NATIVE INSECT POLLINATORS VISITING FLOWERS OF SELECTED INVASIVE PLANT SPECIES IN THREE DISTRICTS OF KERALA

Thesis
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DOCTOR OF PHILOSOPHY IN ZOOLOGY

By

SHYAMNA K. BABOO

DEPARTMENT OF ZOOLOGY
UNIVERSITY OF CALICUT
THENHIPALAM 673635
KERALA, INDIA

2020

DEPARTMENT OF ZOOLOGY
UNIVERSITY OF CALICUT
(Re-Accredited by NAAC "A" Grade)

Dr. M. NASSER
Professor

Tel: Office : (0494) 2407419
HOD : (0494) 2407420
Fax : (0494) 2400269
Mob : 9447446375
E-mail : drnasher@gmail.com
Calicut University (P.O.). 673 635 Kerala, India

Date.......................

CERTIFICATE

This is to certify that this thesis entitled "**NATIVE INSECT POLLINATORS VISITING FLOWERS OF SELECTED INVASIVE PLANT SPECIES IN THREE DISTRICTS OF KERALA**" is an authentic work carried out by **Ms. SHYAMNA K. BABOO** in the Department of Zoology, University of Calicut under my supervision and guidance, and no part thereof has been presented earlier for any other degree, diploma or similar titles.

University of Calicut

Dr. M. Nasser
(Supervising Teacher)

DECLARATION

I do hereby declare that this thesis entitled "**NATIVE INSECT POLLINATORS VISITING FLOWERS OF SELECTED INVASIVE PLANT SPECIES IN THREE DISTRICTS OF KERALA**" submitted to the University of Calicut in partial fulfilment for the Doctoral degree in Zoology, is a bonafide research work done by me under the supervision of Dr. M. Nasser, Professor, Department of Zoology, University of Calicut and no part of this thesis presented by me thereof used for the award of any other degree, diploma or similar title.

University of Calicut **Shyamna K. Baboo**

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Plants display a spectacular diversity of reproductive mechanisms. The two important aspects of plant reproductive biology are reproductive phenology and pollination (Rathcke and Lacey, 1985). Plant reproductive biology of tropical species has helped in studying the mechanism of speciation and gene flow in plant communities (Fedorov, 1966; Bawa, 1974; Ibarra-Manriquez and Oyama, 1992). Over the past few years, threats to pollination system from anthropogenic sources have increased such as fragmentation, habitat loss, herbicide and pesticide usage, introduction of invasive species and modern agricultural practices.

During Cenozoic era, flowering plants started to dominate all the world's landscapes. Angiosperms found in almost every habitat, displaying a variety of forms like herbs, trees, epiphytes, bulbs and submerged aquatics. They are considered to be the highest evolved plants on the surface of the earth and are characterized by seeds enclosed within the mature ovary. Angiosperm flowers are diverse in colour, shape and size. Most of the angiosperms have evolved elaborate mechanisms or structures to help in pollination. As they evolved, insects played a major role in their evolutionary diversification. Plants must rely on pollen vectors for pollination. By the end of Cretaceous period, they evolved flowers with specific and complex adaptations for pollination.

Pollination is the process by which pollens from the male part of a flower (anther) are released, transported and deposited onto the stigma. Plant species are either self-pollinated or cross pollinated. Successful pollination occurs only if viable compatible pollen gets deposited on the receptive part of stigma (Dafni, 1992). Transfer of pollen grains occurs with the help of any of the external agents like water, wind, animal, growth contact or gravity. Pollen transfer by means of wind, water is abiotic pollination, whereas biotic pollination involves insects, birds and bats. Without pollination, most plants would not be able to reproduce and life would not be able to persist on Earth for long. Pollen is essential for plant reproduction and also serves as food for pollinating insects and flower visiting insects.

Pollen is transferred to a lesser extent through wind pollination, but helps to supplement pollen spread in some of the animal pollinated species (Aronne and Wilcock, 1994). In wind pollinated flowers, the pollen gets scattered all over the place. Only by a small chance pollen gets deposited on another flower of the same species. To make up for this pollen waste, they produce large amount of pollen. They tend to have dull colored flowers and do not attract animals with flower colour, scent and nectar. Their pollen grains are not sticky, to reduce the chance of pollens sticking to other obstacles. Stigmas are sticky in order to hold onto the pollens carried by the wind. Agricultural grasses and some other species of family Juglandaceae are pollinated by wind.

Most plants that have conspicuous, colored and scented flowers are well adapted for pollination by insects (Free, 1970). When an insect visits a flower, plants provide nectar and pollen. As the insect visitor tries to feed on this reward, its body gets brushed against the anther, and pollen gets attached onto their body. Most of the bird pollinated flowers are colorful, large and contain large amount of nectar at the bottom of the corolla tube. When they try to reach the nectar with long beaks, it brushes against anthers and stigmas. In some bird pollinated trees like fuchsia, before pollination it has a greenish colour, but after pollination colour changes into red (Delph and Lively, 1985).

INSECT- PLANT INTERACTION

Plants makeup the greatest part of biomass on earth. Pollination is a vital stage in the life cycle of all flowering angiosperms and is necessary for the production of fruits and seeds. Most of the insects depend on plants for their food. High degree of food specialization is seen among herbivorous insects. This is one of the most striking features of insect and plant relationships. They can be classified into three categories: monophagous, oligophagous and polyphagous. Insects consume about 10-25% of tropical foliage.

It is commonly interpreted that the co-evolutionary relationships between pollinating insects and plants have resulted in the evolution of angiosperm flower diversity (Dodd et al., 1999). Plant-insect interaction is of importance not only for plant reproduction, but also for crop production and thus involved in human welfare.

INSECT VISITORS

Interaction between plants and insects began over 100 million years ago with the origin of angiosperms. The key components of global biodiversity are pollinators, as they provide vital ecosystem services to both wild plants and crops (Potts *et al.*, 2010). Plant-pollination interactions are highly specialized and tightly co-evolved. During the Early Cretaceous Period, Angiosperms were dominantly pollinated by insects. About 250000 species of angiosperms, depends on animals for pollination especially insects (Buchmann and Nabhan, 2012).

About 90 % of angiosperms bear bisexual flowers. These hermaphroditic flowers could increase the chances of self-fertilization resulting in inbreeding. Plants tend to avoid such self-fertilization. As cross-fertilization is of crucial importance in the evolution of plants, they have developed various mechanisms to prevent self-fertilization. Plants provide food in the form of nectar and pollen to their pollinators, in return gets their pollen transferred and promotes out crossing. Important food sources of insects are pollen and nectar. Pollen contains 15- 60% proteins and other elements, whereas nectar contains 50% sugars

INSECT POLLINATORS

Pollinators not only provide essential services in nature, but are also necessary for a healthy and productive agricultural ecosystems as they play a pivotal role in pollination of many agricultural cropping systems. It is a multi-trophic function, which is driven by the interaction between plants and pollinators (Kremen *et al.*, 2007). There are approximately 2,00,000 different species of animals which acts as pollinators, which includes vertebrates such as, bats, birds, some mammals, and rest are invertebrates such as bees, butterflies, moths, beetles and flies. Approximately 75 % of the crop plants such as fiber, food crops, spices, beverages are pollinated by animals.

Recent decline in the abundance and diversity of native pollinators as well as the decline in honey bees has resulted in a widespread concern about the future of pollination. Pollination by insects permits effective out-crossing by accurately transferring pollen between widely spaced individuals and lower plant population densities. Plants with incompletely pollinated flowers produce inferior fruits with low market value (Ricketts *et al*., 2004; Kasina *et al*., 2009).

Most pollinators belong to insect orders Hymenoptera, Diptera, Lepidoptera and Coleoptera and other vertebrates, in particular some birds and bats (Proctor *et al*., 1996). They feed on the pollen and nectar to obtain nutrition. Few of them feed on petal tissues too. In addition to food, flowers are frequented by these insects to seek larval hosts, shelter and mates. Among these, bees and butterflies are the dominant visitors. Bees are considered as the most important pollinators. About 75 % of crops utilized as food by humans worldwide are pollinated mostly by bees (Klein *et al*., 2007). Flowers provide both nectar and pollen for bees. Bees are particularly important in cross-pollinating flowering plants since they spend more time probing into flowers for feeding nectar and thus collecting pollens. Female worker bees collect the pollen and carry huge amount of pollen from flowers which in turn serve as food for bee larvae. This pollen which is lost for feeding larvae, indirectly benefits pollination as it serves to feed future pollinators.

Apoidea receives nourishment from feeding on both nectar and pollen, and are well equipped for collecting them. Bees are covered with hairs which stick on the pollen, when they move over the anthers of a flower. In most terrestrial ecosystem, they provide an important pollination service. They visit flowers to get nectar and pollen. Bees are relied upon for crop pollination and honey production. Depending on the species, they can be specialist feeders or generalist feeders. Generalist bees gather pollen and nectar from a wide range of flowers. On the other hand, specialist feeds from a single plant or closely related species. Bumble bees are excellent but unmanageable pollinators (Holm, 1966).

These features of honeybees are most useful for plants which need them for the transport of their pollens. Insects other than bees are often considered to play a supplementary role in pollination. They lack sufficient body hairs and necessary behavior patterns, and probably transfer only few pollen from anther to stigma of a flower during their visit. Furthermore, unlike bees which forage consistently for obtaining food for their young, most of the other insects forage to fulfill their immediate needs only.

Among the group of insects, butterflies are considered as one of best taxonomically studied group (Robbins and Opler, 1997). About 1501 sp of butterflies are seen in Indian Subcontinent, mainly because of the diverse terrain, climate and vegetation hosts (Wynter-Blyth, 1957; Kunte, 2000). They are exposed to a wide range of environmental influences, and are highly sensitive to changes in abiotic factors such a slight intensity, humidity and temperature (Erhardt, 1985; Kremen, 1992). Pollination is the basic ecological function of adult Lepidopterans. The diversity of insect visitors like butterfly is generally influenced by plant diversity. Butterflies play a very crucial role in our ecosystem as they act as biodiversity indicators (Kunte, 2000) as well as nature’s gardeners. Lepidopterans are one among the most efficient pollinators of flowers, which in turn help in the production of fruits, seeds and food crops, and hence essential for the survival of all animals. Adult butterflies solely rely on nectar for food. They usually prefer colorful flowers with a landing platform.

Majority of moths are nocturnal and most of the night blooming flowers rely upon them for pollination. Beetles and flies are also two important groups of native pollinators. Beetles also serve as pollen carriers. They feed on flower parts. Bats also pollinate some plants with nocturnal blossoms. The diets of bats vary from species to species, some may be frugivorous, nectivorous or insectivorous.

Several factors affect the insect visitation to a flower, especially the colour of a flower which guides the insects to it from a distance, and scent provides the stimulus to alight. Flowers attract insect visitors by providing ample nectar of the right composition (Faegri and van der Pijl, 1971). Some flowers have nectar-guides which lead them towards the nectarines. Pollinators usually forage between flowers of neighboring plants (Bateman, 1947; Levin and Kerster, 1969). Generalized pollinators tend to visit specialized plant species, whereas generalized plant species tend to have specialized pollinators. It was observed that specialized plant species tend to have generalized pollinators, whereas specialized pollinators tend to visit generalized plant species (Vázquez *et al*., 2009).

ECONOMIC IMPORTANCE OF INSECT POLLINATION

Around 3000 plant species have been used worldwide as food. 90% of world's crops include: maize, wheat, rice, millet, sorghums, rye, cassavas, sweet potato, potatoes, coconuts and bananas (Thurston, 1969). The plants belonging to family Poaceae are basically anemophilous. Coconuts are partially insect pollinated and partially wind pollinated. One third of our diet is dependent directly or indirectly upon plants pollinated by insects (McGregor, 1976; Klein *et al*., 2007). Most crops primarily depend on honeybees for pollination. Some crops such as almond, apples, cherries, vegetables are directly dependent on bee pollination (Levin, 1983). Majority of wild plant pollination are mediated by animals (Ollerton *et al*., 2011).

Gallai *et al*. (2009) reported that in 2005, 46 insect pollinated direct crops contributed about €625 billion which constitute around 39 % of total world production value of crops used by humans. €153 billion was the economic value of insect pollination to world agriculture in 2005. In the United States, the value of insect-pollinated crops was reported to be $ 1.6-5.7 billion in 1986 (Southwick and Southwick, 1992), $ 14.6 billion in 1996-098 (Morse and Calderone, 2000).Vegetables and fruits contribute €50 billion each (Gallai *et al*., 2009). Losey and Vaughan (2006) estimated that during 2001-03 the annual value of native pollinators was over $ 3.07 billion.

Biological Invasion

During the last five centuries, invasion has increased considerably due to the rapid increase in travel and trade across the globe. Plant species have been inadvertently or deliberately been introduced, resulting in altering the structure of communities. Darwin (1859) observed several introduced species and advanced the first general hypothesis about the species which are most likely to become highly invasive. Until the mid-1900s, invasion was not viewed as a major threat to biodiversity till Elton (1958), who brought about further studies in this field.

One of the major consequences of globalization and global trade is that in addition to movement of humans and products, there has been accidental or intentional introduction of exotic species into new habitat. Many of the native pollinator's habitats have been destroyed and fragmented by human activities. Invasive species are one of the most important threats to the native organisms. Invasive animals and plants causes economic or ecological harm to the environment where they are newly introduced. They are capable of altering habitats, reduces biodiversity, compete for resources with the native species which may lead to the extinction of the local species. Native organisms may not have evolved defenses against the invasive species.

Invasive plant species have the ability to thrive and flourish outside its own native range. As a result of human activity, about 13,168 species of plants have become naturalized in different parts of the world (van Kleunen *et al*., 2015). Since, the insects, foraging animals and diseases which normally kept their growth in check in its native range are absent in its new habitat, the invasive species spread aggressively and may gain an ecological edge. In India, there are 1,599 alien plant species which constitute about 8.5% of the total vascular flora of India.

Introducing an exotic species into a new environment may result in various outcomes. Among all the negative impacts caused by invasive species, widespread loss of habitat is the most significant. An alien species introduced into a habitat may not always have a negative consequence. However, when these exotic species begin to have a negative impact on the new habitat, then they are considered as invasive. After it gets established, invasive plants began to compete with native species. Some species alter the environment making it more favorable to them, but less favorable to the natives. With the uncontrolled spread of alien species, rich and diverse plant communities get converted into inhospitable, barren expanses of invasive plants. They may even diminish groundwater resources.

Exotic plant invasion have resulted in loss of billions of dollars as they continue to compete with native vegetation in places that they have invaded. In the United States, invasive species is the second largest cause of species extinction. It brings about 12% reduction in potential yield of crops. They spend around $100 million a year in combating aquatic invasive plants (Congress, 1993).

Experts have estimated that every year invasive species have caused over $1.4 trillion worth of damage to the world economy (Pimentel *et al*., 2001). In Australia, weeds led to the total loss of $ 5 billion per annum in agriculture production (Sinden *et al*., 2004). In India, weeds caused an actual economic loss to rice (USD 4420 million), wheat (USD 3376) and soyabean (USD 1559 million) (Gharde *et al*., 2018).

After habitat destruction, invasion is considered as the second most widespread threat to global biodiversity (Park, 2004; Leadley, 2010). The large-scale disturbance of plant communities and native habitats has further facilitated invasions. Plant invasions may affect pollinator community composition and population dynamics, which in turn could have an indirect impact on the pollinators foraging the native plants (Carvalheiro *et al*., 2008; Moron et *al*., 2009)

Alien invasive plants possessing attractive flowers can affect the interactions between native plants and their pollinators. Thus, they are currently one of the biggest threats for biodiversity. Invasive species are seen to successfully invade natural communities by utilizing biotic interactions (Orians, 1986; Mack *et al*., 2000), and to understand the invasion process, a general knowledge of such new associations among species is fundamental (Parker *et al*., 1999).

They are threatening the conservation of biodiversity through the changes in community structure, local displacement of native species, and the modification of ecosystem function (Vitousek *et al*., 1997; Enserink, 1999). It has long been established that invasive plants can interfere with native plants through direct competition for abiotic resources (Levine *et al*., 2003). Understanding the mechanisms by which they compete with native species is a key factor to managing the problem.

One type of indirect interactions between flowering plants occurs when two plant species compete for a common pollinator, with negative consequences for the reproductive success of one or both species (Real, 1983; Campbell and Motten, 1985). For example pollinators may neglect certain flowering species because neighboring plants offer larger amounts of nectar (Chittka and Schürkens, 2001) or pollinators may transfer large quantities of heterospecific pollen that interfere with fertilization by conspecific pollen (Campbell and Motten, 1985; Feinsinger, 1987). Such situation occurs when invasive plant species invade new communities and indirectly interact with native plants through shared pollinators (Richardson *et al*., 2000; Stout *et al*., 2002; Ghazoul 2002).

In some cases, there are many species of plants, or many flowers of the same species, open at the same time, resulting in a shortage of possible pollinators and competition among the plants for visits (Waser, 1983). This may result in shift in flowering time, thus the competition for pollinators gets reduced (Anderson and Schelfhout, 1980) or in changes in floral structure (Waser, 1983; Medel *et al*., 2003). Native insect pollinators have co-evolved with the plants flowers they visit, such that they can most efficiently exploit the rewards like pollen and nectar resources of the flower upon which they specialize. For pollinators that are physiologically adapted to specialize on particular plants, non-natives may present floral structures that are inaccessible to local pollinating animals, preventing them from reaching the nectar reward that lies within. Due to this, the non- native plant steals there productive opportunity to spread its pollen by attracting pollinators that accidentally transfers the pollen grains while visiting flower after flower, seeking nectar that is physically unprocurable to them.

Invasive plant species may change pollination patterns in many ways, such as through the decline of certain pollinator species, the disappearance of certain plant- pollinator interactions or in exotic pollinators (Morales and Aizen, 2002; Olesen *et al*., 2002; Lopezaraiza- Mikel *et al*., 2007; Bartomeus *et al*., 2008). Alien plant species can also increase the floral display in a community and, by attracting more pollinator species, facilitate pollination of neighboring resident species

(Feldman *et al*., 2004; Ghazoul, 2006).The role of indirect interactions in determining community composition of flowering plants has been seldom explored (Levin and Anderson, 1970; Waser, 1978), and this has been recently addressed experimentally (Chittka and Schürkens, 2001; Lopezaraiza–Mikel *et al*., 2007).

Indirect interactions of invasive plants may become particularly important when they invade native habitats and cause shifts in native pollination systems (Kaiser-Bunbury and Müller, 2009). Many island habitats are severely degraded through the invasion of alien plant species. Negative effects of alien plants include the displacement of nearby native plant species due to strong competition for resources with exotic plants (Smith, 1985; Simberloff, 1995; Daehler, 2003).The studies conducted so far on the presence of an invasive species have reported positive, negative and neutral effects on the pollinator visitation rates and seed output of native species. Although, a large number of invasive plant species have naturalized in India, only few have been studied with their respect to their impact on the native ecosystem. The information is also scarce on the economic impact of invasive plants in India.

- Diversity of insect floral visitors visiting the invasive plants *Lantana camara*, *Sphagneticola trilobata* and *Mimosa diplotricha* at three different altitudes.
- Foraging behaviour of insect floral visitors to the invasive plants
- Impact of Seasonal/Diurnal Factors and Nectar content on frequency and visitation rate of insect floral visitors

Studies on biological invasion dates back as early as Darwin (1859), but its alarming and widespread invasion in the middle of 19th century grabbed the attention of Elton (1958), whose work had a great influence in shaping the current research on biological invasion. It is one of the rapidly developing branches of ecology and in the past few decades, studies carried out by many authors have provided substantial new insights about the general patterns and impact of biological invasions. Many research contributions have been made in the field of plant invasion and are briefly reviewed.

INSECT VISITORS AS POLLINATORS

Aristotle was the first one to put forward the idea of relationship between flower and bees which was authenticated by the works of botanist Camerarius (1899) who noted that plants reproduce sexually and Sprengel (1793) pointed out the role of insects and wind in the cross-pollination of plants. Many scientists followed the footsteps of Camerarius and proved the importance of pollination in vigour maintenance and perpetuation of plants (Darwin, 1862). Only by the end of nineteenth century, Müller (1873) discovered the mechanism of pollination and plant reproduction.

Around one third of the crops depend on insect pollination to produce seeds and fruits. Of this about 35% of crops in the world depend on animals for pollination, with insects playing the major role (Klein *et al*., 2007). Pollinating over 90 crops, honey bees play a vital role in contributing over $14 billion towards pollination services worldwide (Abrol, 2011).

Worldwide, the total economic value contributed by the pollinators in the production of crops amounts to €153 billion (Gallai *et al*., 2009) and in the United States, Morse and Calderone (2000) reported pollination by honeybees which increased the quality and yield of crops from $9.3 billion in 1987 to $14.6 billion in 2000.

Since Cretaceous period, plants and animals have produced remarkable co-evolutionary interaction. Among these is the obligate mutualism of pollination, where in both plants and their pollinators are dependent upon each other for pollination (Smith *et al.*, 2008). In tropical and temperate parts of the world, many crops like orange (*Citrus sinensis*), apple (*Pyrus malus*), cherries (*P. avium*), pears (*P. communis*), blueberries (*Vaccinium* spp.), almonds (*Prunus amygdalus*), squash (*Cucurbita maxima*), pumpkin (*C. pepo*), strawberries (*Fagaria ananassa*), raspberries (*Rubus* spp.), depends entirely or partially on insect pollination (Free 1970, McGregor, 1976). Kwak *et al.* (1991) observed that in black rampion (*Phyteuma nigrum*), the seed set was dependent on insect visitation. Seed set was seen to increase as pollinator intensity increased.

Among the various insect orders, Lepidoptera and Hymenoptera were studied to be more efficient in pollinating crops. Mattu and Nirala (2013) found that the most abundant insect visitor on Apple in Shimla Hills was *Apis cerana* while Sihag (1986) observed that bee pollination increased the seed production of both umbelliferous and cruciferous crops. Bees were also noted as the only insect visitor which carried pollen and hence act as an effective pollinator. Open plot crops were studied to produce greater number of seeds compared to closed plots.

Amoako and Yeboah-Gyan (1991) reported the effective role played by honeybees in the pollination of three solanaceous vegetable crops, Tabasco pepper (*Capsicum frutescens*), Tomato (*Lycopersicon esculentum*) and Eggplant (*Solanum melongena*) resulting in the increase in fruit set production of these crops. Walter and Taylor (2006) studied the effect of honey bee pollination on Pumpkin and found that as the number of bee visits to *Cucurbita* flowers increased, the fruit set and seed number also increased. Nicodemo *et al.* (2009) studied the pollination of *Cucurbita maxima* and found *Apis mellifera* to be an effective pollinator and as the number of visits by *A. mellifera* increased, the fruit set, fruit size, number and weight of the seeds also increased significantly.

Free (1966) observed that runner bean (*Phaseolus multiflorus*), produced higher seeds/pods when visited by honeybees. Oz *et al.* (2008) correlated pollination by honeybees to increased seed yield in rapeseed (*Brassica napus*). Open pollinated plots were seen to produce higher seed yield when compared to caged plots (without honeybees). Sanda et *al*. (2013) found *Apis mellifera adansonii* to highly increase the pollination of upland cotton (*Gossypium hirsutum*). The fruiting rate and number of seeds produced per fruit of unbagged flowers was higher than the bagged ones.

Morandin and Winston (2006) found that in canola fields with moderate or high bee abundance produced maximum yield. Singh (2008) conducted studies on the impact of *Apis cerana* on Buckwheat (*Fagopyrum esculentum*) flowers and found that *A. cerana* visits increased the grain quality and yield. Honeybees were seen to be an effective pollinator as they have the ability to forage on many sunflower heads, resulting in successful pollination resulting in increased seed sets when pollinated with bees (Nderitu *et al*., 2008).

Rader *et al*. (2016) studied the importance of non- bees as a global crop pollinators which showed that 25-50 % of total flower visits were done by non-bees. Even though, they are less effective pollinators than honey bees, they made more visits to crop flower, thus compensating for the deficit in per visit effectiveness and helps in pollination services. The increased visitation by non- bees and other bees enhanced seed set and crop than honey bees. Non bees were also seen at an advantage as they were less negatively affected by land use change.

Among bees, honey bees (*Apis* sp.), stingless bees were studied to be efficient in carrying out pollination services. Siregar *et al*. (2016) observed bees to be the most abundant visitor to oil palm and rubber plantations feeding on pollen and nectar. Stingless bees were seen to be a dominant visitor among bees in oil palm plantations.

Sharma and Abrol (2015) observed dominant visitor to camphor basil (*Ocimum kilimandscharicum*) was *Amegilla zonata* (L.) followed by *Apis dorsata* and *A. cerana*. Hogendoorn *et al*. (2007) studied the foraging behaviour of *Amegilla chlorocyanea* and observed that female *A. chlorocyanea* are active foragers inside commercial greenhouses and proposed it to be used as pollinator of tomatoes.

Fishbein and Venable (1996) found that hymenopterans were the most effective pollinators of butterfly milkweed (*Asclepias tuberose*), even though the mean duration of visit by lepidopterans was higher than hymenopterans.

Non-bee pollinators form yet another important guild of pollinators on a variety of plants. Goulson and Derwent (2004) found that fruit set of *Lantana camara* were positively correlated with abundance of butterflies in the study area. *Phlox divaricata* (woodland phlox) relies completely on insects for pollination with approximately 90% of total visitation made by lepidopterans especially *Hemaris diffinis*, resulting in increased seed set production (Wiggam and Ferguson, 2005).

FACTORS INFLUENCING POLLINATOR VISITATION

FLORAL TRAITS

Most angiosperms provide rewards to attract and keep the pollinators returning to their flowers. Nectar and pollen are the two most rewards provided by the plants to the floral visitors. The floral visitors are lured to the plants by showcasing a wide variety in their shape, size and colour acting as possible visual cues to various pollinator species.

The difference in inflorescence diameter, corolla length and the number of flowers in the inflorescence of *Lantana camara* along with its source of nectar attract some species of butterflies over others and visit it frequently. This increased frequency in pollination by lepidopteran visitors enhances its pollination success. Although, they are capable of self-pollination, insect visitors help in rapid and higher pollination in *Lantana* (Sharma *et al*. 2005). Inflorescence diameter, corolla length and number of flowers in the inflorescence in *Lantana* were seen to influence the visitation of certain butterfly species also (Pandey and Chauhan, 2012).

Long-tongued and short-tongued bees were seen to visit a greater proportion of open flowers, while butterflies were seen to visit only a small portion of open flowers per bout. In response to flower size, both butterflies and hawk moths showed a greater visitation rate to flowers. Corolla size of flower had a significant effect on the handling time of bumble bees and short-tongued bees (Thompson, 2001).

Tiple *et al*. (2006) tried to determine the relationship of using nectar plant as a nutrient source and the effect of characteristics of floral nectar plants on insect visitors. Butterflies visited more tubular flowers than non-tubular flowers. They prefer flowers of herbs and shrubs rather than trees.

Fontaine *et al*. (2006) observed higher number of insect visitors on tubular flowers than on the open flowers. Syrphids were seen to prefer open flowers, whereas bumble bees mainly visited tubular flowers.

Studies were conducted in the communities in the Himalaya- Hengduan Mountains showed that flower size and shape influenced insect visitation considerably. Pollinators preferred unspecialized flowers over specialized ones and flower size was observed to be positively correlated with pollinator diversity (Zhao *et al*., 2016).

In *Asclepias* sp., larger inflorescence were seen to produce more pods than smaller ones as larger inflorescences were more successful in attracting pollinators and had greater insect visitation rate (Willson and Price, 1977).

Tiple *et al*. (2009) showed that there is a positive correlation between the corolla depth of flowers with the minimum proboscis length of butterfly species. But there is no significant correlation with maximum proboscis length. They showed that there is significant association with corolla depth, flower shape, flower colour and its abundance. Nymphalidae and Hesperiidae are seen to be showing preference to tubular flowers, whereas Lycaenids prefer non-tubular flowers. Pieridae with deeper corolla flower, Papilionidae prefer flowers with deep or very deep corollas. Nymphalidae and Hesperiidae were seen to be feeding from dense flowers. Lycaenidae and Pieridae prefer moderate flowers, whereas Papilionidae with sparse flowers.

Mali *et al*. (2014) studied the relationship between butterflies and plants in Gandhinagar area. It was observed that Pierids and Lycaenids with shorter proboscis preferred smaller flowers, whereas Papilionids with longer proboscis prefer tubular flowers.

Scriven *et al*. (2013) observed that the hoverflies visited umbelled flowers such as hogweed (*Heracleum sphondylium*), dropwort water hemlock (*Oenanthe crocata*) and common hawthorn (*Crataegus monogyna*) suited to their mouthparts.

Barrios *et al*. (2016) studied the insect visitors to *Angadenia berteroi* (pineland golden trumpet) having tubular flower which attract insects with long proboscis. Lepidopterans and long-tongued bees were found to be the most common visitors carrying large quantities of pollen on proboscis.

Duara (2014) studied the importance of butterflies as pollinators of *Ixora coccinea* (Jungle geranium). They found Papilionids having elongate proboscis able to probe the tubular corolla to be the most dominant visitor on *I. coccinea*.

Butterflies preference for exotic and native flowers were depended on their proboscis length (Bergerot *et al*., 2010).

Lázaro *et al*. (2013) observed that visitation rate to flowers increased with pollinator abundance for both unspecialized and specialized flowers. Visitation rate was higher in plant species with unspecialized flowers than those with specialized ones. Seed set was also observed to increase with respect to pollinator abundance. However, specialized flowers produced higher seed set than unspecialized flowers. Seed set increased with flower size, whereas it decreased with flowering duration and flower number.

Pollinators behave as generalists when the floral resources are scarce, whereas they specialize on the single most profitable flower type when the resources are abundant (Kunin and Iwasa, 1996).

Grindeland *et al*. (2005) studied the effect of plant density and floral display on the pollinator visitation rate to Foxglove (*Digitalis purpurea*) and found plant visitation rate to be higher in dense patches and increased with floral display size. Whereas, the flower visitation rate to *D. purpurea* decreased with floral display size.

Sanda *et al*. (2013) found that insect visits were highest, when the number of open flowers were more.

Rianti *et al*. (2010) studied the insect pollinators of *Jatropha curcas* (Barbados nut) and found the pollinator abundance was positively correlated with the number of flowers resulting in increased fruit and seed set production. Compared to noon, insect visitor diversity was observed to be highest in the morning and afternoon.

Penet *et al*. (2012) investigated the impact of capitulum structure in the reproductive success in cornflower (*Centaurea cyanus*). They found that when cross-pollinated, larger capitulum performed better than the smaller ones, whereas smaller inflorescence has a better ability to self than larger ones. Capitulum structure showed a strong impact on the seed sets. In autonomously self- pollinated capitula, the seed set decreased as the number of disc florets increased. While after cross-pollination, it increased with the number of disc florets.

Mukherjee *et al*. (2015) observed a positive correlation between overall density of butterflies and flower density. Their studies justified *L. camara* as a resource for butterflies. Siregar *et al*. (2016) also observed that as flower density increased, the insect pollinators were higher in rubber and oil palm plantations compared to jungle rubber.

Duffy and Stout (2008) found that in the presence of high densities of co-flowering species, *Prunella vulgaris* (common selfheal) and *Mentha aquatic* (water mint), individual *Spiranthes romanzoffiana* (Irish Lady's-tresses) compete intraspecifically for pollinator attraction. It was interestingly noted that at lower density *S. romanzoffiana* attracted more pollinators than in higher densities, but despite the high insect visitation during the flowering season produced no mature fruits.

Scriven *et al*. (2013) studied the effect of flower density on the insect diversity. He showed that flower density is more important than habitat type for insect diversity.

Competition among *Lotus corniculatus* (Bird's foot trefoil), and its commonly co-flowering neighbour, *Potentilla reptans* var. *Sericophyll*a (creeping cinquefoil) for pollination was studied. Under high pollinator abundance, visitation rates and fruit set of *L. corniculatus* were enhanced by the increase in flower densities (conspecific or interspecific). But pollinator visitation to focal species decreased with an increase in the interspecific flower densities (Ye *et al*., 2014).

Julliet *et al*. (2007) studied the impact of nectar-producing co-flowering plants on food-deceptive *Traunsteinera globose* (globe orchid) and observed that fruit sets of *T. globose* were positively correlated with co-flowering species density and altitude. Among the coflowering species, *Trifolium pretense* (red clover) density positively correlated with the reproductive success of *T. globose* as *T. pretense* act as a magnet species, attracting pollinators thus benefiting *T. globose*.

Abundance of insect visitors increased with increasing number of flowers per plot (Sieber *et al*., 2011).

Insect visitation to flowers of non-rewarding *Anacamptis morio* (Green-winged orchid) was strongly and positively related to the density of co-flowering rewarding magnet species, *Allium schoenoprasum* (chives). Bees foraging on purple flowers of *A. schoenoprasum* were seen to prefer purple flower of *A. morio* rather than yellow flowers of *Lotus corniculatu*s (Bird’s foot trefoil) (Johnson *et al*., 2003).

Duara and Kalita (2013) studied the pollination of medicinal plants and found that abundance of insects are positively correlated with the number of flowers and coloured flowers were seen to attract more insects towards them than non-coloured ones.

Muthoka and Mananze (2005) extensively studied the various aspects of pollination in *Lantana camara* in Amani Nature Reserve, Tanzania. They observed butterflies with longer proboscis was a favourable feature for the tubular structure of the corolla tube to be the main pollinators. They observed that at the middle phase of the day i.e. 13:00–13:15, pink flower had high nectar volume and low sugar concentration, due to which yellow florets were more preferable for the pollinators.

Widrlechner and Senechal (1992) studied the relationship between nectar production and bee visitation, found a strong positive correlation exists between nectar volume and bee visitation.

Nectar availability in *Cistus creticus* (rock rose) prolonged the time spend by the pollinator on the flower, thus increasing the probability of successful pollination (Manetas and Petropoulou, 2000).

From the nectar feeding pattern of butterflies, Chowdhury *et al*. (2017) observed that Pieridae preferred Rubiaceae and Verbenaceae, Lycaenidae for Asteraceae, Nymphalidae for Asteraceae and Amaranthaceae, Hesperiidae for Rubiaceae and Asteraceae, while Papilionidae preferred Rubiaceae. Thus, planting nectar plants belonging to aforementioned families were found to help in attracting butterflies accordingly.

Apis cerana was seen to be attracted to flowers by their nectar. It visited more number of flowers, and hence an efficient pollinator (Pudasaini and Thapa, 2014).

Heinrich and Raven (1972) pointed out that the relatively large, energy-demanding pollinators visited flowers with copious supplies of pollen and nectar to get energetic profits from their exertions. Pollinators with low expenditure restrict their visits to individual flowers, thus reducing outcrossing.

McCall and Primack (1992) observed that flower colour and shape of corolla influenced the insect visitation rate considerably. It was noted that yellow and mixed-colour flowers received more insect visits than white and pink-red ones. Insects visited open flowers more than tubular flowers. But, Asteraceae capitula were preferred by insects than flowers in other families. Butterflies were more common on tubular flowers than open flowers while flower colour was seen to influence bees which were seen to prefer yellow flowers over white ones. Visits were also reported highest during the middle of the day, at high light and temperature level, moderate wind and low humidity.

Duara and Kalita (2012) showed a positive influence of nectar and flower colour on the insect visitors. Yellow flowers were studied to be most favoured by lepidopterans than bees. They also concluded that nocturnal insects played no significant role in pollination.

Weiss (1991) showed that around 74 different plant families provide visual cues to pollinators by changing the flower colour directing them to rewarding and sexually viable flowers, thus leading to successful pollination of these plants.

Carrión-Tacuri *et al*. (2014) showed that *Lantana camara* used their showy flowers to attract insect pollinators belonging to 3 insect orders *viz.*, Lepidoptera, Hymenoptera and Diptera. They landed on the inflorescence and inserted the proboscis into these florets in search of the nectar and aid in pollination in the process.

Santhosh and Basavarajappa (2016) found a significant difference existed between coloured flowers visited by lepidopterans. They visited yellow, white, pink, blue coloured flowers more often with the yellow ones favoured the most and orange and red flowers the least. Plant families like Compositae and Acanthaeceae were visited more by butterfly species for nectar collection. 49% of nectar was contributed by weeds to lepidopterans than other plants.

Begum *et al*. (2014) studied the nectar feeding behaviour of butterflies of Dhaka University and found that eight species of lepidopterans visited *L. camara*. Maximum number of lepidopterans were attracted to yellow and violet flowers. Their result also showed that the proboscis length of the studied butterflies are largely correlated with the corolla depth of flowers.

Weiss (1995) observed that in *L. camara*, hawk moths visited yellow florets and ignored red flowers at dusk.

Andersson and Dobson (2003) pointed out that in *L.camara, Heliconius melpomene* used flower colour to select which flower to visit, while the floral scents helped in eliciting behavioural floral responses.

Casper and La Pine (1984) observed that in *Cryptantha humilis* (low cryptantha), insects preferred flowers with yellow coronas more often than those with white corollas. They removed spent flowers from *C. humilis*, but found no effect on pollinator visitation by its removal. Duara and Kalita (2013) found that coloured flowers attracts insects more. It was also observed that Lepidopterans like *Eurema hecabe* and *Catopsilia pyranthe* visited yellow flowers of *L. camara*.

Stanton *et al*. (1986) observed that insect pollinators preferred yellow flowers in wild radish (*Raphanus raphanistrum*). The most frequent visitor, *Pieris rapae* showed a strong preference to yellow colour but it was seen that both yellow and white flowered plants produce equivalent quantity of seeds disregard of the difference in visitation rate. *Eristalis* spp. (Syrphidae) and *Pieris* spp. (Pieridae) strongly preferred the yellow- flowered morphs of *R. raphanistrum* (Kay, 1976).

Stanton *et al.* (1986) observed that yellow flowered individuals of *R. raphanistrum* were more successful as pollen donor compared to the less visited white flowers.

Petal colour plays a major role in signalling pollinators towards them. Bees are attracted towards blue or yellow colour and least to red which appears as black to bees. Honey guides in many flowers lead the bees towards the nectar, thus ensuring pollination. Beetles usually pollinate white or dull flowers, whereas dipterans are attracted to dull red or brown coloured flowers (Miller *et al*. 2011).

Free (1970) observed that nectar guide attracted insect visitors to a flower by providing a direction function. Flower having nectar guide in the centre are seen to slightly increase the proportion of insect visits to the centre.

Barrows (1976) studied the pollination and nectar robbing of *L. camara*. They observed that newly opened flowers were yellow in colour and as day passed colour gradually deepens to darker reddish orange. Yellow flower in the inflorescence were seen to contain both nectar and pollen, whereas older reddish orange flower have no nectar and negligible pollen only. Butterflies and bees were seen to prefer yellow flowers over the reddish orange ones. *Trigona fulviventris* were seen to rob nectar from *L. camara*.

According to Schaal and Leverich (1980), in *Lupinus texensis* (Texas bluebonnet) the banner spot colour change resulted in the increase in efficiency of pollination systems. The colour change is a good indicator of flower fertility. Bees were seen to prefer flowers capable of providing viable pollen.

Lepidopterans preferred yellow and pink coloured flowers for foraging followed by white, purple and yellow-white. Yellow flowers were most frequently visited, while red flowers had the lowest visits. Family-wise visitation was also studied and showed that Noctuidae and Nymphalidae never visited red flowers while Sphingidae visited white, pink and purple coloured flowers and Papilionidae occurred only on yellow and pink flowers. Pink and yellow coloured flowers were seen to be the most visited flowers in the study (Yurtsever *et al*., 2010).

Guez *et al*. (2017) studied the colour and shape preference of *Apis cerana* in Australia and found that during every season, *A. ceran*a preferred yellow coloured flowers.

Jothimani *et al*. (2014) recorded the role of butterflies as pollinators and factors influencing their nectar feeding. Most of the butterflies are attracted to the plants belonging to Asteraceae. They observed that initially butterflies are attracted to flowers only by their attractive colours. Nymphalidae was seen as a dominant visitor.

Naive butterfly *Battus philenor* showed a strong preference for yellow colour, while it had a secondary preference to purple and blue. After about 10 visits to flowers, *B. philenor* learned to associate floral colour yellow or magenta of *L. camara* flowers with the presence of nectar rewards. With continued experience they preferred flower with rewarding colour for foraging (Weiss, 1997).

Ram and Mathur (1984) observed colour change in *L.camara* subsequent to anthesis. Thus, pollination triggered the petal colour change, as pollen stimulates anthocyanin production in petals. The intensity of flower colour depended on the time period the corolla remained attached to the flower. Flower of *Lantana camara* were classified into 6 distinct stages.

Maintenance of older flowers in *Lantana camara* inflorescence increases the plants attractiveness to pollinators from a distance. In *L. camara*, butterflies were seen to prefer rewarding yellow colour flowers more than the other flowers. Pre-change flowers stigma were receptive and offered nectar and pollen rewards, whereas post-change flowers contained less or no nectar and pollen and stigma appeared non-receptive (Weiss, 1991).

In *Tibouchina pulchra* and *T.sellowiana* (Melastomataceae), flower changed colour from white (first day) to pink in the following days. Bees preferred first day flowers and seldom visited older flowers (Pereira *et al.*, 2011).

Schemske (1976) found that large butterflies were the predominant visitor to *L.camara*, whereas *L. trifolia* was preferred by small species of butterflies. The floral colour difference may serve as a cue to maintain constancy and increase pollinator efficiency. Old flowers of both *L. camara* and *L. trifolia* were rarely visited. However, these flowers were seen to be retained maybe for maximizing landing platform. Large and small butterflies were seen to prefer *L. camara* over *L. trifolia*, on the basis of their feeding efficiency and reward rate.

Age of florets within an inflorescence was studied as a possible factor in attracting or retaining the visitor to the same flower. Kudo *et al.* (2007) observed that large floral display by the retention of older flowers in single inflorescence enhanced pollinator attraction and the colour change led to the decreased number of flower visits per stay. But, in case of multiple inflorescences, pollinators are not seen to be attracted by the retention of older flowers.

In *Pachyptera hymenaea* (Bignoniaceae), the flowers change from dark lavender to light lavender colour in three days. The older flowers do not contain nectar or pollen, but they are retained in plant to attract insect visitors (Barrows, 1977).

Gori (1989) reported that in *Lupinus argenteus* (silvery lupine), pollinators preferred yellow flowers and avoided purple flowers as yellow flower contained greater rewards than purple coloured flowers. Yellow flowers were seen to contain viable pollens, receptive stigma and style, whereas purple flowers contained less rewards. It was observed that plants having a greater total number of flowers per inflorescence attracted more pollinators. Thus, these finding suggested that colour change in *L. argenteus* discourages pollinators from visiting non-rewarding and unreceptive flowers.

Ida and Kudo (2003) studied the flower colour change in *Weigela middendorffiana* (middendorff weigela), whose inner part of flower changes colour with age from yellow to red. Retention of less rewarding red phase flowers served as a cue to discourage pollinators from staying on the same plant longer and enhanced the pollination efficiency of the whole plant by reducing the number of successive visits to flower by bumblebees during a single stay.

Niesenbaum *et al*. (1999) showed that the flower colour change in *Aster vimineus* (calico aster) served as a cue for pollinators to visit the flowers. In *A. vimineus*, central disks changed colour from yellow to red. All pollinators exclusively visited the rewarding and more reproductively viable yellow disk asters. Larger patches of asters were visited by pollinators more than the smaller patches. Pollinators were attracted towards floral display having mix of yellow and red disk asters compared to those in which red disks were removed. They observed that the retention of older red disks increases the floral display and thus, served in attracting pollinators from a distance, whereas the floral colour change helped to guide the pollinators towards the rewarding and reproductively viable flowers, increasing their foraging efficiency.

Sunny *et al*. (2015) studied the encounter between invasive plants and native insects and found that pollinator visitation of invasive plants and potential reproductive success is determined by its floral traits such as colour, morphological traits of flower and odour.

Environmental Factors

Altitude

Insect diversity, abundance and species richness were higher in Tropical mountain forests during rainy months. At low elevation, insect communities showed a higher species richness compared to that of the higher elevations (Cuartas-Hernández and Gómez-Murillo, 2015).

Arroyo *et al*. (1982) found that with increasing altitude, the butterfly and fly species richness declines, while the species pollinated by them increases. Collins *et al*. (1983) observed that at higher elevations, open-access flowers are proportionally over-represented. Arroyo *et al.* (2007) observed butterflies at higher elevations preferred larger display size flowers over the smaller ones.

Warren *et al*. (1988) reported that at lower elevation, hymenopterans predominated the pollinator fauna, but at subalpine sites, their relative contribution decreased by almost half. However, at higher elevations, dipterans were seen to dominate and their species richness increased dramatically while the relative species richness of Coleopterans and Lepidopteran visitors declined as elevation increased.

Elberling and Olesen (1999) studied the insect flower visitors to all flowering plants in northern Sweden and found that proportion of total lepidopterans and hymenopterans, dipterans do not vary significantly among high latitude systems. Whereas, the proportion of Dipteran species of total pollinator increases with latitude. Lundgren and Olesen (2005) observed that the bee frequency was more in low latitude, whereas dipterans were higher in high latitudes.

The abundance and species richness of insect visitors (Sanchez-Rodriguez and Baz 1995) and insect visitation rate (Zhao and Wang, 2015) was observed to be highest at lower elevations and declined along increasing altitude.

Sreekumar and Balakrishnan (2001) observed maximum butterfly species diversity at low and mid elevations in Aralam Wildlife Sanctuary, Kerala with Nymphalidae being the dominant family.

Effect of altitude on plant-pollinator relationship was explored extensively. Olesen and Jordano (2002) and Zhao *et al*. (2016) observed the decrease in pollinator diversity with altitude, while Kirk and Gilbert (2009) investigated the insect visitation to flowers on the northeast slope of Tafelberg, South Africa and observed that diversity of insect visitors to flowers increased with elevation. Medan *et al*. (2002) studied the relationship between the plant- pollinators at two altitudes in the Andes of Mendoza, Argentina. Lepidopterans were seen to increase significantly at the higher elevation sites, while, hymenopterans and dipterans were seen to be dominant visitors in both altitudes. Species richness, abundance and butterfly diversity was higher in lower elevations compared to higher elevations (Van Lien and Yuan, 2003).

Idris *et al*. (2002) observed that at lower altitudes hymenopterans were higher compared to the higher altitudes. Species richness was seen to increase up to 800 m altitude, and declined as altitude increases. At higher elevation, hymenopteran especially bees shows a decline in visitation pattern. Mid-elevation sites showed a higher forager rate than high elevation sites (Koch and Sahli, 2012).

Thakur and Mattu (2010) studied the role of Lepidopterans as pollinators in Shiwalik Hills and their foraging activities at different elevations. From the study it was noted that Nymphalidae species were the most dominant visitor and it was also seen that plants belonging to Asteraceae attracted different butterfly species. All the nymphalids and papilionids were found to be very common in the low altitude of Shiwalik Hills. Acharya and Vijayan (2011) found that butterfly species were highest below 1800m. Its diversity and abundance peaked at low-elevation (300-900m), declined towards mid and high elevations. Nymphalidae dominated with high species richness. Species richness of butterflies was seen to be highest during monsoon and lowest during summer.

Acharya and Vijayan (2015) observed that along the elevation gradient of Eastern Himalaya, butterfly species richness declined. Families Nymphalidae, Papilionidae and Pieridae were seen all along the elevation gradient, whereas

Lycaenidae, Hesperidae and Riodinidae were restricted below elevations 2800 m, 2400 m and 2500 m respectively.

The cessation of foraging activity of *Apis cerana* and *Apis mellifera* gets delayed at higher altitudes, but altitudinal variations does not affect peak hours of foraging activity and on the time spent per flower. But, the numbers of flowers visited per flower by them are found to be affected by altitude variation (Ahmad *et al*. 2017).

However, Widhiono *et al*. (2017) reported that in Agricultural Area in Central Java, Indonesia, abundance and species richness increased linearly with elevation. Species diversity was seen to be highest at middle elevations.

Gallou *et al*. (2017) observed that butterfly diversity was particularly high in mountain regions. In Isere it was observed that butterfly species richness first increases and then later decreases non-monotonically at high elevations. At intermediate elevation (700- 1,700 m), species richness was seen to be highest.

Temperature and Humidity

Insect abundance and foraging patterns were observed to be affected by relative humidity and temperature (Amoako and Yeboah-Gyan, 1991).

Wang *et al*. (2009) studied the effect of environmental factors on wild bee visitation to flowering plant Alfalfa (*Medicago sativa*). For bees with univarate foraging behaviour, the number of flower they visited increased with increasing temperature and light intensity, but decreased as relative humidity increased. Whereas, for bees with bimodal diurnal foraging behaviour, initially the number of bees increased as the temperature, light intensity and relative humidity increased, but decreased when the environmental factors continued to increase.

Kunte (1997) observed that butterfly species was highest in late monsoon and early winter in Northern Western Ghats. Kunte *et al*. (1999) studied the pattern of butterflies visiting the Western Ghats and found that many butterfly species prefer only particular set of habitats and are strictly seasonal. Nascimento and Nascimento

(2012) found that *Melipona asilvai* foraging activities decreased about 90% from dry to rainy seasons.

Stefanescu *et al*. (2004) reported that butterfly species richness were negatively correlated with temperature, whereas positively correlated with rainfall. They found that with increase in human pressure resulted in a significant decrease in the species number. Temperature and cloud cover were seen to negatively influence the total insect abundance (Nienhuis *et al*., 2009).

Butterflies visitation to *Lantana camara* showed a peak in occurrence during summer (March- May) and post- monsoon (Sep-Nov) and decreased during mid-monsoon and winter (Mukherjee et al., 2015). Butterfly abundance has a negative relationship with humidity and positive relationship with temperature (Jothimani *et al*., 2014).

Muthoka and Mananze (2005) found that relative humidity and the time of the day had a significant effect on the number of lepidopterans that visited it. The butterflies are found to be inactive at lower temperature. Although, the relationship between temperature and insect visitation were seen to be insignificant.

Kumar *et al*. (2012) studied the insect visitors of pumpkin, *Cucurbita maxima* and their foraging activity with temperature and relative humidity. They found that on sunny and cloudy days, foraging activity of insect visitors showed a negative correlation with temperature and positive correlation with relative humidity.

Abou- Shaara *et al*. (2012) found that temperature and relative humidity have high effects on adult honeybees. Elevated temperature and relative humidity had a negative and positive effect on worker survival respectively.

Duara and Kalita (2012) studied the pollinators of *Lantana camara* and found butterflies to be more active between 09:00 to 13:00 hr. The number of insect visitors were significantly affected by time of the day and temperature.

According to Gebremedhn *et al*. (2014) there is a positive correlation of relative humidity and negative association with temperature with the frequency of foraging bees on *Guizotia abyssinica* (Niger). They observed that higher temperature was needed by the honeybees to collect nectar, while they preferred higher relative humidity for pollen collection.

Artusi (2014) showed that butterflies were more active in warm and sunny areas and also were very useful indicators. During their larval stage, butterflies feed on plant foliage, whereas adults feed on nectar. Due to this dependency, any alteration in their ecosystem because of human disturbances or climate change will lead to the decrease in plant population which in turn will lead to the decrease in butterfly population from the ecosystem.

Yilangai *et al*. (2015) studied the effect of environmental factors such as time of the day, weather parameters on the foraging activities of insect visitors of *Carissa edulis* (Arabian Num Num) and *Jasminum dichotomum* (Gold Coast Jasmine) in a protected Nigerian habitat. It was seen that the mean number of insect visits was higher in the morning and lowest in the evening. Temperature was not found to have a significant effect on the number of insect visits.

Sharma and Abrol (2015) found that temperature and sunshine has a positive influence on *Amegilla zonata* foraging, while wind speed and rainfall exerted a negative impact on foraging camphor basil (*Ocimum kilimandscharicum*).

Nikolova *et al*. (2016) reported temperature to have a negative influence on the bee density while relative humidity had a positive influence on it. They also pointed out that time of the day showed a considerable effect on the density of insect visitors.

Chowdhury *et al*. (2017) found that butterfly species richness showed a negative relationship with temperature, humidity and precipitation.

FORAGING ACTIVITIES OF POLLINATOR

PHASE OF THE DAY

Kajobe and Echazarreta (2005) observed the foraging activity and flight of insect pollinators to be influenced by factors like food quality and climatic conditions. High insect visit was observed during middle and early phase of the day which may be related to the availability of food source during the same.

Šušek and Ivančič (2006) found that bees were dominant visitors to Christmas Rose in Bohinjska Bela (Northwestern Slovenia) and their highest activity occurred between 10:00 to 11:00 hours. Dipterans belonging to family Syrphidae were active between 08:00 to 10:00 hours and between 11:00 to 13:00 hours. They observed that insect activity on Christmas Rose depends on several factors, such as time of the day, species characteristics and location.

Omoloye and Akinsola (2006) observed honeybee visitation to be negatively correlated to weather parameters like temperature, light and solar radiation with the foraging activity of honeybee peaking between 09:00 and 13:00 hours. Chandrashekhar and Sattigi (2006) studied the foraging activities of pollinators in radish (*Raphanus raphanistrum*) and observed that peak foraging activity of *Apis florae* to be at 10:00 hours. *Apis dorsata* activity peaked during 12:00 to 14:00 hours, while that of *A. cerana* peaked between 10:00 and 14:00 hours. Yilangai *et al*. (2015) found that hymenopterans were seen to be having higher foraging activities during morning hours and declined at afternoon hours. But in dipterans and hymenopterans activity reaches its peak at the afternoon and reduces in the evening

In Buckwheat (*Fagopyrum esculentum*), foraging activity of *Apis cerana* started in the morning and ceased by late evening. Peak activity was observed between 08:30 to 10:30 hours and 11:30 to 13:30 hours. The visitation time by individual visitor onto the flowers were highest in the morning and decreased as the day progressed (Singh, 2008).

In Sunflower (*Helianthus annuus*), the foraging activity of *Apis* and non-*Apis* bees peaked between 10:00 and 14:00 hours (Nderitu *et al*., 2008). The total number of visitor to *Heliconia angusta* (Christmas Heliconia) increased during 09:00 and 11:00 hours and decreased during the course of day, the lowest between 15:00 to 17:00 hours. Light was found to show a significant impact on frequency of insect visitation, but not on visitor abundance (Stein and Hensen, 2011). Albrecht *et al*. (2012) also reported that solitary bees were seen active in the morning.

Cruden and Hermann- Parker (1979) recorded butterfly pollination of Peacock flower (*Caesalpinia pulcherimma*) observed that butterflies were seen to be active during 08:30 to 9:00 hours and ceased its activity by 15:00-16:00 hours.

Duara and Kalita (2013) studied the insect diversity of medicinally important plants and the highest abundance was reported during 08:00 to 12:00 hours. Benachour and Louadi (2013) observed insect visitors of Japanese Plum (*Prunus salicina*) and honeybees were noted the dominant visitors mainly visiting during morning hours, peaking at 12:00 hours. Other than the dominant hymenopteran community, lepidopterans were seen visiting more in the morning than in afternoons. Dipterans however were found throughout the day.

Hernández-Baz *et al*. (2014) observed that the peak of insect foraging the flowers of *Simsia amplexicaulis* (Asteraceae) occurred between 12:00-13:00 hours. Shilpa *et al*. (2014) studied the pollinator activity on fennel (*Foeniculum vulgare*) and African marigold (*Tagetus minuta*) and recorded that peak foraging activity of *Apis cerana* and *A. florae* occurred at 11:00 hours.

Binoy *et al*. (2014) observed butterflies as the dominant visitors to *Pentas lanceolata* (Star Cluster) and *Catharanthus roseus* (Madagascar Periwinkle) with a peak in activity during 08:30and 12:30hours. *Amegilla* sp. was seen to be active only during morning hours. In case of lepidopteran visitors, Nymphalidae and Papilionids were seen to be the main pollinators of *C. roseus* with *Junonia atlites* active up to 9:00hoursand after 17:00 hours.

Gebremedhn *et al*. (2014) conducted studies on foraging behaviour of honeybees on Niger (*Guizotia abyssinica*) *a*nd found that honey bee activity was higher during early morning hours. They also recorded that the highest number of honeybee visitation was recorded during 10:30 – 11:30 hours and least occurred during 16:30 – 17:30 hours.

Foraging activity of *Apis cerana* was higher between 12:00 to 14:00 hours, and declined considerably between 17:00 and 18:00 hours (Pudasaini and Thapa, 2014).

Sharma and Abrol (2015) showed that the highest insect foraging activity occurred between 12:00 and 13:00 hours.

Siregar *et al*. (2016) found that foraging activities of insect pollinator were highest during morning hours which may be related to availability of nectar and pollen. They observed that butterflies foraging activity was higher in the afternoon, while hoverflies, solitary bees and social bees were seen to be active more during morning and afternoon hours. They reported higher incidence of insect pollinators in rubber and oil palm plantation than in jungle- rubber might be due to higher floral density.

Surekha and Mayuri (2016) studied the foraging behaviour of *Apis florae* on Coral Vine (*Antigonon leptopus*) and recorded that the highest foraging rate was during 12:30- 13:00 hours. They inferred this trait to be because of suitable climatic conditions and maximum blooming of *A. leptopus* in the noon.

In the apple orchards at Srinagar and Shopian, foraging activity of *Apis cerana* showed an increase as the day passed and decreased in late phase. Peak activity was seen between 11:00–13:00 hours. Among *Apis* species, *A. cerana* visited more number of flowers and spend less time on them compared to *A. mellifera* (Ahmad *et al*. 2017).

In Chitwan (Nepal), *Apis cerana* was seen to be more active in the morning and their foraging activities on the flowers of Buckwheat (*Fagopyrum esculentum*) ceased late in the evening (Aryal *et al*. 2016). Bhagawathi *et al*. (2016) noted *A. cerana* to be the most dominant forager of *Sesamum indicum* (Sesame) L., followed by *A. dorsata*. Peak foraging activity of *A. cerana* was observed during 09:00–10:00 hours.

FORAGING BEHAVIOUR

Free (1964) studied the foraging behaviour of honeybees on *Helianthus annuus* (Sunflower) and observed that while collecting nectars, honeybees were heavily dusted with pollen. Pollen was seen to be collected this way the maximum during early mornings and late afternoons. Nectar gatherer bees with pollen loads were seen to visit more florets per head of sunflower, than nectar gatherers without pollen. Flowers in the female stage were visited by few visitors, but still most of the nectar gatherers were seen to stand on it. However, no correlation could be established between the duration of visit to florets and weather conditions.

Pollen gatherers foraging red clover (*Trifolium pratense*) tended to visit more florets per head and were more efficient pollinators compared to the nectar gatherers (Free, 1965).

Free (1964) observed that while foraging in sunflower (*Helianthus annuus*), honeybees were seen to push its proboscis into the florets for feeding nectar. The head down between anther tubes and corolla, in this process body gets heavily dusted with pollen. Some pack the pollen collected into their corbiculae, but some others discard it while hovering off the flowers.

Papilionids were seen to grasp the flower of Peacock flower (*Caesalpinia pulcherimma*) with their legs and are seen fluttering their wings while they fed on nectar by inserting proboscis into the corolla tube. They were seen to spend less time foraging on flowers, but visits more flowers per unit time. Pierids upon landing on flowers are seen to close their wings and position themselves to insert proboscis into the tube. Nymphalids were seen to flutter their wings while landing only, staying idle following landing on the flower. Only few butterflies forage older flowers of *C. pulcherimma* and those foraging were seen to carry large amount of pollen on their wings (Cruden and Hermann- Parker, 1979).

Brantjes and Bos (1980) recorded the foraging behaviour of hawkmoths and observed that they initially approached the flowers from the front, with its back directed towards the unilateral light source. While foraging, they unroll and extend their proboscis at about 10 to 20 cm from the flower. Close to the flower, they are seen to make a dancing flight with first rising and approaching the flower and thereafter, are seen flying backward and downwards from the flower. Soon after the proboscis gets inserted into the tube or spur, the hawkmoth move towards the flower for feeding nectar. After nectar consumption, they fly backward about 1 to 5 cm from the flower. This movement pattern was repeated several times.

Roubik (1981) compared the foraging behaviour of *Trigona corvina* and *Apis mellifera* on *Baltimora recta* (Beautyhead). *A. mellifera* species were seen to forage more rapidly than *T. corvina*. It was observed that the honeybees landed near the centre of the flower and immediately inserted their proboscis into the disc florets, whereas *T. corvina* frequently landed on ray florets.

Du Toit and Holm (1992) observed honeybees to be the most dominant visitor to sunflower, *Helianthus annuus* L. Megachilidae and Anthophoridae visited florets for both pollen and nectar throughout the day, moving over the florets in a random and rapid manner, making contact with a number of flowers. Halictidae foraged for pollen only and moved systematically in a row, climbing over stigma to reach the next floret. Most dipteran visitors were seen to visit florets to collect dew, and seen to stay still on the capitulum for a long time. While probing for nectar, adult Lepidopterans legs only were seen to come in contact with the florets.

Bosch *et al*. (1997) observed the foraging behaviour of pollinators visiting the tribe *Delphineae* (Ranunculaceae) and found lepidopterans generally visited only few number of flowers per inflorescence, but spent more time on flowers per visit. Diurnal hawkmoth, *Macroglossum stellatarum* was observed to visit more flowers than other lepidopterans and compared to the bumblebees their visits were more randomly dispersed.

Raju and Rao (2001) studied the foraging plants of *Apis cerana indica* in Visakhapatnam and observed that during foraging, they utilize both nectar and pollen, collects rewards sternotribically and carries pollen on abdomen and pollen baskets on the hind leg while handling the flower in upright position. The study suggested *Apis cerana* as a potential pollinator, self-pollinating and cross pollinating plant species on which they forage.

Thompson (2001) studied the visitation pattern of pollinators in Common Jasmine (*Jasminum fruticans*). Except for the visiting hawk moths, the mean number of visits of insect visitors was found to be positively related to the number of open flowers. Hawk moths were seen to visit flowers at a faster rate, whereas butterflies had a lower rate of visitation.

Paiva *et al*. (2002) observed the behaviour of *Apis mellifera* L. on sunflower (*Helianthus annuus*) and studied that honeybees were seen to collect more nectar than pollen during the daytime. Of the hymenopterans, halictid bees were found to be the most frequent pollen gatherers. In sunflower it was duly noted that nectar foragers showed more effect on crop pollination than pollen/nectar foragers and pollen foragers.

Raju *et al.* (2004) studied the foraging pattern of hawkmoth *Macroglossum gyrans*on. While foraging for nectar, hawkmoth hovered at the flowers, stretched out the long proboscis and inserted it into the non-tubular or tubular corollas. In quick succession, within a short time period of 2-3 seconds per insertion, it visited a number of flowers. While feeding the nectar, the hawkmoths transferred pollen to the stigma of the flower, thus acting as a pollinator.

Kunte (2007) studied the insect visitors to *Lantana* and *Wedelia* and found that butterflies with longer proboscis had up to three times long handling time than those with shorter proboscis.

Depending on the state of stigma lobes and anthers of *Mammillaria gaumeri* (Little Nipple Cactus), the foraging behaviour of insect visitors varied. Pollinators spent more time on flowers with opened stigma lobes and anthers with full pollen. This difference highlights the bees recognition of flower status and the reward it would derive (Giovanetti *et al*., 2007).

Valtueña *et al*. (2013) observed that pollinators visiting inflorescence of *Scrophularia* species were seen to follow a pattern of ascending visits followed by horizontal movements. Sexual phases of inflorescence are not arranged in a definite pattern, hence geitonogamy is not avoided.

Kwapong *et al*. (2013) observed bees to be the most dominant visitor to cowpea (*Vigna unguiculata*) flowers. Foraging behaviour of bees was also noted to coincided with the opening and closing of these flowers.

Potential pollinators of critically endangered *Leucas sivadasaniana* were identified as *Macroglossum lepidum*, *Apis cerana*, *Xylocopa pubescens* and *X. latipes*. During nectar collection, *M. lepidum* was seen to insert its proboscis deep into the corolla tube while hovering above the florets, dusting pollen onto its proboscis. The corolla length of the flower tube and length of the proboscis were thus seen to be closely related. Nototribic pollination was seen in the case of *A. cerana* (E. R. and Sunojkumar, 2014).

Ali *et al*. (2014) studied pollination in Summer squash (*Cucurbita pepo*), and found *Nomia* sp., *Apis dorsata* and *Halictus* sp. to be among the most efficient and abundant pollinators. *A. dorsata* preferred and spent more time on pistillate flowers over the staminate flowers compared to other insect visitors, as they forage on flower for nectar rather than for pollen. *Nomia* sp. visited more number of flowers than *A. dorsata*, and collected more pollen than others. Visits to *C. pepo* by *Nomia* sp. was however seen to produce the highest seed set.

IMPACT OF INVASIVE PLANTS

Most of the biological invasion studies have been carried out in developed countries, whereas in continents of Africa (except South Africa) and Asia, research has been least carried out (Pysˇek *et al*., 2008; McNeely *et al*., 2009). India is still in a ‘lag phase’ in biological invasion research (Khuroo et al., 2011) and a recent study has reported around 1,599 alien plant species in India (Khuroo *et al*., 2011).

It is estimated that worldwide the total economic damage by invasive alien species is more than $1.4 trillion per annum (Pimentel *et al*., 2001). In India, weeds have resulted in a reduction of 30% potential crop yields worth about US$ 90 billion per year. Damage caused by *Lantana camara* is estimated around US$ 924 million per year and the cost to control its invasion is US$ 70 per hectare (Singh, 1996). Weeds cause a reduction in total yield of crops in the U.S. and Brazil worth about US$ 33 billion and US$ 17 billion per year respectively (Pimentel *et al.*, 2001).

Weed dandelion (*Taraxacum officinale*) poses a serious threat to fruit trees in orchards, as a great portion of bees were observed to collect nectar only from dandelion. Even though dandelion flower closes in early afternoon, still many bees are seen to prefer the weed only. Hence, it competes with the native plants for wild bees thereby stalling pollination of native species. It was observed that elimination of dandelion from orchards led to an increase in the pollination efficiency of honeybee colonies (Free, 1968).

The host plant of alkali bee, *Nomia melanderi* are primarily cultivated plants and weeds alike, which may draw the pollinator away from the native plants to more rewarding weeds (Bohart, 1972).

Brown *et al.* (2002) showed that the presence of invasive plant purple loosestrife (*Lythrum salicaria*), pollinator visitation rate to winged loosestrife (*L. alatum*) got reduced substantially, decreasing the seed set formation of native *L. alatum*.

Although alien plants are well integrated with native web of flower visitors, fewer animal species visited flowers of alien plants compared to those of native plants. Most of the visitors are generalists. The number of visits by visitors to invasive plant species was positively related to the degree of taxonomic affinity of visitors to the native flora. Visitors were seen to prefer invasive plants belonging to plant families that contributed a large portion of the native flora. As their floral phenotype resembled that of natives, visitors visiting the natives also included the alien plant (Memmott and Waser, 2002).

Butterfly fauna were shown to prefer exotic host plants as their nectar source, if the area contained large number of invasive plants or if these plants belong to the family and genera of plants they prefer and they were not specialized. Negative impacts of these exotic plants were also observed, as few of the Californian butterflies were seen to lay eggs on the introduced plants which are toxic to the larva. Desert and alpine butterflies were seen to interact with introduced plants which were tend to be seen more along transportation corridors and in disturbed areas (Graves and Shapiro, 2003).

A converse to this data was also reported by Jambhekar and Isvaran (2016) who studied the impact of *Lantana camara* on butterflies and found that compared to native-vegetation habitat, fewer butterfly species were seen in *Lantana*-dominated habitat. Though *L. camara* provides nectar for adult butterflies, but may not be larval host plants.

Grombone-Guaratini *et al.* (2004) observed that weed species, *Bidens* L. (Asteraceae) attracted hymenopterans and lepidopterans serving as a major food source to them. It may in turn be beneficial to agricultural crops if planted along plantations attracting more pollinators to the field.

Carvalheiro *et al.* (2011) found that if rudral plants are allowed to co-exist with pollinator-dependent crops, flower visitors are able to persist in cultivation areas in isolated areas, thus benefiting crop production. Within sunflower fields, the pollinators were seen to persist due to the presence of weeds.

Williams *et al.* (2011) recorded more bee visits to alien plants compared to native plants in agricultural habitats. Floral abundance of alien plants were seen to be significantly higher than the native plants in both suburban and farm sites.

Nicholls and Altieri (2013) found that within a crop field certain weed species provide floral resources and refuge, which in turn aid in the survival of population of pollinators. Weed diversity was seen to increase insect flower visitor diversity but should be maintained at tolerable level within the crop fields, as to avoid weed competition with crops.

Blaauw and Issacs (2014) found that by planting wildflowers in marginal lands helped in providing season-long floral resources to insect visitors and hence enhanced the pollination in nearby blueberry crop fields. It also increased the abundance of hoverflies to the adjacent blueberry fields.

Larson *et al*. (2006) observed that in the absence of alien species leafy spurge (*Euphorbia esula*), visitation rates of pollinators to native prairie flax (*Linum lewisii* sp. *lewisii*) and bluebell bellflower (*Campanula rotundifolia*) was higher than in invaded sites, whereas native purple locoweed (*Oxytropis lambertii*) was unaffected by the presence of *E. esula*.

Totland *et al*. (2006) found that introduced lacy phacelia (*Phacelia tanacetifolia*) had a strong negative effect on the visitation rate by bumblebees to the native *Melampyrum pratense* (common cow-wheat), although the number of bees increased in the presence of alien species. The seed production of native plant is unaffected, despite the reduced visitation of bees.

Lopezaraiza-Mikel *et al*. (2007) investigated the impact of alien species ornamental jewelweed (*Impatiens glandulifera*) on the co-flowering native plants. A higher species richness and abundance of insect visitors were observed in invaded plots while the removal of *I. glandulifera* negatively affected the species richness on native plants. At invaded sites, insect visitors were seen to carry more *I. glandulifera* pollen with hymenopterans carrying more pollen from them than any other insect order. Nienhuis *et al*. (2009) studied the impact of alien species *Impatiens glandulifera* on native insects. Sites with *I. glandulifera* attracted more insect visitors than non-invaded sites. Native inflorescence were seen to attract more syrphids and *Bombus* spp. in invaded sites compared to non-invaded sites. Except syrphids, more insect visitors were observed visiting alien plant than native plants in *I. glandulifera* sites. Higher portion of bees were attracted towards the invasive plant and preferred it over the native plants. Although, the localized removal of *I. glandulifera* flowers does not affect insect abundance.

Thijs *et al*. (2012) studied the influence of invasive *Impatiens glandulifera* on the reproductive output of naturalized *Oenothera biennis* (common evening primrose) and indigenous *Alisma plantago-aquatica* (common water-plantain) and *Lythrum salicaria* (purple loosestrife). Presence of invasive plant had a strong negative effect on *L. salicaria* by sharing its pollinator and thus resulting in the reduction of pollen deposition and lower seed production. Whereas, in *O. biennis* and *A. plantago-aquatica*, their pollination and reproductive success was not affected by invasive plants.

Chittka and Schürkens (2001) studied the impact of invasive plant *Impatiens glandulifera* on native plants in course of pollination. The fitness of native plants are negatively affected in the presence of *I. glandulifera*, as they were seen to attract more pollinators reducing the visits to *Stachys palustris* (marsh hedgenettle) by almost 50%. This in turn resulted in the significant decrease in the seed set formation in *S. palustris* placed in *I. glandulifera* patches compared to that of pure patches.

Bartomeus *et al*. (2008) studied the effect of showy flowers of two invasive plants *Opuntia stricta* (common prickly pear) and *Carpobrotus affine acinaciformis* (Hottentot fig) in Mediterranean plant- pollinator networks. *O. stricta* was seen competing with native plants for pollinators, whereas *C. affine acinaciformis* facilitated visits of insect pollinators towards the native plants in invaded sites.

Removal of two alien species, *Carpobrotus* spp. and *Cakile maritime* (sea rocket), resulted in the increase in total visitation rate to the native plant *Dithyrea maritime* (beach spectacle pod), but their fruit production was unaffected (Aigner, 2004). Thus, inferring that the presence of the alien species removed the naturally occurring pollinators away from its natural course of pollination into the weeds.

Moragues and Traveset (2005) found that invasive *Carpobrotus* spp. showed competitive effect only on one native species, *Lotus cytisoides* (Bird’s foot trefoil). Whereas, it showed a facilitative effects on *Cistus salviifolius* (white rock rose) and *Anthyllis cytisoides* (albaida) and had neutral effect on *C. monspeliensis* (Montpelier cistus).

According to Muñoz and Cavieres (2008), low density of invasive plant common dandelion (*Taraxacum officinale*) had a neutral effect on the native plant *Perezia carthamoides*, whereas in another native *Hypochaeris thrincioides* (catsear), the pollinator visitation rate and seed output increased. In contrast, the presence of higher densities of *T. officinalae* had negative effect on the duration of pollinator visits and seed output of the two native plants studied.

Tepedino *et al*. (2008) studied the native bee visitors to the flowers of three species of invasive plants *Tamarix* spp. (saltcedar), *Melilotus albu*s and *M. officinalis* (white and yellow sweet clover) and compared the native bees visiting them with seven concurrently blooming native plants. They observed that on average, invasive plants were visited by twice as many bees as were the native plants. Except one, invasive plants were visited by generalist bees than specialist.

The invasion of goldenrods (*Solidago gigantea* and *S. canadensis*) caused a significant decline in the plant diversity and average cover. Wild pollinator diversity and abundance were negatively affected by the invasion of goldenrods (Moron´*et al*., 2009). The invasion of *Solidago canadensis* (Canada goldenrod) reduced the native plant species richness. A negative correlation was seen between the cover of *S. canadensis* and flower visitation of native plants by honeybees, solitary bees and hoverflies (Fenesi *et al*., 2015).

In the presence of exotic plant musk thistle (*Carduus nutans*) at 1 and 5 m, the visitation rate of flower visitors to native plant *Monarda fistulosa* (wild bergamot) decreased. However, floral visitation rate to *M. fistulosa* did not decrease when adjacent to *C. nutans* or when present 15 m from the exotic plant. The seed set of *M. fistulosa* also tended to be lower in invaded sites (Cariveau and Norton, 2009).

When two invasive plants, *Carduus nutans* and *C. acanthoides* (Plumeless Thistle) co-occurred, they suffered a negative effect on the quantity of pollinator services each received, thus reducing the proportion of seed set produced by the congeneric invasive plant species (Yang *et al*. 2011).

Dietzsch *et al*. (2011) observed that both invasive Common rhododendron (*Rhododendron ponticum*) and native foxglove (*Digitalis purpurea*) overlapped considerably in their insect visitors. More invaded sites showed a decrease in insect visitation rate to *D. purpurea* and an increase in alien abundance resulted in a significant decrease in conspecific deposition of pollen in native flowers. However, the presence of *R. ponticum* does not alter the reproductive success of *D. purpurea*.

A converse of the normal trend was observed. The presence of invasive species favoured the pollination of many native species. Chrobock *et al*. (2013) observed that pollinator visits to native plants to be higher than to invasive plants. A low density of invasive amur honeysuckle (*Lonicera maackii*), increased the pollinator visitation rate to native *Geranium maculatum*. Whereas, at higher density of *L. maackii* resulted in the shorter duration of visits to *G. maculatum* (Iler and Goodell, 2014).

Albrecht *et al.* (2014) observed that invasion by Sourgrass (*Oxalis pes-caprae*), resulted in the pronounced local increase in the floral resources. Bumblebees and honeybees were seen frequently visiting *Diplotaxis erucoides* (White wall-rocket) flowers in sites invaded with *Oxalis* than uninvaded sites. Seed set of native plant *Diplotaxis* was lower in uninvaded sites, compared to sites invaded by invasive plant, *O. pes-caprae*.

Molano- Flores (2014) observed that the pollen deposition and reproductive success of native *Tradescantia ohiensis* (Ohio spiderwort) was significantly reduced in the interior of the invasive *Securigera varia* patch compared to the edges.

Sharma and Raghubanshi (2007) investigated the invasion of *Lantana camara* in the Vindhyan dry tropical deciduous forest of India and found that microenvironments such as pH, temperature and light are altered underneath the lantana shrubs and the invasion also led to the decline of native tree species. Raghubanshi and Tripathi (2009) observed that in Vindhyan dry deciduous forest, sites with high *Lantana* cover reduced the understorey vegetation. However, *Lantana camara* abundance was seen to decrease with increased tree density (Prasad, 2012).

Invasive plants, Silver wattle (*Acacia dealbata*) and Golden wattle (*A. pycnantha*) does not compete for pollinators with each other in invaded sites, as there is a temporal distance between the two flowering peaks. But they compete with native plants, attracting *Apis mellifera* to showy flower heads which provides more resources to foraging bees. (Giuliani *et al*., 2016).

Low density of native plant *Phacelia parryi* (Parry's Phacelia) present near or within a patch of invasive *Brassica nigra* (Black mustard) showed higher pollinator visitation and greater seed production. Whereas, in *B. nigra* surrounded with higher density of invasive plants, they receive larger deposition of heterospecific pollens, thus reducing reproductive fitness (Bruckman and Campbell, 2016).

Because of the high species richness and continuous flowering phenology, weeds contribute directly to the pollen need of honeybees and play a pivotal role in their annual diet (Requier *et al*., 2015). Mukherjee *et al*. (2015) studied the importance of *L. camara* for increasing butterfly diversity. In both urban and rural sites, a positive correlation of butterfly species with number of flowering time of *L. camara* was recorded. They observed that even though, *L. camara* is an invasive plant, it can be a positive host plant and facilitate in the maintenance of butterfly diversity.

Arjun *et al*. (2017) observed that nectar offering flowers of invasive plants attract more butterflies. A total of 128 species of butterflies were seen to visit 36 species of invasive plants. Nymphalidae was the most abundant visitor to invasive plants, whereas members of Papilionidae were the least abundant.

Initially biological invasion had attracted the attention of only ecologists, but recently these studies have been drawing on the practical and theoretical insights from several disciplines such as molecular biology, biogeography, taxonomy, global change biology, commerce, economics, remote sensing and GIS (Khuroo *et al*., 2011).

Study Area

Western Ghats also known as *Sahyadari hills*, formed by chain of mountains and the Malabar Plain, run parallel to the Western Coast of India. They transverse an area of around 140,000 km^2 through the states of Kerala, Tamil Nadu, Karnataka, Goa, Maharashtra and Gujarat and intercept the Southwestern monsoon winds thus mediating the rainfall in regime of Peninsular India (Raju *et al*., 2010). Along with Sri Lanka, Western Ghats is recognized as one of the eight ‘hottest hotspots’, with 2182 endemic plant species. There are about 4000 species of angiosperms, 280 species of liverworts, 682 species of bryophytes. Among the invertebrates, 11% butterflies, 20% ants, 40% odonates and 76% mollusks are endemic to the Western Ghats (Gadgil *et al*., 2011).The unique ecosystem of Western Ghats has been threatened continuously by habitat disturbance (Kasturirangan, 2013). Even though Kerala occupies a small part of southern Western Ghats, it is rich in biodiversity and shows a high rate of endemism with 1272 endemic flowering plants (Nayar, 1997). In India, Parthenium hysterophorus, Lantana camara, Mimosa diplotricha, *Chromolaena* odorata and Mikania micrantha are the major invasive plants (Sankaran, 2017). Invasive plants have led to the deterioration of the Western Ghats as invasion occurs in openings made in the forest by logging, trails, where it becomes established and eventually, naturalize or outcompete other native plants (Muniappan and Viraktamath, 1993).

The study area was physiographically differentiated according to the different altitudes. *viz.*, highland (>75 MSL), midland (7.5-75 MSL) and lowland (<7.5 MSL).

The present study was conducted in three districts, Wayanad, Malappuram and Kozhikode, a part of the southern Western Ghats (Plate 1).

Wayanad district is located in the North-East part of Kerala, with hilly terrain. It lies between latitude 11^0 26’ to 12^{0}00’N and longitude 75^0 75’ to 76^0 56’ with a total geographic area of 2136 sq.km and altitude of 700- 2100m above MSL.

Topographically, it can be divided into two parts, northeastern part and southwestern part.

Kozhikode district is situated on the South-West coast of India, covers an area of about 2, 344 sq. km. The geographical position of the study area lies between the latitude 11°08’N and 11°.50’N and longitude 75°30’E and 76°8’E. Topographically divided into three distinct regions, sandy coastal belt, lateritic midland and rocky highlands. The coastal length covers about 80km, of which 15.55% area is lowland and 26.88% area occupies the highlands.

Malappuram district, in Northern Kerala, is bound in North-West by Kozhikode district and North-East by Wayanad district. It lies between75 to 77 east longitude and 10^0-to 12^0-north latitude with geographical area of 3550 sq.kms. It also consist of three divisions, highland (towards east and north-eastern parts), midland (center), and lowland (along the sea coast).

***Lantana camara* L.**

Class: Dicotyledonae

Order: Lamiales

Family: Verbenaceae

Lantana camara L., commonly called Spanish Flag or West Indian Lantana, native to Central and South America has become naturalized in tropical and warm regions worldwide. *L. camara*, first named and described by Linnaeus, was introduced in the late 1600’s by Dutch explorers from Brazil into Netherland. It was introduced in India only in the 19th century as a ornamental plant to be grown in hedges and gardens, however it started invading throughout the country. Considered by IUCN as one of the world’s 100 most invasive species, and among the world’s 10 worst weeds (Global Invasive Species Database, 2017), they grow individually in clumps or as dense thickets and can become the dominant understorey species, disrupting the succession of plants in that area and hence decreasing biodiversity (Global Invasive Species Database, 2019a).

It is a perennial shrub, root system strong, stem armed with recurved prickles, leaf simple, opposite, ovate, rugose above and have crenate-serrate margins. Flowers small, tubular, gamosepalous, 5 sepals, gamopetalous, 5 petals, terminal, axillary condensed spikes inflorescence, multi-coloured from white to red in various shades (Plate 2-3). Subsequent to anthesis, flowers are seen to change colour. It provides visual cue to insects and helps in pollination. Four stamens, didynamous, basifixed. Gynoecium bicarpellary, superior, syncarpous. Style and stigma simple. Flowers throughout the year. Fruits small, fleshy, greenish-blue to black, two nutlets. Seed germination is faster and easy.

***Sphagneticola trilobata* (L.) Pruski**

Class: Dicotyledonae

Order: Asterales

Family: Asteraceae

Sphagneticola trilobata commonly known as Wedelia or Singapore daisy, native to tropics of Central America. *S. trilobata* is also considered by IUCN as one of the world's 100 most invasive species. Cultivated as an ornamental plant, it has widespread and naturalized in most of the wet tropical areas of the world (Global Invasive Species Database, 2019b). They form a dense ground cover and prevent the growth and regeneration of other plant species.

It is perennial, mat-forming creeping herb, rooting at nodes with rounded stem, ascending flowering portions. Leaves are fleshy, serrate or irregularly toothed. Flowers throughout the year. Involucre campanulate-hemispherical.8-13 ray florets per head, 6-15 mm long, yellow colour, stigma bilobed (Plate 8). Disc corolla 4-5mm long. Calyx represented by pappus. Anthers syngenescious. Style slender with obtuse tip and marginally pubescent. Tuberculate achenes (4-5mm long).

Mimosa diplotricha C. Wright ex Sauvalle var. *diplotricha*

Class : Dicotyledonae

Order : Fabales

Family: Fabaceae

M. diplotricha (thorny mimosa) is native to the Neotropics and introduced in India only last fifty years and is still spreading. It grows best in tropical regions. It was first observed in Kerala in 1964 (Nayar, 1964). It is a major weed and invades cultivated areas like coffee plantations, banana, sugarcane, vacant land and other croplands. It is also seen along the railway tracks, roadside and wastelands. It forms a thorny mat over other natural vegetation, preventing the animals from accessing it. It is an annual but behaves as a perinneal shrub, scrambling climber,. Highly branched root with nodules. Stem four-angulate, with line of sharp, recurved prickles. Leaf bright green, feathery, 20 pairs of leaflets per pinnae. Globose head inflorescence (Plate 12). Corolla gamopetalous. Flowering period between August and February. Pods are clustered.

METHODOLOGY

STUDY DESIGN

Study Period

The present investigation was carried out during 2013–2018. The presented observations were made consecutively during three seasons, namely Pre-Monsoon (February- May), Monsoon (South-West Monsoon, June- September) and Post-Monsoon (October- January). Field observations were carried out during the three seasons at the study sites. The survey on the invasive species covered all the urban areas, vacant lands, abandoned land, major and minor roads and clearings of forest. The study sites were selected in places where the invasive species were seen well-established. Sites selected were evaluated and marked as per the severity of infestation by the invasive plants, determined visually.

During each of the three seasons, five sites of 1x1 m harbouring the invasive plants were selected from each district and the number of opened flowers on each patch was noted. Insect visitors to invasive plants were observed in all 1 sq. m quadrates in each site.

Insect Visitor Survey

Insect visitors to the three invasive plants were surveyed using quadrat observation method. Insect visiting the flowers within the quadrats were monitored and species diversity was recorded based on visual recording. Insects that landed on the inflorescence and moved over the stigma or anthers were counted as floral visitors and observations were made only on these insects. Majority of the insects were identified using field guide and the rest of them were identified by specialist working in that field. For further identification, the insect visitors were captured using sweep net, and killed using ethyl acetate in a killing jar. The insects were observed under Leica stereo microscope for the presence of pollen grains and photographed. They were pinned using entomological pin and labeled. Small hymenopterans were mounted on cards. The insect specimens were properly labeled and kept in insect box.

Methodology described by Munoz *et al.* (2005), with certain modifications was followed for observing the visitation patterns, involving 15 minute observations in which the number of visitors to a known number of flowers was carefully recorded. The observation period (9:30 AM and 5:00 PM) of a day was divided into three phases: Early Phase (9:30 AM – 12:00 PM), Middle Phase (12:01 PM – 2:30 PM) and Late Phase (2:31 PM – 5:00 PM).

Prepared a blank work table with appropriate columns in advance and the details were filled out in the field itself. Identity of these insect visitors, number of flowers visited by individual insect and average time spent on each flower by the visitor and the frequency of the visitors were duly recorded. The number of flowers in each patch was noted down.

Studied the influence of abiotic factors on insect visitors by including light intensity (klux), temperature (°C) and humidity into our analysis. The visiting time (in seconds) was recorded using a stop watch. Climatic factors like air temperature, relative humidity and light intensity were measured using scientifically accurate thermometer cum hygrometer (HTC-1, Hygrometer) and lux meter (Digital Lux Meter Portable, IBS-DLMP) respectively every 30 minutes during the observations

BAGGING

Flowers of Lantana camara in bud stage were labeled, among which 50 were left unattended (treatment 1). Pre- anthesis flowers were bagged using gauze bags net to exclude insect visitors (treatment 2). To check whether self-pollination occurs, bagged flowers were tagged and were left intact for a few days. At maturity, fruits were harvested from both treatment 1 and 2 and number of seeds per fruit was counted. The mean number of seeds per fruit was then calculated for each treatment.

After florets opened, the mesh bags were removed and was constantly watched for insect visitors to land. When one insect visitor landed on the floret, we allowed it to forage, but avoided any other visitor from landing on it. Soon after the insect visitor left, we replaced the bag as to exclude other pollinators and seed predators. After the seed matured, counted the fertile seeds in each inflorescence.

Foraging behaviour

Foraging activity of insect visitor on flowers was recorded using handycam during the three phases of the day. Video recordings helped in studying minute details or behaviour regarding the pollinators like their movement pattern, feeding, nectar or pollen preference, cleaning behaviour. Insect visitors coming in contact with anthers and stigma were recorded. Foragers were categorized based on their specific foraging behaviour, nectar foragers and pollen gatherers. Pollen gatherers were the insect visitors seen collecting pollen grains on their mandibles, legs or rest of the body. The position of pollen grains was also noted. Nectar foragers were the ones seen extending their proboscis to the base of corolla of the stigma, to feed on nectar. We noted the type of floral resources collected by the insect visitors. Insect visitors visiting the flower were observed and recorded by following the individual visitor during its every bout, until it leaves the patch. Foraging duration was recorded using digital stop watch. In between, a single flower is randomly selected and the camera is set recording the visitors to that single flower to study whether insect visitor revisits the same flower, concluding that nectar gets replenished in the florets. The number of florets in *S. trilobata* (ray and disc florets) and *L. camara* (colour) were counted on each inflorescence. The florets visited by the visitors were noted down. Observed the preference of insect visitors to newly opened flowers or old dehiscised flowers. The duration of insect visit was recorded using a stopwatch. Interactions with other visitors were recorded. Detailed description was made. Even though time consuming, efficient analysis in lab without losing details.

Foraging rate= Number of flowers visited by each insect species/minute

Foraging duration= Time spend by the insect visitor on each flower.

During the study, a mobile thermo-hygrometer was used to register the temperature and relative humidity of the site.

The field data collected was converted into comparable tables in Word Excel Sheet for further analysis.

Floral Biology

Before the start of flowering, plants were tagged. The flowering magnitude of ten marked flowers were observed daily for flower opening. The volume of flower nectar was recorded during each phase. The nectar was measured by detaching corolla, and gently squeezing the base of corolla, and spotting the nectar on the Whatman No:1 filter paper. The spot was circled using pencil before it dried. The diameter of each spot was measured and converted to volume measurement using the technique followed by Dafni (1992).

Pollen viability

Pollen viability was tested using Tetrazolium test. Pollen was spread on a glass slide using tooth pick and a drop of 1% TTC (2,3,5- triphenyl tetrazolium chloride) was dropped on it and covered with a coverslip. Pollen grains with TTC were incubated in a dark humid chamber for about two hours, then pollen viability counts were made. Pollen grains stained red in colour were counted as viable (Sulusoglu and Cavusoglu, 2014).

Species diversity indices were calculated using the formula:

1) Shannon-Wiener Diversity Index

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

where,

H’= Shannon-Wiener Diversity of species diversity

p_i = proportion of total abundance represented by ith species

2) Simpson’s Diversity Index

$$D = \frac{\sum n_i (n_i - 1)}{N(N-1)}$$

where,

D = Simpson’s Diversity Index

n = number of individuals of each species

N = total number of individuals of all species

3) Evenness Index

Evar = $1 - 2/\pi \cdot \arctan\left\{\sum_{S=1}^{S}\left(\ln(x_s) - \sum_{t=1}^{S}\ln(x_t)/S\right)^2 / S\right.$

where,

E_{var} = Evenness Index

x_s = number of individuals of the first species

x_t = number of individuals of the second species

S = number of individuals in all species

Statistical analyses were carried out using SPSS (version 20) and the significance level was set at 5%.

Result

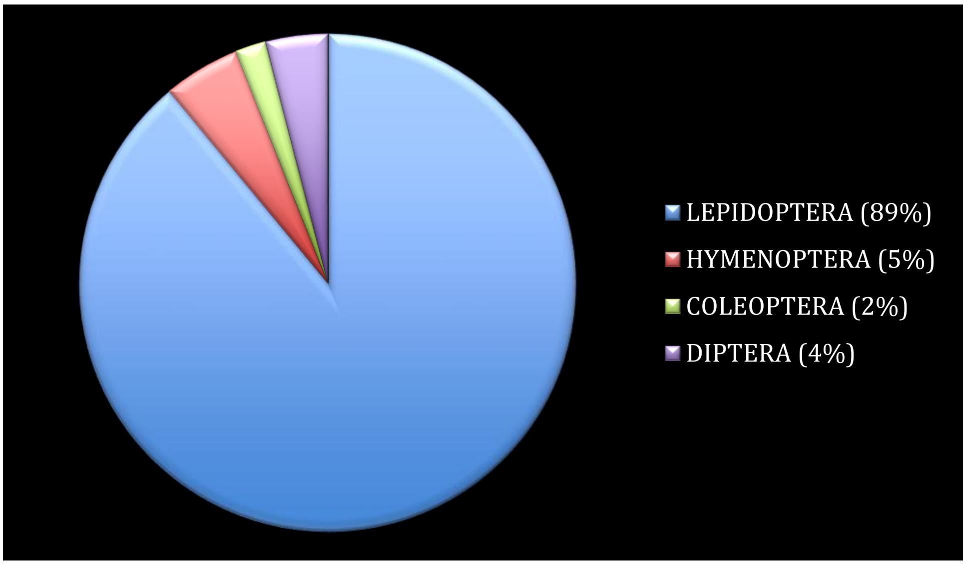
Studies were conducted on the insect floral visitors to the three invasive plants *Lantana camara*, *Sphagneticola trilobata* and *Mimosa diplotricha* during 2013- 2018 in three districts, viz: Kozhikode (Lowland), Malappuram (Midland) and Wayanad (Highland). The invasive plants attracted a large variety of insect floral visitors.

***Lantana camara* L.**

Insect Visitors to *Lantana camara*

A total of 55 species of insect visitors belonging to eleven families visited flowers of *Lantana camara* (Fig.1).

Fig. 1. Percentage of species belonging to different insect orders visiting *Lantana camara*



Among lepidopterans, Nymphalidae (15 species) was the dominant family followed by Hesperiidae (9 species) (Fig. 2). However, members of Papilionidae showed a higher percentage frequency of visits to *L. camara* (Fig. 3). Among Lepidopterans, *Catopsilia pomona* (10.49%) was the most dominant visitor, while among hymenopterans, *Amegilla zonata* (16.12%) was the most dominant visitor, visiting flowers of *L. camara* at all altitudes.

Fig. 2. Number of species of insect visitors belonging to different families visiting *Lantana camara*

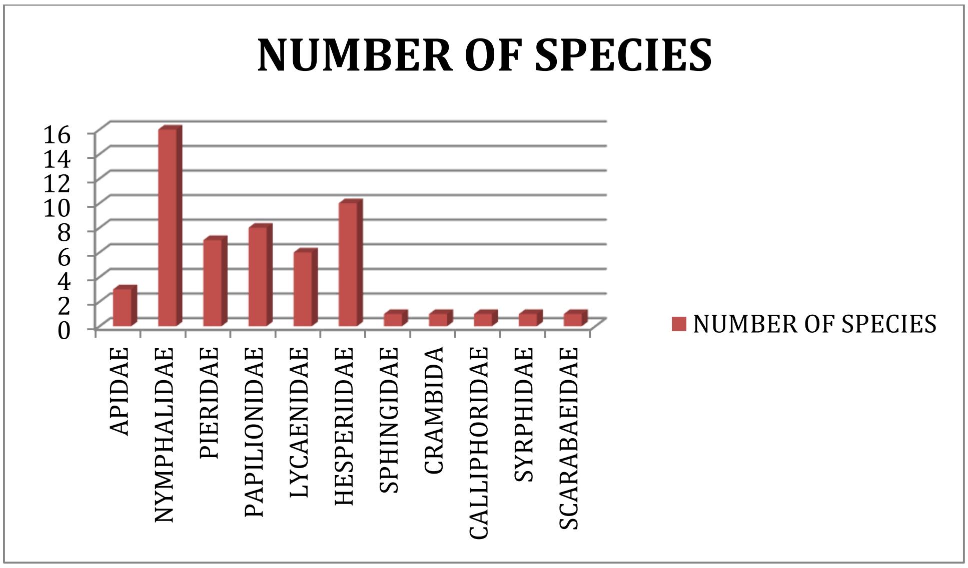
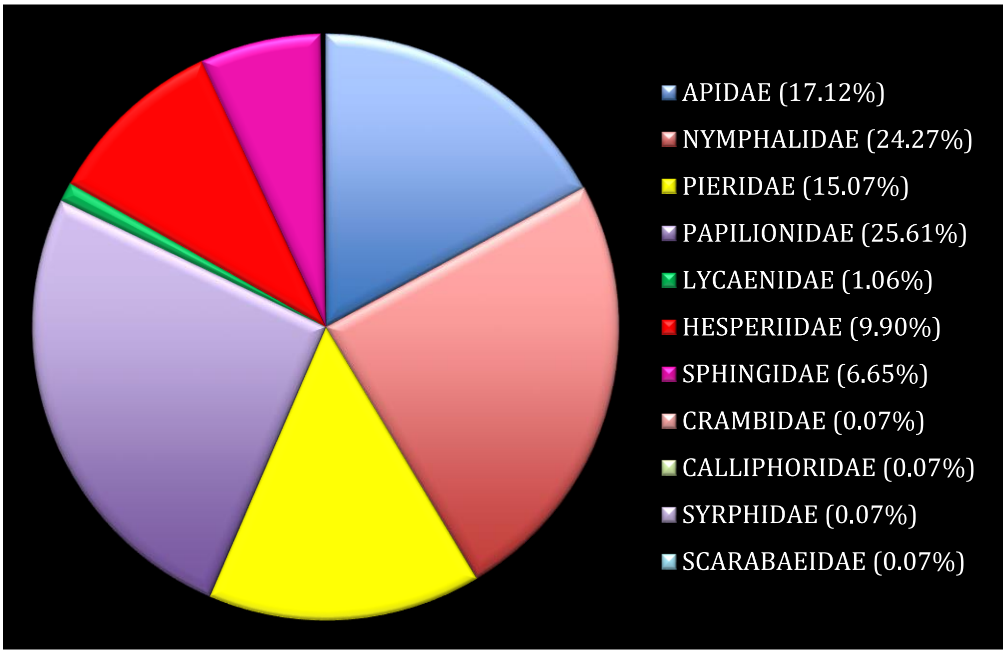


Fig. 3. Percentage frequency of insects of different families visiting flowers of *Lantana camara*



INSECT FLORAL VISITOR DIVERSITY AT DIFFERENT ALTITUDES ON *L. camara*

The number of insect floral visitors in highland situated at an altitude of 700-2100 m above MSL (Mean sea level) (36 species) was seen to be higher than that of midland (34 species) at 60 m above msl and lowland (33 species) 5 m above msl. Shannon diversity index (3.02999) was higher in the highland than midland (2.91722) and lowland (2.46902) (Table 1). The frequency of insect visit was seen to be higher in lowland (35.56%) than other two altitudes. Evenness index showed highest evenness in lowland (0.81990), followed by midland (0.79351) and highland (0.78127).

Table 1. Species diversity indices of insect visitors to *Lantana camara* at three altitudes

PARAMETERS STUDIED	LOWLAND	MIDLAND	HIGHLAND
SHANNON DIVERSITY INDEX (**H’**)	**2.46902**	**2.91722**	**3.02999**
SIMPSON’S DIVERSITY INDEX (**D**)	**0.88448**	**0.92700**	**0.93521**
EVENNESS INDEX (**E_{var}**)	**0.81990**	**0.79351**	**0.78127**
TOTAL SPECIES	**33**	**34**	**36**
MEAN INDIVIDUAL ± S.E.	**10.7663 ± 0.31225**	**11.8384 ± 0.44678**	**14.2594 ± 0.57189**

There is a significant difference in frequency of insect visits between lowland and highland ($p=0.001$) and between midland and highland ($p = 0.001$). Whereas, the difference is not significant between lowland and midland. In lowland, out of the total 33 species, the highest number of species were recorded from the order Lepidoptera (30 species) followed by Hymenoptera (2 species) and Diptera (1 species). In midland, out of the total 34 species, the highest number was recorded from Lepidoptera (32 species) followed by Hymenoptera (2 species). In highland, out of 36 species recorded, Lepidoptera had the highest number of species (31 species), followed by Hymenoptera (3 species), Coleoptera (1 species) and Diptera (1 species).

Among hymenopterans, *Amegilla zonata* L. was the most dominant visitor in lowland (25.94%), midland (6.54%) and highland (15.56%). Another hymenopteran, *Ceratina hieroglyphica* was however, seen only in highland. In case of lepidopteran visitors, in lowland, family Nymphalidae represented by 8 species was the dominant family, followed by Papilionidae (7 species) and Hesperiidae (6 species) (Table 2). *Graphium agamemnon* was recorded as the dominant visitor in lowland (12.87 %), *Catopsilia pomona* (15.74 %) in midland and *Borbo cinnara* (9.90%) in highland. Insects visiting *L. camara* at three altitudes are shown in Table 3.

Lantana camara flowers which were not bagged produced 16- 17 fruits. Bagged flowers (excluding pollinators) produced 11-12 fruits. Plate 4-7 shows the insect visitors to *L. camara*.

Table 2. Number of species of insects belonging to different families visiting *Lantana camara* at three altitudes

FAMILIES	**LOWLAND**	**MIDLAND**	**HIGHLAND**
Apidae	2	2	3
Nymphalidae	8	12	6
Papilionidae	7	7	8
Hesperiidae	6	5	8
Pieridae	5	5	4
Lycaenidae	3	1	2
Crambidae	0	0	1
Sphingidae	1	1	1
Calliphoridae	0	0	1
Syrphidae	1	0	0
Scarabaeidae	0	0	1

Table 3. Insect floral Visitors to *Lantana camara* at three altitudes

INSECT VISITORS	**LOWLAND**	**MIDLAND**	**HIGHLAND**
APIDAE			
Amegilla zonata Linnaeus	✓	✓	✓
Ceratina hieroglyphica Smith	×	×	✓
Xylocopa sp.	✓	✓	✓
NYMPHALIDAE			
Euploea core Cramer	✓	✓	✓
Tirumala limniace Cramer	✓	✓	✓
Junonia atlites Linnaeus	✓	✓	✓
Junonia lemonias Linnaeus	✓	✓	×
Junonia iphita Cramer	×	✓	✓
Junonia almana Linnaeus	×	✓	×
Hypolimnas bolina Linnaeus	✓	✓	✓
Tanaecia lepidea Butler	✓	×	×
Ideopsis vulgaris Butler	✓	×	×
Ypthima huebneri Kirby	×	✓	✓
Vindula erota Fabricius	×	✓	×
Acraea terpsicore Linnaeus	×	✓	×
Cupha erymanthis Drury	×	✓	×
Ariadne ariadne Linnaeus	×	✓	×
Cirrochroa thais Fabricius	✓	×	×
PAPILIONIDAE			
Pachliopta aristolochiae Fabricius	✓	✓	✓
Pachliopta hector Linnaeus	✓	✓	✓
Graphium sarpedon Linnaeus	✓	✓	✓
Graphium agamemnon Linnaeus	✓	✓	✓
Papilio demoleus Linnaeus	✓	✓	✓

Papilio clytia Linnaeus	✓	✓	✓
Papilio polytes Linnaeus	✓	✓	✓
Pareronia hippia Fabricius	×	×	✓
PIERIDAE			
Delias eucharis Drury	✓	✓	✓
Catopsilia pomona Fabricius	✓	✓	✓
Eurema hecabe Linnaeus	✓	✓	✓
Catopsilia pyranthe Linnaeus	✓	✓	×
Leptosia nina Fabricius	✓	×	×
Cepora nerissa Fabricius	×	✓	×
Appias lyncida Cramer	×	×	✓
LYCAENIDAE			
Chilades pandava Horsfield	✓	×	✓
Zizeeria karsandra Moore	✓	×	×
Euchrysops cnejus Fabricius	✓	×	×
Talicada nyseus Guerin-Meneville	×	✓	×
Rapala manea Hewitson	×	×	✓
HESPERIIDAE			
Borbo cinnara Wallace	✓	✓	✓
Telicota sp.	✓	✓	✓
Badamia exclamationis Fabricius	✓	✓	✓
Suastus gremius Fabricius	✓	✓	✓
Pelopidas mathias Fabricius	✓	×	✓
Pseudo cladenia indrana	×	✓	×
Sarangesa desahara Moore	×	×	✓
Iambrix salsala Moore	×	×	✓
Tagiades litigiosa Moschler	✓	×	×
Coladenia indrani	×	×	✓

Unidentified Moth	×	✓	✓
CRAMBIDAE			
Spoladea recurvalis Fabricius	×	×	✓
SPHINGIDAE			
Macroglossum sp.	✓	✓	✓
CALLIPHORIDAE			
Lucilia sp.	×	×	✓
SYRPHIDAE			
Mesembrius sp.	✓	×	×
SCARABAEIDAE			
Flower chaffer	×	×	✓

*✓=Present, ×=Absent

Number of flowers visited by lepidopterans showed a significant difference between lowland and highland (p= 0.001) and between midland and highland (p= 0.001), while the frequency of hymenopterans visiting *L. camara* showed a significant difference between lowland and highland (p= 0.007). Number of flowers visited by hymenopterans showed a significant difference between lowland and highland (p= 0.025) and the number of flowers visited by lepidopterans showed a significant difference between lowland and midland (p= 0.001), between lowland and highland (p= 0.001) and between midland and highland (p= 0.017).

SEASONAL DIFFERENCE IN INSECT FLORAL VISITOR DIVERSITY

Shannon diversity index of insect floral visitors to *L. camara* was highest in Monsoon (2.96424), while Pre- Monsoon had the lowest diversity index (2.25527) (Table 4).

Table 4. Species diversity indices of insect floral visitors to *Lantana camara* during different seasons

PARAMETERS STUDIED	PRE-MONSOON	MONSOON	POST-MONSOON
SHANNON DIVERSITY INDEX (**H'**)	2.25527	2.96424	2.93927
EVENNESS INDEX ($\mathbf{E}_{\mathbf{var}}$)	0.808235	0.805526	0.809825

The frequency of insect floral visitors was higher during Post-Monsoon in lowland (54.25%) and highland (49.29%), while it was higher during Monsoon in midland (55.01%). The frequency of visit was seen to be lower in all the three altitudes during Pre-Monsoon. The frequency of insect visits to *L. camara* showed a significant difference between Monsoon and Post-Monsoon (p= 0.001). Number of flowers visited by lepidopterans was significantly different between Pre-Monsoon and Monsoon (p= 0.037) and between Pre- Monsoon and Post-Monsoon (p= 0.002). The frequency of lepidopteran visits was significant between Monsoon and Post-Monsoon (p= 0.001). Higher frequency of *Amegilla zonata* visited lowland (43.51%) during Pre- Monsoon season, whereas it was highest during Monsoon in midland (87.5%) and highland (63.63%). Frequency of insect floral visitors to *L. camara* at three altitudes during different seasons are shown in Table 5.

Table 5. Frequency of insect visitation at three altitudes during the three seasons on *Lantana camara*.

INSECT VISITORS	**LOWLAND**			Σ_A	**MIDLAND**			Σ_B	**HIGHLAND**			Σ_C	Σ
	Pre -M.	**M.**	**Post -M.**		**Pre -M.**	**M.**	**Post -M.**		**Pre -M.**	**M.**	**Post -M.**		
Amegilla zonata L.	57	43	31	131	0	28	4	32	19	42	5	66	229
Ceratina hieroglyphica Smith	0	0	0	0	0	0	0	0	6	0	2	8	8
Xylocopa sp.	0	2	1	3	0	0	1	1	0	0	1	1	5
Macroglossum sp.	5	5	41	51	0	19	13	32	0	2	8	10	93
Euploea core Cramer	2	12	16	30	2	17	26	45	2	0	6	8	83
Tirumala limniace Cramer	1	2	2	5	0	4	6	10	2	0	14	16	31
Junonia atlites Linnaeus	0	0	26	26	0	1	10	11	11	10	7	28	65
Junonia lemonias Linnaeus	0	8	1	9	0	2	2	4	0	0	0	0	13
Junonia iphita Cramer	0	0	0	0	0	14	14	28	15	11	13	39	67
Junonia almana Linnaeus	0	0	0	0	0	1	1	2	0	0	0	0	2
Hypolimnas bolina Linnaeus	3	7	4	14	0	3	13	16	0	1	18	19	49
Tanaecia lepidea Butler	0	0	1	1	0	0	0	0	0	0	0	0	1
Ideopsis vulgaris Butler	0	1	0	1	0	0	0	0	0	0	0	0	1
Ypthima huebneri Kirby	0	0	0	0	0	1	0	1	1	1	4	6	7
Vindula erota Fabricius	0	0	0	0	0	2	1	3	0	0	0	0	3
Acraea terpsicore Linnaeus	0	0	0	0	5	10	0	15	0	0	0	0	15
Cupha erymanthis Drury	0	0	0	0	0	1	0	1	0	0	0	0	1
Ariadne ariadne Linnaeus	0	0	0	0	0	1	0	1	0	0	0	0	1
Cirrochroa thais Fabricius	0	1	0	1	0	0	2	2	0	0	0	0	3
Pachliopta aristolochiae Fabricius	0	0	2	2	0	8	0	8	0	0	3	3	13
Pachliopta hector Linnaeus	0	2	1	3	0	3	6	9	2	2	1	5	17
Graphium sarpedon Linnaeus	1	6	20	27	0	13	5	18	0	2	16	18	63

Graphium agamemnon Linnaeus	7	12	46	65	0	37	26	63	0	0	10	10	138
Papilio demoleus Linnaeus	2	1	2	5	1	2	4	7	0	1	17	18	30
Papilio clytia Linnaeus	2	4	5	11	0	18	11	29	0	3	13	16	56
Papilio polytes Linnaeus	8	6	14	28	6	4	5	15	1	0	3	4	47
Pareronia hippia Fabricius	0	0	0	0	0	0	0	0	0	3	0	3	3
Delias eucharis Drury	0	0	1	1	0	5	5	10	2	0	16	18	29
Catopsilia pomona Fabricius	1	15	24	40	4	39	34	77	0	5	27	32	149
Eurema hecabe Linnaeus	0	2	5	7	0	7	1	8	0	2	1	3	18
Catopsilia pyranthe Linnaeus	0	1	1	2	0	3	0	3	0	0	0	0	5
Leptosia nina Fabricius	0	0	2	2	0	0	0	0	0	0	0	0	2
Cepora nerissa Fabricius	0	0	0	0	0	1	0	1	0	0	0	0	1
Appias lyncida Cramer	0	0	0	0	0	0	0	0	0	6	1	7	7
Chilades pandava Horsfield	1	0	1	2	0	0	0	0	3	2	2	7	9
Zizeeria karsandra Moore	0	0	1	1	0	0	0	0	0	0	0	0	1
Euchrysops cnejus Fabricius	0	0	2	2	0	0	0	0	0	0	0	0	2
Talicada nyseus Guerin- Meneville	0	0	0	0	0	2	0	2	0	0	0	0	2
Rapala manea Hewitson	0	0	0	0	0	0	0	0	0	0	1	1	1
Borbo cinnara Wallace	1	6	19	26	0	15	10	25	0	32	10	42	93
Telicota sp.	0	1	1	2	0	1	0	1	0	0	1	1	4
Badamia exclamationis Fabricius	0	0	2	2	0	0	1	1	0	0	3	3	6
Suastus gremius Fabricius	1	0	0	1	0	3	0	3	0	5	0	5	9
Pelopidas mathias Fabricius	0	0	2	2	0	0	0	0	0	0	5	5	7
Pseudo cladenia indrana	0	0	0	0	0	1	0	1	0	0	0	0	1
Sarangesa desahara Moore	0	0	0	0	0	0	0	0	2	2	0	4	4
Iambrix salsala	0	0	0	0	0	0	0	0	1	3	0	4	4

Moore													
Tagiades litigiosa Moschler	0	1	0	1	0	0	0	0	0	0	0	0	1
Coladenia indrani	0	0	0	0	0	0	0	0	0	11	0	11	11
Spoladea recurvalis	0	0	0	0	0	0	0	0	0	0	0	1	1
Unidentified Moth	0	0	0	0	0	4	0	4	0	2	0	2	6
Lucilia sp.	0	0	0	0	0	0	0	0	0	0	1	1	1
Mesembrius sp.	0	1	0	1	0	0	0	0	0	0	0	0	1
Flower chafer	0	0	0	0	0	0	0	0	0	1	0	0	1
$\sum$	92	139	274	**505**	18	269	202	**489**	67	149	210	**426**	**1420**

*Pre-M. =Pre-Monsoon, M. = Monsoon, Post-M. =Post-Monsoon, $\sum A$=Sum of frequency of insect visitation to Lowland; $\sum B$=Sum of frequency of insect visitation to Midland, $\sum C$= Sum of frequency of insect visitation to Highland

The Shannon diversity index of lowland and highland was higher during Post-Monsoon (2.60465 and 2.93613 respectively). In midland, diversity index was highest during Monsoon (2.88865). Insect diversity was lowest during Pre-Monsoon in all the three altitudes, of which midland showed the lowest (1.46097). Evenness index was highest during Pre-Monsoon in both lowland (0.8230) and midland (0.8197), whereas it was highest during Monsoon in highland (0.7980) (Table 6).

Table 6. Species diversity indices of insect visitors to *Lantana camara* during different seasons at three altitudes

PARAMETERS STUDIED	**LOWLAND**			**MIDLAND**			**HIGHLAND**		
	Pre-M.	**M.**	**Post-M.**	**Pre-M.**	**M.**	**Post-M.**	**Pre-M.**	**M.**	**Post-M.**
SHANNON DIVERSITY INDEX (**H'**)	**1.5194**	**2.4622**	**2.6046**	**1.4609**	**2.8886**	**2.6835**	**2.0566**	**2.3613**	**2.9361**
EVENNESS INDEX (**E_{var}**)	**0.8230**	**0.7868**	**0.7908**	**0.8197**	**0.7803**	**0.7711**	**0.7908**	**0.7980**	**0.7665**

*Pre-M. = Pre-Monsoon, M. = Monsoon, Post-M. = Post-Monsoon

INSECT VISITOR DIVERSITY DURING DIFFERENT PHASES OF THE DAY

Insect floral visitors were highest during Early phase (40.98%) than Middle (36.88%) and Late (22.14%) phase. Percentage frequency of visits of lepidopterans was low during late phase and they also spent less time on flowers during late phase. The frequency of *Amegilla zonata* was highest during Early phase (46.72%) and decreased as the day progressed and was lowest during Late phase (17.03%). The frequency of lepidopteran visit to *L. camara* was highest during Early phase and lowest during Late phase. Number of flowers visited by hymenopterans showed a significant difference between Early and Late phase (p= 0.047). Evenness index was highest during Early phase (0.8049) (Table 7).

Table 7. Species diversity indices of insect visitors to *Lantana camara* during different phases

PARAMETERS STUDIED	EARLY PHASE	MIDDLE PHASE	LATE PHASE
SHANNON DIVERSITY INDEX (**H'**)	**2.9726**	**2.98806**	**3.1892**
EVENNESS INDEX (**E_{var}**)	**0.8049**	**0.7994**	**0.7774**

The Shannon diversity was higher during Middle phase at all three altitudes (Table 8).

Table 8. Species diversity indices of insect visitors to flowers of *Lantana camara* during three phases at three altitudes

PARAMETERS STUDIED	**LOWLAND**			**MIDLAND**			**HIGHLAND**		
	E.P.	**M.P.**	**L.P.**	**E.P.**	**M.P.**	**L.P.**	**E.P.**	**M.P.**	**L.P.**
SHANNON DIVERSITY INDEX (**H'**)	**2.4897**	**2.5278**	**2.5246**	**2.8088**	**2.8454**	**2.7670**	**2.9109**	**2.9603**	**2.9173**
EVENNESS INDEX (**E_{var}**)	**0.7882**	**0.7820**	**0.7748**	**0.7655**	**0.7795**	**0.7839**	**0.7774**	**0.7933**	**0.8046**

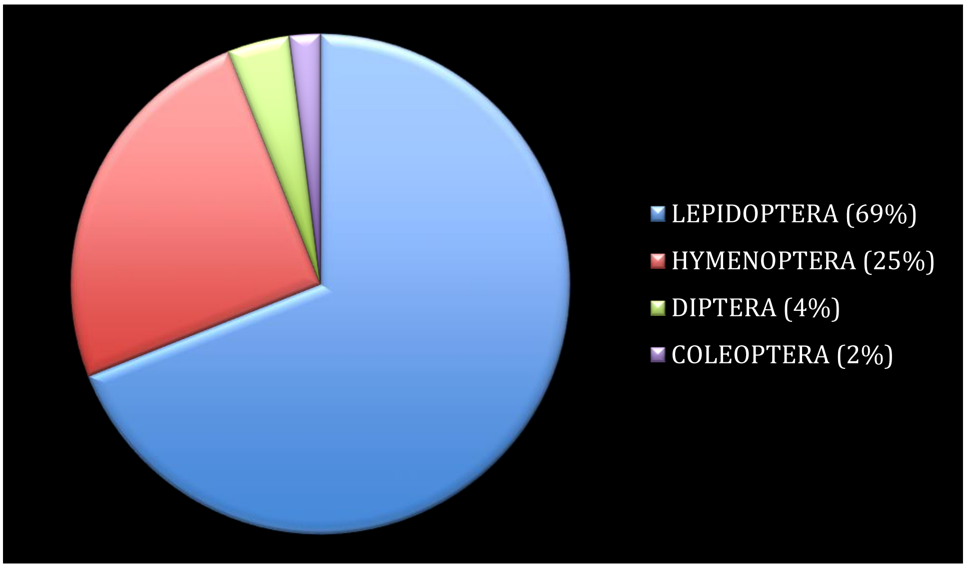
*E.P. =Early Phase, M.P. =Middle Phase, L.P. =Late Phase

Sphagneticola trilobata (L.) Pruski

Insect Visitors to flowers of *Sphagneticola trilobata*

Total of 51 species of insect visitors belonging to 14 families were reported from *Sphagneticola trilobata* (Fig. 4). Bees constituted 53.93% of the total flower visitors with Apidae having the highest percentage frequency of visits (42.8%) followed by Halictidae (9.1%). Among the different bee species, *Apis cerana* (25.58%) was the predominant followed by *A. dorsata* (10.57%).

Fig. 4. Percentage of species belonging to different insect orders visiting *Sphagneticola trilobata*



Among lepidopterans, Nymphalidae was the most dominant family (13 species) followed by Lycaenidae (8 species) (Fig. 5). Percentage frequency of visits was highest for Nymphalidae (16.6%) followed by Hesperiidae (14.4%). *Borbo cinnara* (Hesperiidae) (7.44%) was the predominant visitor to *S. trilobata* (Fig. 6). Thrips were recorded from the flowers also.

Fig. 5. Number of species of insects belonging to different families visiting flowers of *Sphagneticola trilobata*

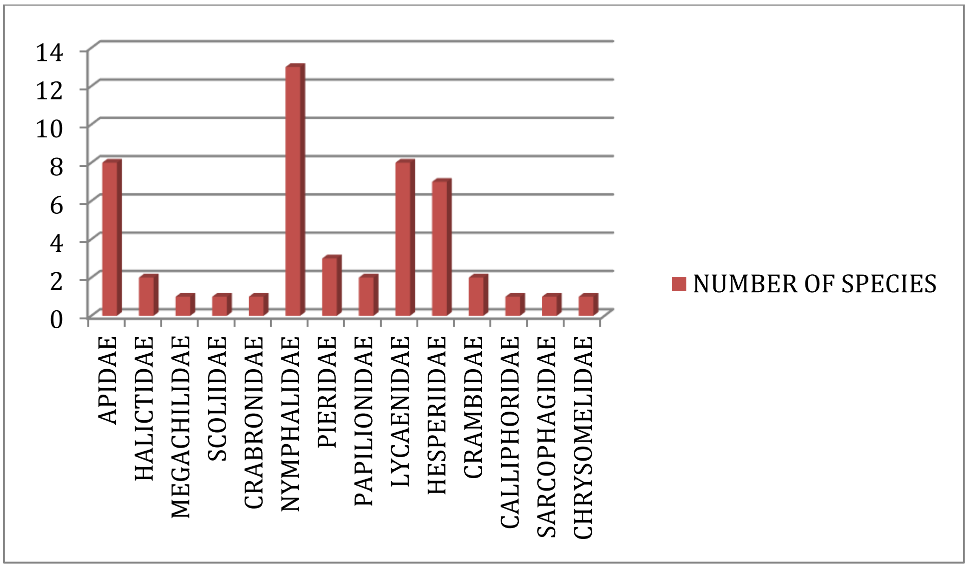
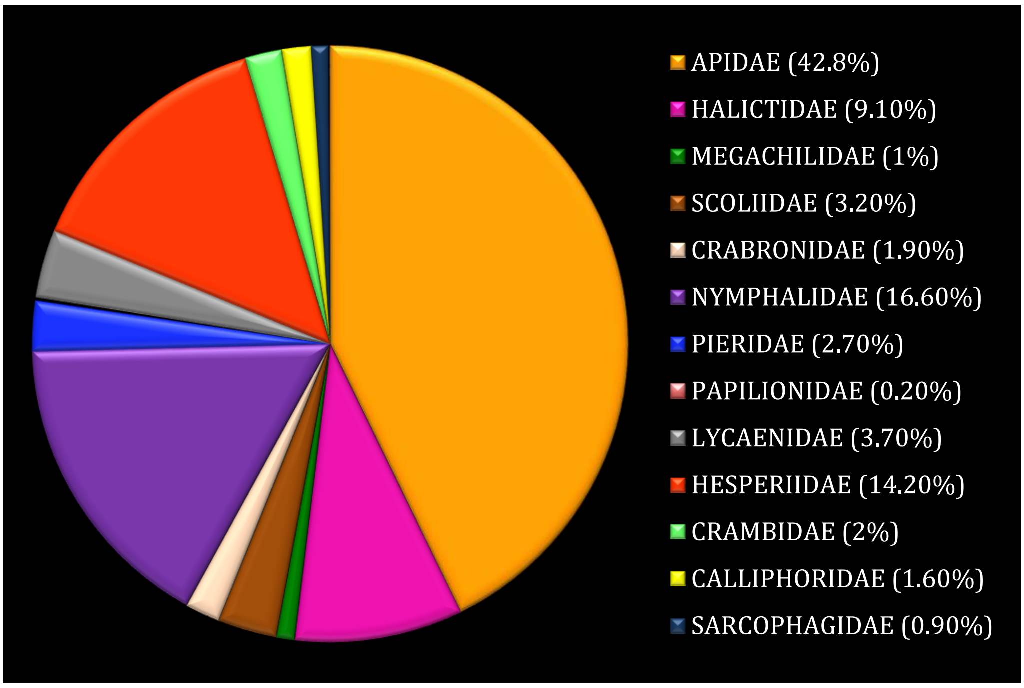


Fig. 6. Percentage frequency of insects of different families visiting flowers of *Sphagneticola trilobata*



INSECT VISITOR DIVERSITY AT DIFFERENT ALTITUDES ON *S.trilobata*

The number of insect species in lowland (37 species) was higher than that of highland (35 species) and midland (32 species). Midland (2.83873) showed a higher Shannon diversity index than lowland (2.80934) and highland (2.50759) (Table 9). The frequency of insect visit was highest in highland (39.27%). Highest species evenness was observed in highland (0.83358), followed by lowland (0.80989) and midland (0.79803).

Among hymenopterans, *A. cerana* was the most dominant visitor in lowland (21.35%) and highland (35.39%), whereas *A. dorsata* was the dominant visitor in midland (18.09%). *Halictus* sp. visited *S. trilobata* only in lowland. In the case of lepidopterans, *B. cinnara* was the dominant visitor in lowland (7.63%) and highland (7.88%). *Junonia atlites* was the dominant visitor in midland (7.91%).

Table 9. Species diversity indices of insect visitors to *Sphagneticola trilobata* at three altitudes

PARAMETERS STUDIED	LOWLAND	MIDLAND	HIGHLAND
SHANNON DIVERSITY INDEX (**H'**)	**2.80934**	**2.83873**	**2.50759**
SIMPSON'S DIVERSITY INDEX (**D**)	**0.89987**	**0.914028**	**0.84447**
EVENNESS INDEX ($\mathbf{E_{var}}$)	**0.80989**	**0.79803**	**0.83358**
TOTAL SPECIES	**37**	**32**	**35**
MEAN INDIVIDUAL ± S.E.	**10.1241 ± 0.44599**	**12.2882 ± 0.58044**	**9.8609 ± 0.44843**

In lowland, out of the total 37 species, the highest number of species were recorded from the order Lepidoptera (25 species) followed by Hymenoptera (11 species) and Diptera (1 species). In midland, out of the total 32 species, the highest number was recorded from Lepidoptera (21 species) followed by Hymenoptera (11 species). In highland, out of 35 species, Lepidoptera had the highest number of species (23 species), followed by Hymenoptera (9 species), Diptera (2 species) and the lowest was Coleoptera (1 species). Among lepidopterans, Nymphalids are the most dominant species in all the three altitudes (Table 10). *Nonathra* sp. and *Sarcophaga* sp. was found only in highland. Insects visiting *S. trilobata* in the three altitudes are shown in Table. 11. Plate 9- 11 shows the insect visitors to *S. trilobata*.

Sphagneticola trilobata flowers which were not bagged produced 11-12 seeds, whereas flowers which were bagged completely (excluding the insect visitors) did not produce any seed sets.

Table 10. Number of species of insects belonging to different families visiting flowers of *Sphagneticola trilobata* at three altitudes

FAMILIES	**LOWLAND**	**MIDLAND**	**HIGHLAND**
Apidae	6	7	5
Megachilidae	1	1	1
Halictidae	2	1	1
Scoliidae	1	1	1
Crabronidae	1	1	1
Nymphalidae	10	10	9
Papilionidae	0	1	2
Hesperiidae	4	4	5
Pieridae	3	3	2
Lycaenidae	6	2	3
Crambidae	2	1	2
Calliphoridae	1	0	1
Sarcophagidae	0	0	1
Chrysomelidae	0	0	1

Table 11. Insect floral Visitors to flowers of *Sphagneticola trilobata* at three altitudes

INSECT VISITORS	**LOWLAND**	**MIDLAND**	**HIGHLAND**
APIDAE			
Apis cerana indica Fabricius	✓	✓	✓
Apis dorsata laboriosa Fabricius	✓	✓	✓
Apis florea Fabricius	✓	✓	×
Ceratina hieroglyphica Smith	✓	✓	✓
Ceratina smaragdula (F.)	✓	✓	×
Braunsapis sp.	✓	✓	✓
Xylocopa sp.	×	✓	×
Amegilla zonata Linnaeus	×	×	✓
MEGACHILIDAE			
Megachile sp.	✓	✓	✓
HALICTIDAE			
Nomia sp.	✓	✓	✓
Halictus sp.	✓	×	×
SCOLIIDAE			
Scolia sp.	✓	✓	✓
CRABRONIDAE			
Bembix sp.	✓	✓	✓
NYMPHALIDAE			
Euploea core Cramer	✓	✓	✓
Tirumala limniace Cramer	✓	✓	✓
Junonia atlites Linnaeus	✓	✓	✓
Junonia lemonias Linnaeus	✓	×	✓
Junonia almana Linnaeus	✓	✓	✓
Junonia iphita Cramer	×	✓	✓
Hypolimnas bolina Linnaeus	✓	✓	✓
Danaus chrysippus Linnaeus	✓	✓	×
Acraea terpsicore Linnaeus	✓	✓	×
Phalanta phalantha Drury	✓	×	×

Neptis hylas Linnaeus	✓	✓	×
Ypthima huebneri Kirby	×	✓	✓
Vindula erota Fabricius	×	×	✓
LYCAENIDAE			
Tarucus ananda Niceville	✓	×	×
Zizula hylax Fabricius	✓	×	×
Euchrysops cnejus Fabricius	✓	×	×
Spindasis vulcanus Fabricius	✓	×	×
Castalius rosimon Fabricius	✓	✓	×
Chilades pandava Horsfield	✓	✓	✓
Rapala manea Hewitson	×	×	✓
Zizeeria karsandra Moore	×	×	✓
HESPERIIDAE			
Borbo cinnara Wallace	✓	✓	✓
Telicota sp.	✓	✓	✓
Badamia exclamationis Fabricius	✓	✓	✓
Ampitta sp.	✓	×	×
Sarangesa desahara Moore	×	✓	×
Iambrix salsala Moore	×	×	✓
Tagiades litigiosa Moschler	×	×	✓
PIERIDAE			
Catopsilia pomona Fabricius	✓	✓	✓
Eurema hecabe Linnaeus	✓	✓	✓
Leptosia nina Fabricius	✓	✓	×
PAPILIONIDAE			
Graphium agamemnon Linnaeus	×	✓	✓
Papilio clytia Linnaeus	×	×	✓
CRAMBIDAE			
Aethaloessa calidalis Guenee	✓	✓	✓
Spoladea recurvalis Fabricius	✓	×	✓
CALLIPHORIDAE			
Lucilia sp.	✓	×	✓

SARCOPHAGIDAE			
Sarcophaga sp.	×	×	✓
CHRYSOMELIDAE			
Nonathra sp.	×	×	✓

*✓= Present, ×= Absent

The frequency of insect visitors between midland and highland showed a significant difference (p= 0.003). Frequency of hymenopterans visiting *S. trilobata* showed a significant difference between lowland and highland (p= 0.001) and between midland and highland (p= 0.001). Frequency of lepidopterans visitation between lowland and midland showed a significant difference (p= 0.014).

INSECT VISITOR DIVERSITY DURING DIFFERENT SEASON

The frequency of insect visit was higher in all the three altitudes during Post-Monsoon, the highest in highland (54.86%) followed by lowland (51.21%) and midland (58.59%). The frequency of insect visit was lower during Pre-Monsoon in all the three altitudes. Shannon diversity index was higher during Post- Monsoon in all the three study areas (Table 12). Evenness index was the highest during Post-Monsoon.

Table 12. Species diversity indices of insect floral visitors to *Sphagneticola trilobata* during different seasons

PARAMETERS STUDIED	PRE-MONSOON	MONSOON	POST-MONSOON
SHANNON DIVERSITY INDEX (**H’**)	**1.7652**	**2.6511**	**2.8728**
EVENNESS INDEX (**E_{var}**)	**0.8010**	**0.8279**	**0.8304**

Frequency of *A. cerana* was higher during Monsoon in both midland (67.56%) and highland (67.68%), whereas it was higher during Post- Monsoon in lowland (49.59%). Papilionids were seen only during Post- Monsoon season. Frequency of insect visitation to *S. trilobata* is given in Table 13.

Table 13. Frequency of insect visitation at three altitudes during the three seasons on *Sphagneticola trilobata*.

INSECT VISITORS	**LOWLAND**			**Σ A**	**MIDLAND**			**Σ B**	**HIGHLAND**			**Σc**	**Σ**
	Pre-M.	**M.**	**Post-M.**		**Pre-M.**	**M.**	**Post-M.**		**Pre-M.**	**M.**	**Post-M.**		
Apis cerana indica Fabricius	14	48	61	123	0	50	24	74	0	155	74	229	426
Apis dorsata laboriosa Fabricius	0	7	16	23	0	35	45	80	0	0	73	73	176
Apis florea Fabricius	0	13	6	19	0	2	5	7	0	0	0	0	26
Ceratina hieroglyphica Smith	4	10	9	23	1	11	7	19	0	15	20	35	77
Ceratina sp.	0	0	2	2	1	1	0	2	0	0	0	0	4
Braunsapis sp.	0	1	6	7	0	2	5	7	1	0	0	1	15
Xylocopa sp.	0	0	0	0	0	0	1	1	0	0	0	0	1
Amegilla zonata Linnaeus	0	0	0	0	0	0	2	2	0	0	1	1	3
Megachile sp.	0	5	3	8	2	4	0	6	0	3	0	3	17
Nomia sp.	1	70	39	110	2	12	10	24	3	4	10	17	151
Halictus sp.	1	0	1	2	0	0	0	0	0	0	0	0	2
Scolia sp.	0	14	17	31	0	3	16	19	0	0	3	3	53
Bembix sp.	0	4	9	13	0	6	11	17	0	1	1	2	32
Euploea core Cramer	1	6	5	12	0	0	6	6	0	0	1	1	19
Tirumala limniace Cramer	0	4	3	7	0	4	6	10	0	0	10	10	27
Junonia atlites Linnaeus	0	8	18	26	0	6	29	35	0	11	12	23	84
Junonia lemonias Linnaeus	0	4	3	7	0	0	0	0	0	0	5	5	12
Junonia almana Linnaeus	0	0	19	19	0	7	33	40	0	0	5	5	64
Junonia	0	0	0	0	0	1	2	3	0	2	7	9	12

iphita Cramer													
Hypolimnas bolina Linnaeus	0	0	1	1	0	1	1	2	0	0	2	2	5
Danaus chrysippus Linnaeus	0	1	0	1	0	2	9	11	0	0	0	0	12
Acraea terpsicore Linnaeus	0	1	0	1	0	5	1	6	0	0	0	0	7
Phalanta phalantha Drury	0	0	1	1	0	0	0	0	0	0	0	0	1
Neptis hylas Linnaeus	0	1	0	1	0	1	0	1	0	0	0	0	2
Ypthima huebneri Kirby	0	0	0	0	0	2	0	2	0	10	19	29	31
Vindula erota Fabricius	0	0	0	0	0	0	0	0	0	0	1	1	1
Tarucus ananda Niceville	0	1	0	1	0	0	0	0	0	0	0	0	1
Zizula hylax Fabricius	0	5	0	5	0	0	0	0	0	0	0	0	5
Euchrysops cnejus Fabricius	0	4	1	5	0	0	0	0	0	0	0	0	5
Spindasis vulcanus Fabricius	0	0	1	1	0	0	0	0	0	0	0	0	1
Castalius rosimon Fabricius	0	3	1	4	0	6	0	6	0	0	0	0	10
Chilades pandava Horsfield	1	10	5	16	0	3	3	6	0	14	2	16	38
Rapala manea Hewitson	0	0	0	0	0	0	0	0	0	0	3	3	3
Zizeeria karsandra Moore	0	0	0	0	0	0	0	0	0	1	0	1	1
Borbo cinnara Wallace	1	8	35	44	0	3	26	29	0	2	49	51	124
Telicota sp.	0	8	11	19	0	3	6	9	0	11	14	25	53
Badamia exclamationis	0	1	2	3	0	2	0	2	0	28	17	45	50

Fabricius													
Ampitta sp.	0	0	1	1	0	0	0	0	0	0	0	0	1
Sarangesa desahara Moore	0	0	0	0	0	1	0	1	0	0	0	0	1
Iambrix salsala Moore	0	0	0	0	0	0	0	0	0	3	8	11	11
Tagiades litigiosa Moschler	0	0	0	0	0	0	0	0	0	0	1	1	1
Catopsilia pomona Fabricius	0	1	1	2	0	1	1	2	0	0	1	1	5
Eurema hecabe Linnaeus	0	5	3	8	0	2	6	8	0	8	9	17	33
Leptosia nina Fabricius	0	2	0	2	0	0	2	2	0	0	0	0	4
Graphium agamemnon Linnaeus	0	0	0	0	0	0	2	2	0	0	1	1	3
Papilio clytia Linnaeus	0	0	0	0	0	0	0	0	0	0	1	1	1
Aethaloessa calidalis Guenee	0	11	3	14	0	1	0	1	0	1	2	3	18
Spoladea recurvalis Fabricius	0	0	9	9	0	0	0	0	0	7	0	7	16
Lucilia sp.	0	2	3	5	0	0	0	0	0	8	3	11	16
Sarcophaga sp.	0	0	0	0	0	0	0	0	0	3	0	3	3
Nonathra sp.	0	0	0	0	0	0	0	0	0	1	0	1	1
∑	23	258	295	**576**	6	177	259	**442**	4	288	355	**647**	**1665**

*Pre-M. =Pre-Monsoon, M. = Monsoon, Post-M. =Post-Monsoon, ∑A=Sum of frequency of insect visitation to Lowland; ∑B=Sum of frequency of insect visitation to Midland, ∑C= Sum of frequency of insect visitation to Highland

Shannon diversity index during Post- Monsoon was highest in lowland (2.79086) followed by midland (2.74085) and highland (2.59201). Diversity index was lowest during Pre- Monsoon at all three altitudes, with highland having the lowest diversity index (0.56234). Frequency of hymenopteran visitation between Pre-Monsoon and Monsoon ($p= 0.026$) and between Monsoon and Post-Monsoon (p= 0.007) shows a significant difference. Evenness index was highest during Pre-Monsoon at all three altitudes (Table 14).

Table 14. Species diversity indices of insect visitors to *Sphagneticola trilobata* during different seasons at three altitudes

PARAMETERS STUDIED	LOWLAND			MIDLAND			HIGHLAND		
	Pre-M.	**M.**	**Post-M.**	**Pre-M.**	**M.**	**Post-M.**	**Pre-M.**	**M.**	**Post-M.**
SHANNON DIVERSITY INDEX (**H'**)	**1.2880**	**2.6359**	**2.7908**	**1.3296**	**2.6112**	**2.7408**	**0.5623**	**1.8827**	**2.5920**
EVENNESS INDEX (**E_{var}**)	**0.7945**	**0.7931**	**0.7885**	**0.9435**	**0.8018**	**0.7789**	**0.8813**	**0.8294**	**0.8023**

*Pre-M. =Pre-Monsoon, M. = Monsoon, Post-M. =Post-Monsoon

INSECT VISITOR DIVERSITY DURING DIFFERENT PHASES OF THE DAY

The frequency of hymenopterans visiting *S. trilobata* was higher during Early phase and reduced as the day progressed and was lowest during Late phase. The frequency of lepidopterans visiting *S. trilobata* increased as the day progressed and was highest during Middle phase and lowest during Late phase. Frequency of hymenopteran visitation showed a significant difference between Early and Late Phase (p=0.043). Evenness index was highest during Early phase (0.817422). Table 15 shows the species diversity indices of insect visitors during different phases.

Table 15. Species diversity indices of insect visitors to *Sphagneticola trilobata* during different phases

PARAMETERS STUDIED	EARLY PHASE	MIDDLE PHASE	LATE PHASE
SHANNON DIVERSITY INDEX (**H'**)	**2.8303**	**2.8377**	**2.6826**
EVENNESS INDEX (**E_{var}**)	**0.8174**	**0.8159**	**0.8054**

Evenness index was higher during Late phase in both midland (0.8014) and highland (0.8123), whereas it was higher during Early Phase in lowland (0.7977) (Table 16).

Table 16. Species diversity indices of insect visitors to flowers of *Sphagneticola trilobata* during three phases at three altitudes

PARAMETERS STUDIED	LOWLAND			MIDLAND			HIGHLAND		
	E.P.	**M.P.**	**L.P.**	**E.P.**	**M.P.**	**L.P.**	**E.P.**	**M.P.**	**L.P.**
SHANNON DIVERSITY INDEX (**H'**)	**2.5370**	**2.7806**	**2.8212**	**2.7838**	**2.8427**	**2.4253**	**2.5389**	**2.4590**	**2.2200**
EVENNESS INDEX (**E_{var}**)	**0.7977**	**0.7895**	**0.7881**	**0.7801**	**0.7832**	**0.8014**	**0.7935**	**0.7971**	**0.8123**

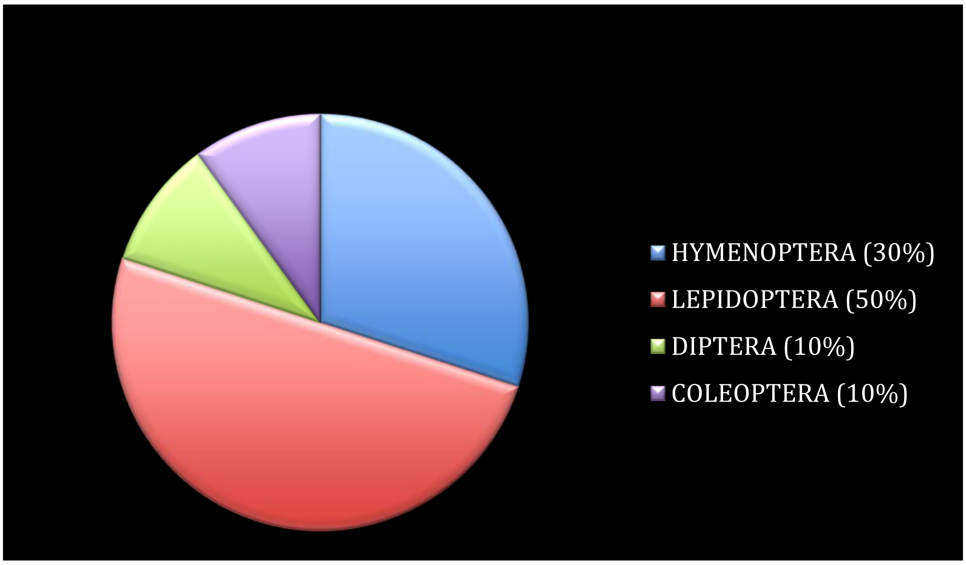
*E.P. =Early Phase, M.P. =Middle Phase, L.P. =Late Phase

Mimosa diplotricha C. Wright ex Sauvalle var. *diplotricha*

Insect Visitors to *Mimosa diplotricha*

Total of 21 species of insect visitors belonging to 10 families were reported from *Mimosa diplotricha* (Fig. 7). Bees constituted 91.68 % of the total flower visitors. Percentage frequency of visits were higher for Apidae (82.3%), followed by Halictidae (8.70%). Among the different bee species, *Tetragonula iridipennis* (36.89%) was the predominant followed by *A. dorsata* (25.44%).

Fig.7. Percentage of species belonging to different insect orders visiting flowers of *Mimosa diplotricha*



Among lepidopterans, Pieridae (4 species) was the dominant family (Fig. 8). Lycaenids (*Chilades pandava*) showed a higher percentage frequency of visits (2.60%) to *M. diplotricha* (Fig. 9).

Fig. 8. Number of species of insects belonging to different families visiting flowers of *Mimosa diplotricha*

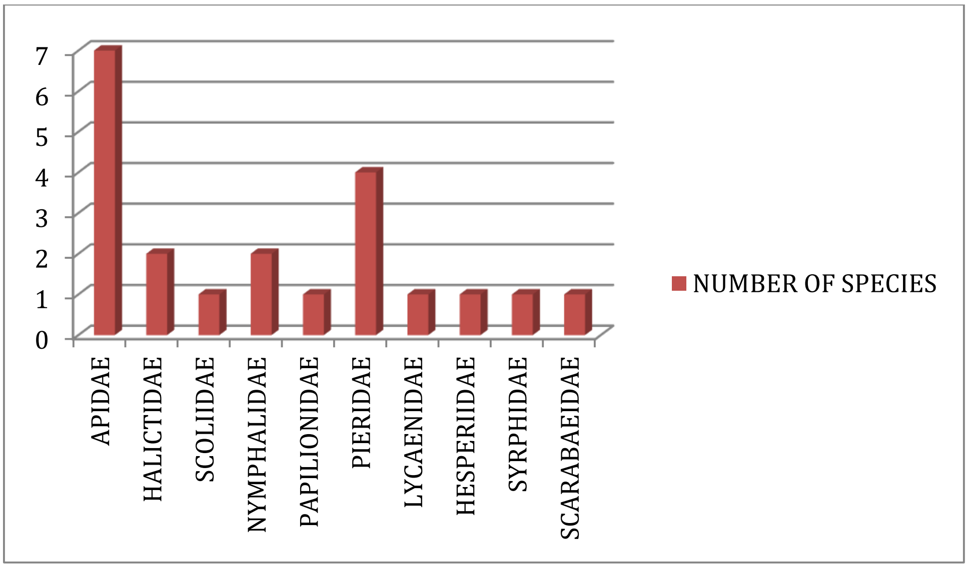
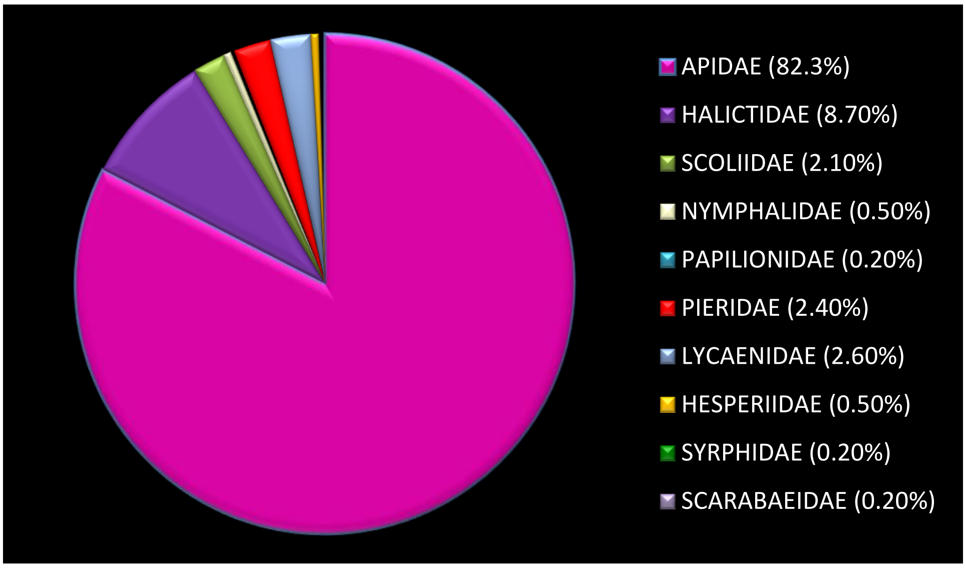


Fig. 9. Percentage frequency of insects of different families visiting flowers of *Mimosa diplotricha*



INSECT VISITOR DIVERSITY IN DIFFERENT ALTITUDES ON *M. diplotricha*

The number of insect visitors to *Mimosa diplotricha* in lowland (19 species) was higher than midland (11 species) and highland (11 species). Lowland showed a higher Shannon diversity index (2.22591) followed by highland (1.5952) and midland (1.40814) (Table 17). The frequency of insect visits was higher in highland (43.70%) than lowland (33.2%) and midland (23.05%). Evenness index was higher in midland (0.81531) followed by highland (0.81522) and lowland (0.78041).

Table 17. Species diversity indices of insect visitors to *Mimosa diplotricha* at three altitudes

PARAMETERS STUDIED	LOWLAND	MIDLAND	HIGHLAND
SHANNON DIVERSITY INDEX (**H'**)	**2.22591**	**1.40814**	**1.5952**
SIMPSON'S DIVERSITY INDEX (**D**)	**0.85817**	**0.60438**	**0.73170**
EVENNESS INDEX ($\mathbf{E_{var}}$)	**0.78041**	**0.81531**	**0.81522**
TOTAL SPECIES	**19**	**11**	**10**
MEAN INDIVIDUAL ± S.E.	**4.8803 ± 0.39633**	**5.7938 ± 0.50426**	**3.7826 ± 0.30221**

Among hymenopterans, *Tetragonula iridipennis* was the most dominant visitor in midland (60.82%) and highland (36.41%), whereas in lowland, *Apis cerana* was the frequent visitor (23.57%). In lowland, out of the total 19 species, the highest number of species was recorded from Hymenoptera (10 species) followed by Lepidoptera (7 species), Coleoptera (1 species) and Diptera (1 species). In midland, out of the total 11 species, highest number was recorded from Hymenoptera (7 species) followed by Lepidoptera (4 species). In highland, out of the 11 species, Hymenoptera (8 species) had the highest number of species, followed by Lepidoptera (3 species). *Mimosa diplotricha* flowers kept open to insect visit produced 18- 19 pods. Whereas, insect visitors were excluded from the flower by bagging, no pods were formed. Insects visiting *M. diplotricha* at three altitudes are shown in Table 19 (Plate 13- 14). The insect species richness on flowers of *M. diplotricha* is given in Table 18.

Table 18. Number of species of insects belonging to different families visiting *Mimosa diplotricha* at three altitudes

FAMILIES	LOWLAND	MIDLAND	HIGHLAND
Apidae	7	5	6
Halictidae	2	2	2
Scoliidae	1	0	0
Syrphidae	1	0	0
Nymphalidae	1	0	1
Pieridae	4	2	1
Papilionidae	0	1	0
Hesperiidae	1	1	0
Lycaenidae	1	0	1
Scarabaeidae	1	0	0

Table 19. Insect floral Visitors to *Mimosa diplotricha* at three altitudes

INSECT VISITORS	**LOWLAND**	**MIDLAND**	**HIGHLAND**
APIDAE			
Apis cerana Fabricius	✓	✓	✓
Apis dorsata laboriosa Fabricius	✓	✓	✓
Apis florea Fabricius	✓	✓	✓
Tetragonula iridipennis Smith	✓	✓	✓
Amegilla zonata Linnaeus	✓	✓	✓
Ceratina hieroglyphica Smith	✓	×	×
Xylocopa sp.	✓	×	✓
HALICTIDAE			
Nomia sp.	✓	✓	✓

Halictus sp.	✓	✓	✓
SCOLIIDAE			
Scolia sp.	✓	×	×
SYRPHIDAE			
Mesembrius sp.	✓	×	×
PIERIDAE			
Catopsilia pomona Fabricius	✓	✓	✓
Eurema hecabe Linnaeus	✓	×	×
Delias eucharis Drury	✓	✓	×
Leptosia nina Fabricius	✓	×	×
NYMPHALIDAE			
Junonia almana Linnaeus	✓	×	×
Ypthima huebneri Kirby	×	×	✓
PAPILIONIDAE			
Graphium agamemnon Linnaeus	×	✓	×
HESPERIIDAE			
Borbo cinnara Wallace	✓	✓	×
LYCAENIDAE			
Chilades pandava Horsfield	✓	×	✓
SCARABAEIDAE			
Flower chafer	✓	×	×

*✓= Present, ×= Absent

Frequency of hymenopterans visiting *M. diplotricha* was significantly different between lowland and midland ($p= 0.044$), between lowland and highland ($p=0.009$) and between midland and highland ($p= 0.001$).

INSECT VISITOR DIVERSITY DURING POST- MONSOON

Frequency of Insect floral visitors during Post- Monsoon to *Mimosa diplotricha* is shown in Table 20.

Table 20. Frequency of insect visitation at three altitudes during the three seasons on *Mimosa diplotricha*

INSECT VISITORS	**LOWLAND**	**MIDLAND**	**HIGHLAND**	**Σ**
	Post-Monsoon	**Post-Monsoon**	**Post-Monsoon**	
Apis cerana Fabricius	33	3	20	56
Apis dorsata laboriosa Fabricius	32	4	64	100
Apis florea Fabricius	8	2	6	16
Tetragonula iridipennis Smith	19	59	67	145
Amegilla zonata Linnaeus	13	2	9	24
Ceratina hieroglyphica Smith	1	0	0	1
Xylocopa sp.	5	0	2	7
Nomia sp.	10	14	3	27
Halictus sp.	1	8	1	10
Scolia sp.	7	0	0	7
Mesembrius sp.	1	0	0	1
Catopsilia pomona Fabricius	3	2	1	6
Eurema hecabe Linnaeus	1	0	0	1
Delias eucharis Drury	1	1	0	2
Leptosia nina Fabricius	1	0	0	1
Junonia almana Linnaeus	1	0	0	1
Ypthima huebneri Kirby	0	0	1	1
Graphium agamemnon Linnaeus	0	1	0	1
Borbo cinnara Wallace	1	1	0	1
Chilades pandava Horsfield	1	0	10	11
Flower chafer	1	0	0	1
Σ	**140**	**97**	**184**	**421**

INSECT VISITOR DIVERSITY DURING DIFFERENT PHASES OF THE DAY

Both hymenopterans and lepidopterans frequently visited *M. diplotricha* during Early phase. *Apis florea* visited the flowers only during Early phase. Evenness index was highest during Early phase (0.8109). Table 21 shows the species diversity indices of insect visitors visiting *M. diplotricha*.

Table 21. Species diversity indices of insect visitors to flowers of *Mimosa diplotricha* during different phases

PARAMETERS STUDIED	EARLY PHASE	MIDDLE PHASE	LATE PHASE
SHANNON DIVERSITY INDEX (**H'**)	**2.0345**	**1.8040**	**1.4442**
EVENNESS INDEX (**E_{var}**)	**0.8109**	**0.8030**	**0.7821**

In midland and highland, the Shannon diversity index was higher during Early phase (1.5386 and 1.6072 respectively). In lowland, diversity was higher during Middle phase (2.2208) (Table 22). Diversity was lowest during Late phase at all the three altitudes.

Table 22. Species diversity indices of insect visitors to flowers of *Mimosa diplotricha* during three phases at three altitudes

PARAMETERS STUDIED	**LOWLAND**			**MIDLAND**			**HIGHLAND**		
	E.P.	**M.P.**	**L.P.**	**E.P.**	**M.P.**	**L.P.**	**E.P.**	**M.P.**	**L.P.**
SHANNON DIVERSITY IN6DEX (**H'**)	**2.1166**	**2.2208**	**1.2730**	**1.5386**	**1.0022**	**0**	**1.6072**	**1.5431**	**0.9303**
EVENNESS INDEX (**E_{var}**)	**0.7712**	**0.8492**	**0.8911**	**0.7962**	**0.7869**	**0.9618**	**0.7837**	**0.7765**	**0.7632**

*E.P. =Early Phase, M.P. =Middle Phase, L.P. =Late Phase

Foraging of Insect Visitors on flowers of *Lantana camara*

Among hymenopterans visiting *Lantana camara*, the foraging time was shortest for *Amegilla zonata* and *Xylocopa* sp. (1 sec). Fig. 10 shows the average time spent by hymenopterans foraging on *L. camara* at three altitudes. Among hymenopterans, *A. zonata* recorded the highest visitation rates (17.8750 ± 2.84823) in midland (Fig. 16). Visitation rate of *A. zonata* was higher during Late phase (21.5382 ± 0.02564) compared to Middle (17.4980 ± 1.96839) and Early phase (14.0950 ± 1.17915) (Fig. 28). It spent an average of 1.0087 second per floret.

There is a significant difference in the visitation rate of *A. zonata* between Early and Late phase (p= 0.045). *Ceratina hieroglyphica* foraged only in highland and spent more time on flowers than other hymenopterans (mean 3.8 sec). Visitation rate of hymenopterans showed a significant difference between Early and Late phase (p= 0.044). *Ceratina hieroglyphica* was more active and spent more time (mean 4.5 sec) on flowers during Early phase (Fig. 22).

Time spent by lepidopterans showed a significant difference between lowland and highland (p= 0.001) and between midland and highland (p= 0.001). There is a significant difference in the time spent by lepidopterans between Pre-Monsoon and Post- Monsoon (p= 0.003) and between Monsoon and Post- Monsoon (p= 0.001). Visitation rate of lepidopterans was significantly different between lowland and midland (p= 0.046), between lowland and highland (p= 0.001) and between midland and highland (p= 0.001). There is a significant difference in the visitation rate of lepidopterans between Pre-Monsoon and Monsoon (p= 0.001), between Pre-Monsoon and Post- Monsoon (p= 0.012).

Macroglossum sp. showed a higher mean visitation rate during the Late phase (30.2305 ± 4.63712). The time spent by *Macroglossum* sp. was significantly different between lowland and midland (p= 0.010), between lowland and highland (p=0.001) and between midland and highland (p= 0.001).

Eurema hecabe spent more time in midland (7.5 sec) (Fig. 11). Their foraging time on flowers was longer during Early phase (5.2 sec) and lowest during Late phase (1 sec). *Leptosia nina* spent the longest time foraging on flowers during Middle phase (6 sec) (Fig. 23). *Catopsilia pomona* visitation rate was higher during Late phase (17.08 ± 3.2988) followed by Middle (14.0346 ± 1.80462) and Early phase (13.2830 ± 2.02284) (Fig. 29). Visitation rate of *C. pomona* showed a significant difference between lowland and highland (p= 0.019) and between midland and highland (p= 0.004). It spent more time on flowers during Early phase (2.1 sec) than the other two phases. Time spent between Early and Middle phase showed a significant difference (p= 0.011). There is a significant difference in the time spent by *C. pomona* between midland and highland (p= 0.009). A significant difference in the visitation rate between Pre- Monsoon and Monsoon (p= 0.024) and between Monsoon and Post-Monsoon (p=0.001) was observed. The number of flowers visited by *C. pomona* between lowland and highland (p= 0.037) and between Monsoon and Post-Monsoon (p= 0.030) showed a significant difference. Among Pierids, visitation rate was highest for *Cepora nerissa* (35) in midland and lowest in *L. nina* in lowland (1) (Fig. 17). *Cepora nerrisa* was seen only during Middle phase (Fig. 20). *Appias lyncida* showed a higher visitation rate during Early phase (15.3333 ± 12.38727), while, *Catopsilia pyranthe* shows a higher visitation rate during Late phase (22 ± 6).

The visitation rate (12.1760 ± 2.50322) and the average time spent (2.4 sec) on the flower by *Delias eucharis* is higher in midland. Time spent by *D. eucharis* showed a significant difference between lowland and midland (p= 0.010), between lowland and highland (p= 0.001) and between midland and highland (p= 0.001). There is a significant difference in the visitation rate between lowland and highland (p= 0.000) and between midland and highland (p= 0.001). Visitation rate of *D. eucharis* was significantly different between Pre- Monsoon and Monsoon (p= 0.004). There is a significant difference in the number of flowers visited by *D. eucharis* between lowland and midland (p= 0.002), between lowland and highland (p= 0.001) and between midland and highland (p= 0.003). The visitation rate of *D. eucharis* was higher during Early phase (13.1667 ± 2.8915) but declined as the day progressed. Number of flowers visited also showed a significant difference between

Pre- Monsoon and Monsoon (p= 0.036) and between Pre- Monsoon and Post- Monsoon (p= 0.001).

In lowland, papilionids foraged on the flowers for the shortest period (1 sec). *Pachliopta aristolochiae* (2.4 sec) and *Papilio clytia* (2.3 sec) spent the highest time foraging in midland and highland respectively (Fig. 12). *Pachliopta aristolochiae* showed higher visitation rate during Middle phase (33.8050 ± 8.92005) compared to Early (15 ± 11.06044) and Late phase (18.25 ± 8.32041) (Fig. 30). There is a significant difference in the time spent between lowland and midland (p= 0.010), between lowland and highland (p=0.001), and between midland and highland (p= 0.001). Visitation rate showed a significant difference between lowland and highland (p= 0.001) and midland and highland (p= 0.001). Visitation rate showed a significant difference between Pre- Monsoon and Monsoon (p= 0.004). Number of flowers visited by *P. aristolochiae* shows a significant difference between lowland and midland (p= 0.002), between lowland and highland (p=0.001), and between midland and highland (p= 0.003). There is a significant difference in the number of flowers visited between Pre- Monsoon and Monsoon (p= 0.036) and between Pre- Monsoon and Post- Monsoon (p= 0.001). Papilionids spent longer time foraging on *L. camara* flowers during Middle phase (Fig. 24).

Graphium sarpedon showed the highest visitation rate in lowland (38.0830 ± 4.13715) (Fig. 18) and the difference in the visitation rate between lowland and highland (p= 0.038) was significant. Number of flowers visited by *G. sarpedon* also showed a significant difference between lowland and midland (p=0.042) and had the highest visitation rate during Early phase (32.6429 ± 4.58312) and increased during Middle phase (32.9514 ± 4.16763), as the day progressed the visitation rate declined (24.6071 ± 5.27543). The visitation rate of *Graphium agamemnon* was highest during Early phase (26.9455 ± 2.66096). The visitation rate was highest in lowland (27.7891 ± 2.31239) and lowest in highland (24.9989 ± 2.46741). There is a significant difference in the visitation rate of *G. agamemnon* between lowland and highland (p=0.005), and between midland and highland (p= 0.019). Number of flowers visited by *G. agamemnon* shows a significant difference between lowland and highland (p= 0.009).

Nymphalids spent more time foraging on *L. camara* in midland. *Ypthima huebneri* (9 sec) spent longest time foraging in midland (Fig. 15). The visitation rate of *Tirumala limniace* was highest during Middle phase (13.7725 ± 2.83473). There is a significant difference in the time spent by *T. limniace* between lowland and midland (p= 0.010), between lowland and highland (p= 0.001) and midland and highland (p= 0.001). Visitation rate showed a significant difference between lowland and highland (p= 0.001) and between Pre- Monsoon and Monsoon (p= 0.004). There is a significant difference in the number of flowers visited between lowland and midland (p= 0.002), between lowland and highland (p= 0.001) and between midland and highland (p= 0.003). Number of flowers visited by *T. limniace* showed a significant difference between Pre- Monsoon and Post- Monsoon (p= 0.001).

Ideopsis vulgaris and *Cirrochroa thais* were present only in lowland. Higher visitation rate was shown by *Ideopsis vulgaris* in lowland (24), *Cupha erymanthis* and *T. limniace* in midland (17) and highland (11.12) respectively (Fig. 21). The visitation rate of *Junonia atlites* was highest during Late phase (10.591 ± 1.60084). They spent more time foraging on flowers more during Middle phase (4 sec) (Fig. 27). There is a significant difference in the time spent by *Junonia atlites* between Pre- Monsoon and Post- Monsoon (p= 0.015). The visitation rate of *J. iphita* shows a significant difference between Pre- Monsoon and Monsoon (p= 0.008) and between Post- Monsoon and Monsoon (p= 0.033). Among Nymphalids, *Tanaecia lepidea* spent the highest time (8 sec) in flowers during Early phase (Fig. 18). Among nymphalids, *Ideopsis vulgaris* had the highest visitation rate (24) during Early phase. *Tirumala limniace* and *Acraea terpsicore* had the highest visitation rate during Middle (13.77) and Late phase (20.16) respectively. The visitation rate of Nymphalids foraging on *L. camara* during different phases of the day is shown in Fig. 33.

Among Lycaenids, *Zizeeria karsandra* spent the highest time foraging in lowland (13 sec) (Fig. 14). *Chilades pandava* spent more time during Late phase

(6.5 sec). It spent more time foraging flowers in lowland (8 ± 1 secs). Time spent by *Chilades pandava* showed a significant difference between lowland and midland (p= 0.010), between lowland and highland (p= 0.001), and between midland and highland (p= 0.001). There is a significant difference in the visitation rate between lowland and highland (p= 0.001), between midland and highland (p= 0.001) and also between Pre- Monsoon and Monsoon (p= 0.004). Number of flowers visited by *C. pandava* showed a significant difference between lowland and midland (p= 0.002), between lowland and highland (p= 0.001) and between midland and highland (p= 0.003). There is a significant difference between Pre-Monsoon and Monsoon (p= 0.036) and between Pre- Monsoon and Post- Monsoon (p= 0.001). *Talicada nyseus* is present only in midland but had the highest visitation rate (6.16) among Lycaenids (Fig. 20). *Zizeeria karsandra* and *Rapala manea* was seen only during the Early phase and spent more time (13 and 11 sec respectively) on flowers compared to other Lycaenids (Fig. 26). *Chilades pandava* (3 ± 2) had the highest visitation rate during Early phase. *Talicada nyseus* visited *L. camara* only during Middle phase and had the highest visitation rate (6.165 ± 1.165). *Euchrysops cnejus* (4) had the highest visitation rate during Late phase (Fig. 32).

Sarangesa dasahara was present only in highland, but they foraged for longer duration (14.5 sec) among the other hesperiids (Fig. 13). Among hesperiids, visitation rate was highest for *Telicota* sp. (23) followed by *Pseudo cladenia dan* (21) in midland (Fig. 19). *Borbo cinnara* (4.8905 sec) spent longer time on florets in highland compared to other altitudes. There is a significant difference in the time spent by *Borbo cinnara* between lowland and highland (p= 0.023). *Pelopidas mathias* shows a higher visitation rate during Middle Phase (7.3333 ± 2.24598). *S. dasahara* spent more time on flowers during Early phase (17 ± 8) and decreased during Middle phase (12 ± 2) (Fig. 25). Among Hesperiids, *B. cinnara*, *Telicota* sp. and *P. dan* displayed the highest visitation rate during Early (8.7678 ± 1.17896), Middle (14.5 ± 8.5) and Late phase (21) respectively (Fig. 31).

FORAGING ACTIVITY AT DIFFERENT ALTITUDES

AVERAGE TIME SPENT BY INSECT VISITORS

Fig. 10. Average time spent by hymenopterans foraging on *Lantana camara* at three altitudes

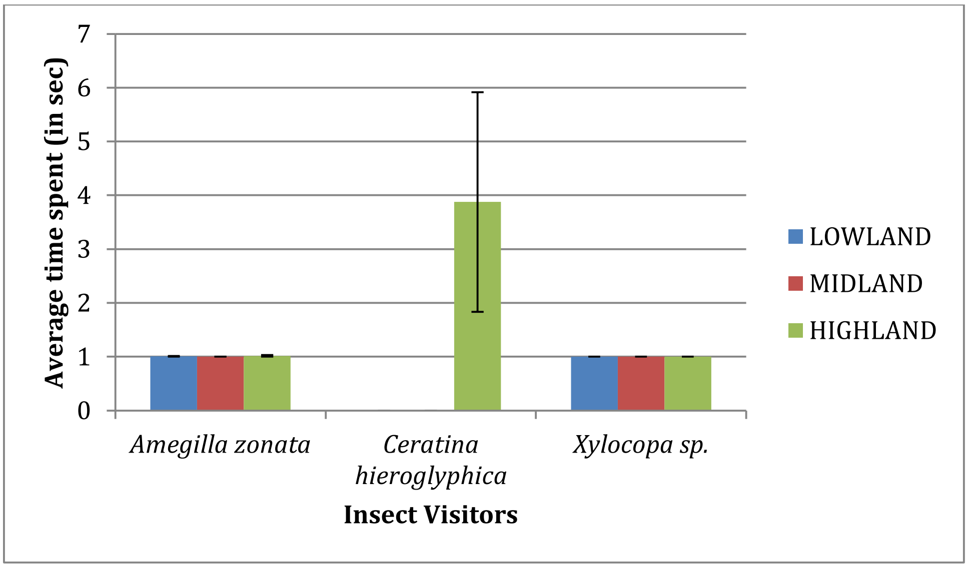


Fig. 11. Average time spent by pierids foraging on *Lantana camara* at three altitudes

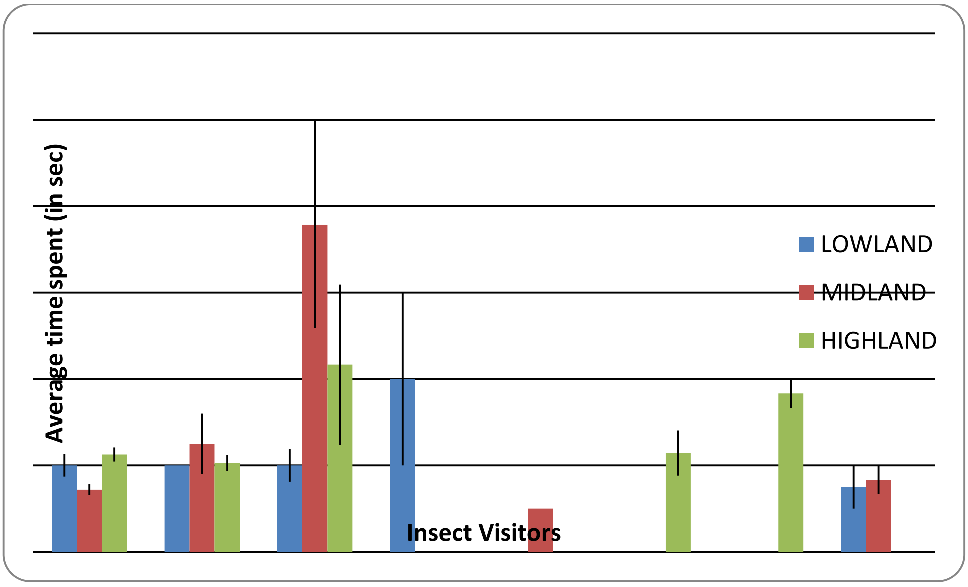


Fig. 12. Average time spent by papilionids foraging on *Lantana camara* at three altitudes

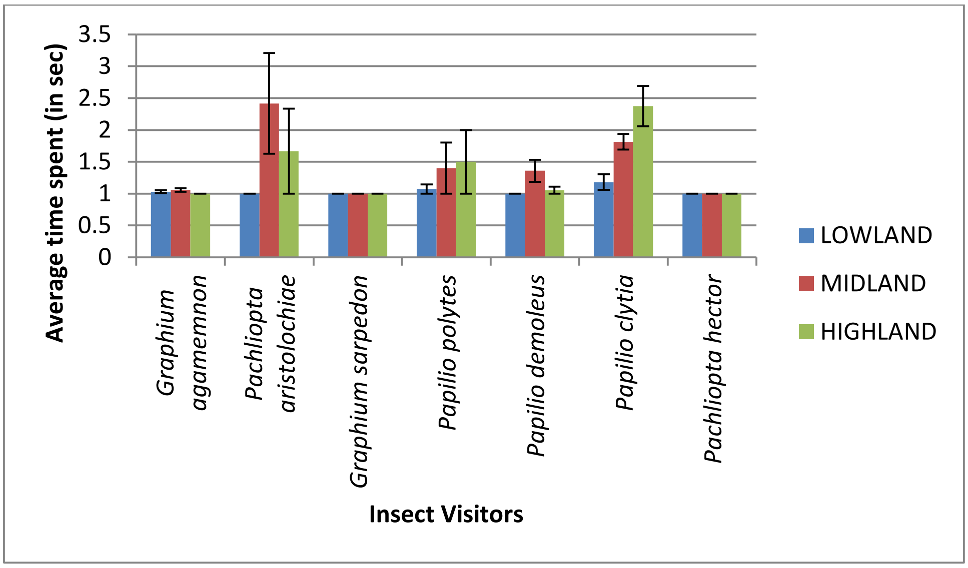


Fig. 13. Average time spent by hesperiids foraging on *Lantana camara* at three altitudes

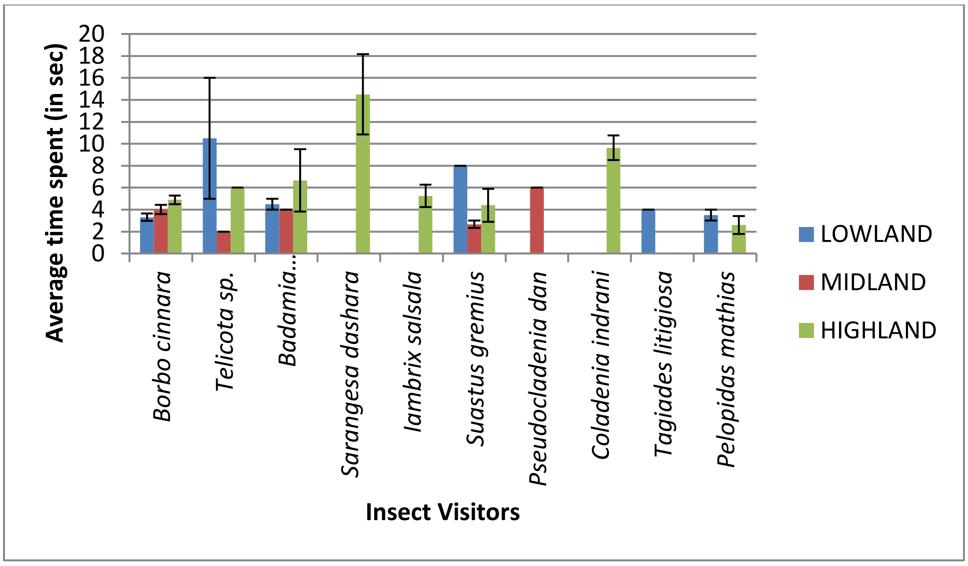


Fig. 14. Average time spent by lycaenids foraging on *Lantana camara* at three altitudes

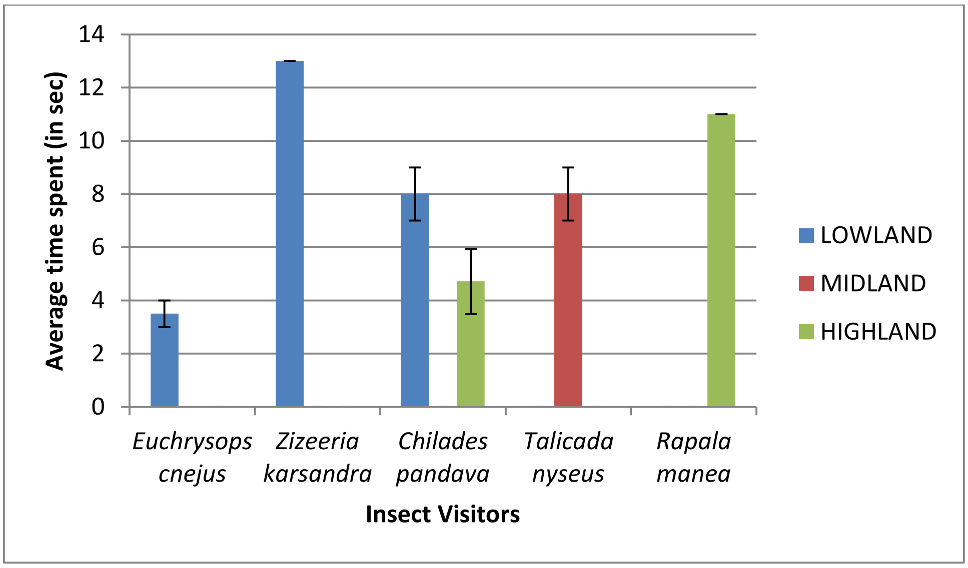
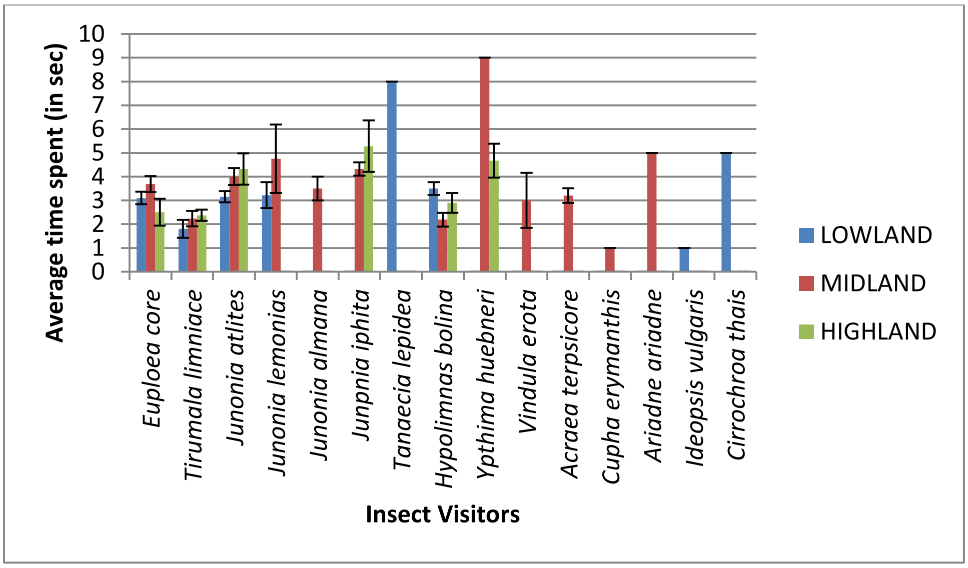


Fig. 15. Average time spent by nymphalids foraging on *Lantana camara* at three altitudes



VISITATION RATE OF INSECT VISITORS

Fig. 16. Visitation Rate of hymenopterans foraging on *Lantana camara* at three altitudes

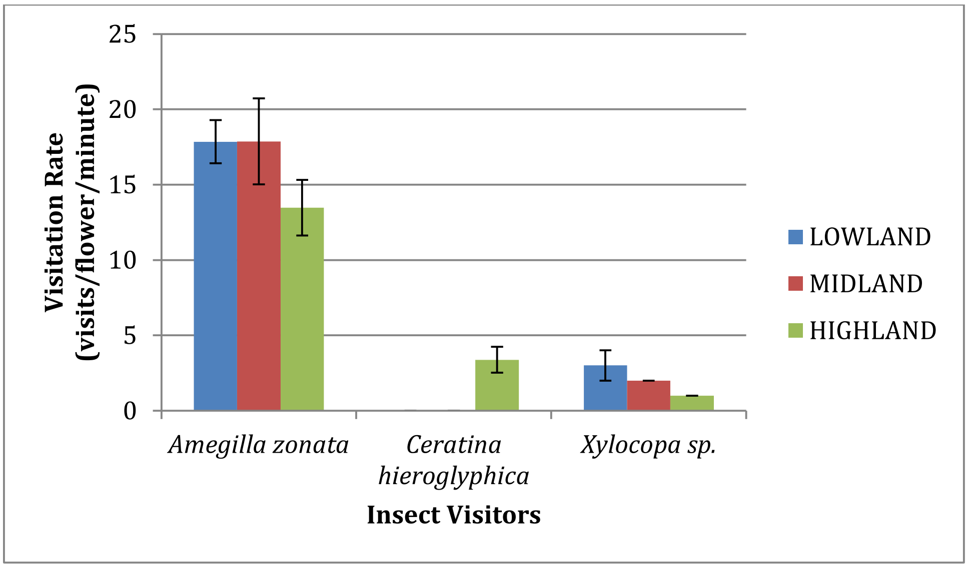


Fig. 17. Visitation Rate of pierids foraging on *Lantana camara* at three altitudes

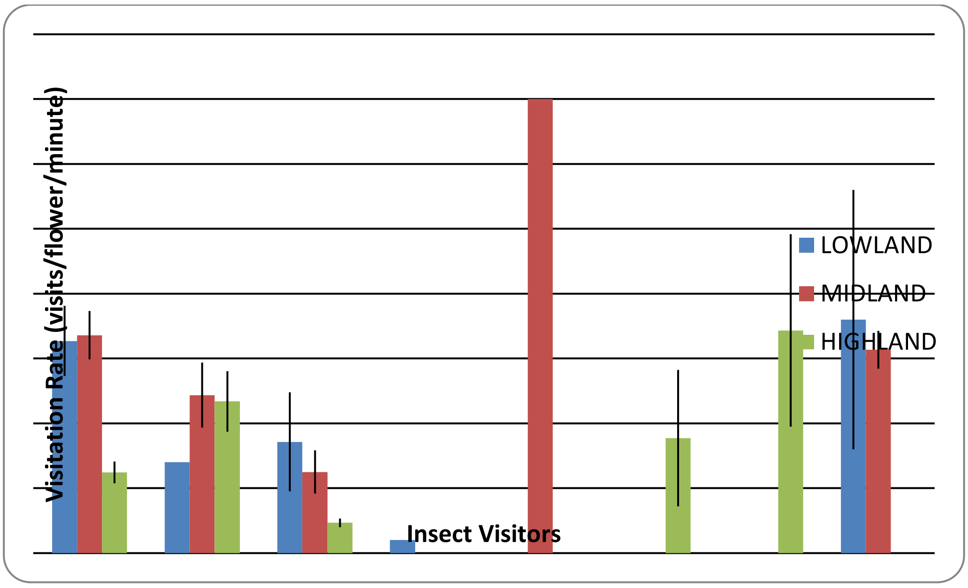


Fig. 18. Visitation Rate of papilionids foraging on *Lantana camara* at three altitudes

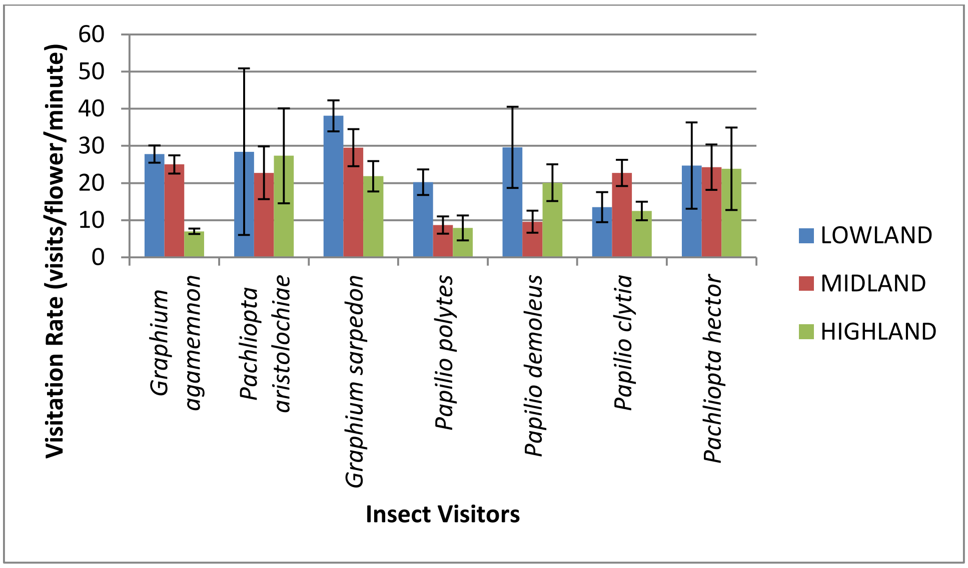


Fig. 19. Visitation Rate of hesperiids foraging on *Lantana camara* at three altitudes

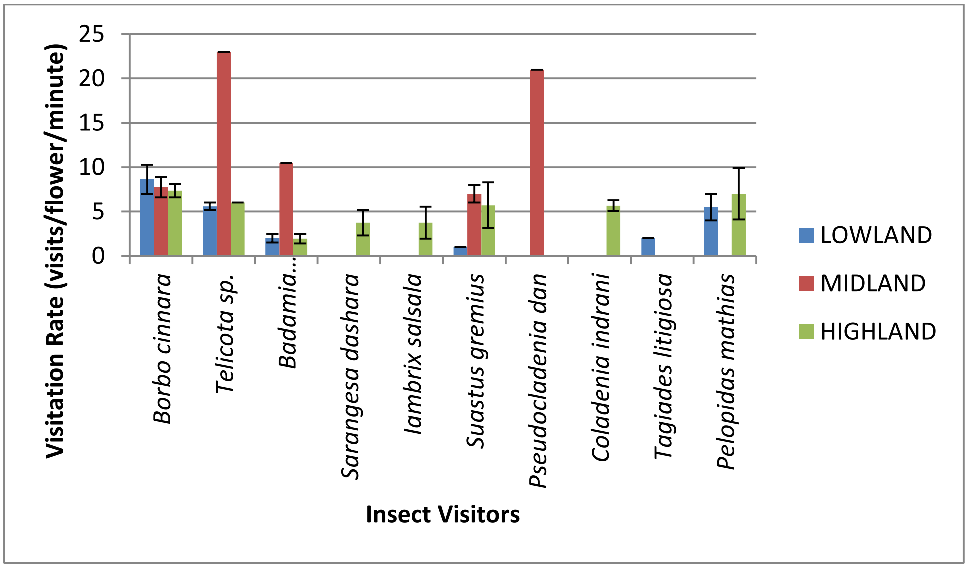


Fig. 20. Visitation Rate of lycaenids foraging on *Lantana camara* at three altitudes

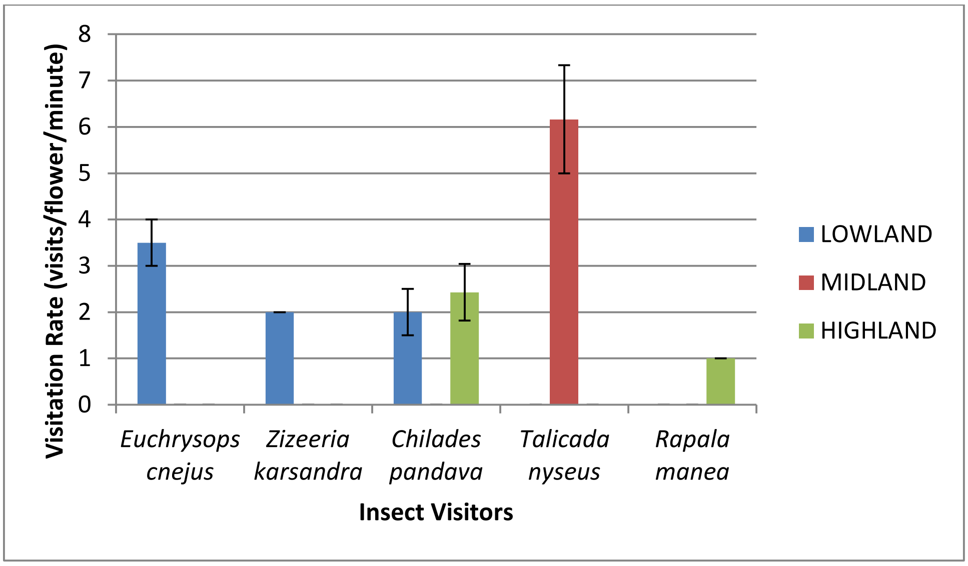
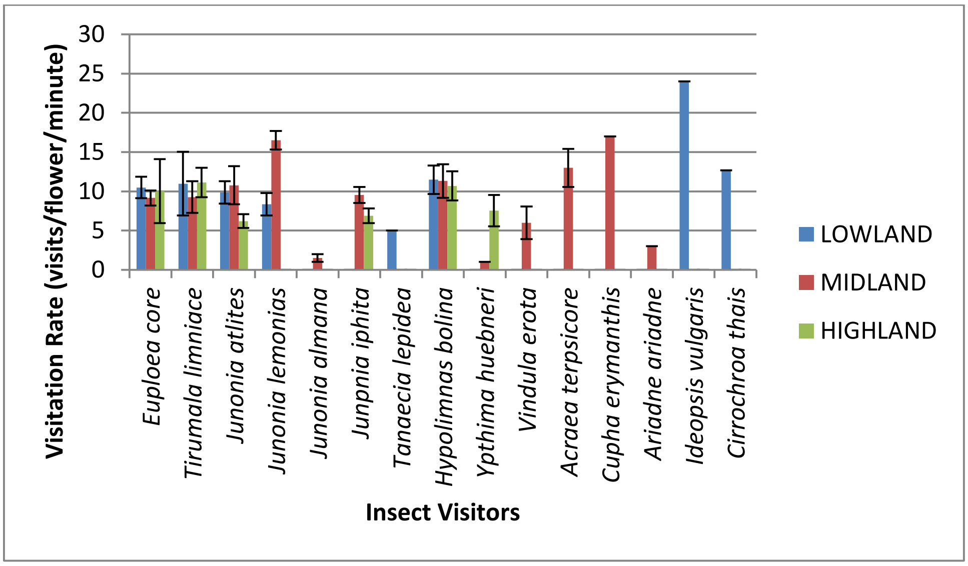


Fig. 21. Visitation Rate of nymphalids foraging on *Lantana camara* at three altitudes



FORAGING ACTIVITY DURING THE DIFFERENT PHASES OF THE DAY

AVERAGE TIME SPENT BY INSECT VISITORS

Fig. 22. Average time spent by hymenopterans foraging on *Lantana camara* during different phases of the day

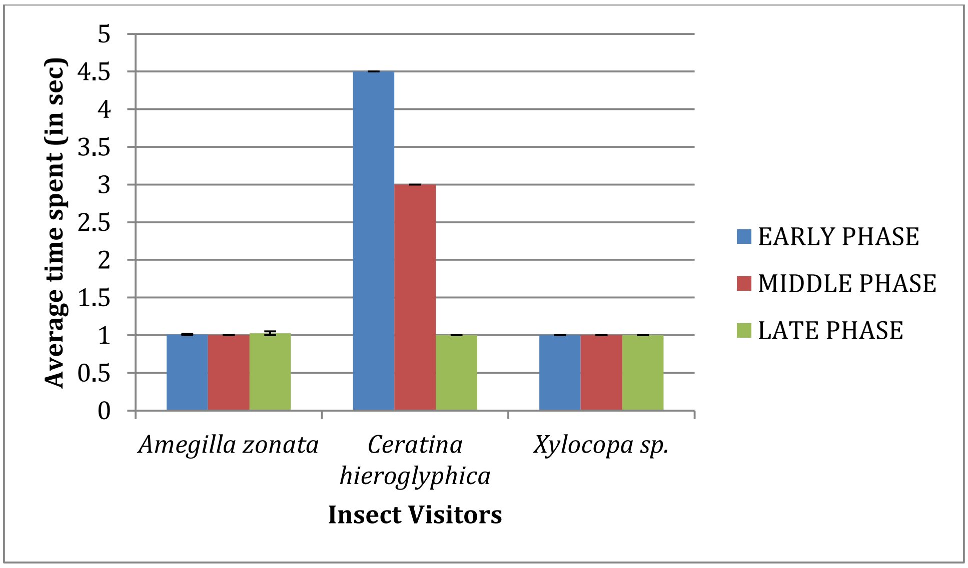


Fig. 23. Average time spent by pierids foraging on *Lantana camara* during different phases of the day

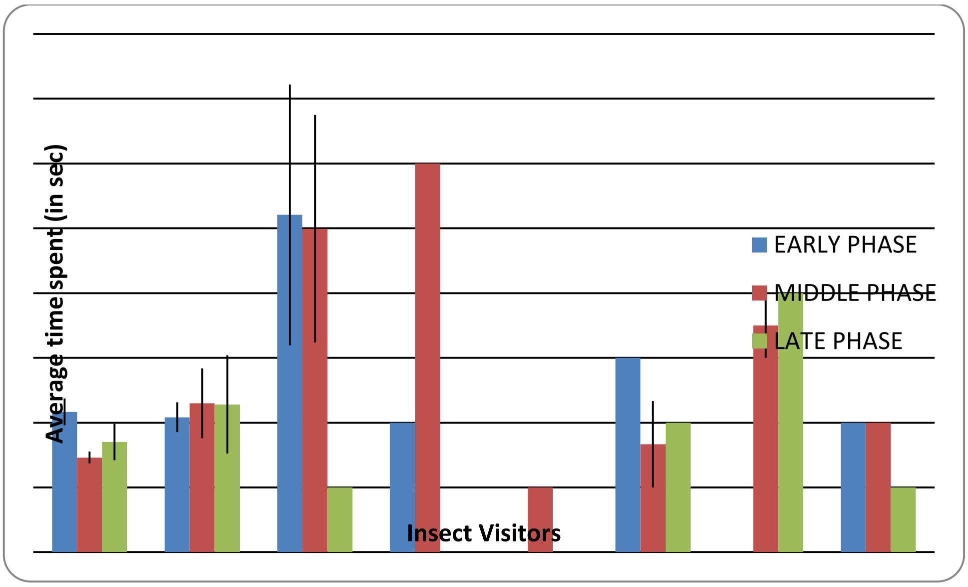


Fig. 24. Average time spent by papilionids foraging on *Lantana camara* during different phases of the day

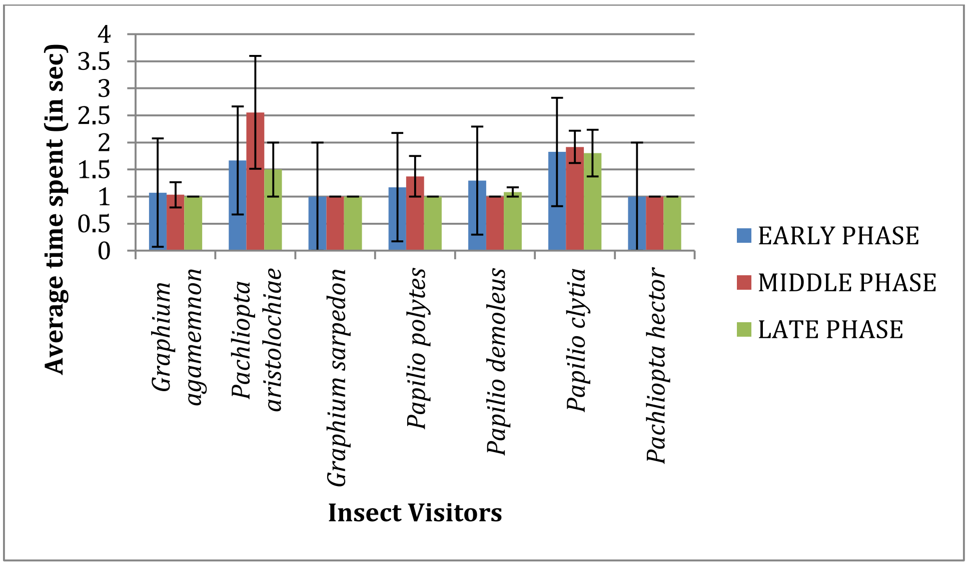


Fig. 25. Average time spent by hesperiids foraging on *Lantana camara* during different phases of the day

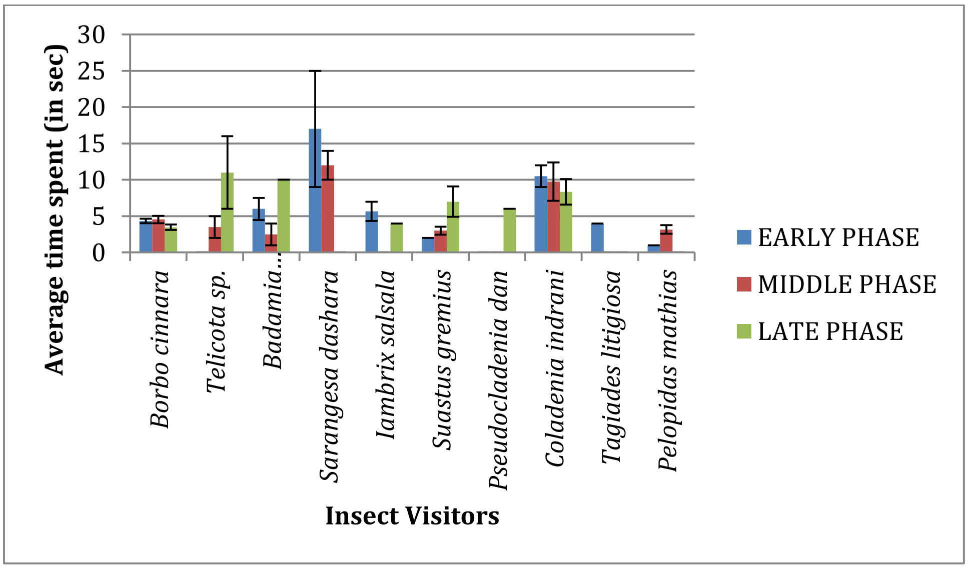


Fig. 26. Average time spent by lycaenids foraging on *Lantana camara* during different phases of the day.

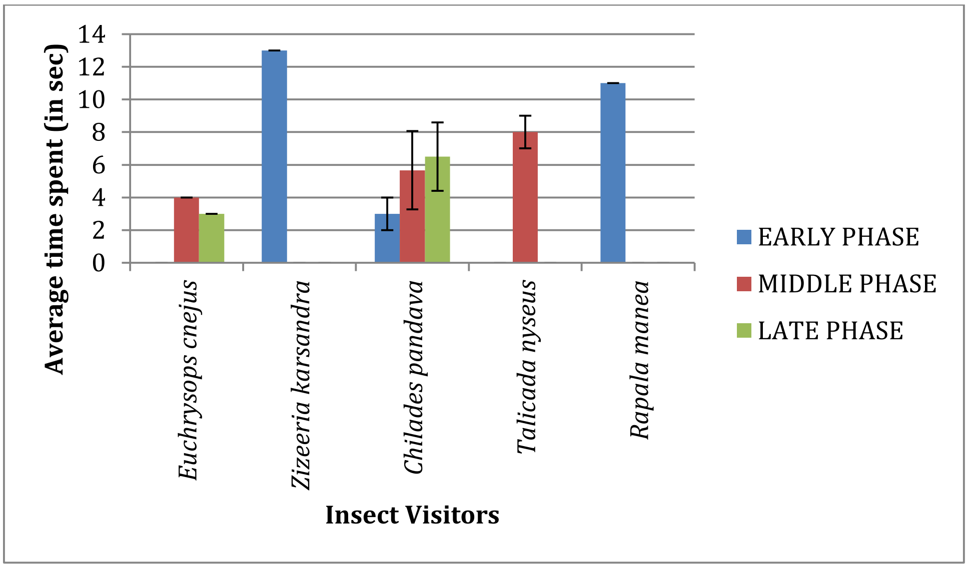
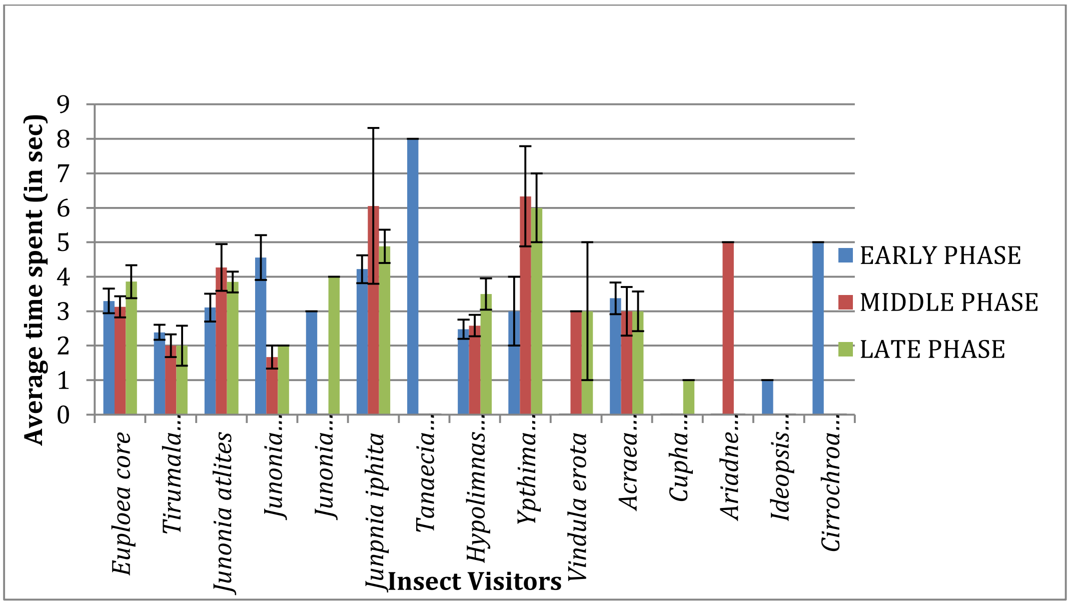


Fig. 27. Average time spent by nymphalids foraging on *Lantana camara* during different phases of the day.



VISITATION RATE OF INSECT VISITORS

Fig. 28. Visitation Rate of hymenopterans foraging on *Lantana camara* during different phases of the day

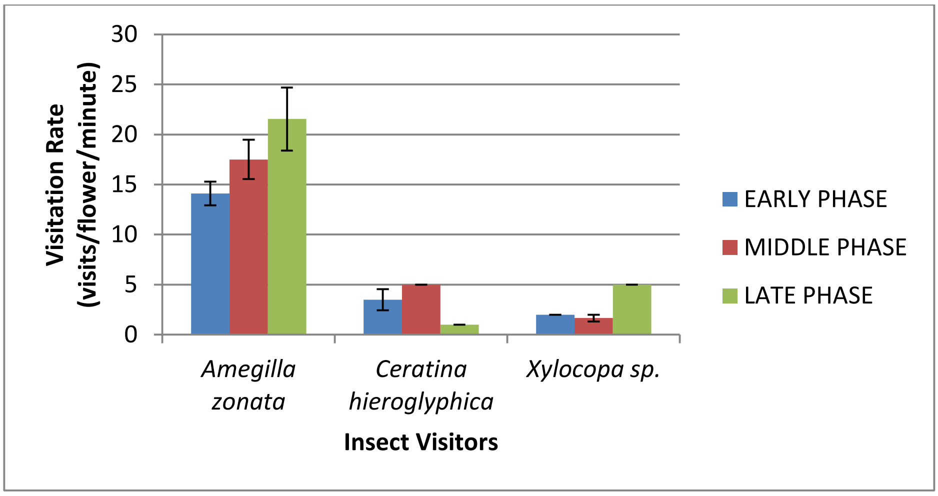


Fig. 29. Visitation Rate of pierids foraging on *Lantana camara* during different phases of the day

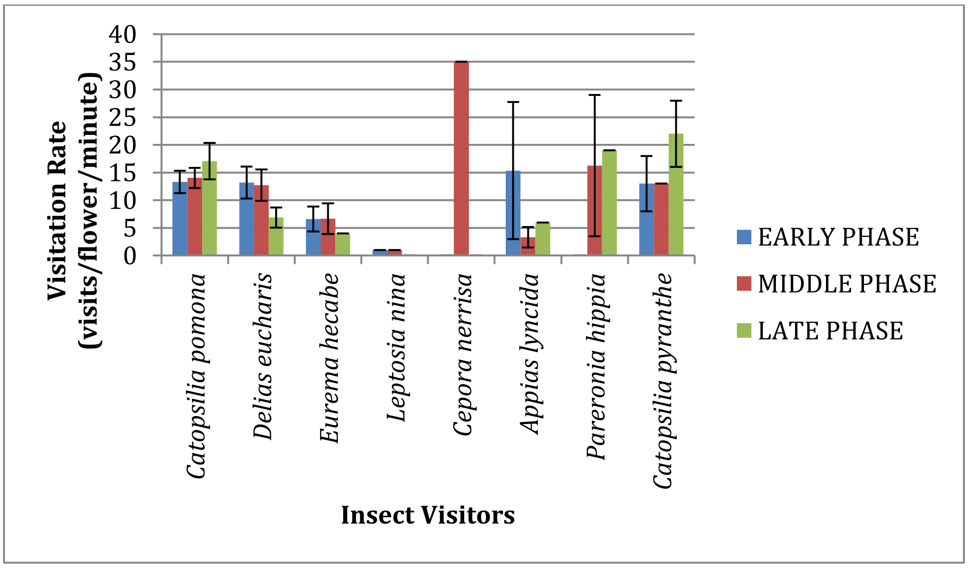


Fig. 30. Visitation Rate of papilionids foraging on *Lantana camara* during different phases of the day

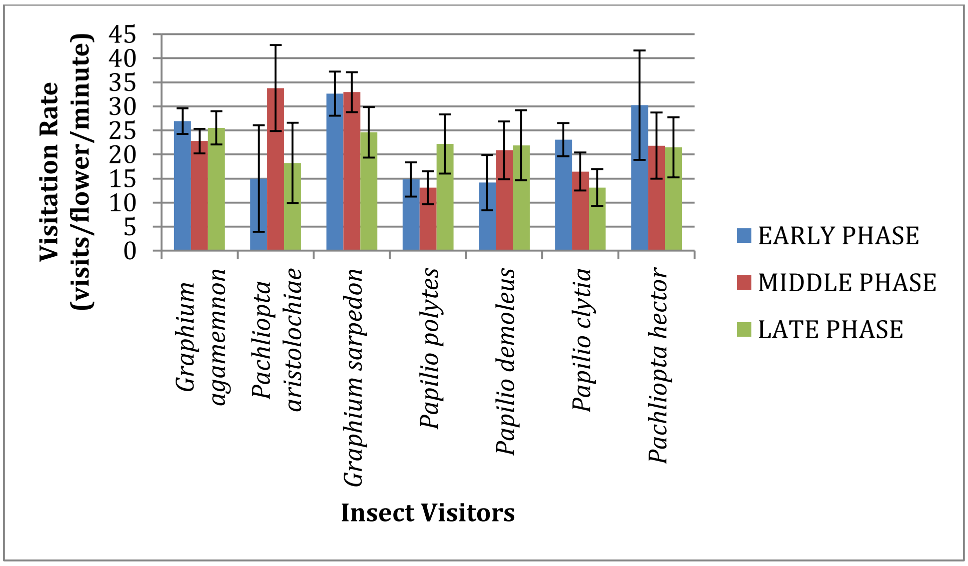


Fig. 31. Visitation Rate of hesperiids foraging on *Lantana camara* during different phases of the day

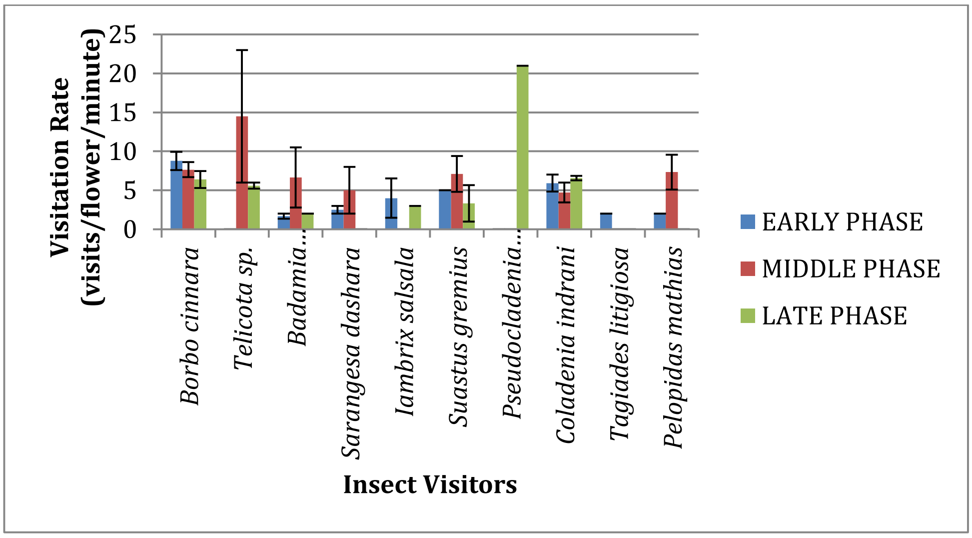


Fig. 32. Visitation Rate of lycaenids foraging on *Lantana camara* during different phases of the day

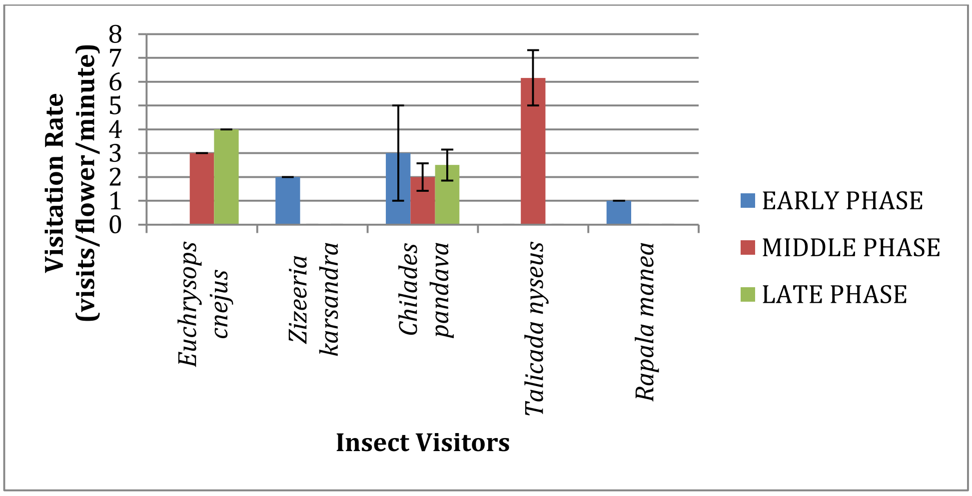
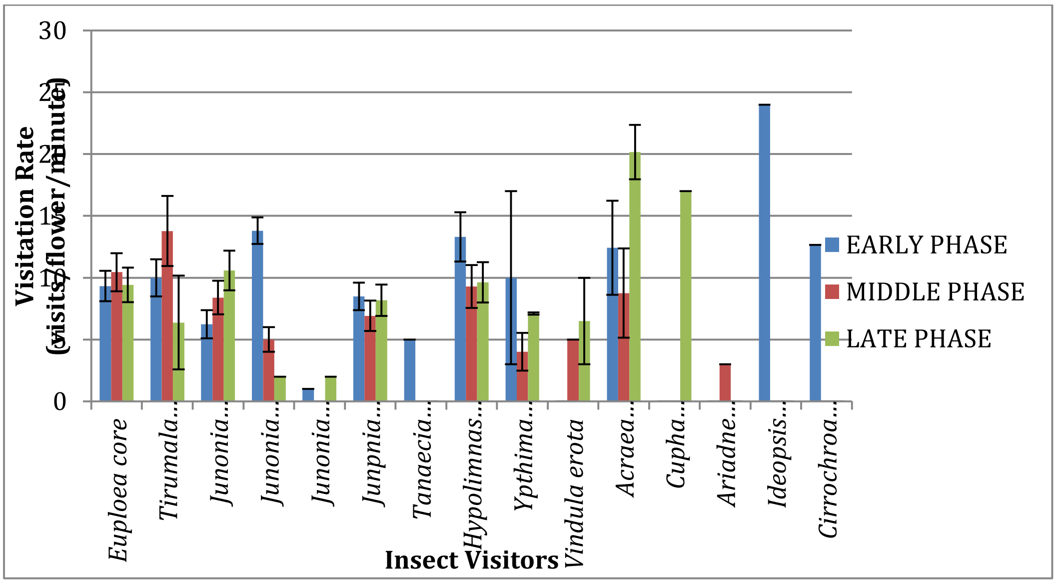


Fig. 33. Visitation Rate of nymphalids foraging on *Lantana camara* during different phases of the day



FORAGING BEHAVIOUR

Amegilla zonata frequently visited florets during all phases of the day and moved in a random manner. They hovered above the flower, extended the proboscis and fed nectar from the florets and spent an average of 1 second per floret. Plate 19 shows the pollen grains adhered on *A. zonata*. Lepidopterans inserted the proboscis into the florets in a random manner. Butterflies belonging to families Nymphalidae, Pieridae, Lycaenidae and Hesperiidae rested on the florets and probed into the floret for nectar. Whereas, papilionids, hovered above the flower, extending and inserting the proboscis into the flower while in flight. They spent less time probing for nectar (1 second) but are seen visiting a greater number of flowers. The sphingid *Macroglossum* sp. also foraged in a similar manner to papilionids. Pollen is observed sticking to the proboscis (Plate 18). Behavioural differences were observed when individuals of the same species and of different species visited flowers. For e.g. *Borbo cinnara* flew away, when *Amegilla zonata* disturbed them during foraging, whereas, *Junonia atlites* were not disturbed, when an individual of the same species visits the same inflorescence.

Sphagneticola trilobata

The visitation rate of hymenopterans was highest in highland. Visitation rate of hymenopterans between lowland and highland (p= 0.001) and between midland and highland (p= 0.001) showed a significant difference. There is also a significant difference in visitation rate of hymenopterans between Pre- Monsoon and Monsoon (p= 0.007) and between Monsoon and Post- Monsoon (p= 0.001). Time spent by hymenopterans between Pre- Monsoon and Monsoon (p= 0.001) and between Monsoon and Post- Monsoon (p= 0.001) had a significant difference.

Apis cerana was the dominant visitor to *S. trilobata* and spent an average 4.7072 seconds per floret and has the highest visitation rate among hymenopterans (9.2869 ± 7.92688). The visitation rate was higher in highland (11.0314 ± 0.66661) (Fig. 40). The time spent by *A. cerana* on flowers of *S. trilobata* is significantly different between Pre- Monsoon and Monsoon (p= 0.001), between Monsoon and Post- Monsoon (p= 0.001) and between Post- Monsoon and Pre- Monsoon (p= 0.005). There is a significant difference in the visitation rate of *A. cerana* between lowland and highland (p= 0.001) and between midland and highland (p= 0.013). Visitation rate showed a significant difference between Monsoon and Post- Monsoon (p= 0.001). The phase of the day shows a positive correlation with the time spent by *A. cerana* (p= 0.019, r= 0.114). In both lowland (7.7239 ± 0.54126 sec) and midland (8.1775 ± 0.43403 sec), *A. dorsata had* the highest visitation rate

The visitation rate of *A. cerana* (10.1017 ± 0.77813) and *A. dorsata* (8.5936 ± 0.44870) was highest during Early phase and declined as the day progressed. Whereas the visitation rate of *Megachile* sp. increased as the day progressed and was highest during Late phase (6.7767 ± 2.07795). During Middle phase, the visitation rate of *Scolia* sp. (8.7716 ± 1.29976) was highest, followed by *A. florea* (6.7614 ± 1.78453) and (Fig. 52).

Ceratina hieroglyphica spent highest time (22.6605 ± 14.14007 sec) foraging on florets in midland, followed by *A. florea* (17.6871 ± 6.41732 sec). *Nomia* sp. spent more time foraging florets in highland (15.6241 ± 5.03986 sec) compared to other altitudes (Fig. 34). There is a significant difference in the time spent by *Nomia* sp. between Monsoon and Post- Monsoon (p= 0.001) and between Early and Late phase (p= 0.005). Time spent by *Scolia* sp. showed a significant difference between lowland and midland (p= 0.011). Visitation rate of *Scolia* sp. showed a significant difference between Early and Middle phase (p= 0.015).

Ceratina hieroglyphica spent more time on flower during Early phase (20.3353 ± 8.30256 sec) followed by Middle phase (14.2709 ± 2.68364 sec) and lowest during Late phase (9.8340 ± 3.40438 sec). *Apis cerana*, *Apis dorsata*, *Apis florea* and *Nomia* sp. were seen foraging longest on florets during Late phase (5.3717± 0.40170 sec, 6.0231 ± 0.47128 sec, 21.7980 ± 7.29739 sec, 17.5621 ± 3.90384 sec respectively). The average time spent by hymenopterans foraging on *S. trilobata* during different phases of the day is shown in Fig. 46.

Time spent by lepidopterans between lowland and midland (p= 0.007) and also between Monsoon and Post- Monsoon shows a significant difference (p= 0.011). The time spent by lepidopterans on the flowers between Early and Late phase (p= 0.001) and between Middle and Late phase (p= 0.003) was significant.

Among nymphalids, in lowland (75 sec) and highland (34.25 sec), *Neptis hylas* spent highest time foraging on flowers. Among hesperiids, in highland, *Ypthima huebneri* (56.8345 ± 13.58205 sec) spent more time on florets. Fig. 35 shows the average time spent by nymphalids foraging on *S. trilobata* at all three altitudes. *Junonia almana* (2.5153 ± 0.19285) had the highest visitation rate in lowland. The visitation rate of *Euploea core* was the highest in midland (14.1150 ± 9.57460) and highland (14.1150 ± 9.57460) (Fig. 41). Time spent by *J. almana* showed a significant difference between Early and Late phase (p=0.021).

Among nymphalids, *Ypthima huebneri* spent longer time foraging during Early phase (80.38 ± 42.9737 sec), *Neptis hylas* during Middle phase (75 sec) and *Euploea core* during Late phase (48.97 ± 14.65832 sec) (Fig. 47). *Euploea core* had the highest visitation rate (10.9862 ± 7.30340) during Early phase (Fig. 53).

Telicota sp. spent longer time foraging in lowland (39.6011 ± 11.68129 sec) (Fig. 36). Among hesperiids, *Badamia exclamationis*, *Sarangesa desahara* and *Iambrix salsala* showed a high visitation rate in lowland (5 ± 4), midland (5.2564 ± 3.04397) and highland (5) respectively (Fig. 42). *Borbo cinnara* and *Telicota* sp. spent less time during Early phase (25.5929 ± 3.28165 sec and 18.1232 ± 3.67866 sec respectively), whereas they stayed longer foraging on florets during Late phase (34.7882 ± 4.00746 sec and 49.1692 ± 15.74745 sec respectively). *Iambrix salsala* foraged longer during Early phase (44.55 ± 11.52327 sec) compared to other Hesperiids (Fig. 48). *Iambrix salsala* had the highest visitation rate (35) during Middle phase (Fig. 54).

Among lycaenids, *Tarucus ananda* (56 sec) spent longer time, followed by *Spindasis vulcanus* (49 sec) in lowland (Fig. 37). *Euchrysops cnejus* has the highest visitation rate (6.532 ± 1.89236) in lowland (Fig. 43). Lycaenids spents more time foraging on florets during Middle phase (Fig. 49). *E. cnejus* showed the highest visitation rate (7.415 ± 2.16076) during Middle phase (Fig. 55).

Pierids spent more time in highland compared to others. *Catopsilia pomona* (18 sec) spent the highest time foraging on florets (Fig. 38). In lowland, *C. pomona* had the highest visitation rate (10.5 ± 5.5).The visitation rate of Pierids to *S.*

trilobata at three altitudes is shown in Fig. 44. *C. pomona* spent longer time on florets during Middle phase (12.4533 ± 3.12114 sec) (Fig. 50). During Late phase, the visitation rate (16) of *C. pomona* was the highest (Fig. 56).

Even though, *Graphium agamemnon* was present only in highland, they spent the highest time (2 sec) foraging on florets (Fig. 39) with maximum visitation rate (5.5 ± 3.5) (Fig. 45). They spent longer time during Early phase (2 sec) (Fig. 51). The visitation rate of *G. agamemnon* (5.5 ± 3.5) was higher than *Papilio demoleus* (3) during Early phase (Fig. 57).

FORAGING ACTIVITY AT DIFFERENT ALTITUDES

AVERAGE TIME SPENT BY INSECT VISITORS

Fig. 34. Average time spent by hymenopterans foraging on flowers of *Sphagneticola trilobata* at three altitudes

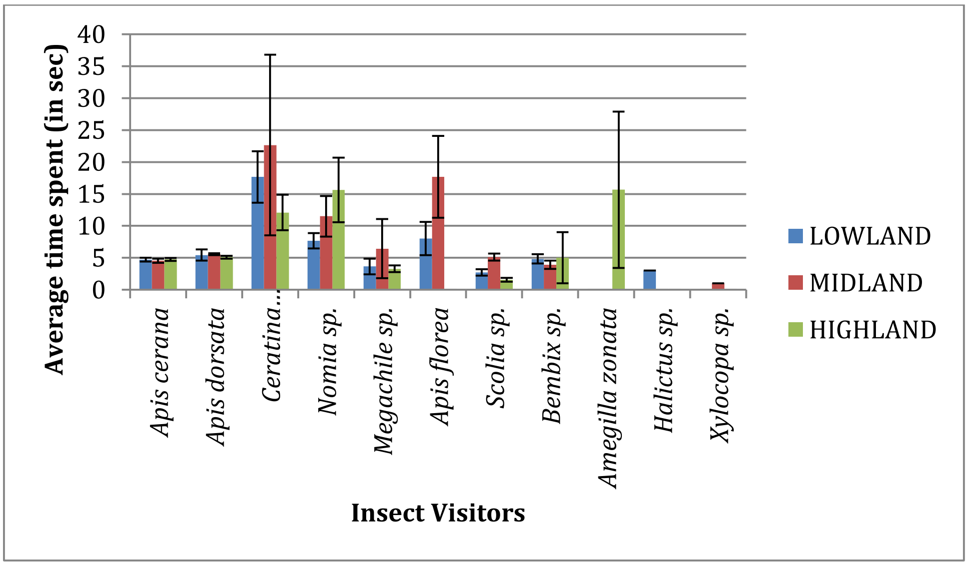


Fig. 35. Average time spent by nymphalids foraging on flowers of *Sphagneticola trilobata* at three altitudes

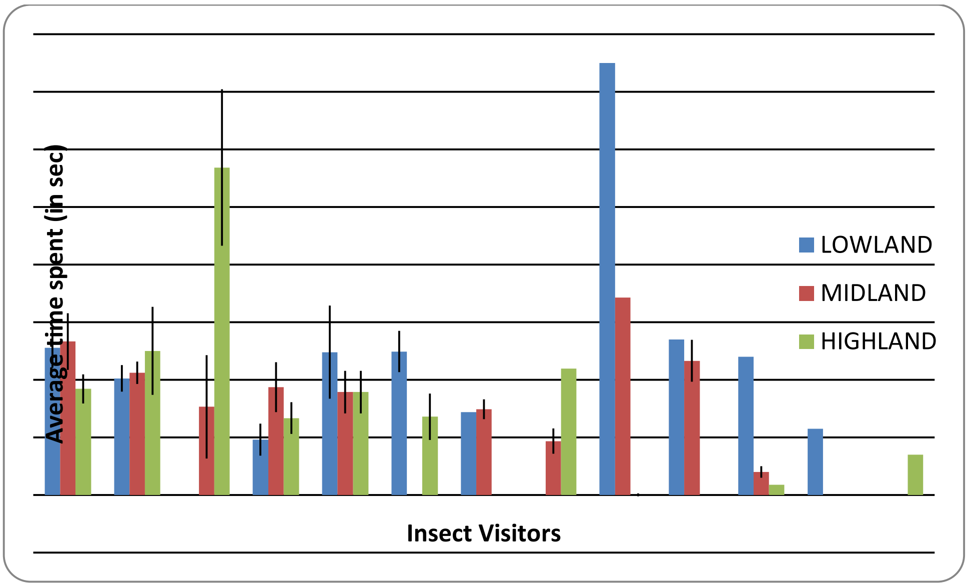


Fig. 36. Average time spent by hesperiids foraging on flowers of *Sphagneticola trilobata* at three altitudes

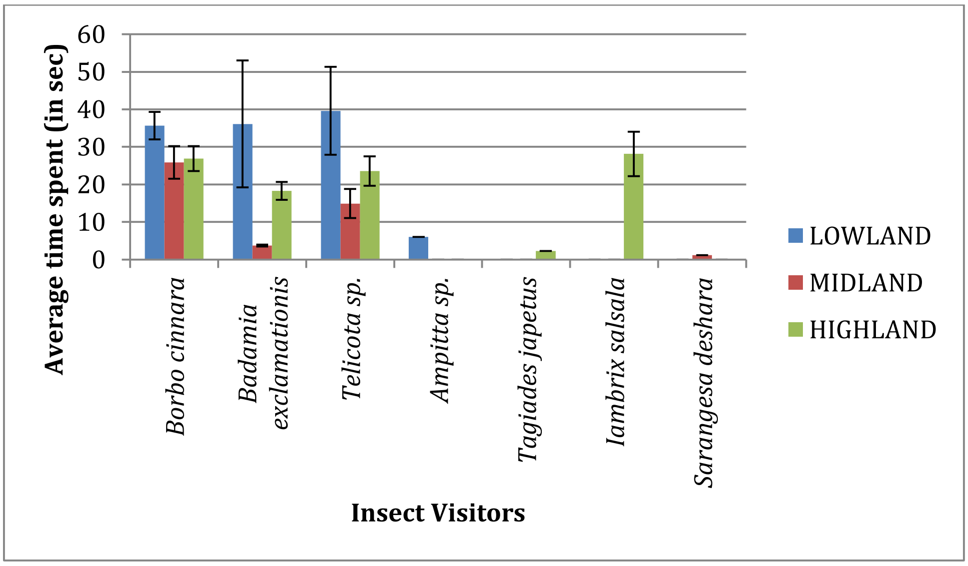


Fig. 37. Average time spent by lycaenids foraging on flowers of *Sphagneticola trilobata* at three altitudes

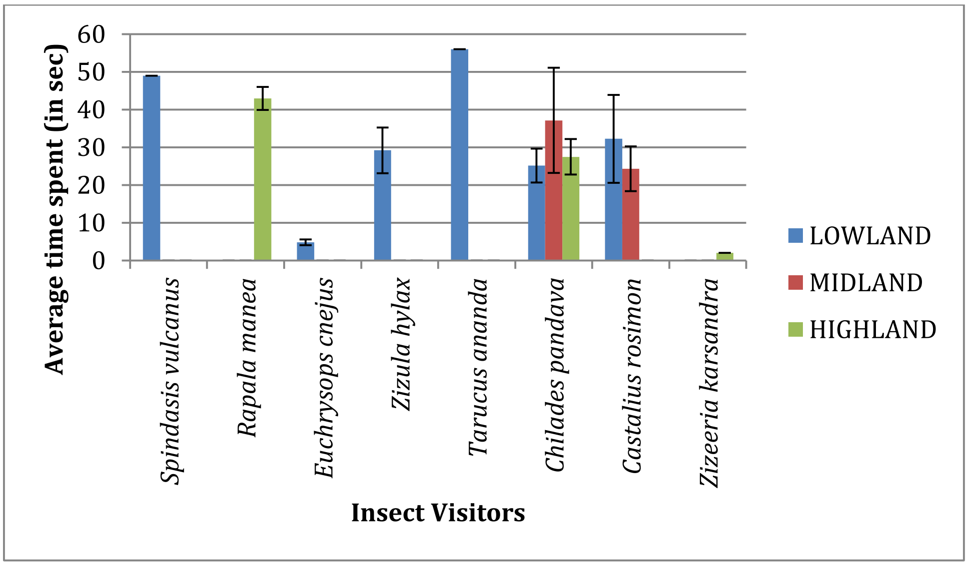


Fig. 38. Average time spent by pierids foraging on flowers of *Sphagneticola trilobata* at three altitudes

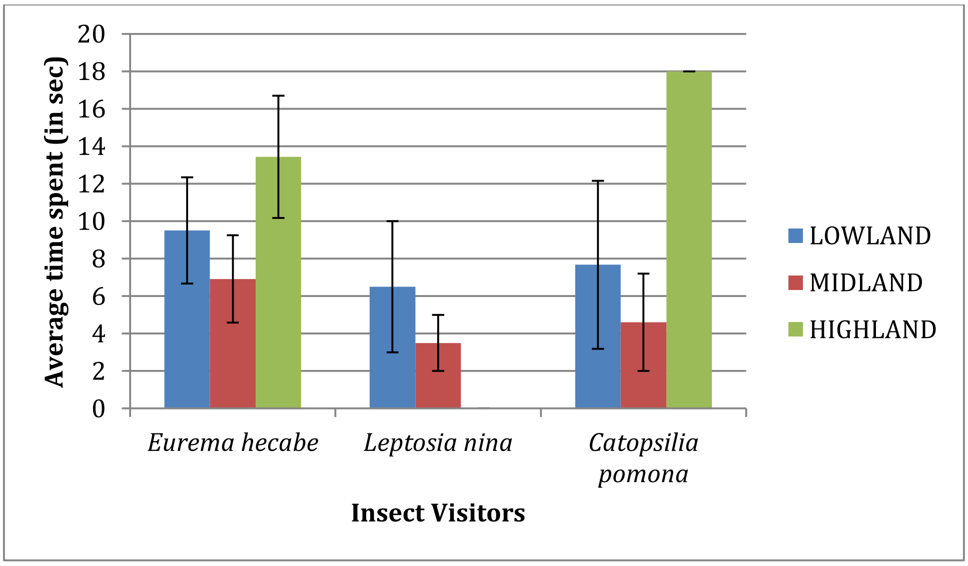
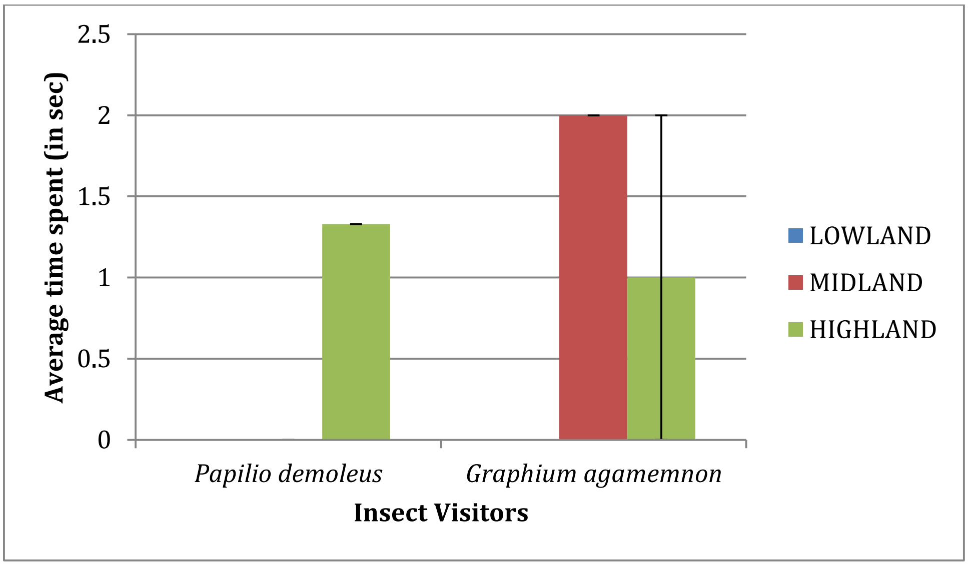


Fig. 39. Average time spent by papilionids foraging on flowers of *Sphagneticola trilobata* at three altitudes



VISITATION RATE OF INSECT VISITORS

Fig. 40. Visitation Rate of hymenopterans foraging on flowers of *Sphagneticola trilobata* at three altitudes

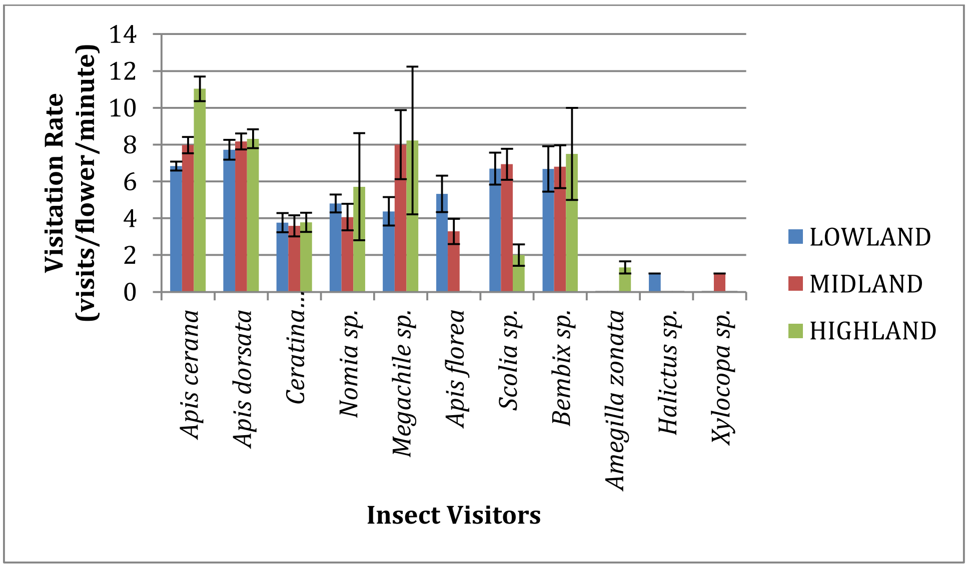


Fig. 41. Visitation Rate of nymphalids foraging on flowers of *Sphagneticola trilobata* at three altitudes

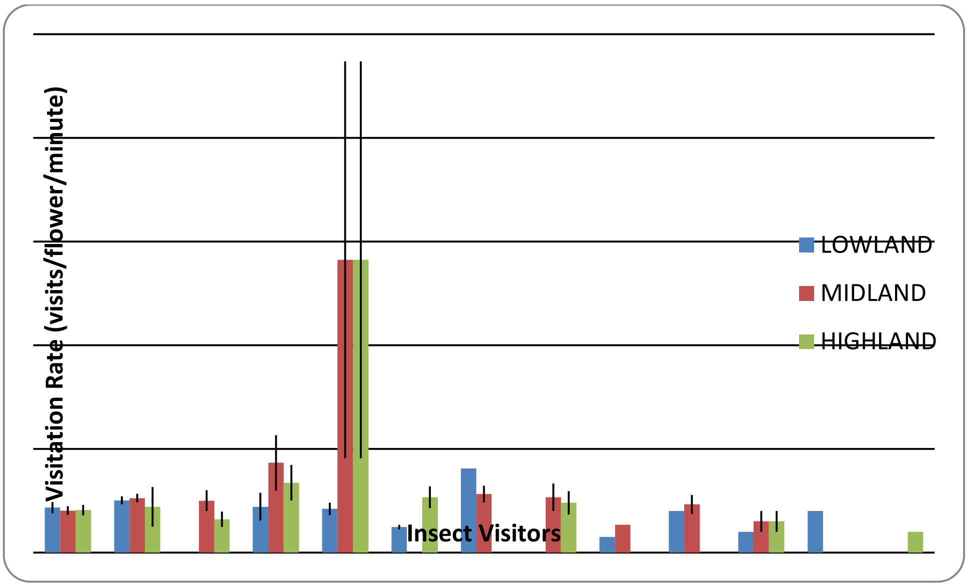


Fig. 42. Visitation Rate of hesperiids foraging on flowers of *Sphagneticola trilobata* at three altitudes

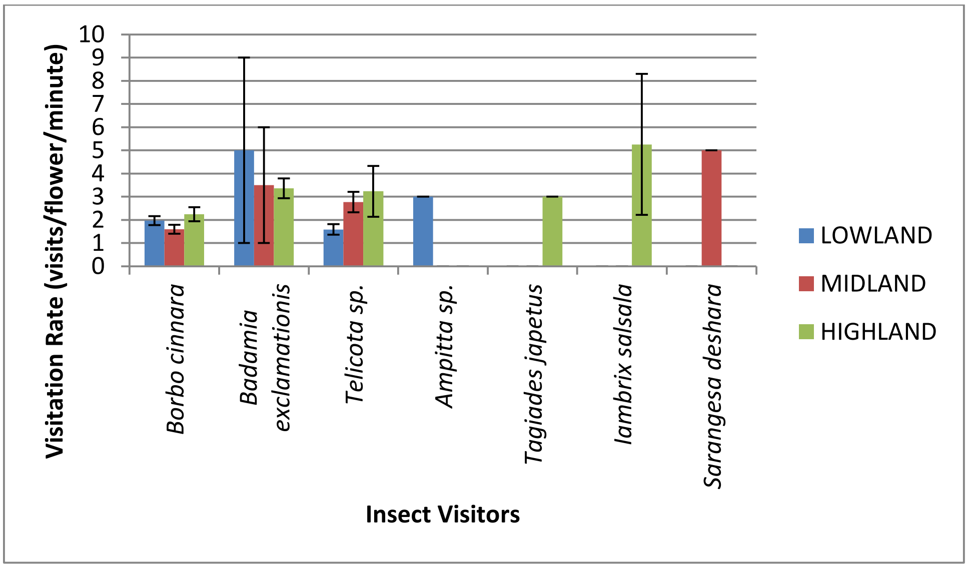


Fig. 43. Visitation Rate of lycaenids foraging on flowers of *Sphagneticola trilobata* at three altitudes

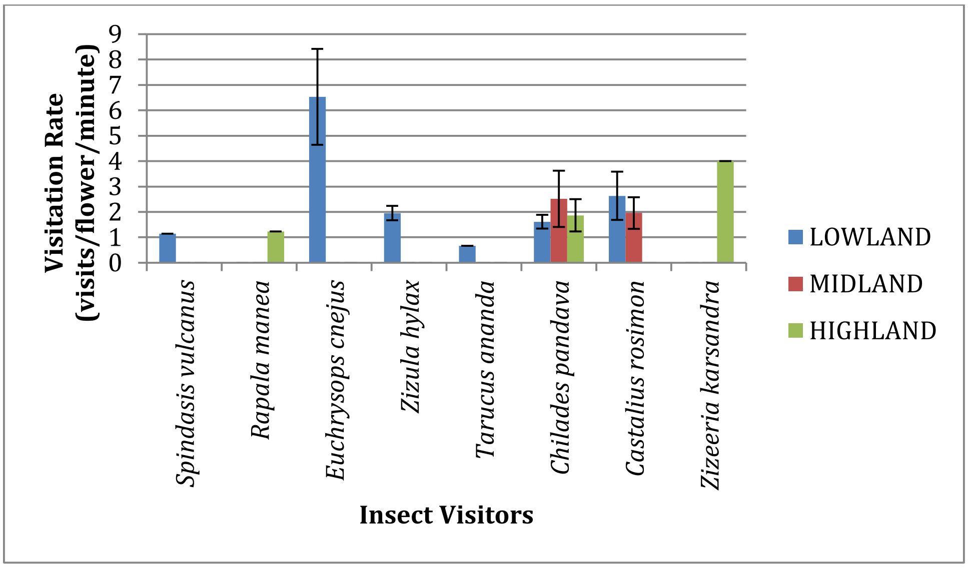


Fig. 44. Visitation Rate of pierids foraging on flowers of *Sphagneticola trilobata* at three altitudes

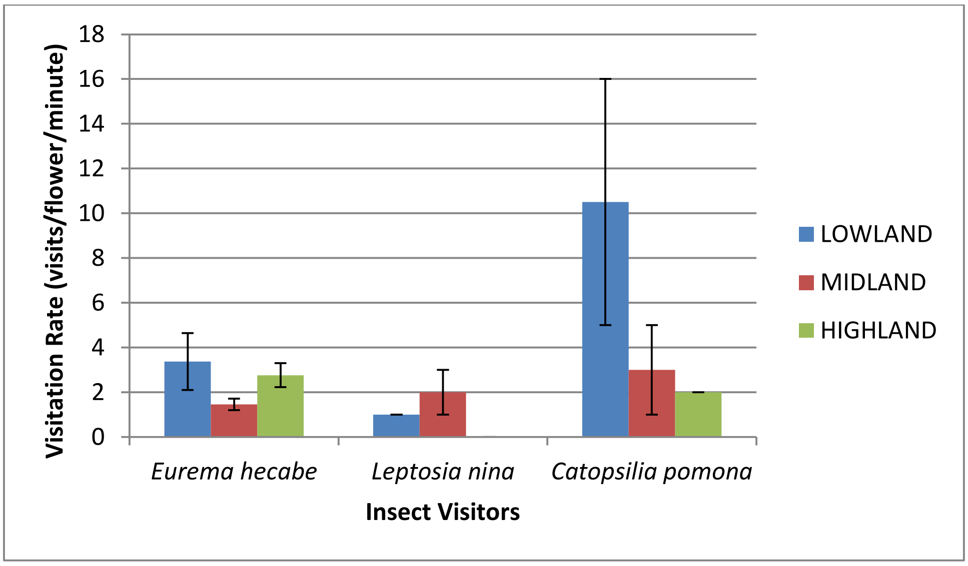
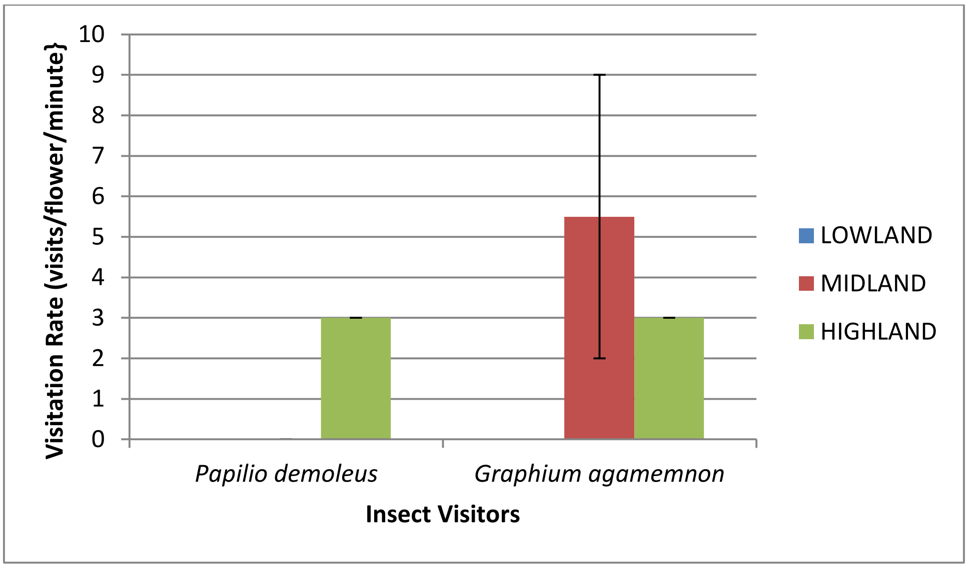


Fig. 45. Visitation Rate of papilionids foraging on flowers of *Sphagneticola trilobata* at three altitudes



FORAGING ACTIVITY DURING THE DIFFERENT PHASES OF THE DAY

AVERAGE TIME SPENT BY INSECT VISITORS

Fig. 46. Average time spent by hymenopterans foraging on *Sphagneticola trilobata* during different phases of the day

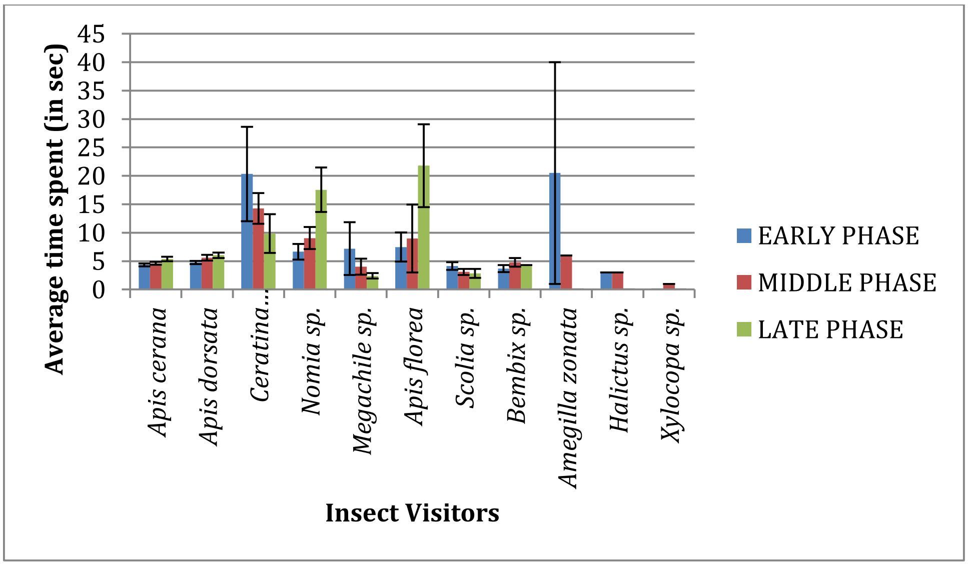


Fig. 47. Average time spent by nymphalids foraging on flowers of *Sphagneticola trilobata* during different phases of the day

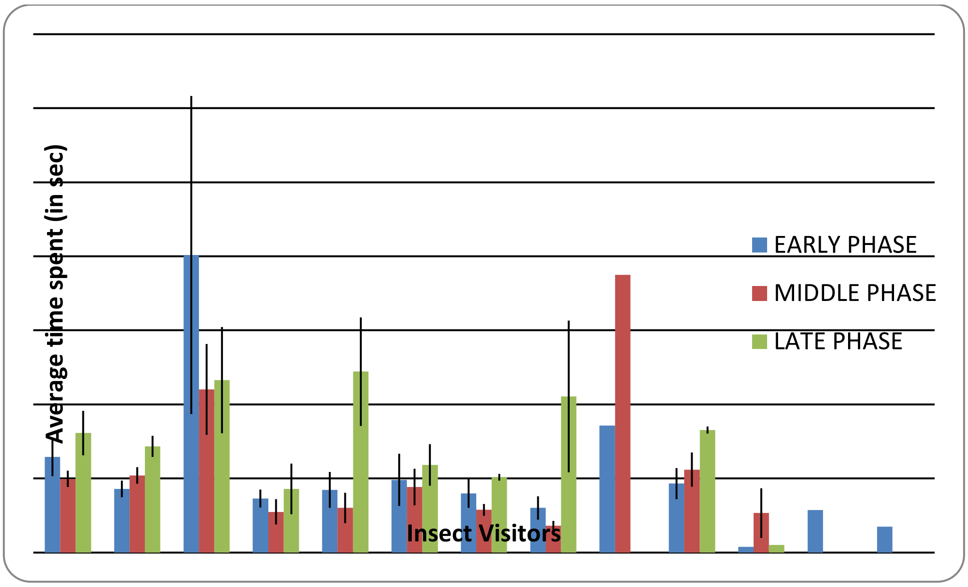


Fig. 48. Average time spent by hesperiids foraging on flowers of *Sphagneticola trilobata* during different phases of the day

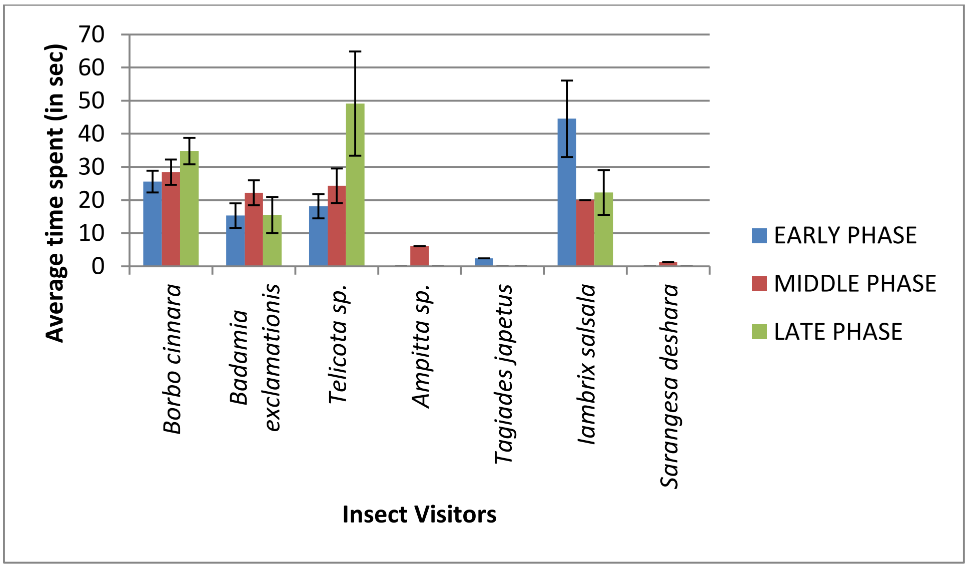


Fig. 49. Average time spent by lycaenids foraging on flowers of *Sphagneticola trilobata* during different phases of the day

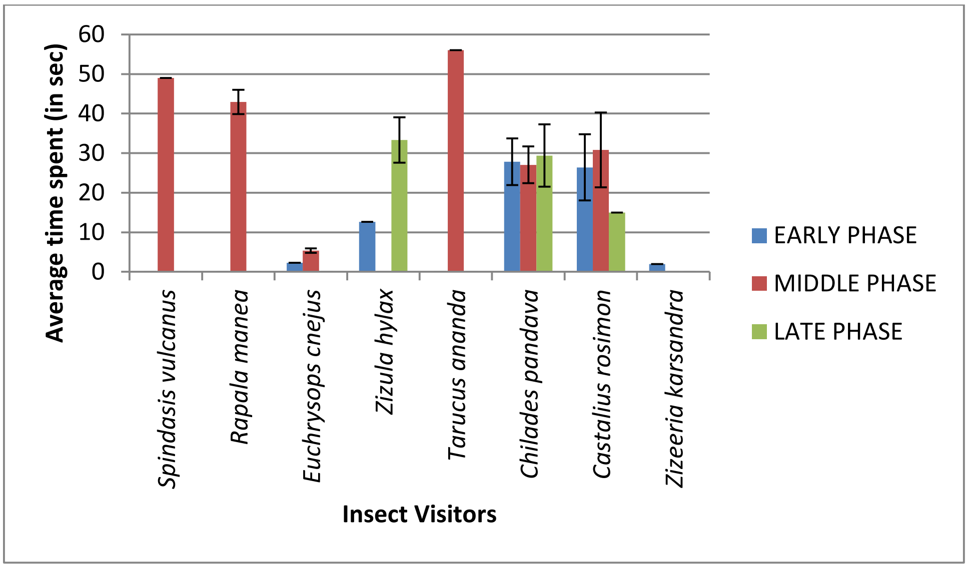


Fig. 50. Average time spent by pierids foraging on flowers of *Sphagneticola trilobata* during different phases of the day

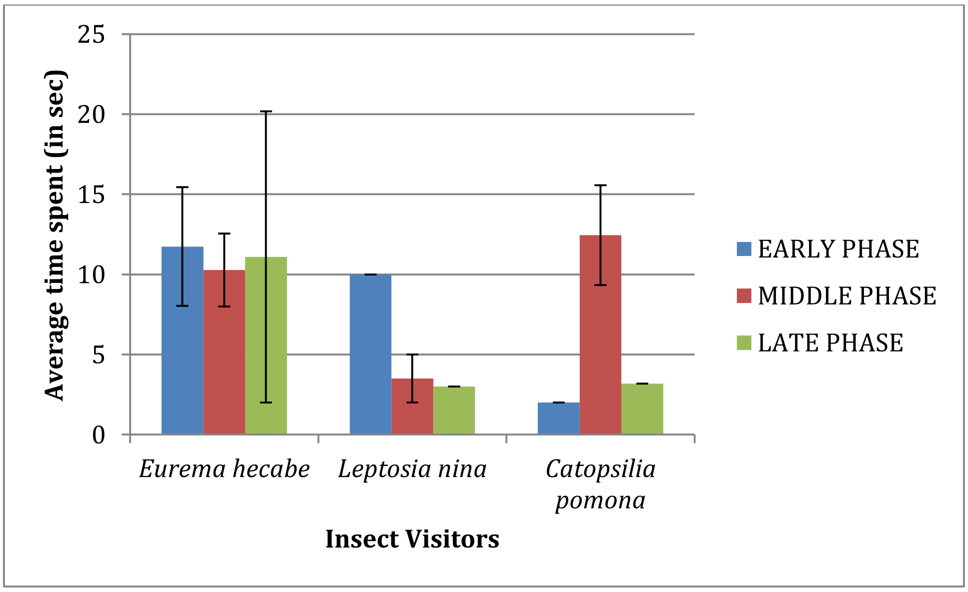
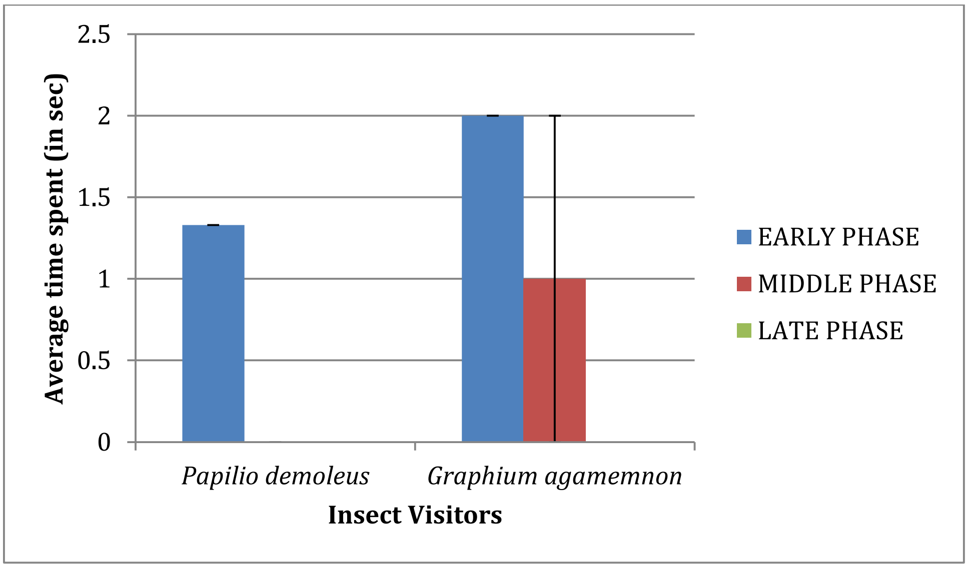


Fig. 51. Average time spent by papilionids foraging on flowers of *Sphagneticola trilobata* during different phases of the day



VISITATION RATE OF INSECT VISITORS

Fig. 52. Visitation Rate of hymenopterans foraging on flowers of *Sphagneticola trilobata* during different phases of the day

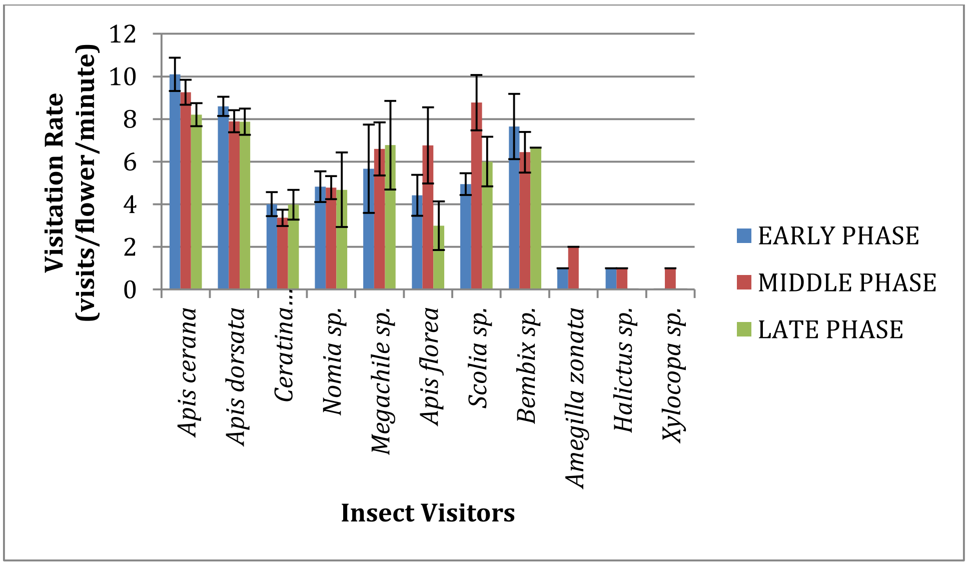


Fig. 53. Visitation Rate of nymphalids foraging on flowers of *Sphagneticola trilobata* during different phases of the day

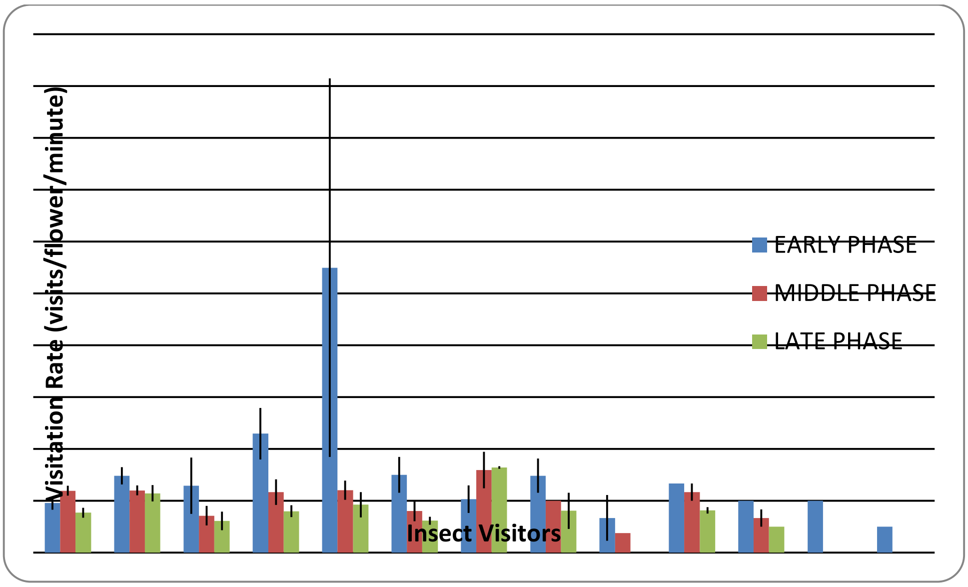


Fig. 54. Visitation Rate of hesperiids foraging on flowers of *Sphagneticola trilobata* during different phases of the day

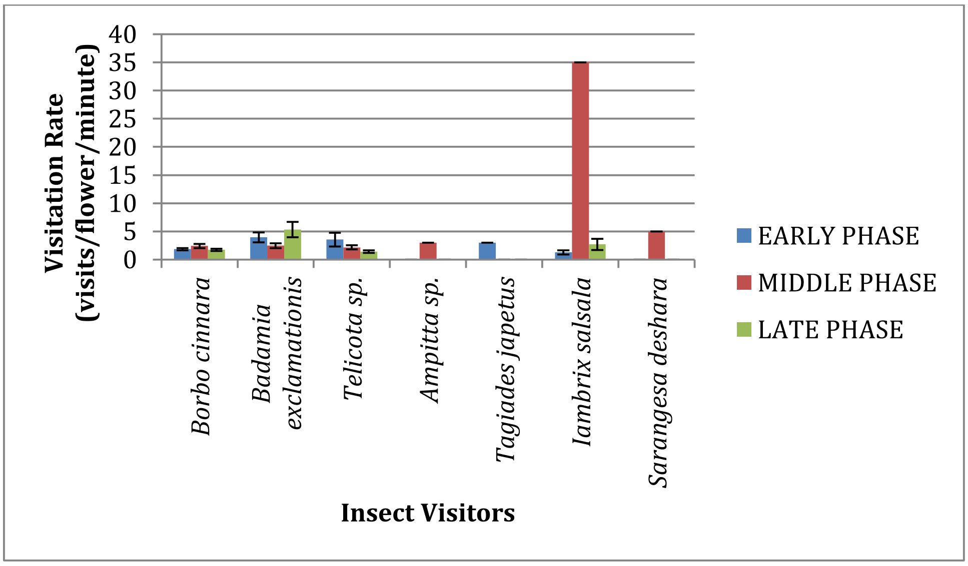


Fig. 55. Visitation Rate of lycaenids foraging on flowers of *Sphagneticola trilobata* during different phases of the day

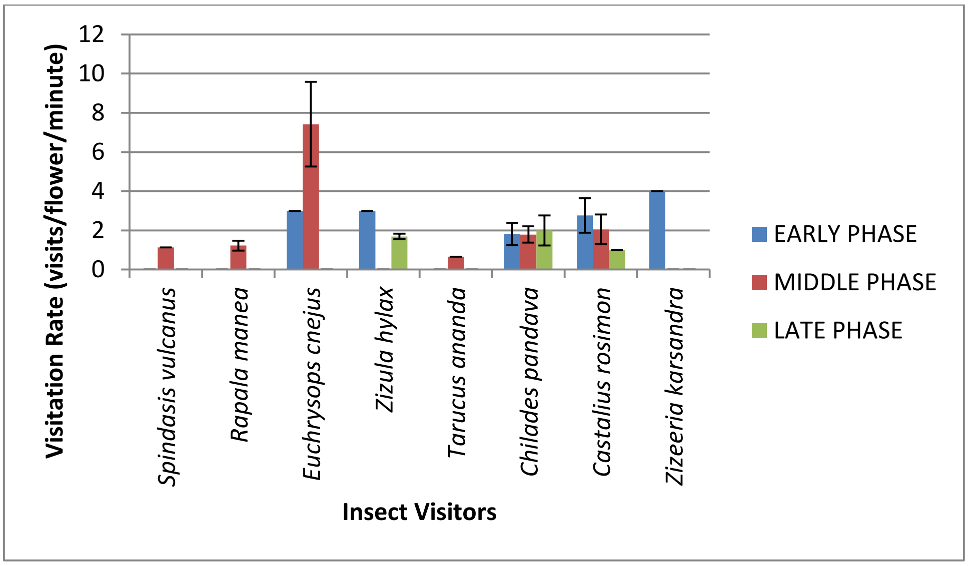


Fig. 56. Visitation Rate of pierids foraging on flowers of *Sphagneticola trilobata* during different phases of the day

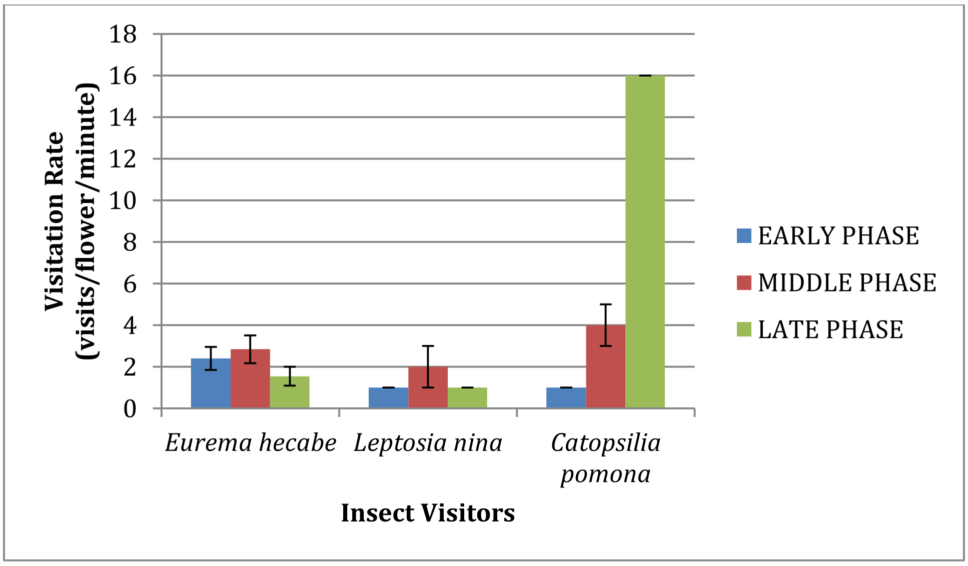
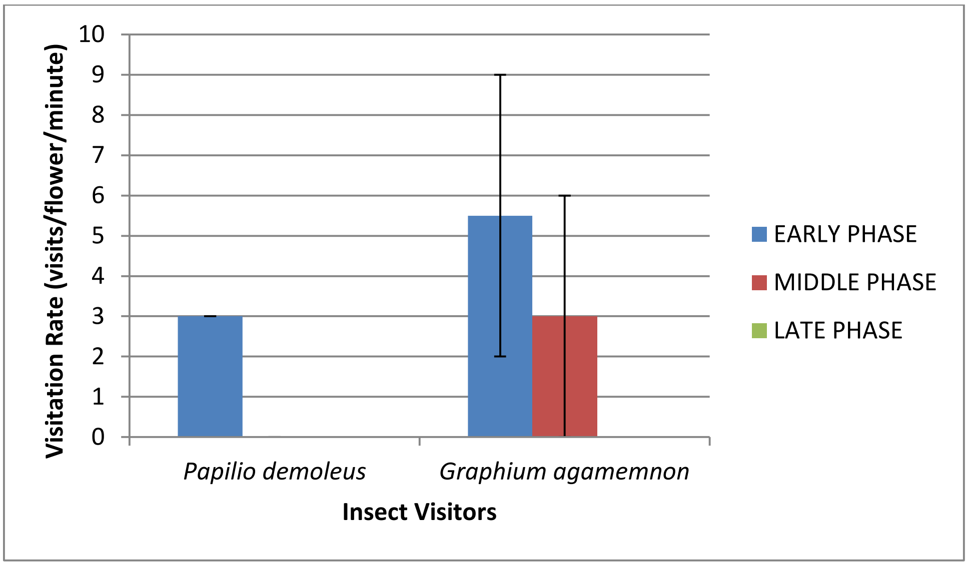


Fig. 57. Visitation Rate of papilionids foraging on flowers of *Sphagneticola trilobata* during different phases of the day



FORAGING BEHAVIOUR OF POLLINATORS

Sphagneticola trilobata

Hymenopterans like *Apis cerana*, *A. dorsata*, *A. florea*, *Ceratina hieroglyphica*, *Nomia* sp. and *Megachile* sp. were seen consistently contacting stigma and anther, after landing on the flower. While foraging over the florets, they extended their proboscis and inserted it completely into the florets to feed on nectar. Pollen grains were retained onto the body surface, beneath the abdomen after each visit to the flower (Plate 20). They were groomed and collected as pollen clumps on the hindlegs.

Apis cerana moved in both clockwise and anti-clockwise pattern over the florets. Antenna and proboscis were cleaned using forelegs before flying off. They spent less time (1 sec) foraging on flowers compared to other pollinators but visited a higher number of flowers during each visit.

Cleaning behaviour was observed in certain species such as *A. florea*, *Ceratina hieroglyphica* and *Nomia* sp. Forelegs were rubbed against each other and hindlegs rubbed against the sides of the abdomen, thus shaking the abdomen over the florets. Proboscis and antenna were groomed using forelegs before flying away. In *Nomia* sp., the forelegs were used to clean the left antenna, while the right antenna and midlegs were rubbed with the hindlegs. *Apis florea* was also seen to rub hindlegs against each other, against midlegs and sometimes on the flower petals too. *Halictus* sp. cleaned the proboscis with forelegs and right antenna was cleaned thrice using forelegs before flying away. *Scolia* sp. cleaned the antenna with forelegs before flying off. They moved in a clockwise manner while feeding on nectar.

Lepidopterans being mostly nectar feeders, inserted the proboscis into florets, but very few pollens were retained on the body compared to hymenopterans.

Borbo cinnara and *Tirumala limniace* probed the flowers for nectar while sitting on the petals. *Castalius rosimon* and *Telicota* sp. extends the proboscis and feeds on the nectar from the florets in a clockwise pattern.

areronia hippia, *Sarangesa desahara*, *Acraea terpsicore*, *Euploea core* and *Tagiades japetus* extended and inserted the proboscis into the flowers in a random manner. *Zizula hylax* inserted proboscis in a clockwise pattern, whereas *Euchrysops cnejus* moved in anti-clockwise pattern and inserts proboscis completely into the florets.

Lucilia sp. extends the proboscis and moves over the entire florets. The forelegs were groomed by rubbing against each other and moved in a clockwise pattern. *Sarcophaga* sp. inserts the proboscis into the florets and moves in anti-clockwise pattern. They also climb onto the petal before flying away.

Mimosa diplotricha

Among hymenopterans, *Halictus* sp. (46.85 sec) spent longer duration on flowers in highland followed by *Apis florea* (36.6067 ± 7.5557 sec) (Fig. 58). During Early phase, *A. florea* spent longer time (23.2675 ± 4.30901 sec) foraging on florets, followed by *Halictus* sp. (13.84114 ± 5.98061 sec) and *Nomia* sp. (11.1659 ± 5.5249 sec) (Fig. 62). Time spent by *A. florea* showed a significant difference between lowland and highland (p=0.046). There is a significant difference in visitation rate between midland and highland (p=0.041). Time spent by *Amegilla* *zonata* showed a significant difference between lowland and midland (p=0.001) and between highland and midland (p=0.001).

The time spent by *Tetragonula iridipennis* was highest in highland (12.9625 ± 0.98937 sec) and lowest in lowland (7.9242 ± 1.3879 sec). There is a significant difference in the time spent by *T. iridipennis* between lowland and highland (p= 0.033) and also between Middle and Late phase (p= 0.006).

Apis dorsata spent more time foraging during Early phase (2.5979 ± 0.11848 sec) in lowland (3.1813 ± 0.16858 sec) compared to other altitudes. Time spent by *A. dorsata* showed a significant difference between lowland and highland (p= 0.001). Visitation rate also differed significantly between lowland and highland (p= 0.027).

The visitation rate was highest during Middle phase in *Apis cerana* (14.9869 ± 2.4524), *Apis dorsata* (19.5727 ± 1.7528), *T. iridipennis* (6.8719 ± 0.6270) and *Amegilla zonata* (20.1844 ± 6.8229). During Early phase, *Scolia* sp. (32.5 ± 9.3479) had the highest visitation rate, followed by *Xylocopa* sp. (25.5 ± 12.5863). Visitation rate of hymenopterans is shown in Fig. 64.

Scolia sp. had the highest visitation rate in lowland (29.4286 ± 8.47646). *Apis cerana* and *Amegilla zonata* had the highest visitation rate in midland (15) and highland (20.0733 ± 6.82014). The visitation rate of hymenopterans foraging on flowers of *M. diplotricha* at three altitudes is shown in Fig. 60. The visitation rate of *Nomia* sp. was highest during Late phase (21.665 ± 2.33500) and showed a significant difference between Middle and Late phase (p= 0.022).

Time spent by hymenopterans as a group showed a significant difference between lowland and midland (p= 0.004) and between lowland and highland (p= 0.002). There is a significant difference in the visitation rate between lowland and midland (p= 0.020) and between midland and highland (p= 0.005).

Lepidopterans had a higher visitation rate during Middle phase. Visitation rate of *Delias eucharis* had the highest visitation rate during Middle phase (4 visits/min.). *Chilades pandava* had the highest visitation rate during Early (2.54± 0.8245) and Late phase (2) (Fig. 65).

Among lepidopterans, *Ypthima huebneri* spent the highest time (56 sec) foraging in highland (Fig. 59). They were seen only during Early phase (Fig. 63). *Delias eucharis* (4) had the highest visitation rate in lowland (Fig. 61).

FORAGING ACTIVITY AT DIFFERENT ALTITUDES

AVERAGE TIME SPENT BY INSECT VISITORS

Fig. 58. Average time spent by hymenopterans foraging on flowers of *Mimosa diplotricha* at three altitudes

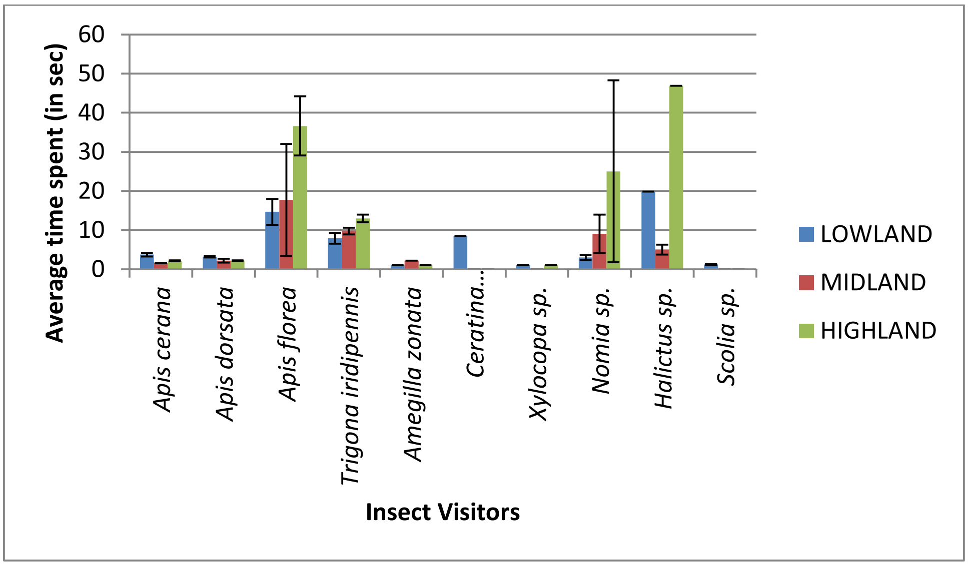
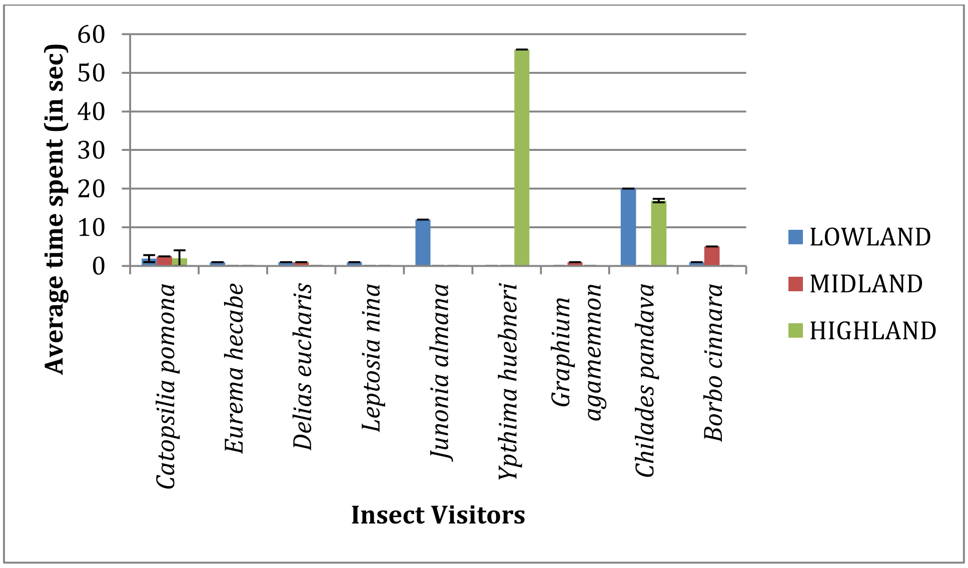


Fig. 59. Average time spent by lepidopterans foraging on flowers of *Mimosa diplotricha* at three altitudes



VISITATION RATE OF INSECT VISITORS

Fig. 60. Visitation rate of hymenopterans foraging on flowers of *Mimosa diplotricha* at three altitudes

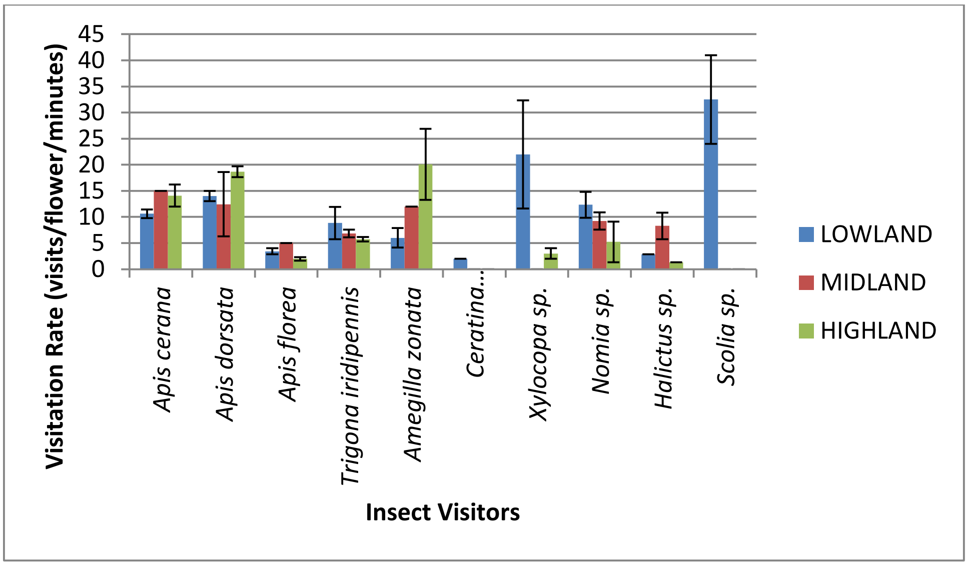
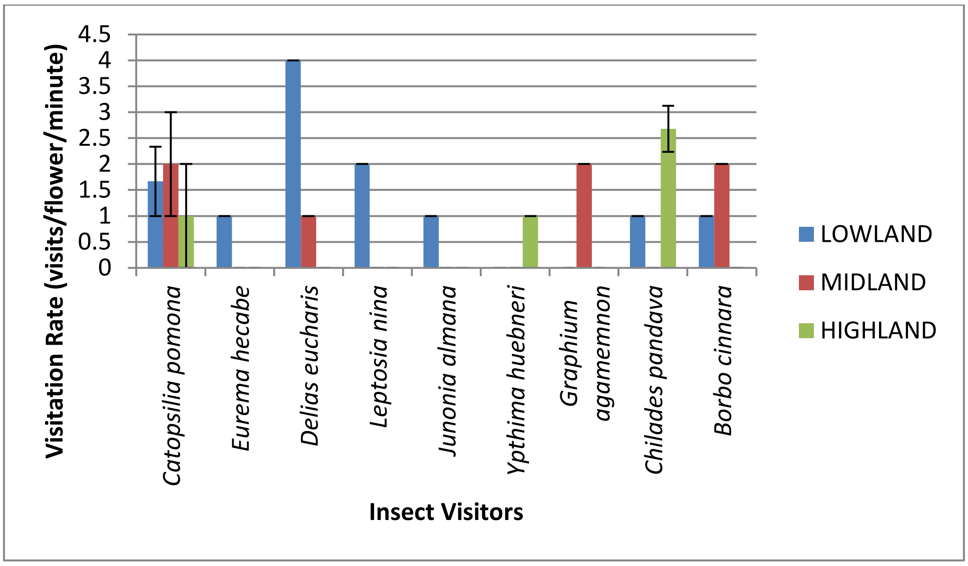


Fig. 61. Visitation rate of lepidopterans foraging on flowers of *Mimosa diplotricha* at three altitudes



FORAGING ACTIVITY DURING THE DIFFERENT PHASES OF THE DAY

AVERAGE TIME SPENT BY INSECT VISITORS

Fig. 62. Average time spent by hymenopterans foraging on flowers of *Mimosa diplotricha* during the different phases of the day

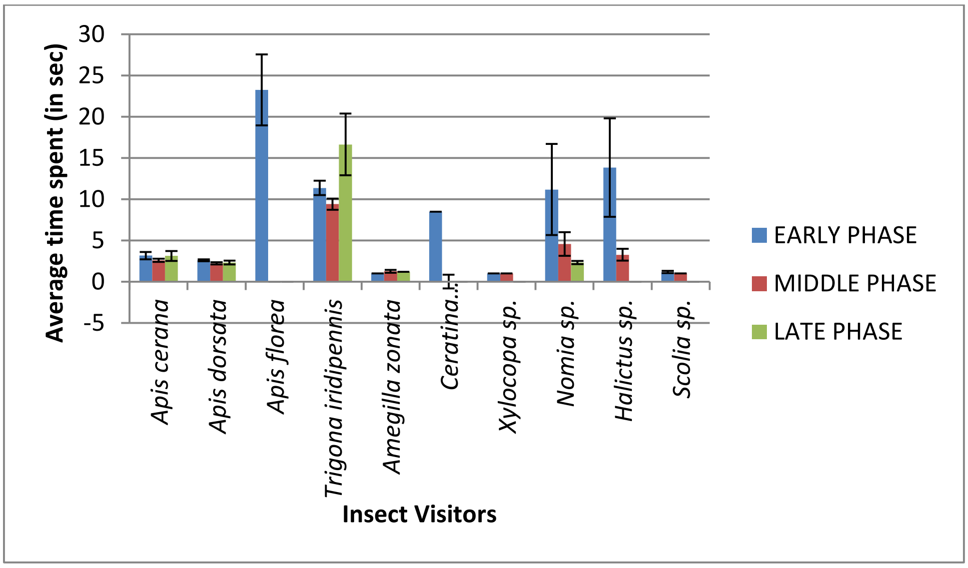
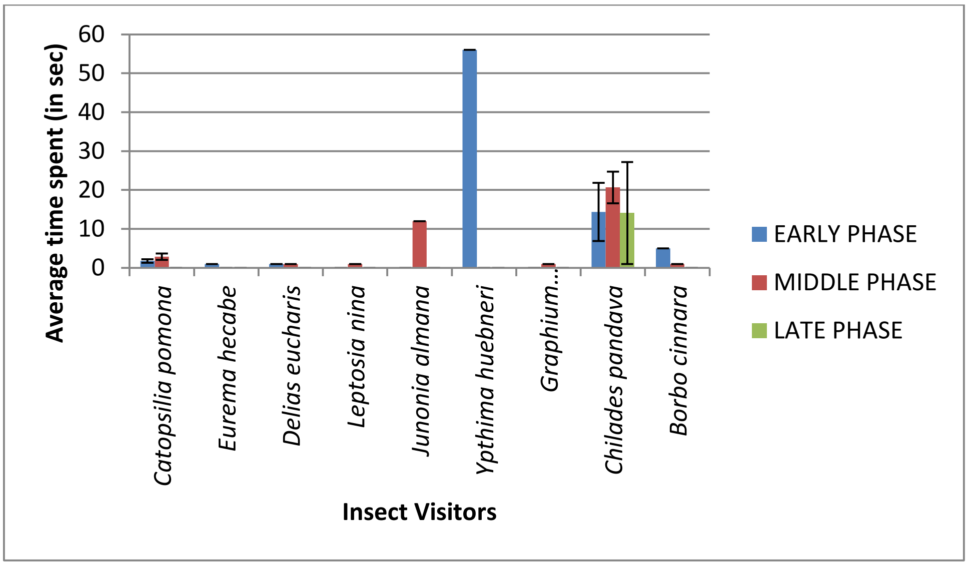


Fig. 63. Average time spent by lepidopterans foraging on flowers of *Mimosa diplotricha* during the different phases of the day



VISITATION RATE OF INSECT VISITORS

Fig. 64. Visitation rate of hymenopterans foraging on flowers of *Mimosa diplotricha* during the different phases of the day

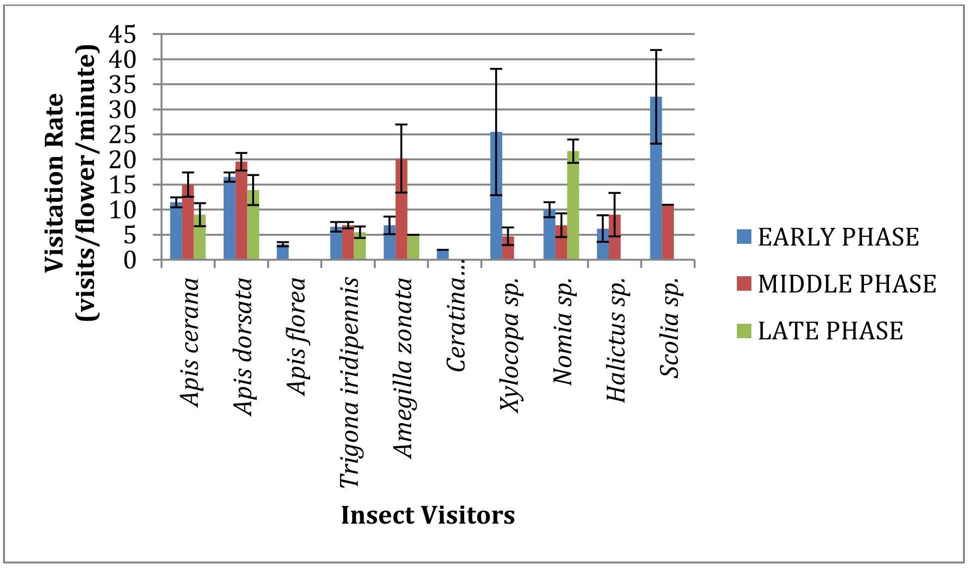
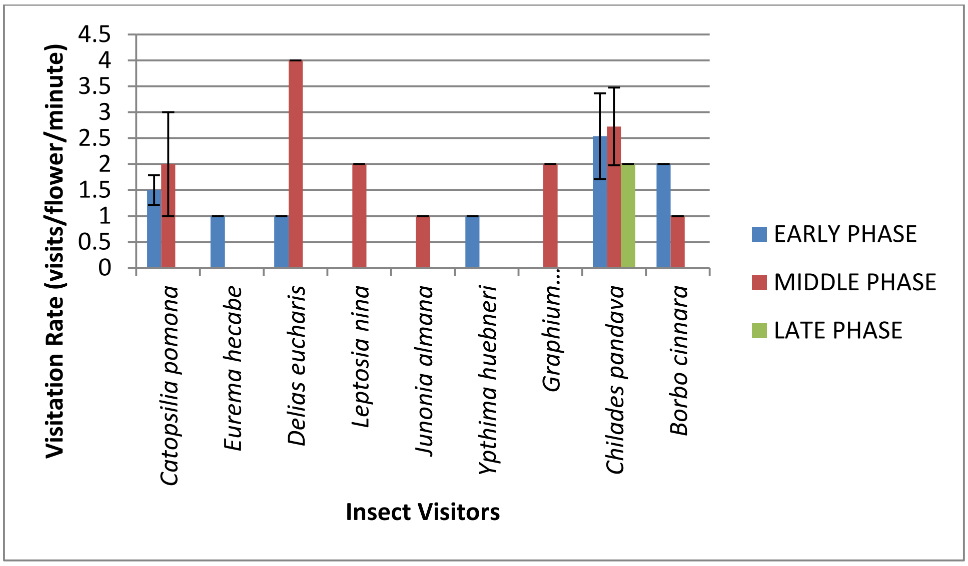


Fig. 65. Visitation rate of lepidopterans foraging on flowers of *Mimosa diplotricha* during the different phases of the day



FORAGING BEHAVIOUR

Mimosa diplotricha

All hymenopterans viz: *Tetragonula iridipennis, Apis cerana, A. dorsata, Nomia* sp., *Xylocopa* sp. and *Megachile* sp. observed in the present study moved randomly over the florets. and collected pollen using forelegs. Pollen clumps were present on the hindlegs. They visited only new flowers, avoiding older flowers. Newly opened flowers only had viable pollens. Antenna and proboscis were cleaned using forelegs. *Amegilla zonata* hovers above the flower extending the proboscis during flight. On the average they spent less than 1 second per each flower.

Tetragonula iridipennis grabbed the individual floret with all its legs and collected pollen using forelegs. Pollen is seen all over the body (Plate 21). More than one *T. iridipennis* visited a single flower of *M. diplotricha*. *Apis dorsata* moved over the flowers randomly with the abdomen bend. After visiting flowers, *A. dorsata* and *A. florea* rested on the underside of the leaves and flowers rubbing the mid and hind legs against each other and the sides of the abdomen. In *Megachile* sp. pollen clumps are seen on the ventral side of the abdomen. Hindlegs were rubbed against each other while flying. Syrphidae was seen collecting the pollens using the forelegs. They extend the proboscis and moves in a random manner over the flower.

FACTORS AFFECTING INSECT VISITATION

Flower Colour And Insect Visitation

In *Lantana camara*, flowers was seen changing colour as the day passes. The colour of florets gives an important cue on the rewarding nature of florets. The young buds at the apices have pink coloration. After the first day, the buds present at the periphery freshly opens into yellow coloured florets. Within 24 hours, the colour changes from yellow to pink. There are numerous colour forms in *Lantana camara*, of which yellow and pink florets were most visited (49.08%) by insect visitors, followed by dark yellow and pink florets (14.95%) and orange and red florets (13.82%). Whereas, the inflorescence with complete yellow florets (7.68%) had a lesser number of visitation compared to yellow and pink florets. Among hymenopterans, *Amegilla zonata* (15.37%) was seen visiting yellow and pink inflorescence frequently. *Catopsilia pomona* was also seen preferring yellow and pink (41.61%) inflorescence, followed by orange and red (31.54%) inflorescence. The lowest visitation was seen on white and pink (2.25%) florets.

While foraging, they were seen inserting proboscis into yellow florets and avoiding visitation to pink florets. Among lepidopterans, *Borbo cinnara* (10.35%) was seen visiting the yellow florets the most, followed by *Junonia iphita* (9.52%) and *Catopsilia pomona* (8.33%). Light Pink floret was the least visited floret and it was visited by *J. iphita* (3) only. White florets (17.72%) and orange florets (45.09%) were frequently visited by *C. pomona*. Pollen viability of yellow florets were higher than pink florets (80%).

FLOWER SIZE AND POLLINATORS

PROBOSCIS LENGTH OF INSECT VISITORS

Insect visitors were seen visiting flowers of invasive plants for nectar and pollen. Lepidopterans were seen preferring the flowers with longer corolla tube. Hymenopterans preferred to feed nectar from flowers with smaller corolla tubes.

Lantana camara has a tubular corolla with a length of 0.85 cm. The dominant visitors to *L. camara* were long tongued butterflies. *Macroglossum* sp. (2 cm) had the longest proboscis among all the insect visitors. While foraging, they hovered above the flower and inserted the proboscis into the floret.

In *Sphagneticola trilobata*, the insect visitors were attracted by the yellow petal of ray florets and feeds nectar from the disc florets. Disc florets have tubular corolla tube, which ranged between 0.8 - 1.0 cm long. Hymenopterans are the most dominant visitors, inserting their proboscis completely into the florets. *Mimosa diplotricha* had a globose inflorescence and the insect visitors did not collect nectar but collected pollen. Insect visitors visited flowers on the plants *Lantana camara*, *Mimosa diplotricha* and *Sphagneticola trilobata* with 0.85 cm, 0.23 cm and 0.9 cm long corolla length respectively.

Hymenopterans were always seen visiting florets having corolla tube which were nearly equal to their proboscis length. They (*Apis dorsata*, *Apis cerana* and *Apis florea*) were seen preferring both *S. trilobata* and *M. diplotricha* florets. The proboscis length of hymenopteran species observed during the present study varied between 0.47 cm and 0.04 cm. Among the eight hymenopteran species, *Tetragonula iridipennis* had the shortest proboscis having 0.04 cm length. *Amegilla zonata*, frequent visitor to *L. camara* had proboscis length of 0.30 cm *Ceratina hieroglyphica* with proboscis length of 0.10 cm was seen probing completely inside the corolla tube of *L. camara* while feeding on nectar. Papilionids and Pierid butterflies had comparatively longer proboscis, with *Pachliopta aristolochiae* and *Papilio clytia* having a proboscis length of 1.70 cm. Papilionids had longer proboscis than the corolla length of the flowers they visited. Among lepidopterans, *Tagiades litigiosa* (hesperiid) had the smallest proboscis (0.40 cm). In nymphalids, the maximum proboscis length was recorded in *Hypolimnas bolina* (1.40 cm) and minimum in *Ypthima huebneri* (0.55cm). Pierids and lycaenids preferred flowers with corolla tube matching with the length of their proboscis *Eurema hecabe* and *Chilades pandava* have a mean proboscis length of 1.05 cm and 0.60 cm respectively and are common visitors to all the three invasive plants.

NUMBER OF FLOWERS IN A PATCH

In all the three invasive plants, the number of insects visiting a patch was positively correlated with the number of flowers in a patch. The frequency of insect visits to invasive plants was higher in patches with higher number of flowers.

Number of insects visiting patches of *Lantana camara* (r= 0.343, p= 0.001); *Sphagneticola trilobata* (r= 0.610, p= 0.001) and *Mimosa diplotricha* (r= 0.610, p= 0.001) showed a positive correlation with the number of flowers in a patch (r= 0.343, p= 0.001).

NECTAR

In Lantana camara, nectar quantity was highest in orange florets (1.48 µl), followed by yellow florets (1.07µl). It was lowest in dark pink florets (0.27µl). It shows a positive correlation between the phases of the day and nectar in florets (r= 0.071, p= 0.005). Nectar in florets showed a significant difference between Early and Late phase (p= 0.020). *Sphagneticola trilobata* showed a positive correlation between phase and nectar content (r= 0.007, p= 0.918). In *S. trilobata*, disc florets (1.7 µl) had higher nectar content than ray florets (0.6 µl). *Mimosa diplotricha* showed a negative correlation between phase and nectar content but the difference is not significant (r= -0.023, p= 0.808). In all the three plants, nectar content in florets was highest during Early phase and decreased as the day progressed.

ABIOTIC FACTORS AFFECTING INSECT VISITORS

Lantana camara

Temperature had an influence on time spent on the flowers and visitation rate of both hymenopterans and lepidopterans. The activity of insect visitors was high when the temperature ranged from 30- 35^{0}C and relative humidity 70- 80 %. The activity was low when temperature was below 25^{0}C and humidity 30- 40 %.

Hymenopterans visiting *L. camara* showed a negative correlation with temperature (r= -0.093, p= 0.001). Time spent by hymenopterans on flower had a negative correlation with temperature (r= -0.154, p= 0.001) (Table 23).

Time spent by lepidopterans on the flower showed a negative correlation with temperature (r= -0.154, p= 0.001). Visitation rate also had a negative correlation with temperature (r= 0.082, p= 0.005) (Table 24). But light intensity and humidity did not have a significant effect on the frequency and foraging activity of any of the insect orders.

Table 23. Correlation coefficients among different weather parameters and hymenopteran visitors to *Lantana camara*

PARAMETERS	**TEMPERATURE**		**HUMIDITY**		**LIGHT INTENSITY**	
	r	p	r	p	r	P
FREQUENCY OF INSECT VISIT	-0.093	0.001	0.013	0.667	-0.040	0.271
AVERAGE TIME OF VISIT	-0.154	0.001	0.028	0.335	-0.041	0.263
VISITATION RATE	0.082	0.005	0.029	0.314	-0.52	0.158

Table 24. Correlation coefficients among different weather parameters and lepidopteran visitors to *Lantana camara*

PARAMETERS	**TEMPERATURE**		**HUMIDITY**		**LIGHT INTENSITY**	
	r	p	r	p	r	P
FREQUENCY OF INSECT VISIT	-0.093	0.001	0.013	0.667	-0.040	0.271
AVERAGE TIME OF VISIT	-0.154	0.001	0.028	0.335	-0.041	0.263
VISITATION RATE	0.082	0.005	0.029	0.314	-0.052	0.158

Sphagneticola trilobata

Temperature had a significant influence on time spent and visitation rate of hymenopterans, whereas light intensity influenced the time spent and visitation rates of both lepidopterans and dipterans. The activity of insect visitors was high when the temperature ranged from 30- 35 ^{0}C and relative humidity 70- 75 %. The activity was less when temperature was below 25 ^{0}C and humidity 40- 45 %. Hymenopterans visiting *S. trilobata* showed a positive correlation with temperature (r= 0.118, p= 0.001). Time spent by hymenopterans on flower had a positive correlation with temperature (r= 0.074, p= 0.022). Visitation rate had a negative correlation with temperature (r= -0.103, p= 0.002) (Table 25). Time spent by lepidopterans on the flower showed a negative correlation with light intensity (r= -0.111, p= 0.027) (Table 26). As light intensity increased, time spent by insect visitors decreased. Visitation rate also had a positive correlation with light intensity (r= 0.108, p= 0.031). Time spent by dipterans on the flower showed a negative correlation with light intensity (r= -0.376, p= 0.037) (Table 27). Visitation rate also had a positive correlation with light intensity (r= 0.382, p= 0.034). Humidity did not have any significant effect on the foraging activity and frequency of any of the insect orders.

Table 25. Correlation coefficient between different weather parameters and Hymenopteran visitors to *Sphagneticola trilobata*

PARAMETERS	**TEMPERATURE**		**HUMIDITY**		**LIGHT INTENSITY**	
	r	p	r	p	r	p
FREQUENCY OF INSECT VISIT	0.118	0.001	0.006	0.864	0.077	0.073
AVERAGE TIME OF VISIT	0.074	0.022	-0.049	0.133	-0.023	0.598
VISITATION RATE	-0.103	0.002	0.034	0.294	0.067	0.118

Table 26. Correlation coefficient between different weather parameters and Lepidopteran visitors to *Sphagneticola trilobata*

PARAMETERS	**TEMPERATURE**		**HUMIDITY**		**LIGHT INTENSITY**	
	r	p	r	p	r	p
FREQUENCY OF INSECT VISIT	0.042	0.285	-0.019	0.636	0.015	0.762
AVERAGE TIME OF VISIT	-0.035	0.380	-0.022	0.572	-0.111	0.027
VISITATION RATE	0.001	0.975	0.067	0.089	0.108	0.031

Table 27. Correlation coefficient between different weather parameters and Dipteran visitors to *Sphagneticola trilobata*

PARAMETERS	**TEMPERATURE**		**HUMIDITY**		**LIGHT INTENSITY**	
	r	p	r	p	r	p
FREQUENCY OF INSECT VISIT	0.069	0.679	-0.164	0.326	0.114	0.541
AVERAGE TIME OF VISIT	-0.164	0.326	-0.255	0.122	-0.376	0.037
VISITATION RATE	0.267	0.106	-0.039	0.818	0.382	0.034

Mimosa diplotricha

Temperature influenced the time spent by hymenopterans and lepidopterans. Humidity had a significant influence on the frequency of visitation of both hymenopterans and lepidopterans. Light intensity was seen to influence only the frequency of hymenopteran visitation to *M. diplotricha*. Hymenopterans visiting *M. diplotricha* showed a positive correlation with temperature (r= 0.266, p= 0.001). Time spent by hymenopterans on flower had a negative correlation with temperature (r= -0.128, p= 0.011). Hymenopterans visiting *M. diplotricha* showed a negative correlation with humidity (r= -0.150, p= 0.003). Frequency of hymenopterans visiting the flower had a negative correlation with light intensity (r= 0.144, p= 0.020) (Table 28).

Time spent by lepidopterans on the flower showed a negative correlation with temperature (r= -0.426, p= 0.034). Lepidopterans visiting *M. diplotricha* showed a positive correlation with humidity (r= 0.497, p= 0.011) (Table 29). Humidity and light intensity did not have a significant effect on the time spent and visitation rate of any of the insect orders.

Table 28. Correlation coefficient between different weather parameters and Hymenopteran visitors to *Mimosa diplotricha*

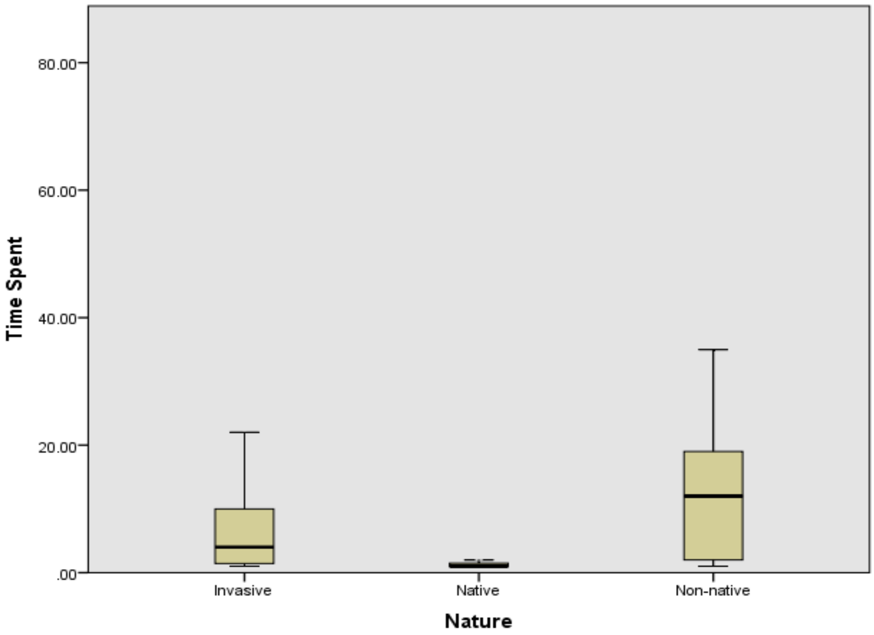
PARAMETERS	**TEMPERATURE**		**HUMIDITY**		**LIGHT INTENSITY**	
	r	p	r	p	r	p
FREQUENCY OF INSECT VISIT	0.266	0.001	-0.150	0.003	0.144	0.020
AVERAGE TIME OF VISIT	-0.128	0.011	-0.027	0.595	-0.065	0.299
VISITATION RATE	0.057	0.262	-0.045	0.373	0.072	0.246

Table 29. Correlation coefficient between different weather parameters and Lepidopteran visitors to *Mimosa diplotricha*

PARAMETERS	**TEMPERATURE**		**HUMIDITY**		**LIGHT INTENSITY**	
	r	p	r	p	r	p
FREQUENCY OF INSECT VISIT	-0.298	0.148	0.497	0.011	-0.372	0.074
AVERAGE TIME OF VISIT	-0.426	0.034	0.284	0.169	-0.115	0.593
VISITATION RATE	-0.126	0.549	0.082	0.698	-0.078	0.719

Plates 15- 17 shows the insect visitors to neighboring native plants in proximity of the invasive plants. There was a significant difference (p=0.00) between insect visits to the invasive plant *Lantana camara* and the native plants. Insect floral visitors spent more time on invasive plants than on native plants (Fig. 66). Frequency of visit was more towards flowers of *Lantana camara* than to native plants, when *L. camara* was present in the locality (Fig. 66).

Fig. 66 Average time spent by insect visitors on invasive, native and non-native plants



The diversity and abundance of native pollinators visiting three species of invasive plants viz: *Lantana camara, Sphagneticola trilobata* and *Mimosa diplotricha* in different localities are assessed in the present study.

Lepidopterans are the predominant floral visitors to *Lantana camara*, while bees favour *Sphagneticola trilobata* and *Mimosa diplotricha*. Earlier studies on *L. camara* have also revealed high levels of lepidopteran visitation (Goulson and Derwent, 2004; Muthoka and Mananze, 2005; Sharma *et al*., 2005; Tiple *et al*., 2006; Pandey and Chauhan, 2012) and lower levels of attractiveness to hymenopterans because of their smaller floral size and the fact that nectar is present at the base of the corolla tube which can only be accessed by means of a retractable and elongate tube like proboscis. This agrees with the findings of McCall and Primack (1992); Mali *et al*. (2014) and Barrios *et al*. (2016) that lepidopterans with long proboscis were more common on tubular flowers. The present study has shown that *Amegilla zonata* which is known to be an effective pollinator of other plants (Hogendoorn *et al*., 2007) is also seen to provide valuable pollination services for invasive *L. camara*. Although dipterans play an important role as pollinators in many crops (Ollerton *et al*., 2017; Bashir *et al*., 2013; Orford *et al*., 2015), only two species viz. *Lucilia* sp. and *Mesembrius* sp. were observed visiting *L. camara* in the present study.

Although short-tongued bees preferred open flowers, long-tongued bees preferred flowers with long corolla tube (May, 1992). In the present study *Ceratina hieroglyphica* with a shorter proboscis probed head deep into the corolla tube of *L. camara*. These observations agree with those of Sahli and Conner (2007) who observed that in *Raphanus raphanistrum*, *Ceratina* sp. was the effective pollinator and they foraged for nectar by completely plunging into the tube of flower.

In the present study, pollen grains have been recovered from proboscis of butterflies which visited *L. camara*, indicating their potential as pollinators. The correlation of the proboscis length with the corolla tube length explains the preference of lepidopterans for flowers of *L. camara*. Similar observations have been made by De Vries (1979) and Penz and Krenn (2000).

In the present study, insect visitors to *L. camara* preferred yellow and pink florets over other colours, which is in accordance with the observations recorded by McCall and Primack (1992) who observed that insects preferred yellow and mixed-colour flowers over white and pink-red flowers. This observation disagreed with Barrows (1976) and Santhosh and Basavarajappa (2016) who found that insects preferred yellow florets over other colours. Miller *et al*. (2011) and Guez *et al*. (2017), also found that *A. cerana* preferred yellow coloured flowers. It was observed that the yellow petal of ray florets of *S. trilobata* attracted the insect visitors towards them and studies indicate that yellow flowers have a higher nectar reward and viable pollen for the incoming visitor which was in concordance with the findings of Gori (1989) who observed pollinators preferring highly rewarding yellow flowers over purple flowers in *Lupinus argenteus*. More specifically bees prefer yellow flowers while *Macroglossum* sp. visited only yellow florets (Weiss, 1995). In *L. camara*, florets changed colour as the days passed and the older florets were retained, thus increasing the attractiveness of inflorescence. In the present study, insect visitors were seen visiting only rewarding florets. This was in concordance with the findings of Weiss (1991) and Ida and Kudo (2003) who reported that butterflies preferred rewarding yellow florets over other florets.

In the present study, we observed a high frequency of visits by *A. cerana*, a generalist pollinator to *S. trilobata*, which points to the probability that *S. trilobata* may be negatively impacting visits of *A. cerana* to native crops resulting in lower pollination in these plants. These mass flowering invasive plants provide nectar and pollen to generalist bees like *A. cerana* throughout the year.

The resource availability in different florets decides the foraging behavior of insect floral visitors. Insect visitors to *S. trilobata* fed exclusively from central disc floret, which was in concordance with the findings of Niesenbaum *et al*. (1999), who observed the pollinators visiting only central disk florets in *Aster vimineus* as they are more reproductively viable.

Besides hymenopterans, several lepidopterans visited *S. trilobata*. Among lepidopterans, Nymphalidae was the dominant family, this agreed with the finding of

Jothimani *et al*. (2014). Lepidopterans visited the florets of the family Compositae for feeding on nectar (Santhosh and Basavarajappa, 2016). Lycaenids and hesperiids were seen to prefer Asteraceae for nectar feeding (Chowdhury *et al*., 2017). In the present study, among dipterans, *Calliphora* sp. was seen frequently visiting *S. trilobata*. Syrphids were also seen visiting *S. trilobata* regularly. Similar observations have been made by Conner *et al*. (2003) and Clement *et al*. (2007) who observed dipterans to be an efficient pollinator of leek (*Allium ampeloprasum*)and radish (*Raphanus raphanistrum*) respectively.

Tetragonula iridipennis was the predominant visitor to *Mimosa diplotricha* followed by *A. dorsata*. *T. iridipennis* was the most abundant visitor on bitter gourd (*Momordica charantia* L.). Putra and Kinasih (2014) found that in native species of tomato (*Lycopersicon esculentum*), *A. cerana* had a higher visitation rate but significantly shorter handling time compared to *T. iridipennis*. This advanced handling time in *T. iridipennis* adds to high floral constancy and higher pollen transfer.

FORAGING/ VISITATION ALONG THE ALTITUDINAL GRADIENT

Study sites at 700–2100 m above MSL (Average Mean Sea Level) showed higher diversity of insect floral visitors to *L. camara* compared to midland and lowland. This is supported by similar findings of Widhiono *et al*. (2017) who studied the insect visitation to agricultural ecosystem of Central Java and found that species diversity and abundance increased linearly with increasing elevation. Whereas, in *S. trilobata* and *M. diplotricha*, species richness was higher in lowland compared to that in highland. Floral visitation by *Amegilla zonata* was highest in lowland, which is supported by evidence that in lowland communities, hymenopterans were seen to be the dominant pollinators (Arroyo *et al*., 1982; Warren *et al*., 1988). Nymphalids were the dominant visitors to all the three invasive plants in both midland and lowland. Thakur and Mattu (2010) found that nymphalids were dominant visitors in low altitudes of Shiwalik hills, however papilionids and hesperiids were more abundant in highlands. This contrasts with the findings of Acharya and Vijayan (2015) who observed that nymphalids and papilionids were seen all along the elevation gradient of Eastern Himalaya, whereas hesperiids were restricted below elevations 2400 m.

FORAGING/VISITATION ALONG SEASONAL VARIATIONS

In the present study, frequency of insect visit was lower in all the three altitudes for all the three species of invasive plants during Pre-Monsoon. However, frequency of insect visit to *S. trilobata* was higher during Monsoon in midland and during Post Monsoon in both lowland and highland. Acharya and Vijayan (2011) observed a similar trend, where butterfly species richness was highest during Monsoon in Sikkim. Butterflies showed a seasonal variation trend in all habitats (Kunte, 1997; Arun, 2000) and showed higher abundance peaks during March–April and October in India (Arun and Vijayan, 2004). The results were in confirmation with the observations recorded by Mukherjee *et al*. (2015) that in *L. camara*, butterfly visit peaked during summer and Post- Monsoon. In the present investigation, frequency of *A. cerana* was higher during Monsoon in both Midland and Highland, whereas it was higher during Post- Monsoon in Lowland. According to Mattu and Verma (1985), foraging activity of *A. cerana* was highest during summer and autumn in Simla hills of Northwest Himalayas. These changes in abundance and foraging activity of insect visitors during different seasons may be related to favorable temperature, relative humidity and light intensity.

INSECT FLORAL VISITATION DURING DIFFERENT PHASES OF THE DAY

The maximum number of insect floral visitors to all the invasive plants was observed during mid-morning hours to afternoon which was in concordance with the findings of Singh *et al*. (2000). This might be due to the production of floral as well as extra floral nectar which become active from morning and reached maximum secretions during different hours of the day.

Colour along with nectar content does play a role in attraction of floral insect visitors. In *L. camara*, orange florets had the highest nectar content followed by yellow florets, whereas pink florets had the lowest nectar content. However, contrasting results were obtained by Muthoka and Mananze (2005), who found that pink flowers had a higher nectar volume than yellow flowers, but with a low sugar concentration.

Frequency of visits of *Amegilla zonata* to *L. camara* was highest during Early phase and declined as the day progressed which is in accordance with Yilangai *et al*. (2015) who recorded frequency of insect visit to be highest in the morning and lowest during evening. According to Binoy *et al.* (2014), activity of *Amegilla* sp. on *Pentas lanceolata* and *Catharanthus roseus* was seen only during morning hours. Temperature had a positive influence on foraging activity of *Amegilla zonata* (Sharma and Abrol, 2015; Latif *et al*., 2016).

Frequency of lepidopteran visit to *L. camara* was highest during Early phase and lowest during Late phase. Hawk moth, *Macroglossum* sp. visited flowers during Early Phase only. This is in concordance with the findings of Kajobe and Echazarreta (2005). Other studies on *L. camara* reveal high levels of lepidopteran visitation during Middle phase (Muthoka and Mananze, 2005).

Frequency of hymenopterans visits to *S. trilobata* was higher during Early phase and reduced as the day progressed. Ssymank *et al*. (2008) also observed bees to be active during late morning and noon, whereas dipteran visitation to flowers was highest during morning or late afternoon. *Apis cerana* initiated foraging early in the morning which was in tune with the findings of Verma and Dulta (1986) recording the peak foraging activity of *A. cerana* in apple flowers between 0900 and 1130 hours between temperatures 15.5° to 21°. Kopel'kievski (1953) also described that insect pollinators to be mostly abundant on the buckwheat flowers between 0900 and 1200 hours. In the studies of Stanghellini *et al*. (2002), the total number of bees increased over time of day on watermelon, cucumber and muskmelon which supports the present findings.

In the present study, Lepidopteran foraging on the study plants was much reduced at lower temperatures and increased as the day progressed, and temperature increased. Similar results were observed by Muthoka and Mananze (2005) who observed that the frequency of lepidopterans to *L. camara* decreased with increasing relative humidity, whereas it increased with increasing temperature. Owen (1971) had also noted that butterflies derive most of their heat from the sun and hence, are more active at higher light intensities, with a threshold in temperature limit. But, the time spent on the flowers by lepidopterans visiting *L. camara* showed a negative correlation with temperature, which is in concordance with the findings of Duara and Kalita (2012).

It was also observed that the activity of insect visitation was less when the temperature was below 25°C and humidity at 30–40 %. However, time spent by hymenopterans visiting *L. camara* flowers showed a negative correlation with temperature. This is in concordance with the findings of Abou- Shaara *et al*. (2012) and Gebremedhn *et al*. (2014) who found that elevated temperature had a negative effect on worker bees. Visitation rate of insect visitors also had a negative correlation with temperature. This agreed with the findings of Heinrich and Raven (1972) which stipulated that the time of the day and consequently temperature has significant effect on pollinators. This may be explained by the fact that higher temperature deters an insect from spending more time on a flower, but this is compensated by visiting more flowers to feed on nectar. In addition, the amount of nectar in flowers do decrease at higher temperatures and hence, the insects may spent less time on the flowers for feeding on nectar.

But light intensity and humidity did not have a significant effect on the frequency and foraging activity of any of the insects visiting *L. camara* except in *S.trilobata* and *M. diplotricha*, where light intensity had an influence on frequency of hymenopteran visitation. The results were in confirmation with the observations recorded by Stein and Hensen (2011), who found that light intensity had a significant impact on visitor frequency.

VISITATION RATES AND FORAGING TIME

Foraging time was shortest for hymenopteran visitors in *L. camara*. *A. zonata* and *Xylocopa* sp. with the duration of visit lasting for an average of one second per floret. The present study also recorded *A. zonata* having highest visitation rate in Midland. The time spent by *A. cerana* per flower was not affected by altitudinal variation. This result was in confirmation with the observations recorded by Ahmad *et al.* (2017) who found that altitudinal variation does not affect the time spent per flower by *Apis cerana*. Visitation rate of *A. cerana* was highest in highland. However, contrasting results were obtained by Ahmad *et al*. (2017) who observed that altitudinal variation affects the foraging activity of *A. cerana* on apple bloom and they visited more number of flowers at lower elevations. Visitation rate of *A. zonata* was higher during Late phase compared to Middle and Early phase. Latif *et al*. (2016) observed that in *Capparis aphylla*, compared to other hymenopterans, *Amegilla* sp. had the highest visitation rate. In the present study, floral visitation rate of hymenopterans showed a significant difference between Early and Late phase and was highest during early phase. Omoloye and Akinsola (2006) observed that foraging activity of honeybees peaked between 0900 and 1300 hours. The present findings were in close similarity with the views of Verma and Partap (1994) and Joshi (2000) having similar observations on initiation, cessation and duration of honeybee (*A. cerana*) foraging activity on *Brassica juncea*. Singh (2008) recorded that the time spent on the flowers of buckwheat (*Fagopyrum esculentum*) by *A. cerana* was more during early hours than in the afternoon.

Both hymenopterans and lepidopterans frequently visited *M. diplotricha* during Early phase. They were more active during Early phase and ceased foraging activity in the Late phase which was in concordance with the findings of Aryal *et al*. (2016). This might be because of the suitable weather available for foraging. Foraging activity of *A. cerana* and *T. iridipennis* on rambutan (*Nephelium lappaceum* L.) was higher during the morning hours with the peak activity at 1000–1100 hours (Shivaramu *et al*., 2013). Foraging rate of *A. florea* was highest during 1230–1300 hours on Mexican creeper (*Antigonon leptopus*) (Surekha and Mayuri, 2016). Shilpa *et al*. (2014) found that the foraging activity of *A. florea* peaked during 1100 hours. Peak foraging activity of *A. cerana* and *A. dorsata* was seen during 1200 hours (Subhakar *et al*., 2011). According to Nderitu *et al*. (2008), the foraging activity of *Apis* and non- *Apis* bees in sunflower peaked between 1000 and 1400 hours. Foraging at higher temperatures may not ne thermodynamically viable for the floral visitors and hence, the decrease in foraging activity.

FORAGING BEHAVIOUR

Majority of honeybee visitors of *S.trilobata* were seen probing for nectar more than collecting pollen. Bees walked over the heads of florets and inserted proboscis completely into them. While probing, the proboscis reached the base of corolla, and the insect visitors get heavily dusted with pollen. The results were in confirmation with the observations of Free (1964). A small portion of pollen was seen on the head which was also cleaned with legs while cleaning the body. This foraging behaviour of honeybees makes them an important pollinator of *S. trilobata*. This trend agrees with Shenkute (2009) and Free (1970). Bees such as *Tetragonula iridipennis*, *Apis cerana* and *A. florea* foraged on *M. diplotricha* only for pollen and moved over the florets in a rapid and random manner, contacting several florets. Whereas, lepidopterans legs come into contact with pollen while visiting the flower (du Toit and Holm, 1992).

Crowding of florets on the head of Sunflower ensured that during a single insect visit, maximum numbers of florets are visited (Hurt, 1944). The retention of old florets in *L. camara* increases the landing platform for insect visitors (Schemske, 1976). Lepidopterans were seen probing into the florets while sitting on this inflorescence. They visited a smaller number of florets, but spent more time on each floret per visit (Bosch *et al*., 1997; Kunte, 2007). Papilionids were seen to flutter wings while inserting proboscis into the corolla tube (Cruden and Hermann- Parker, 1979). While probing for nectar in *L. camara*, *Macroglossum* sp. was observed to hover above the flower and extending their proboscis at about 10 cm above the flower. Our observations support previous findings (Brantjes and Bos, 1980; Raju *et al*., 2004). They visited higher number of flowers compared to other lepidopterans, but spent a short time period of one second, which was in agreement with the observations of Bosch *et al*. (1997) and Thompson (2001). In the present study, *Lucilia* sp. a dipteran, was seen to stay still on the florets of head capitulum of *S. trilobata*. Similar observations have been made by du Toit and Holm (1992) who also observed that dipterans stayed still for a long time on capitulum.

The time of the day when insect visitors initiate and cease foraging often depends on the air temperature, relative humidity and light intensity as well as the available floral resources (Koetz, 2013). In the present investigation, visitation rate of *A. cerana* and *A. dorsata* on *S. trilobata* and *M. diplotricha* was highest during Early phase and gradual reduction was observed as the day progressed. Similar reports were also made by other investigators for foraging activities of honeybees (Hussain, 2011; Joshi and Joshi, 2010).

In all the three invasive plants, it was observed that the number of insects visiting a patch had a positive correlation with the number of flowers in a patch. The larger the patch size more the insect visits to the flowers. The results were in confirmation with the observations recorded by Duara and Kalita (2013), who observed that abundance of insect visitors was positively correlated with the number of flowers. Similar results were found by Mukherjee *et al*. (2015), who also found a positive correlation between flower density and butterfly density. According to Gori (1989), plants having a greater total number of flowers per inflorescence attracted more pollinators. Plants having larger inflorescence (*Corydalis ambigua*) had more visitors than those with smaller inflorescence. Longer visits to flowers strongly enhanced the seed production, whereas it was independent of large number of visits with shorter duration (Ohara and Higashi, 1994). Both the flower number and corolla size were seen to increase the pollinator visitation in radish (Conner and Rush, 1996). Insects visiting a floral patch with high floral density should result in high pollen and nectar rewards at lower foraging costs and should again result in high floral visitation rates (Zimmerman, 1981; Goulson, 2000; Nielsen *et al*., 2000)

Bagged flowers (to exclude visitors) of both *S.trilobata* and *M. diplotricha* completely failed to set seeds. The results were in confirmation with the observations recorded by Wanigasekara and Karunaratne (2012) who found that bagged *Solanum violaceum* flowers which exclude pollinators completely produced no fruits. All the bagged *L. camara* inflorescence produced seed sets by autonomous self- pollination. The result was in confirmation with the observations recorded by Carrión–Tacuri *et al*. (2014).

IMPACT OF INVASIVE PLANTS ON NEIGHBORING NATIVE PLANTS

It was observed that *L. camara* attracted significantly more floral visitors than the natives growing in its vicinity. This agrees with observation of Vila *et al.* (2009) that the invader plants were visited by half of all pollinator species occurring in a site, whereas native species received visits from only 18.18 per cent of pollinator species. In addition, on average, pollinators depended upon the invasive plant species significantly more than on native plant species. In most sites, the invader was the plant species ranking highest in terms of number of interactions with pollinators and dependence of pollinators upon plants. These observations indicate that entomophilous invader species are super generalists and are well assimilated in the introduced plant–pollinator network (Richardson *et al*., 2000), but they also play a pivotal role compared with native plant species that have long evolved with native pollinators (Lopezaraiza-Mikel *et al*., 2007).

Most of the insect visitors to the three invasive plants under study were generalists. According to Memmott and Waser (2002), floral visitors preferred invasive plants as their floral phenology resembled that of natives. Higher insect abundance was found in sites containing *L. camara* attracting a larger proportion of lepidopterans, with majority preferentially visiting *L. camara* (Mukherjee *et al*., 2015). The results were in confirmation with the observations recorded by Graves and Shapiro (2003) who found that butterflies preferred exotic host plants as their nectar sources. Recently, Arjun *et al*. (2017) found that nymphalids were the most abundant visitors to invasive plants which was also the case in the present study. Lepidopterans were seen to be the most common visitor to *L. camara* and native *Ixora coccinea*. This is foreseeable considering the similarity in floral morphology between them (tubular corolla). This is in accordance with the findings of Weiss (1995), Muthoka and Mananze (2005), Bergerot *et al*. (2010) and Duara (2014). Hence, the abundance of hymenopteran visits to native plant did not vary, since they still attracted insect visitors which tended not to visit *L. camara*. *Sphagneticola trilobata* acted as a major food source for pollinators which were in concordance with the findings of Grombone-Guaratini *et al*. (2004), who found that invasive

Bidens L. belonging to family Asteraceae provided food source to insect visitors. Honeybees were seen preferring invasive *S. trilobata* and *M. diplotricha* compared to nearby native plants. This observation supports previous findings of Williams *et al*. (2011) and Requier *et al*. (2015) who found that bees visits more invasive plants compared to native plants.

In invaded plots, a higher species richness and abundance of insect visitors were observed. Similar results were found for the invasive *Impatiens glandulifera* (Lopezaraiza-Mikel *et al*., 2007). However, the presence of invasive plant *L. camara*, *S. trilobata* and *M. diplotricha* near the native plants reduced the visitation rate of insect visitors to the neighboring native plants. Another study that explored the impact of invasive *Lythrum salicaria* on native found a result very similar to my data, that visitation rate of pollinators to native *Lythrum alatum* reduced in the presence of invasive plant (Brown *et al*., 2002). Another study that explored the impact of invasive *Solidago canadensis* on native plants found a result very similar to my data, they reduced native plant species richness (Fenesi *et al*., 2015).

Invasive plants were seen to co- exist with each other and along with the natives sharing the visitors mutually. The abundant source of pollen and nectar in invasive plants may help the foraging insects, but on the other hand the dense population of invasive plants is a threat to native plant biodiversity.

These results indicate, thus, that for a generalization on the extent to which exotic species influence pollination success of native plants studies on more than one population of native plants needs to be carried out along with invasive plants within the same locality. If invasive are apomicts and attract pollinators that they do not need competition for pollination between natives and invasive will only negatively affect the natives (Kandori *et al*., 2009**)**

The light of the fact that these three invasive species observed during the present study, have spread and is still spreading very rapidly along the Western Ghats of Kerala, it will be interesting to examine in detail its impact on other native flora in future studies.

The study indicates that flowers of invasive plants are visited by many species of insects which may impact the reproduction in native plant species, thus leading to their decline. Studies have shown that competition for pollinator services can affect two important components of pollination: quantity and quality (e.g., Caruso, 1999; Herrera, 2000; Brown *et al*., 2002; Bell *et al*., 2005). The quantity component denotes the number of visits or the amount of pollen received. “Showy invasive species may attract pollinators that would otherwise visit native species, resulting in decreased visitation rates to the native species” (i.e., exploitation competition, e.g., Free, 1968; Armbruster and Herzig, 1984; Brown *et al*., 2002). Such reduction in visitation may reduce the amount of pollen deposited on stigmas and, in turn, seed and fruit production (Burd 1994). The quality component signifies the effect of heterospecific pollen transfer that results from varying foraging behaviour of pollinators. Pollen mixture and interspecific pollen transfer decrease the reproductive success of male and female (i.e. interference competition).

It is also observed that, on average, pollinators depended upon the invader significantly more than on native plant species. In most sites, the invasive was the plant species ranking the highest in terms of number of interactions with pollinators and dependence of pollinators upon plants. These observations support not only that entomophilous invader plant species are super generalists and are well assimilated in the introduced plant–pollinator network (Richardson *et al*., 2000), but also that they play a pivotal role compared with native plant species that have long evolved with native pollinators (Lopezaraiza-Mikel *et al*., 2007). Detailed quantitative studies need to be carried out on the preference of native pollinators for invasive plants over native plants, in order to assess the threat, they pose to the stability of our ecosystems.

Insect floral visitors foraged on the invasive plants for nectar and pollen. Hymenopterans fed on nectar from flowers with smaller corolla tube, whereas lepidopterans preferred flowers with longer corolla tube. Among the three invasive plants, *Lantana camara* was visited by the highest number of species of insect visitors. Lepidopterans were the dominant visitors to *L. camara*. In *L. camara* and *Sphagneticola trilobata*, Nymphalidae was the dominant family. *Catopsilia pomona* and *Amegilla zonata* are the dominant visitors to *L. camara*. Hymenopterans were the dominant visitor to *S. trilobata* and *Mimosa diplotricha*. *Apis cerana* was the dominant visitor to *S. trilobata*. *Tetragonula iridipennis* was the predominant visitor to *M. diplotricha*. The number of insect visitors to *L. camara* was highest in highland, whereas frequency of insect visit was highest in lowland. Frequency of insect visit to *S. trilobata* and *M. diplotricha* was highest in highland. Number of species visiting *S. trilobata* was highest in lowland. *Ceratina hieroglyphica* visiting *L. camara* was seen only in Highland. *Nonathra* sp. and *Sarcophaga* sp. visiting *S. trilobata* was found only in highland. In *L. camara*, bagged flowers and unbagged produced seeds. In *S. trilobata* and *M. diplotricha*, bagged flowers did not produce any seed set, whereas flowers which were not bagged produced seeds, indicating the need for insect visitation to effect pollination. The frequency of insect visit was higher in patches with higher number of flowers. Diversity index of insect visitors to *L. camara* was highest in Monsoon and lowest during Pre- Monsoon. The frequency of insect visit to *S. trilobata* was highest during Post- Monsoon in all the three altitudes. Papilionids was seen visiting *S. trilobata* only during Post-Monsoon. The frequency of insect visitors to the invasive plants *L. camara* and *M. diplotricha* was highest during Early phase and decreased as the day progressed. Insect visitors to *S. trilobata* was highest during Middle phase and lowest during Late phase. *Apis florea* was seen visiting *M. diplotricha* only during Early phase.

In *L. camara*, foraging time was shortest for hymenopterans. *C. hieroglyphica* spent more time on *L. camara* and *S. trilobata* flowers than other hymenopterans. *Apis florea* spent longest time foraging on *M. diplotricha* florets during Early phase. Among lepidopterans, *Ypthima huebneri* spent the longest time on *M. diplotricha*. Among hymenopterans, *Amegilla zonata* and *Apis cerana* recorded the highest visitation rate to *L. camara* and *S. trilobata* respectively. The visitation rate of hymenopterans to *S. trilobata* was highest in highland. In *L. camara*, highest visitation rate was seen in *Cepora nerissa*, *Graphium sarpedon*, *Telicota* sp., *Talicada nyseus* and *Ideopsis vulgaris* belonging to families Pieridae, Papilionidae, Hesperiidae, Lycaenidae and Nymphalidae respectively. In *S. trilobata*, highest visitation rate was seen in *Euploea core*, *Iambrix salsala*, *Euchrysops cnejus*, *Catopsilia pomona* and *Graphium agamemnon* belonging to families Nymphalidae, Hesperiidae, Lycaenidae, Pieridae and Papilionidae respectively. The visitation rate of *Scolia* sp. and *Delias eucharis* was highest in *M. diplotricha*.

Among lepidopterans, *Sarangesa dasahara* and *Neptis hylas* foraged the longest on *L. camara* and *S. trilobata* flowers respectively. Lepidopterans hovered above the flower, extending the proboscis and inserting it into the florets in a random manner. Pollen grains were observed on the proboscis of insect visitors. *Macroglossum* sp. had the longest proboscis among the other insect visitors. They hovered above the flower and inserted the proboscis into *L. camara* florets. Hymenopterans visited florets having corolla tube which were nearly equal to their proboscis length. Among hymenopterans and lepidopterans, shortest proboscis was seen in *T. iridipennis* and *Tagiades litigiosa* respectively. While foraging on *S. trilobata*, hymenopterans consistently contacted the anther and stigma after landing on the flower. Pollen grains adhered to the body surface of insect visitors. They are groomed and collected as pollen clump on hindlegs. All hymenopteran floral visitors including *Apis florea*, *C. hieroglyphica* and *Nomia* sp. visiting *S. trilobata* showed cleaning behaviour. All the hymenopterans visiting *M. diplotricha* collected pollen using forelegs. They were seen visiting only new flowers, avoiding older flowers, as newly opened flowers only have viable pollen.

In *L. camara*, the colour of the floret serves as an important cue on the rewarding nature of the florets. Insect visitors preferred Yellow and pink florets over other colours. Pollen viability of yellow florets was higher than pink florets. In *L.*

camara, orange florets had the highest nectar content and dark pink had the lowest. Insect visitors are attracted by the yellow petal of ray florets of *S. trilobata* and feed nectar from the disc florets. In *S. trilobata*, disc florets had higher nectar content than ray florets. Nectar content in florets was highest during Early phase and decreased as the day progressed. Insect visitors are seen to collect pollen from *M. diplotricha*. Temperature had an influence on time spent on the flowers of *L. camara* and visitation rate of both hymenopterans and lepidopterans. Hymenopterans and lepidopterans visiting *L. camara* showed a negative correlation with temperature. Time spent and visitation rate also showed a negative correlation with temperature. Light intensity did not have any effect on foraging activity of insect visitors on *L. camara*. Temperature had a significant influence on time spent and visitation rate of hymenopterans to *S. trilobata*, whereas light intensity influenced the time spent and visitation rates of both lepidopterans and dipterans. Humidity did not have any effect on foraging activity of insect visitors on *L. camara* and *S. trilobata*. Temperature influenced the time spent by hymenopterans and lepidopterans on *M. diplotricha*. Humidity had a significant influence on the frequency of visitation of both hymenopterans and lepidopterans to *M. diplotricha*. Light intensity was seen to influence only the frequency of hymenopteran visitation to *M. diplotricha*. But in *M. diplotricha*, humidity and light intensity did not have any influence on the time and visitation rate of any of the insect orders.

Insect floral visitors spent more time on invasive plants than on native plants. Frequency of visit was more towards flowers of *L. camara* than to native plants, when *L. camara* was present in the locality.

Detailed quantitative studies need to be carried out on the preference of native pollinators for invasive plants over native plants, in order to assess the threat, they pose to the stability of our ecosystems.

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