khola Saipal, at 3,600 m (Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

Genus *Melanostoma* Schiner, 1860

26. *Melanostoma orientale* (Wiedemann, 1824) (Fig. 10A-B)

Syrphus orientalis Wiedemann, 1824: 36. Type locality: India.

Material examined. 1♀, 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1800 m; 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 14.x.2018, 1800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.x.2018, 2300 m; 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1400 m; 1♀, 1♂, Nagarjun, 27.68°N, 85.29°E, 24.x.2018, 1400 m; 1♀, Nagarjun, 27.74°N, 85.27°E, 24.x.2018, 2100 m; 1♀, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1700 m; 1♀, Shivapuri, 27.60°N, 85.37°E, 03.x.2018, 2300 m; 1♀, 2♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1500 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.4211 °E, 12.x.2018, 2000 m; 1♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 05.xi.2018, 2000 m.

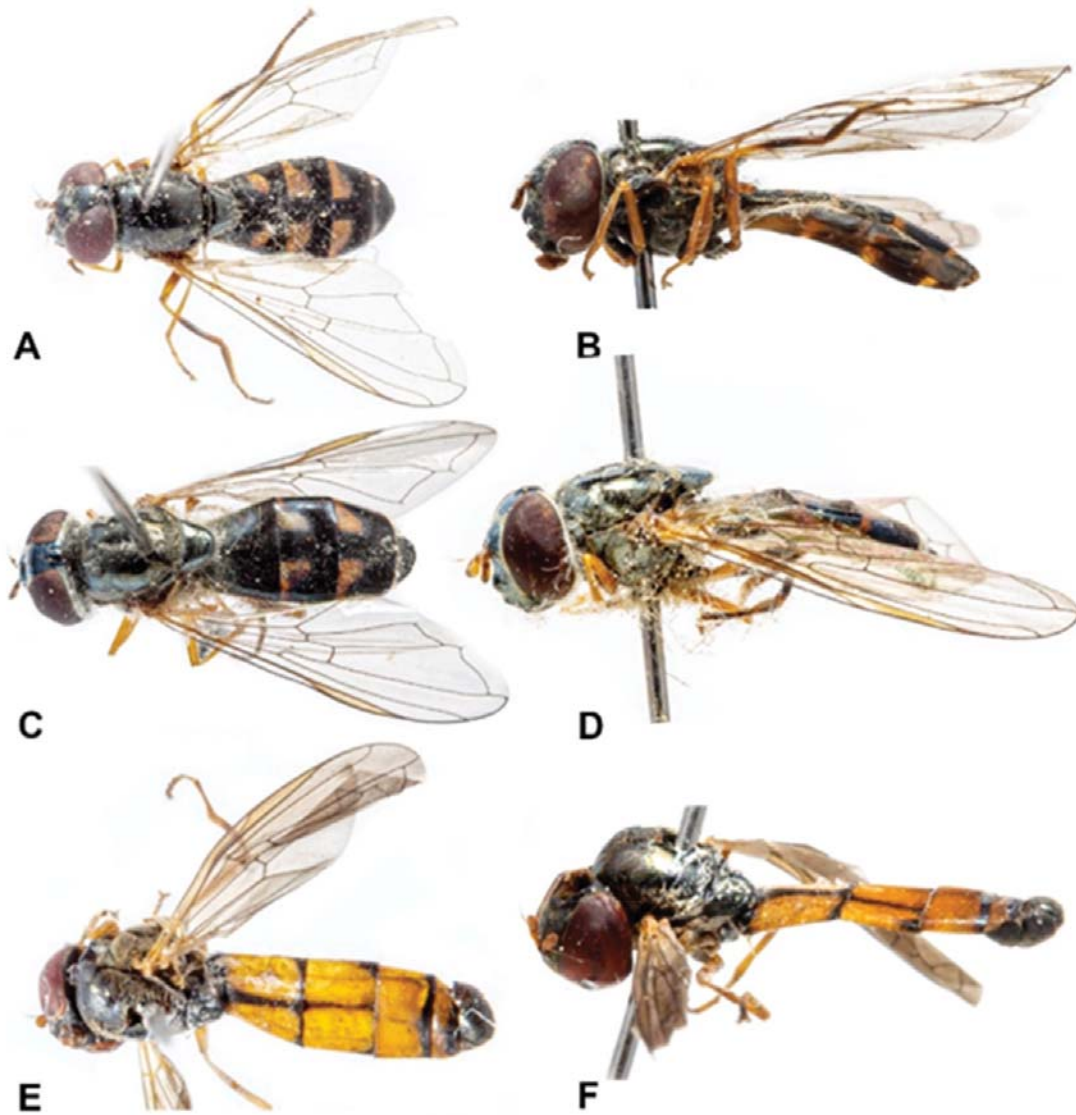


Figure 10A-F. Dorsal and lateral habitus: A–B, *Melanostoma orientale*; C–D, *Melanostoma scalare*; E–F, *Melanostoma univittatum*.

Distribution in Nepal. Taplejung District: Sangu (=Sanghu), 1890 m, Dobhan, 1067 m; Sankhuwassabha District: Chichila, 1600–1900 m; Solukhumbu District: Lukla, 2800 m; Kathmandu District: Gokarna Safari, 1350; Lalitpur District: Godawari Botanical Garden, 1400 m, Phulchoki, 2300–2500 m; Kaski District: Pokhara, 900 m; Dolpa District: Rimi Kaigaon, 2900–3100 m; Humla District: Simikot, 3100 m; Jumla District: Gothichour, 2800 m, Gothigaon, 2600 m, Tatopani, 2200 m, Chala Sankha, 4400–4700 m; Bajura District: Kuwadi khola, 2900 m (Coe 1964; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

27. *Melanostoma scalare* (Fabricius, 1794) (Fig. 10C-D)

Syrphus scalare Fabricius, 1794: 308. Type locality: Denmark.

Material examined. 2♀, 2♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2300 m; 2♀, 1♂, Nagarjun, 27.68°N, 85.27°E, 26.iii.2018, 1400 m; 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2100 m; 2♀, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1700 m; 1♀, 1♂, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2300 m; 2♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 04.iv.2018, 1500 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2000 m; 1♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2000 m.

Distribution in Nepal. NEPAL (Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

28. *Melanostoma univittatum* (Wiedemann, 1824) (Fig. 10E-F)

Syrphus univittatum Wiedemann, 1824: 36. Type locality: India.

Material examined. 2♀, 2♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1800 m; 1♀, 2♂, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2300 m; 1♀, 2♂, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1400 m; 1♀, 1♂ Nagarjun, 27.74°N, 85.29°E, 28.iii.2018, 1600 m; 2♀, 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1700 m; Shivapuri, 2♀, 1♂, 27.60°N, 85.37°E, 20.iv.2018, 2300 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1500 m; 2♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2000 m; 2♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2000 m.

Distribution in Nepal. Taplejung District: Arun Valley, Tumlingtar, River Sabhaya, 549 m; Kathmandu District: Kirtipur; Lalitpur District: Godawari (Coe 1964; Kapoor et al. 1979; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Ageratum houstonianum*, *Bidens pilosa* (Asteraceae).

Genus *Meliscaeva* Frey, 1946**29. *Meliscaeva cinctella* (Zetterstedt, 1843) (Fig. 11A-B)**

Scaeva cinctella Zetterstedt, 1843: 742. Type locality: Sweden.

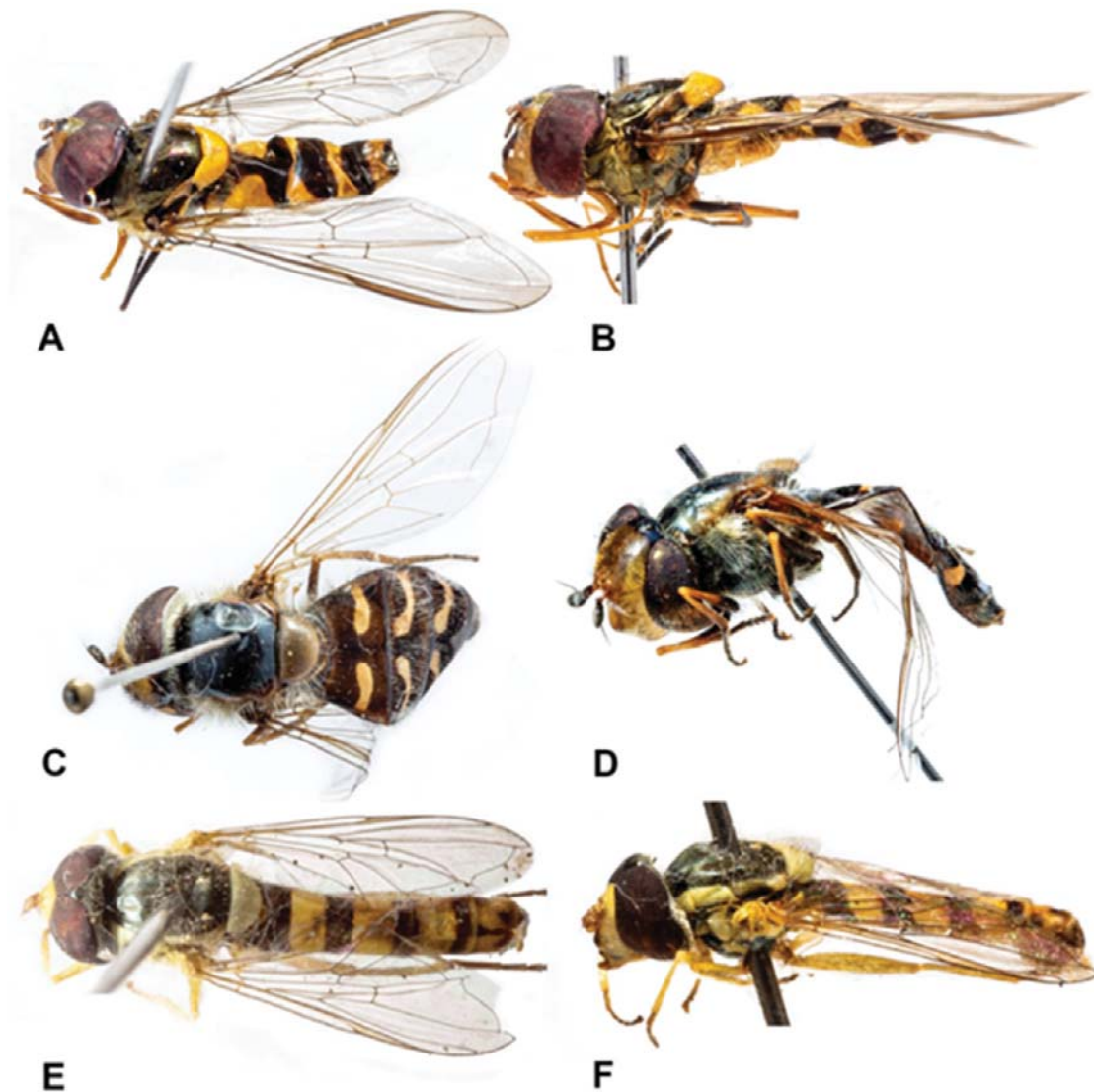


Figure 11A-F. Dorsal and lateral habitus: A–B, *Meliscaeva cinctella*; C–D, *Scaeva pyrastrii*; E–F, *Sphaerophoria bengalensis*.

Material examined. 1♂, Kathmandu, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1400 m; 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1500 m.

Distribution in Nepal. Taplejung District: Sanghu, 1890 m; Solukhumbu District: Dudhkosi valley, 3154 m; Bagamati Province: East of Kathmandu (Coe 1964; Thapa 2015)

Floral association. *Ageratina adenophora*, *Ageratum houstonianum* (Asteraceae).

Genus *Scaeva* Fabricius, 1805

30. *Scaeva pyrastris* (Linnaeus, 1758) (Fig. 12C-D)

Musca pyrastris Linnaeus, 1758: 594. Type locality: Sweden.

Material examined. 1♀, Kathmandu, Sundarijal, 27.77°N, 85.42°E, 03.iv.2018, 1800 m.

Distribution in Nepal. NEPAL (Ghorpadé 1994).

Floral association. *Ageratina adenophora* (Asteraceae).

Genus *Sphaerophoria* Lepeletier & Serville, 1828

31. *Sphaerophoria bengalensis* Macquart, 1842 (Fig. 11E-F)

Sphaerophoria bengalensis Macquart, 1842: 104. Type locality: India (Bengale).

Sphaerophoria flavobdominalis Brunetti, 1915: 214. Type localities: India.

Material examined. 1♂, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2300 m; 1♀, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2100 m; 1♂, Shivapuri, 27.79°N, 85.38°E, 15.iv.2018, 1700 m; 1♀, Shivapuri, 27.60°N, 85.37°E, 20.iv.2018, 2300 m; 1♀, 1♂, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1500 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2000 m; 2♀, 1♂, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2000 m.

Distribution in Nepal. Kathmandu District: Tribhuvan, 1400 m, Chhauni, 1400 m (Lambeck and Kiauta 1973; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora* (Asteraceae).

32. *Sphaerophoria indiana* Bigot, 1884 (Fig. 12A-B)

Sphaerophoria indiana Bigot, 1884. Type locality: India.

Material examined. 1♀, Kathmandu, Manichud, 27.75°N, 85.47°E, 15.iii.2018, 1800 m; 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 20.iii.2018, 2000 m; 1♀, Nagarjun, 27.68°N, 85.29°E, 26.iii.2018, 1400 m; 1♀, 1♂, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2100 m; 1♀, 1♂, Shivapuri, 27.79°N, 85.376°E, 15.iv.2018, 1700 m; 1♀, Shivapuri, 27.60°N, 85.37°E, 20.

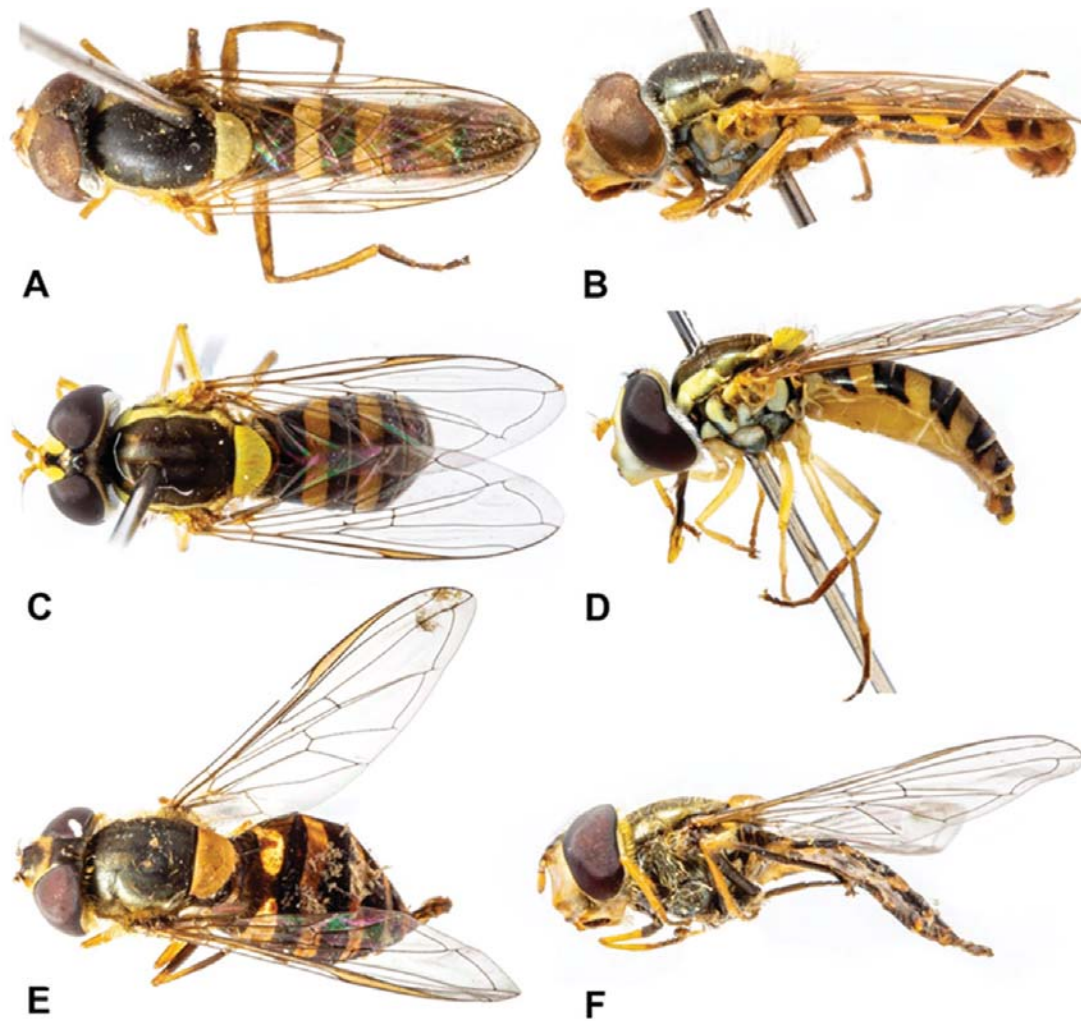


Figure 12A-F. Dorsal and lateral habitus: A–B, *Sphaerophoria indiana*; C–D, *Sphaerophoria scripta*; E–F, *Syrphus torvus*.

iv.2018, 2300 m; 1♀, Sundarijal, 27.76°N, 85.42°E, 02.iv.2018, 1500 m; 1♀, 1♂, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2000 m; 2♀, Nuwakot, Gurjebhanjyang, 27.80°N, 85.32°E, 08.iv.2018, 1600 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2000 m.

Distribution in Nepal. Taplejung District: Sanghu; Sankhuwasbha District: Uwa, 1600 m; Kathmandu District: Kirtipur, Lalitpur District: Godawari Botanical Garden; Dolpa District: Rimi Kaigaon, 2800–3100 m; Humla District: Simikot, 2200 m (Kapoor et al. 1979; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora* (Asteraceae).

33. *Sphaerophoria scripta* (Linnaeus, 1758) (Fig. 12C-D)

Musca scripta Linnaeus, 1758: 594. Type locality: Sweden.

Material examined. 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 20.iii.2018, 2000 m, 1♀, Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2100 m, 1♀, Shivapuri, 27.80°N, 85.39°E, 17.iv.2018, 1900 m; 1♀, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2000 m; 1♀, Nuwakot, Gurjebhanjyang, 27.81°N, 85.31°E, 12.iv.2018, 2000 m.

Distribution in Nepal. Lalitpur District: Godawari, 1400 m; Jumla District: Tatopani, 2200 m (Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Bidens pilosa* (Asteraceae).

Genus *Syrphus* Fabricius, 1775

34. *Syrphus torvus* Osten Sacken, 1875 (Fig. 12E-F)

Syrphus torvus Osten Sacken, 1875: 139. Type locality: Canada.

Material examined. 1♀, Kathmandu, Manichud, 27.77°N, 85.47°E, 22.iii.2018, 2300 m, 1♀; Nagarjun, 27.75°N, 85.27°E, 30.iii.2018, 2100 m; 1♀, Shivapuri, 27.61°N, 85.37°E, 20.iv.2018, 2,300 m; 1♀, Sundarijal, 27.79°N, 85.42°E, 05.iv.2018, 2000 m.

Distribution in Nepal. Taplejung District: Sangu, 1900 m; Solukhumbu District: Tengpoche Gonda, 3850 m; Jumla District: Gothichour, 2900–3100 m, Maharigaon, 3,680 m, Khari La, 3285 m; Mugu District: Rara Lakeside, 2945 m; Bajura District: Kuwadi Khola, 2900 m (Coe 1964; Lambeck and Kiauta 1973; Thapa 2015; Ghorpadé 2015a).

Floral association. *Ageratina adenophora*, *Bidens pilosa* (Asteraceae).

Discussion

The present study of hoverflies from SNNP documents 34 species for the first time from SNNP. Among them, three species, *Graptomyza nigripes* Brunetti, 1913, *Lycastris albipes* Walker, 1857, and *Volucella trifasciata* Wiedemann, 1830 are new country records. Hoverfly fauna of SNNP account for only 20% of all Nepalese Syrphidae (34 out of 169 species) and the surface area of SNNP (159 km²) accounts for 0.096% of total surface area (147,516 km²) of Nepal. Therefore, despite the lower surface area of SNNP, the distribution pattern is interestingly diverse. New findings are possible in SNNP, adding to the list of characteristics that make hoverflies appealing, important, and exciting to study.

The field collection showed an equal number of species in the Eristalinae (17 species) and Syrphinae (17 species), but no species of Microdontinae were collected. This result is concurrent with the study of Ramani et al. 2019 who also reported less Microdontinae. While there are diverse species in Eristalinae and Syrphinae (Kazerani et al. 2013; Reemer 2016). From field-work, two abundantly collected species are *Episyrphus balteatus* (64) and *Episyrphus viridaureus* (61) in Nepal, which are also the most common aphidophagous species in the Oriental region. However, *Episyrphus balteatus* is cosmopolitan in distribution whereas *Episyrphus viridaureus* is only known from China (Fujian, Taiwan), India, Java, Malaysia (Peninsular), New Caledonia, Nepal and Pakistan (Fazlullah et al. 2018; Yang et al. 2020; van Steenis et al. 2021).

Conclusions

Hover flies are subject of curiosity in public and scientific field, environmental services, and economic welfare however there is still much less explored the different aspects of these flies in Nepal. Many facts about their life cycles, reproducing areas, larval stages, behaviour patterns, habitat preferences, and population trend are unavailable.

To provide a clearer view, a more extensive investigation in different areas of SNNP is required. Furthermore, this is the first list presenting the currently available species of SNNP utilising the most recent nomenclature, which may aid other scholars in their research on this fascinating group of dipterans.

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References

- Barkalov AV, Ståhls G. 2022. *Cheilosia* (Diptera, Syrphidae: Rhingiini) of Nepal with descriptions of 29 new species. *European Journal of Taxonomy*. 829:1–27. doi:10.5852/ejt.2022.829.1863.
- Bhatia HL, Shaffi M. 1933. Life histories of some Indian Syrphidae. *Indian Journal of Agricultural Science*. 2:543–570.
- Bigot JM. 1884. Dipteres nouveaux ou peu connus. 24 partie, XXXII: syrphidi (2 partie). *Annales de la Société entomologique de France*. Vol. 6. Espèces nouvelles, number III; p. 73–80.
- Brunetti E. 1907. Notes on the Oriental Syrphidae. *Records of the Zoological Survey of India*. 1:0379–0380. doi:10.26515/rzsi/v1/i4/1907/163412.
- Brunetti E. 1908. Notes on Oriental Syrphidae with Descriptions of new species I. *Records of the Zoological Survey of India*. 2:49–96. doi:10.26515/rzsi/v2/i5/1908/163365.
- Brunetti E. 1913. Zoological results of the Arbor Expedition, 1911–12. XI. Diptera. *Records of the Indian Museum*. 8:149–190.
- Brunetti E. 1915. Notes on Oriental Syrphidae with descriptions of new species. Part II *Records of the Indian Museum*. 11:201–256.
- Brunetti E. 1923. *The Fauna of British India, including Ceylon and Burma*. Vol. 3. London: Taylor & Francis; p.1–424.
- Brunetti E. 1925. Some notes on Indian Syrphidae, Conopidae and Oestridae. *Records of the Indian Museum*. 27:75–79.
- Cannings RA, Kelly–McArthur B, Skevington JH, Higgins RJ, Gibson JF. 2021. *Microdon tristis* (Diptera: Syrphidae): notes on biology with a new ant host record from British Columbia. *Journal of the Entomological Society of British Columbia*. 118:76–81.
- Claussen CJ, Weipert J. 2003. Zur Schwebfliegenfauna Nepals (Insecta: Diptera:Syrphidae) unter besonderer Berücksichtigung Westnepals. *Erfurt: Biodiversität und Naturlausstattung im Himalaya. Verein der Freunde und Förderer des Naturkundemuseums Erfurt ev.* p. 343–380.
- Claussen C, Weipert J. 2004. Notes on the subgenus *Paragus* (*Pandasyopthalmus*) (Diptera, Syrphidae) from Nepal, with the description of a new species. *Volucella*. 7:75–88.
- Coe RL. 1964. Diptera from Nepal. *Bulletin of the British Museum of Natural History, Entomology*. 15:255–290. doi:10.5962/bhl.part.20541.
- Coquillett DW. 1898. Report on a collection of Japanese Diptera, presented to the U.S. National Museum by the Imperial University of Tokyo. *Proceedings of the United States National Museum*. 21:301–340. doi:10.5479/si.00963801.21-1146.301.
- Dawah HA, Abdullah MA, Ahmad SK, Al–Dhafer H, Turner J. 2020. An overview of the Syrphidae (Diptera) of Saudi Arabia. *Zootaxa*. 4855:1–69. doi:10.11646/zootaxa.4855.1.1.
- De Geer C. 1776. *Mémoires pour servir à l'histoire des insectes*. Tome Sixième. Stockholm: P Hesselberg.

- Doyle T, Hawkes WLS, Massy R, Powney GD, Menz MHM, Wotton KR. 2020. Pollination by hoverflies in the Anthropocene. *Proceedings. Biological Sciences.* 287:20200508. doi:10.1098/rspb.2020.0508.
- Enderlein G. 1938. Beiträge zur Kenntnis der Syrphiden. *Sitzungsberichte der Gesellschaft Naturforschender Freunde Berlin.* 1937:192–237.
- Fabricius JC. 1775. *Systema entomologiae, sistens insectorum classes, ordines, genera, species, adiectis synonymis, locis, descriptionibus, observationibus.* Flensburg and Leipzig: Kortii, Flensbvirgi et Lipsiae. p. 832.
- Fabricius JC. 1787. *Mantissa Insectorum sistens species nuper detectas.* Vol. 2. Copenhagen: C.G. Proft, Hafniae. p. 382.
- Fabricius JC. 1794. *Entomologia systematica emendata et aucta. Secundum classes, ordines, genera, species adiectis synonymis, locis, observationibus, descriptionibus.* Copenhagen: Tom. IV. C.G. Proft, Fil. et Soc., Hafniae. p. 472.
- Fabricius JC. 1805. *Systema antliatorum secundum ordines, genera, species adiecta synonymis, locis, observationibus, descriptionibus.* Brunsvigae [= Brunswick]: C. Reichard. p. 30.
- Fazlullah MS, Hassan MA, Mastoi I, Arshad A. 2018. A preliminary list of hover flies (Diptera: Syrphidae) with a new locality records from swat, Khyber Pakhtunkhwa, Northern Pakistan. *Genus.* 15:20.
- Geoffroy EL. 1762. *Histoire abrégée des insectes qui se trouvent aux environs de Paris; dans laquelle ces animaux sont rangés suivant un ordre méthodique.* Tome second. Paris: Durand. p. 690.
- Ghorpadé K. 1994. Diagnostic keys to new and known genera and species of Indian subcontinent Syrphini (Diptera: Syrphidae). *Colemania.* 3:1–15.
- Ghorpadé K. 2015a. A summary, updated account of the Hoverflies (Diptera–Syrphidae) of the Nepal Himalaya. *Colemania.* 49:1–11.
- Ghorpadé K. 2015b. Hover–flies (Diptera—Syrphidae) documented from the Northwest Frontier of the Indian sub–continent: a circumstantial history and inclusive bibliography. *Colemania.* 50:1–151.
- Guérin-Ménéville FE. 1833. Insectes. In: Bélanger C, editor. *Voyage aux Indes–Orientales, par le nord de l’Europe, les provinces de Caucase, la Géorgie, l’Arménie et la Perse, suivi de détails topographiques, statistiques et autres sur le Pégou, les îles de Java, de Maurice et de Bourbon, sur le Cap–de–Bonne Espérance et Saint–Hélène, pendant les années 1825, 1826, 1827, 1828 et 1829, publié sous les auspices de LL. EE. MM. les Ministres de la Marine et de l’Intérieur.* (Zool.). Paris: H. Bertrand; p. 441–512.
- Hassan MA, Bodlah I, Aihetasham A, Bodlah MA, Hussain K. 2019. First record of *Baccha maculata* Walker, 1852 (Diptera: Syrphidae) from the Pothwar Punjab, Pakistan. *Punjab University Journal of Zoology.* 34:133–135. doi:10.17582/journal.pujz/2019.34.2.133.135.
- Hassan MA, Bodlah I, Shehzad A, Fatima N, Fazal S. 2021. First record of the genus *Myolepta* Newman, 1838 (Diptera: Syrphidae) for Pakistan, with description of a new species. *Oriental Insects.* 55:564–573. doi:10.1080/00305316.2020.1848656.
- Hassan MA, Ghorpadé K, Mahmood K, Shehzad A, Nazir N, Fatima N. 2018. Preliminary studies on the Syrphidae (Diptera) of Poonch District, Azad Kashmir, Pakistan. *Oriental Insects.* 52(2):190–209. doi:10.1080/00305316.2017.1394924.
- Hassan MA, Mahmood K, Nazir K, Fatima N. 2017. Faunistic work on the Hover flies (Diptera: Syrphidae) of District Narowal, Pakistan. *Journal of Entomology and Zoology Studies.* 5:626–630.
- Hippa H, Ståhls G. 2005. Morphological characters of adult Syrphidae: descriptions and phylogenetic utility. *Acta Zoologica Fennica.* 215:1–72.

- Kanervo E. 1938. Zur Systematic und Phylogenie der westpalaarktischen Eristalis–Arten (Dipt. Syrphidae) mit einer Revision derjenigen Finnlands. *Annales Universitatis Turkuensis (A)*. 6:1–54.
- Kapoor VC, Malla YK, Rajbhandari Y. 1979. Syrphid flies (Diptera: Syrphidae) from Kathmandu Valley, Nepal with a Check List of Syrphids of Nepal. *Journal of Natural History Museum, Kathmandu*. 3:51–68.
- Kazerani F, Talebi AA, Gilasian E. 2013. An annotated checklist of the subfamily Syrphinae (Diptera: Syrphidae) of Iran. *Entomofauna*. 34:409–448.
- Knutson LV, Thompson FC, Vockeroth JR. 1975. Family Syrphidae. In: Delfinado MD, Hardy DE, editors. *A catalog of the diptera of the oriental region. Vol. II. Suborder Brachycera through division Aschiza, suborder Cyclorrhapha*. Honolulu: University of Hawaii Press; p. 307–374.
- Lambeck HJP, Kiauta B. 1973. On a small collection of syrphid flies (Diptera: Syrphidae) from the Kathmandu Valley and the Khumbu Himal region (Nepal). *Entomologische Berichten, Deel*. 33:72–78.
- Latreille PA. 1804. Tableau méthodique des insectes. In: *Société de Naturalistes et d’Agriculteurs* editor. *Nouvelle dictionnaire d’Histoire naturelle*. Vol. 24. Paris: F. Dufart; p. 129–200.
- Le Peletier ALM, Serville JGA. 1828. [Various articles]. In: Latreille PA, Lepeletier ALM, Serville JGA, Guérin–Méneville FE, editors. *Entomologie, ou histoire naturelle des Crustacés, des Arachnides et des insectes. Encyclopédie Méthodique, Histoire Naturelle. Insectes*. Vol. 10. Paris: Agasse; p. 345–833.
- Linnaeus C. 1758. *Systema Naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis*. Editio decima, reformata. Tomus I. Laurentii Salvii, Holmiae.
- Macquart PJM. 1842. *Dipteres exotiques nouveaux ou peu connus*. Roret (Paris): Tome deuxième. –2e partie.
- Macquart PJM. 1855. *Diptères exotiques nouveaux ou peu connus*. 5.e supplément. Vol. 2. *Mémoires de la Société des Sciences, Agriculture et des Arts, de Lille, Series*. p. 25–156.
- Marín AJC. 1969. Nota sobre las larvas de *Mesograpta polita* (Say) (Syrphidae, Diptera) en espigas de maíz (*Zea mays* L.) en El Limón, Aragua, Venezuela [Note on the larvae of *Mesograpta polita* (Say) (Syrphidae, Diptera) on the staminate flowers of corn (*Zea mays* L.) in El Limón, Aragua, Venezuela]. *Agronomía Tropical*. 19:335–339.
- Matsumura S, Adachi J. 1917. Synopsis of the economic Syrphidae of Japan (pt. III). *The Entomological Magazine, Kyoto*. 3:14–46.
- Mengual X, Bot S, Chkhartishvili T, Reimann A, Thormann J, von der Mark L. 2020. Checklist of hover flies (Diptera, Syrphidae) of the Republic of Georgia. *ZooKeys*. 916:1–123. doi:10.3897/zookeys.916.47824
- Mengual X, Mayer C, Burt TO, Moran KM, Dietz L, Nottebrock G, Pauli T, Young AD, Brasseur MV, Kukowka S, et al. 2022. Systematics and evolution of predatory flower flies (Diptera: Syrphidae) based on exon capture sequencing. *Systematic Entomology*. 1–28. doi:10.1111/syen.12573
- Mengual X, Ståhls G, Rojo S. 2015. Phylogenetic relationships and taxonomic ranking of pipizine flower flies (Diptera: Syrphidae) with implications for the evolution of aphidophagy. *Cladistics*. 31:491–508. doi:10.1111/cla.12105.
- Moran KM, Skevington JH, Kelso S, Mengual X, Jordaens K, Young AD, Ståhls G, Mutin V, Bot S, Van Zuijen M, et al. 2022. A multigene phylogeny of the eristaline flower flies (Diptera: Syrphidae), with emphasis on the subtribe Criorhinina. *Zoological Journal of the Linnean Society*. 194:120–135. doi:10.1093/zoolinnean/zlab006.

- Mullens N, Sonet G, Virgilio M, Goergen G, Janssens SB, De Meyer M, Jordaens K. 2022. Systematics of Afrotropical Eristalinae (Diptera: Syrphidae) using mitochondrial phylogenomics. *Systematic Entomology*. 47:315–328. doi:10.1111/syen.12532.
- Nayar JL. 1968. A contribution to our knowledge of high altitude Syrphidae (Cyclorhapha: Diptera) from NW Himalaya. Part II—Subfamily Eristalinae. *Agra University Journal of Research, Science*. 16:27–31.
- Nielsen TR. 2016. Records and notes on some Oriental *Platycheirus* species and description of the female *P. himalayensis* Brunetti, 1915 (Diptera, Syrphidae). *Norwegian Journal of Entomology*. 63:169–174.
- Nielsen TR, Barkalova AV. 2017. Revision of and key to the Holarctic and Oriental *Platycheirus manicatus* group species (Diptera, Syrphidae). *Norwegian Journal of Entomology*. 64:28–52.
- Osten Sacken CR. 1875. A list of the North American Syrphidae. *Bulletin of the Buffalo Society of Natural Science*. 3:38–71.
- Osten Sacken CR. 1877. Western Diptera: descriptions of new genera and species of Diptera from the region west of the Mississippi and especially from California. *Bulletin of the United States Geological and Geographic Survey of the Territories*. 3:189–354.
- Pape T, Blagoderov V, Mostovski MB. 2011. Order Diptera Linnaeus, 1758. In: Zhang ZQ, editor. *Animal biodiversity: an outline of higher-level classification and survey of taxonomic richness*. Vol. 3148. New Zealand: Zootaxa; p. 222–229.
- Pauli T, Burt TO, Meusemann K, Bayless K, Donath A, Podsiadlowski LARS, Mayer C, Kozlov A, Vasilikopoulos A, Liu S, et al. 2018. New data, same story: phylogenomics does not support Syrphoidea (Diptera: Syrphidae, Pipunculidae). *Systematic Entomology*. 43:447–459. doi:10.1111/syen.12283.
- Ramani S, Mohanraj P, Yeshwanth HM. 2019. *Indian insects: diversity and science*. India: CRC Press.
- Reemer M. 2013. Review and phylogenetic evaluation of associations between Microdontinae (Diptera: Syrphidae) and ants (Hymenoptera: Formicidae). *Psyche*. 1–9. doi:10.1155/2013/538316.
- Reemer M. 2016. Syrphidae (Diptera) of Surinam: eristalinae and synthesis. *Tijdschrift voor Entomologie*. 159:97–142. doi:10.1163/22119434-15902002.
- Reemer M, Rotheray GE. 2009. Pollen feeding larvae in the presumed predatory syrphine genus *Toxomerus* Macquart (Diptera, Syrphidae). *Journal of Natural History*. 43:939–949. doi:10.1080/00222930802610576.
- Riley CV, Howard LO. 1888. The corn-feeding Syrphus-fly (*Mesograpta polita*) (Order Diptera; family Syrphidae). *Insect Life*. 1:5–8.
- Rojo S, Gilbert F, Marcos-García MA, Nieto JM, Mier MP. 2003. A world review of predatory hoverflies (Diptera, Syrphidae: Syrphinae) and their prey.
- Rondani C. 1845. Ordinamento sistematico dei generi italiani degli insetti ditteri. *Nuovi Annali delle Scienze Naturali e Rendiconto delle Sessioni della Società Agraria e dell'Accademia delle Scienze dell'Istituto di Bologna, Series*. 2:443–459.
- Rondani C. 1857. *Dipterologiae Italicae prodromus*. Vol. II. Species Italicae ordinis dipterorum in genera characteribus definita, ordinatim collectae, methodo analitica distinctae, et novis vel minus cognitis descriptis. Parmae [= Parma]: Pars prima. Oestridae: Syrphidae: Conopidae. A. Stocche. p. 264.
- Rotheray GE. 1993. *Colour guide to Hoverfly Larvae (Diptera: Syrphidae) in Britain and Europe*. *Dipterist Digest Number 9*. Sheffield: Derek Whiteley. p. 156.
- Rotheray GE, Gilbert F. 2008. Phylogenetic relationships and the larval head of the lower Cyclorhapha (Diptera). *Zoological Journal of the Linnean Society*. 153:287–323. doi:10.1111/j.1096-3642.2008.00395.x.

- Rotheray GE, Gilbert F. 2011. The natural history of hoverflies. Ceredigion: Forrest Text. p. 333.
- Sankararaman H, Daniel JA, Manickavasagam S, Pennards G. 2020. First record of two interesting genera of hover flies (Diptera: Syrphidae) in South India. *Journal of Insect Biodiversity*. 14:54–63. doi:10.12976/jib/2020.14.2.4.
- Scopoli JA. 1763. *Entomologia carniolica exhibens insecta carnioliae indigena et distribute in ordines, genera, species, varietates. Methodo Linnaeana. Vindobonae [=Vienna]: Trattner.* p. 420. doi:10.5962/bhl.title.119976.
- Sengupta J, Naskar A, Maity A, Hazra S, Sarkar NK, Banerjee D. 2017. Hover flies (Diptera: Syrphidae) from Darjeeling Himalaya—A part of Indo–Burmese hotspot. *Indian Journal of Entomology*. 79:336–353. doi:10.5958/0974-8172.2017.00065.7.
- Shehzad A, Ghorpadé K, Rafi MA, Zia A, Bhatti AR, Ilyas M, Shah SW. 2017. Faunistic study of hover flies (Diptera: Syrphidae) of Pakistan. *Oriental Insects*. 51:197–220. doi:10.1080/00305316.2016.1274275.
- Skevington JH, Locke MM, Young AD, Moran K, Crins WJ, Marshall SA. 2019. *Field guide to the flower flies of northeastern North America*. Princeton (NJ): Princeton University Press. doi:10.2307/j.ctv7xbrvz.
- SNNP. 2017. Shivapuri Nagarjun National Park and buffer zone management plan Fiscal Year 074/075-078/079 (2017/018- 2021/022). Shivapuri Nagarjun National Park office. p. 268.
- Speight MCD, Castella E, Sarthou JP, Vanappelghem C. 2020. Species accounts of European Syrphidae. In: *Syrph the net, the database of European Syrphidae (Diptera)*. Vol. 105. Dublin: Syrph the Net publications; p. 1–46.
- Speight MCD. 2017. Species accounts of European Syrphidae. *Syrph the Net, the Database of European Syrphidae (Diptera)*. 97:294.
- Ssymank A, Jordaens K, De Meyer M, Reemer M, Rotheray GE. 2021. Syrphidae (flower flies or hoverflies). In: Kirk-Spriggs AH, Sinclair BJ, editors. *Manual of Afrotropical Diptera*. Volume 3. Brachycera- Cyclorrhapha, excluding Calyptratae. Pretoria: South African National Biodiversity Institute; p. 1439–1491.
- Thapa VK. 2015. *Insect diversity in Nepal*. Kathmandu (Nepal): VK Thapa Publication. 1097 pp.
- Thompson FC. 1966. A new *Sphegina* from Nepal (Diptera: Syrphidae). *Bulletin of the Brooklyn Entomological Society*. 59:42–45.
- Thompson FC. 1974. The genus *Spheginobaccha* de Meijere (Diptera: Syrphidae). *Transactions of the American Entomological Society*. 100:255–287.
- Thompson FC. 2012. Fabulous flower flies for famous fly fanatics (Diptera: Syrphidae). A tribute to the Dipterists of the Canadian National Collection. *The Canadian Entomologist*. 144:1–16. doi:10.4039/tce.2012.4.
- Thompson FC. 2019. Syrphidae. *Systema Dipterorum*, version 2.4, 13,431 records. Available from: <http://sd.zoobank.org/Nomenclator>.
- Thompson FC, Vockeroth JR. 1989. Family Syrphidae. *Catalog of the Diptera of the Australasian and Oceanian Regions*. Bishop Museum Special Publication. 86:437–458.
- van Steenis J, Hippa H. 2012. Revision and phylogeny of the Oriental hoverfly genus *Korinchia* Edwards (Diptera: Syrphidae). *Tijdschrift voor Entomologie*. 155:209–268. doi:10.1163/22119434-00002014.
- van Steenis J, Hippa H, Mutin VA. 2018. Revision of the oriental species of the genus *Sphegina* Meigen, 1822 (Diptera: Syrphidae). *European Journal of Taxonomy*. 1–198. doi:10.5852/ejt.2018.489.
- van Steenis J, Wu TH, Ssymank AM, van Steenis W, Skevington JH, Young AD, Palmer CJ, van Zuijlen MP, Lechner-Ssymank B, Shiao SF. 2021. Preliminary Results of the 2016.

- International Taiwan Expedition on Syrphidae (Diptera). Formosan Entomologist. 41:78–134. doi:10.6662/TESFE.202105_41(2).004.
- Vockeroth JR. 1971. The identity of some holarctic and Old World species of *Sphaerophoria* (Diptera: Syrphidae). The Canadian Entomologist. 103:1627–1635. doi:10.4039/Ent1031627-11.
- Vockeroth JR, Thompson FC. 1987. Chapter 52. Syrphidae. In: McAlpine JF, Peterson BV, Shewell GE, Teskey HJ, Vockeroth JR, Wood DM, editors. Manual of Nearctic Diptera. Vol. 2. Ottawa: Research Branch, Agriculture Canada, Monograph No. 28; p. 713–743.
- Walker F. 1852. Diptera. Part III. In: Saunders WW, editor. Insecta Saundersiana: or characters of undescribed insects in the collection of William Wilson Saunders, Esq., F.R.S., F.L.S., & c. Vol. 1. London: Van Voorst; p. 157–252, 474.
- Walker F. 1857. Characters of undescribed Diptera in the collection of W. W. Saunders, Esq., F.R.S., & c. Transactions of the Entomological Society, London. 4:119–158.
- Wiedemann CRW. 1818. Neue Insecten vom Vorgebirge der guten Hoffnung. Zoologisches Magazin. 1:40–48.
- Wiedemann CR. 1819. Beschreibung neuer Zweiflügler aus Ostindien und Afrika. Zoologisches Magazin Kiel. 1:1–39.
- Wiedemann CRW. 1820. Munus rectoris in Academia Chrisiano–Albertina iterum aditurus nova dipterorum genera offert iconibusque illustrat. Kiliae: Christiana Friderici Mohr. p. 1–23.
- Wiedemann CRW. 1824. Munus rectoris in Academia Christiana Albertina aditurus analecta entomologica ex Museo Regio Havniensi maximw congesta profert iconibusque illustrat. Kiliae [= Kiel]: Eregio typographeo scholarum. p. 60.
- Wiedemann CRW. 1830. Aussereuropäische zweiflügelige Insekten. Hamm: Zweiter Theil. Schulz.
- Wiegmann BM. 1986. A new species of *Myolepta* (Diptera: Syrphidae) from Nepal, with its phylogenetic placement and a key to oriental species. Journal of the New York Entomological Society. 94:377–382.
- Yang D, Wang MQ, Li WL 2020. Species catalog of China. Vol. 2. Animals, Insecta (VII), Diptera (3), Brachycera Cyclorrhaphous. Beijing: Science Press. p. 1312.
- Young AD, Lemmon AR, Skevington JH, Mengual X, Ståhls G, Reemer M, Jordaens K, Kelso S, Lemmon EM, Hauser M, et al. 2016. Anchored enrichment dataset for true flies (order Diptera) reveals insights into the phylogeny of flower flies (family Syrphidae). BMC Evolutionary Biology. 16:143. doi:10.1186/s12862-016-0714-0.
- Zetterstedt JW. 1843. Diptera Scandinaviae. Disposita et descripta. Vol. 2. Lundae [=Lund]: Officina Lundbergiana. p. 409.

Appendix XV : Photo Plates



A.



B.



C.



D.



E.

A. Measuring transect ; B. Insect identification in Entomolpgy Department of CDZ ; C. Pinning of butterfly ; D. Plant identification by expert ; E. Team of students in survey field.