SEASONAL VARIATION OF HORNETS IN THE APIARIES OF NATURAL HISTORY MUSEUM, SWAYAMBHU, KATHMANDU

Ganga Kafle
TU Registration Number: 5-2-37-362-2010
TU Examination Roll Number: 114/071
Batch: 2071/072

A Thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Zoology with special paper Entomology

Submitted to

Central Department of Zoology
Institute of Science and Technology
Tribhuvan University
Kirtipur, Kathmandu
Nepal

January, 2021

DECLARATION

I hereby declare that the work presented in this thesis has been done by myself, and has not been submitted elsewhere for the award of any degree. All sources of information have been specifically acknowledged to the author(s) or institution(s).

Date: 26 January 2021

.....

Ganga Kafle

TRIBHUVAN UNIVERSITY ☎ 01-4331896
CENTRAL DEPARTMENT OF ZOOLOGY
Kirtipur, Kathmandu, Nepal.

Ref.No.:

RECOMMENDATION

This is to recommend that the thesis entitled "**SEASONAL VARIATION OF HORNETS IN THE APIARIES OF NATURAL HISTORY MUSEUM, SWAYAMBHU, KATHMANDU**" has been carried out by Ganga Kafle for the partial fulfillment of Master's Degree of Science in Zoology with special paper Entomology. This is her original work and has been carried out under my supervision. To the best of my knowledge, this thesis work has not been submitted for any other degree in any institutions.

Date: 26 January 2021

Dr. Ishan Gautam
Associate Professor
Natural History Museum
Tribhuvan University
Swayambhu, Kathmandu, Nepal

TRIBHUVAN UNIVERSITY ☎ 01-4331896
CENTRAL DEPARTMENT OF ZOOLOGY
Kirtipur, Kathmandu, Nepal.

Ref.No.:

LETTER OF APPROVAL

On the recommendation of supervisor **Dr. Ishan Gautam,** this thesis submitted by Ganga Kafle entitled "**SEASONAL VARIATION OF HORNETS IN THE APIARIES OF NATURAL HISTORY MUSEUM, SWAYAMBHU, KATHMANDU**" is approved for the examination [redacted] in partial fulfillment of the requirements for Master's Degree of Science in Zoology with special paper Entomology.

Date: 26 January 2021

Prof. Dr. Tej Bahadur Thapa
Head
Central Department of Zoology
Tribhuvan University
Kathmandu, Nepal

TRIBHUVAN UNIVERSITY ☎ 01-4331896
CENTRAL DEPARTMENT OF ZOOLOGY
Kirtipur, Kathmandu, Nepal.

Ref.No.:

Central Department of Zoology T.U. Kirtipur

CERTIFICATE OF ACCEPTANCE

This thesis work submitted by Ganga Kafle entitled **"SEASONAL VARIATION OF HORNETS IN THE APIARIES OF NATURAL HISTORY MUSEUM, SWAYAMBHU, KATHMANDU"** has been accepted as a partial fulfilment for the requirements of Master's Degree of Science in Zoology with special paper Entomology.

EVALUATION COMMITTEE

.....

Supervisor
Dr. Ishan Gautam
Associate Professor
Natural History Museum
Tribhuvan University
Swayambhu, Kathmandu, Nepal

.....

Head of Department
Dr. Tej Bahadur Thapa
Professor
Central Department of Zoology
Tribhuvan University
Kirtipur, Kathmandu, Nepal

.....

External Examiner
Prof. Dr. Bhaiya Khanal
Date of Examination: 9 March 2021

.....

Internal Examiner
Dr. Prem Bahadur Budha
Associate Professor
Central Department of Zoology
Tribhuvan University
Kirtipur, Kathmandu, Nepal

ACKNOWLEDGEMENTS

I would like express my sincere gratitude to my supervisor **Dr. Ishan Gautam, Associate Professor**, Natural History Museum for his incessant support and invaluable guidance for the completion of this thesis work.

I am indebted to Prof. Dr. Tej Bahadur Thapa, Head of Central Department of Zoology (TU), Kirtipur for providing valuable suggestions and support during this work. I am also thankful to Prof. Dr. Ranjana Gupta, former Head of Central Department of Zoology (TU), Kirtipur for her kind inspiration and suggestions.

I am extremely thankful to Natural History Museum for providing me space to keep traps and store my collections.

Likewise I am grateful to Ms. Jamuna Kafle and Ms. Monica Shrestha for their immense help I acquired during all field works.

Lastly I cannot stay without thanking all my friends and family members who directly or indirectly supported me with all possible means to accomplish this thesis work.

Ganga Kafle

ABSTRACT

Predation of honeybees in the apiaries of Natural History Museum, Swayambhu, Kathmandu had been a serious problem causing a significant loss of bees in the apiaries. The aim of this study was to investigate the different species of hornets occurring seasonally during 2016 and 2017 at the apiaries there. Two traps with bait made from locally available substances (mixture of local beverage, water, honey, egg, orange, banana and sugar) were set on the branches of trees near the hives. With periodic replacement of the bait (once a week), number of hornets which fell into the trap were collected, counted and identified. Five species of hornets (*Vespa velutina, Vespa. basalis, Vespa tropica, Vespa orientalis* and *Vespa magnifica*) were collected in the whole study. The highest average occurrence of hornets was found in October (23.75±1.920) due to colony expansion and lowest occurrence was found in January (0.25±0.25) due to over-wintering. *V. velutina* made the highest occurrence in number (951) followed by *V. basalis* (122) while *V. magnifica* made the lowest occurrence (1) followed by *V. orientalis* (3).The Simpsons, Shannon and Evenness indices for the species were 0.214, 0.39611 and 0.246 respectively.

Monthly average occurrence of hornets was statistically significant with p-value 0.87592465 (11, 59) at 0.05 level of significance for one way ANNOVA. Occurrence of hornets, on the other hand, was positively correlated to temperature (0.5212) and humidity (0.6924).

Keywords: hornets, over-wintering, trap, bait, occurrence

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I: INTRODUCTION

1.1 Background

Some honeybee pests

Honeybee, honey and apiculture have been related to human beings since the beginning of human civilization. People used to hunt honey from the wild bees. Then they started domesticating the bees and eventually evolved the modern practice of rearing the bees by building the hives. Now farmers all over the world practice apiculture. Besides being a economic and popular profession, it is not free of problems and limitations. Among these limiting factors, honeybee enemies constitute a major factor. Wax moths, hornets and wasps cause heavy losses to beekeepers throughout the world, therefore, got maximum attention by researchers (Gulati and Kaushik 2004). In addition to these, bee lice, hive beetles, mites, ants, birds, rodents and mammals occasionally attain the status of serious honeybee pests (Gulati and Kaushik 2004).

In the context of Nepal, hornets and wasps are reported to cause serious threat to apiculture (Bhatta 2005). These social insects are predacious by nature and found widely distributed throughout the world and have the tendency to enter into the bee-hives and catch the honeybees from the combs or snapping the foraging honeybees with the greatest ease resulting the weakening of colonies and minimizing the hive productivity (Bhatta 2005). A strong honeybee colony can defend through mass attacked or terrifying by mimic nature whereas a weak colony may be destroyed or depleted or the colony may abscond after such prolonged pestering attack by wasps (Butler 1974). As a result it becomes a limiting factor in the success of beekeeping.

Distribution of honeybees and hornets:

Honeybees: Honeybees are common insects and are found to be ubiquitous. They prevail from Asia to Africa, Europe and America. Among the 30,000 estimated population of honeybees worldwide, 17,000 species are formally described (Status of Pollinators).

Six species of honeybees are found in Nepal, 4 of which are indigenous viz. *A. cerana* (Asian hive bee), *A. laboriosa* (Himalayan cliff bee), *A. dorsata* (Giant bee) and *A. florea* (Dwarf bee). Stingless bees *Trigona* and *Mellipona* sp. build a small hive and collect relatively low

amount of honey reported so far from Nepal (Thapa and Wongsiri 2003). *A. mellifera*, the European honey bee was introduced to Nepal like other Asian countries. So it is an exotic species for Nepal.

Hornets

Hornets commonly occur in Tropical Asia, Europe, Africa and North America. Depending upon the environmental conditions the abundance of the species vary. Kshirsagar and Mahindra (1975) reported several species of *Vespa* some of them are *V. orientalis, V. cincta, V. auraria*, *V. ducalis*, *V. basalis* and *V. magnifica* from the plains and valleys of India. William (1983) recorded ten different species of hornets (*V. analis, V. velutina, V. vivax, Vespula asiatica, V. austrica, V. flaviceps, V. germinica, V. nursei, V. structur*and *V. vulgaris)* from Kashmir Himalayas. The oriental hornet (*V. orientalis*), Greater banded hornet (*Vespa tropica/V. cincta*), Asian Giant hornet (*V. mandarina*), Lesser banded hornet (*V. affinis*), Yellow vented hornet (*V. analis*), European hornet (*V. crabro*), *Vespa binghami*are also reported from Kashmir Himalayas. The yellow-legged hornet or Asian hornet *Vespa velutina nigrothoraxis* is naturally distributed in southeast Asia and it is the first invasive Vespidae predator accidently introduced to Europe from Asia (Monceau et al. 2013 and Braganca, 2019). In addition, *V. velutina* is widespread in Asia, from north-eastern India throughout southern and central China including Taiwan as far south as Indonesia (Archer 1994). The species is recorded from many countries of the world (Afghanistan, Bhutan, China including HongKong, India, Indonesia except Kalimantan and Irian Jaya, Japan, Laos, Malaysia, Myanmar, Nepal, Pakistan, South Korea) (Archer 2012).

The Oriental and Palaearctic regions of the world being the revolutionary center of the hornets has their diverse prevalence; four genera of the subfamily Vespinae (*Vespa* Linnaeus, 1758; *Provespa* Ashmead, 1903; *Dolichovespula* Rohwwer, 1916 and *Vespula* Thomson, 1869 (Carpenter and Kojina 1997 as mentioned in Bista et al. 2020) are found to encompass extant species (*V. affinis* Linnaeus, 1764; *V.analis* Fabricius, 1775; *V. basalis* Smith, 1852; *V. bellicose* de Saussure, 1854; *V. bicolor* Fabricius, 1787; *V. binghami* du Buysson, 1905; *V. crabro* Linnaeus, 1758; *V. ducalis* Smith, 1852; *V. dybowskii* Andre; *V. farvida* Smith, 1858; *V. fumida*van darVecht, 1959; *V. luctuosa* de Saussure, 1854; *V. mandarina* Smith, 1852; *V. mocsaryana* du Buysson, 1905; *V. multiculata* Perez, 1910; *V. orientalis* Linnaeus, 1771; *V. philippinensis* de Sassure, 1854; *V. simillima* Smith, 1868; *V. soror* du Buysson, 1905; *V.*

tropica Linnaeus, 1758; *V. velutina* Lapeletier, 1836; *V. vivax* Smith, 1870) and seven fossil species (*V. bilineata, V. ciliate, V. codifera, V. crabroniformis, V. dasypodia, V. nigra*and *V. picea*) (Carpenter and Kojima 1997 and Kumar et. al 2015 as mentioned in Bista 2020).

According to Kumar et al. (2020), distribution of hornets is mostly restricted to the Asian region with highest diversity in the Indo-Malayan region. Indian continent serves habitat for 16 species of hornets (Bista 2020) and Nepal alone is the home of 11 different species of hornets (*V. affinis, V. analis, V. basalis, V. bicolor, V. ducalis, V. fumida, V. mandarina, V. orientalis, V. tropica, V. velutina*and *V. vivax*) (Archer 2012, Bista and Dangi 2012, Kafle 2014, Thapa 2015 as mentioned in Bista 2020).

V. basalis, a native species to Taiwan, is a venomous hornet whose sting can be severe enough to cause edema (wikipedia). European hornet (*V. crabro*), *V. binghami* are the common hornets associated with honeybees in Asia.

In a study conducted to measure relative abundance of *Vespa* spp. in dry rain-fed and moist sub-humid ecology in five locations of Pakistan (Islamabad, Haripur, Khour, Chakwal and Karak, five species of hornets (*V. orientalis* L., *V. velutina pruthii*., *V. tropica hometyde* L., *V. basalis* S. and *V. vulgaris* L.) were found in different ecological locations (Munawar and Camphor 2004). The study also revealed that *V. vulgaris* was restricted to temperate zones, *V. orientalis* was found in all locations while the *V. velutina pruthii, V. tropica hometyde, V. basalis* and *V. vulgaris* are restricted to moist sub-humid and temperate ecology. Hornets were found active between the months of monsoon to December, the number being highest on the onset of monsoon rainy season in their respective habitats. High peaks in population was observed between September to October. *V. orientalis, V. velutina pruthii* and *V. basalis* were found to be predacious most during the first week of December at hive entrances. However no adults of *V. tropica* and *V. vulgaris* were seen during December. No species of hornets were found active after the month of January (Munawar and Camphor 2004).

Most species are native to Asia except the European species, *V. crabro* and the Oriental hornet, *V. orientalis*, which is only found in sub-Mediterranean region (Spradberry 1973, Matsuura and Yamane 1990). *V. velutina* is common to eastern Asia (Abrol 1994) and is currently spreading throughout Korea (Choi et.al 2012). Various hornet species have been reported to prey on different honeybee species such as *Vespa simillima, V. analis* and *V. crabro* assail on hives of *Apis mellifera* and *Apis cerana* in Japan (Matsuura and Yamane

1990), *V. tropica* on *A. mellifera* in Thailand (Burgett and Akratanakul 1982), *V. orientalis* on *A. mellifera* in Mediterranean countries (Wafa 1956 and Ishay 1964), *V. velutina, V. orientalis, V. basalis* on drones *of A. cerana* in India (Singh 1962), and *V. affinis, V. affinis* and *V. multimaculata* found to be attacked on nests of *A. nuluensis* in East Borneo (Koeniger et al. 1994 and Koeniger et al. 1996). The reason is hornet species attack honeybee colonies to feed on the honey and carry the bee larvae back to their colony to rear their developing brood. Consequence is destruction of the honeybee colonies and declination of honeybee populations and honey yield.

It has been reported to limit colony development of European bees in Asia by persistent predation of adult bees (Shah and Shah 1991). The attempts by hornets to attack honey bee colonies are numerous and frequent at the end of the season (September to December) when the production of new queen makes high demands on hornet workers (Mollet and Torre 2006).

In Nepal, hornets are found in plains and hilly region. Bista (2011) reported seven species (*V. analis, V. basalis, V. mandarina, V. tropica, V. affinis, V.orientalis* and *V. velutina*) of hornets from a survey conducted around the eastern and central parts of Nepal and Kafle (2012) reported six species (*V. affinis, V. basalis, V. mandarina, V. orientalis, V. tropica* and *V. velutina*) as chief predators of honeybees in different parts of Nepal (Bista 2020). Ranabhat and Tamrakar (2009) reported the prevalence of four hornet species (*V. basalis, V. bicolor, V. tropica and V. velutina*) Kaski district of Nepal .In a study carried out at Bhatkyapati-12 and Tyangla-3, Kirtipur Municipality under apiary and filed condition during July, 2004 to September, 2004, four species of hornets belonging to family Vespidae (*V. velutina* Smith, *V. tropica* L., *V. mandrina* Smith, *V. basalis* Smith) were recorded as the major vespid predators (Bhatta 2005). The highest occurrence and percentage of predation was observed to be 4.26± 0.36 in 10:00 to 12:00 hrs during September and 46.71±8.39 in 12:00 to 14:00 hours during the monthly of July in apiary 'A' and 12.18±0.79 and 58.75±5.23 in 8:00 to 10:00 hrs during September in apiary 'B' respectively. It was also found that the occurrence of hornets continuously increased from July to September with decrease in rainfall and relative humidity and increase in temperature. Apiary condition had higher hornet predation compared to that in the field condition.

Colonies in Natural History Museum of Swayambhu, Kathmandu were heavily infested with these predators during 2016/17, so altogether eight colonies of *A. cerena* and *A. mellifera* were selected for the study. This study aimed to investigate the prevalence and seasonal variation of hornets invading the colonies by using traps and bait made from locally available materials.

1.2 Objectives

- To investigate the diversity of hornets predating the colonies of *A. cerena* and *A. mellifera* at Natural History Museum, Swayambhu, Kathmandu premises.
- To determine the seasonal occurrence of the hornets around the *A. cerana* and *A. mellifera* colonies at Natural History Museum, Swayambhu, Kathmandu.

1.3 Significance of the study

Though prone to a number of enemies, apiculture is predominantly affected by the predation of hornets worldwide. Predation by hornets and wasps of different species has been a major concern in the apiary of Nepal as well (Ranabhat and Tamrakar 2008). Hornet predators and its presence in and around *A. mellifera* colonies in Kathmandu valley indicates that apiculture in this area is not free of problems. So more of such systematic explorations of the hornet species diversity is needed to be done to explore preventive and control measures.

Apiaries in the present study area were also at the serious threat of hive absconding due to extreme predation pressure of hornets during 2016 and 2107. So the present study helps us to contemplate on whether the Natural History Museum site is suitable for apiculture since the extreme probable predation will never allow successful beekeeping in any area. Besides, the study may also assist us in finding the diversity of hornets predating the honeybee colonies in this area. As the traps with baits made from locally available materials were used to entrap the hornets, locally made traps and baits in environment-friendly control of hornets can also be practically used. In addition, this study may contribute in finding the species of hornets invading the area. This may lay the path for new work which could find the efficacy of locally made trap and easily available baits in pesticide-free control of the hornets.

CHAPTER II: LITERATURE REVIEW

Hornets live similar eusocial life as bees. They have their colonies constructed inside the paper nests where a foundress (queen) is reared along with males and workers. Worker hornets search the food for themselves and to feed the growing larva. Basically hornets feed on carbohydrates and protein, the feeding is quite different in larval and adult stage; adults may consume nectar, ripe fruits, tree sap, larval regurgitation (Matsuura and Yamane 1990), even meat (but not compulsorily). Larvae, however have a specific dietary requirement; protein diet is essential for larval development which makes these hymenopterans to predate on efficient prey which can supply both carbohydrates and protein. Bees serve as the best option for this availing both honey and worker muscles as a source of carbohydrates and protein. The predation is actually a matter of survival but draws the attention at the policy level due to its ecological and economic significance (Matsuura and Yamane 1990).

2.1 Morphology, Biology and Life-cycle

Table 1: Key morphological features of few hornets

S.N.	Hornet species	Identifying characters
1.	*V. velutina*	Normally black and yellow (Perrad et.al. 2012, Monceau et.al. 2013). An orange-yellow band in 4thtergite, towards the end of the abdomen and yellow legs are present (Villemant 2013).
2.	*V. basalis*	• Dull testaceous yellow head, thorax, basal abdominal segment clouded irregularly with dark and brown, covered with golden pile. • The 2nd and following segments of the abdomen vary dark brown or black and the basal segment may have a short subapical transverse black band in the middle above, and some irregular black spots on the each sides near the base. The wings are flavor-hyaline in colour .
3.	*V. tropica*	• Remarkable brownish red head, the protonum, tegulae

		and scutellum and bright yellow, 2nd abdominal segment, with its base narrowly black. • Rest of the thorax and abdomen black (Chan 1972).
4.	*V. orientalis*	• Light chestnut-red coloured, 3rd and 4th segments bear a small spot on each side above reddish brown.
5.	*V. magnifica*	• Thorax and abdomen are smooth, with a fine silky lustre. • It is very dark brown with a golden tint in certain lights. • Legs are covered with a glistening golden ferruginous pile and the wings are dark fuscous brown.

(From the identification key of Fauna of British India, Hymenoptera, Vol. I).

Foraging behaviour:

Hornets have an advanced mechanism of foraging for collecting the food. The study carried out by Toh and Okamura in (2003) revealed that hornets can forage in wide range of light intensity and distance. According to them, luminosity of 8 lux is sufficient for hornets to identify their feeding place so even in the dark they can forage. It is believed that individuals use some structures as navigational landmarks to negotiate and these landmarks differ individually. Hornets are found to use cues for navigation; few external cues are used for short distance, visual cues for mid-range navigation and visual cues and wider scenery in the approach flight. They use olfactory cues to find a new feeding place and multiple navigational cues for visiting familiar feeding place (Toh and Okamura 2003).

V. velutina is found to be faster and more agile than other hornet species. Although adult do not themselves consume meat (they may ingest meat juices), they predate on insects and bee colonies to feed the larvae in the colony. Larvae in the colony are fed on insect prey and meat from the mammals and bird carcasses, as well as fish and meat from fishmongers and butchers stalls. An adult *V. velutina* feeds on sweet carbohydrates, such as nectar, ripe fruit and tree sap and on special regurgitations from the larvae (Matsuura and Yamane 1990).

V. orientalis, on the other hand, has brood and adult provided with different types of nutrition. Brood are fed with animal protein like insects and pieces of meat while adults

prefer to carbohydrates. These predacious species thus favour beehives which serve as the source of both proteins and carbohydrates (Nicholaos et. al 2006 as mentioned in Mohammad and Yasser 2009). Consequently, they lay siege to the hive and not only enter and rob the hives but destroy the hives at extreme (Dejong 1979).

Foraging range

Compared to honeybees, hornets are found to have a wider foraging range. Normally bees fly 600-800 meters in search of food (Seeley 1982), largest recorded is range of 13.5 km (Frisch 1967). Hornets, on the other hand, can fly 10 to 30 km away from their hives to collect their food (Sauvard et al. 2018). Sauvard et al. (2018) revealed this fact in a study of flight capabilities of *V. velutina* workers using computerized flight mills.

Mating Behavior

Hornets show sexual dimorphism, has holometabolous larval division and female provides considerable parental care. Queens induce copulatory responses (Ono and Sasaki 1987 as mentioned in Ayasse 2001). In vespine wasps, female produce sex hormones and attractants. Courtship behavior is stimulated as mounting and copulation (Downing 1991, Jaenne 1996 and Landolt et al. 1998 as mentioned in Ayasse 2001). *V. crabro germana* is supposed to produce four hormones contributing in mating behavior; an aggregation pheromone in female faeces, a defensive pheromone in venom, a cephalic territory marking pheromone released by male and a contact pheromone. Contact pheromone is secreted by thoraces of queens which is responsible for evoking copulatory behavior in males (Batra 1980).

Nesting Behavior and nest location

Hornets build paper nests from the material obtained from gnawing at the tree branches.

a) *V. velutina*: It is found to build two types of nests in a season, one type, in or on man-made structures and the other on natural structures (tree canopies, undisturbed and sheltered areas in buildings such as stairwells, in abondoned barns, chicken coops or sections of buildings), in bramble bushes and underground also which is very rare (Martin 1995).
b) *V. orientalis*: It builds an underground nest. Individuals communicate with each other through sound vibrations (Archer 1998).

Nests can be initiated any time of the year in tropical regions but are only built yearly in spring in temperate climates; they are left empty during winter.

Life-cycle

Hornets undergo annual life-cycle and pass through four typical stages of hymenopterans; eggs, larva, pupa and adult. The life-cycle starts every year with the emergence of queens (also known as foundresses) undergone over-wintering and hibernation in the autumn of previous season. Depending upon the species, hibernation may vary from soil to tree crevices (Matsuura and Yamane 1990). *V. velutina* foundresses are found to hibernate in wood piles, shelters or burrows in the winter (Matsuura and Yamane 1990). After the arrival of spring, from mid-March to late June foundress starts flying (Monceau et al. 2012 and Monceau et al. 2013). She builds a small embryo nest to rear her first batch of workers (females). Initially the nest is of the size of a lemon and consists of only 30-40 cells. The nest is built in an enclosed and protected place (a wall cavity, tree hollow, shed, porch etc). First batch of workers emerge in 30-50 days in sub-tropical and temperate regions (Dong and Wang 1989 and Choi et al. 2012). If colony can't expand due to site, then relocation of the colony occurs building the secondary nest up to 200m away from the primary nest (Matsuura and Yamane 1990).

Vecht (1957) reported that colonies of hornets are annual with fertilized queen over wintering in dipausing stage in temperate region, where as in the tropics, perpetuation is cyclic and all stages of development are found in the colony round the year.
The life cycle is similar for *V. basalis, V. tropica, V. orientalis and V. magnifica.*

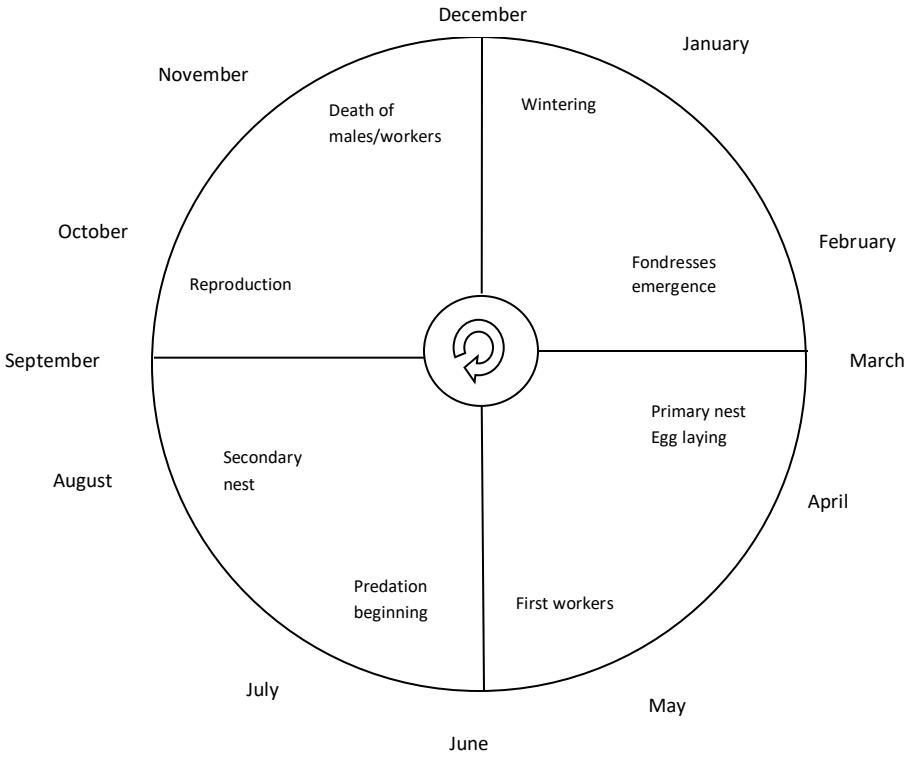

Figure 1. Life-cycle of *Vespa velutina*

Source: Monceau et al. (2014)

2.2 Effects of invasion:

Primary effect of hornet invasion is the predation upon honeybee. Due to high ecological significance of honeybee, hornet invasion ultimately has ecological impact as well. In domesticated condition farmers may bear loss due to the attack of these predators. The loss is commensurate with the investment and predation pressure of the predators (Monceau et al. 2013). Hornet's sting can be detrimental to human beings. But these insects are also taken as delicacies in different parts of the world. To sum up, these hymenopterans have environmental, ecological as well as health significances.

2.3 Defence mechanism of *Apis cerana* and *Apis mellifera* against hornets

In spite of their stings, *A. mellifera* and *A. cerana* are prone to attack of these hornets/ wasps, so they have developed defence mechanisms against their attacks. However, *A .mellifera* are more susceptible to hornet/wasp attack than the later (Muzaffar and Ahmad 1986).

A combined defence behavior of *A. cerana* against the Asian giant hornet *V. mandarinia* is caused by "balling behaviour" (bees surrounds hornets) (Ono et al. 1987), *A. mellifera* against *V. velutina* (Ken et al. 2005), and *A. mellifera cypria* against *V. orientalis* (Papachristoforouet al. 2007) raising the temperature to as high as 47 °C, as hornets enter into beehive, which is lethal to the hornet but not the bees (Ono et al. 1987). Apart from temperature, carbon dioxide generation during bee balling also contributes to the protection of workers bees against hornets (Sugahara and Sakamoto 2009). In addition, since the lethal temperature threshold is considerably higher in *V. orientalis*, *A. mellifera cypria* kills the hornets by asphyxia, blocking abdominal pumping and thus indirectly increasing carbon dioxide concentration (Papachristoforou et al. 2007) and this honeybee species produces a characteristic high-frequency hissing sound during *V. orientalis* attacks, which could be an alert signal for the colony (Papachristoforou et al. 2008).

2.3.1 Predation

The yellow-legged hornet (*Vespa velutina*) is the first invasive Vespidae predator of honeybees to be accidentally introduced into Europe from Asia. In the current pollinator decline, *V. velutina* is an additional stressor for honeybees and other pollinators and invasive species to Europe and China (Monceau et al. 2013).

Monceau et al. (2013) interpreted the impact of *V. velutina*, an important stressor for the bee colony, as ecological impact (on biodiversity), economic impact (on beekeepers and citizens) and sanitary impact. These predators predating on hives and other insects not only reduces the number of honeybees but also affects plant bio-diversity by reducing pollinator populations (Monceau et al. 2013). Hornet workers preying on honeybee foragers reduces foragers number which ultimately decreases food storage and eventually collapse of the hive during winter (Arca 2012). Additionally, studies in China have shown that the predation pressures of the hornet impacted the learning ability of the honeybees (Wang et al. 2016) and neonicotinoid pesticides reduce predator avoidance (Tan et al. 2014).

About 20-25 per cent bee colonies desert their nest every year due to wasp attack (Adhalakha and Sharma 1975). The largest of the social wasps, *Vespa* sp. are physically capable of preying on honeybees with ease. *V. orientalis* L. (Yellow branded brown wasp), *V. magnifica* Smith (large black wasp), *V cincta* F. (Yellow banded wasp), *V. ducalis* Smith and *V. auraria*

Smith (Golden wasps) are some of the species which destroy the weak and queen less colonies for honey and the brood in apiaries (Kshirsagar and Mahindre 1975 and Sharma et al. 1979) and foragers in field (Abrol 1994 and Abrol and Kakroo 1998).

Sharma et al. (1985) reported *V. mandarina*, *V. tropica*, *V. velutina* and *V. basalis* attacking colonies of *A. mellifera* and *A. cerana* in Kangra (H.P. India). Shah and Shah (1991) observed *V. velutina* as a serious pest of honeybees in Kashmir. In New Zealand, *V. germanica* destroyed 3900 colonies and affected more than 10,000 others (Walton and Reid, 1976). Akre and Davis (1978) reported that in Japan a group of thirty *V. magnifica* was able to kill 25,000- 30,000 bees in just three hours at the rate of one bee per hornet every 14 seconds. Hitschfeldar (1952) estimated that a single female wasp consumes 60-80 bees as food during her lifetime.

Matsuura and Sakagami (1973) described that widely distributed hornet species *Vespa crabro* L. constructs its nests chiefly at above ground cavities and few underground. This type of habitat makes it easier to attack and catch the foraging bees in the field. The unavailabity of other bees leads the hornets upto the hive entrance. Attack of the hornets may be either in 'hunting' (the initial stage of attack when one hornet attacks one bee) or 'slaughter' phase (attacking a single bee by several hornets normally due to close presence of apiary and shift of attack to the bee hive). Hornets attack the counter attacking bees to death. This kind of sequence of hunting, slaughter and occupation was recorded with the attack of *V. tropica* upon *A. mellifera* colony in Thailand (Burgett and Akratanakul, 1982). *Vespa* preferably attacked *A. mellifera* in mixed apiaries containing *A. mellifera* and *A. cerena* (Adhlakha, 1975). Seeley et al. (1962) observed the abandoning of an *A. florae* colony due to attack of three *V. tropica* individuals.

Dejong (1979) observed that *V. crabro* has an interesting behavior of "pouncing" on any dark object on a flower, which occasionally results in the successful capture of a honeybee. Olberg (1959) described attacks in which *V. carbo* opens a bit of the bee's abdomen to expose honey stomach contents. Rivnay and Bitinsky (1949) explained the oriental hornet, *Vespa orientalis* as a major predator of honeybees in the Mediterranean sea. In Israel, the hornet has been known to destroy entire apiaries. The hornets forage regularly at the entrance of the hives and can deplete a colony's field force. After the hornets killed the guard bees, they enter the hive

and feed on the young and brood bees. Kloft and Schneider (1969) reported that *A. cerana* guards display a "shimmering" behavior when attacked by hornets. They form group of about 30 bees parallel to each other and face their adversary. Humming loudly, they raise their abdomen at an obtuse angle and bend their heads down. Butler (1974) described shimmering by *A. mellifera* in Cyprus. A similar defense by *A. mellifera* against *V. orientalis* is reported from Israel (Ishay et al. 1967).

2.3.2 Seasonal occurrence of hornets

Abrol and Kakroo (1998) noticed that *V. orientalis* was the most abundant and serious enemy of honeybees throughout the year with peak predatory activity during July to September which coincide with the floral dearth period. *V. cincta* and *V. magnifica* are soil resting species and show predaceous behavior by nature and feed on bees and other insects.

Mohammad and Yasser (2009) studying the population fluctuation of oriental hornet (*V. orientalis* L.) in Giza Governorate, Egypt for two successive seasons of 2007 and 2008 found the predation of the hornet, highest during October. The highest mean number of hornet individuals recorded during the month of October were 41.9% and 65.7% of the total hornets trapped in two successive seasons of 2007 and 2008 respectively. It was also the month of October when honeybee colonies wiped out at the highest (29.03% and 17.65% for the successive years respectively). They used modified screen trap fixed on empty brood box provided with some honey combs to entrap the oriental hornets in Giza Governorate of Egypt. These traps could successively entrap 42242.5 individuals/trap and 9577.9 individuals/trap during 2007 and 2008, respectively. The percentage of the wiped out colonies during the active seasons of these successive years were 45.16% and 35.29% of the total wiped out colonies during each year.

In a study carried out at a private apiary in DiarbNegm, Sharkia governorate and Meat Ghamr Region, El-Dakhlia Governorate, Egypt, during 2012 and 2013, the monthly average number for catching of *V. orientalis* adult was recorded highest at October followed by September and November. The best trap was the new trap with mean captured wasps 72.11, 82.34, 77.63 and 75.31 for Sharkia, Dakhlia governorate at both 2012, and 2013 years, respectively. Studying the effect of four directions and three heights in the installed trap, the

highest occurrence of *V. orientalis* was at east and south direction and the lowest mean at north and west directions. Results showed the monthly average numbers for collecting *V. orientalis* adults 0.5, 1.0 and 1.5 m above the land during 2013 which showed the highest occurrence of *V. orientalis* was at 1.0 m above the apiary land as best height 0.5 m as the lowest efficient. New trap (plastic bottle 2L.) was found to be the best trap for the *V. orientalis*. Study suggested that trapping can be used to control the wasp populations in Egypt (Abdelaal and El-Defrawy 2014).

Bista et al. (2020) studied the incidence and predation rate throughout the year at two locations of rural and forest areas of mid-hill in Lalitpur district during 2016/2017 to 2017/2018 and observed the number of hornets and honeybee captured by hornets in three different times of the day for three continuous minutes fortnightly on five honeybee colonies. Four species of hornets (*V. velutina* L., *V. basalis* S., *V. tropica* S., and *V. mandarina* S.) were found predating in the colonies. Incidence was lowest in the spring and summer and this increased gradually to reach the maximum rate during October and November. Highest incidence was noticed in mid- November (62.01%) and early-November (53.49%) at rural and forest locations in 2016/2017. The results of 2017/2018 showed the highest incidence (70.27%) on early November at rural area and mid-November (58.62%) for the apiaries near forest area. Apiaries at the forest location had higher predation of hornets than those at the rural area. Effect of rainfall showed negative correlation with the predation rate.

2.4 Pest management

2.4.1 Bait and trap setting

Methods to limit the impact and proliferation of *V. velutina* in Europe are based on nest destruction, trapping, population genetics, and biological control. Destruction of *V. velutina* nests at an early stage is required in order to short-circuit the colony cycle and thus limit both its impact on honeybees and its expansion through Europe.

Mohammad and Yasser (2009) used modified screen trap fixed on empty brood box fixed some honey combs to entrap the oriental hornets in Giza Governorate of Egypt. These traps could successively entrap 42242.5 individuals/trap and 9577.9 individuals/trap during 2007 and 2008, respectively.

A number of methods and techniques have been practiced to control Asian hornets and wasps hunting honeybees in the apiary site in Asian countries. One of the common practices is swatting individuals to kill them (Matsuura and Sakagami, 1973). Similarly, destruction of nests by burning and fumigation with Calcium Cyanide (Sihag 1992 as mentioned in Islam, Iftikhar and Mahmood 2015) is effective in controlling of this predator. As a new practice, water bowl with a little kerosene has been used as a trap in South Africa. The kerosene containing water bowl when placed under the hive entrance have been found to be deleterious to the predators (Smith 1960). Use of traps and bait is another popular technique of this insect control. Higo (1983) has reported the trapping of 10,000 *Vespa xanthoptera*, 100 *V. mandarina* and 8 *V. insulasis* during his study using fermented honey as a trap. Bait trapping technique applied for study effectiveness of baited traps in Sohag Governorate, Egypt showed wooden trap with honey as the most effective trap-bait over plastic trap and syrup and pollen as baits (Ahmed 2021). However, the wasps were found selective in their feeding and show preferences for certain baits.

Putting traps with baits of different composition is in practice in Nepal also. A study carried out by Bhatta and Tamrakar (2008) at Bhatkyapati-12 and Tyangla-3, Kirtipur Municipality, investigated the efficacy of eight different types of baits (rotten fish, rotten chicken, honey syrup, sugarcane syrup, sugarcane juice, apple, pear and mango).The baits of rotten fish and pear were found to be the best attractants for the management of predatory hornets because they attracted highest number of hornets and lowest number of honeybees followed by chicken bait. The highest number of hornets attracted were 8.600 and 8.667 per five minutes during September at rotten fish and pear baits respectively at apiary 'A'. Similarly, highest number of hornets attracted by rotten fish and pear in apiary 'B' were 8.533 in September and 6.952 in August.

CHAPTER III: MATERIALS AND METHODS

3.1 Materials

The materials and equipment used in the study are:

- Plastic Bottle (25 cm)
- Bait (mixture of locally made beverage (Raksi), water, honey, egg, orange, banana and sugar)
- Rope
- Tray
- Specimen holding bottles
- Insect box (For pinning and mounting)

3.2 Research Method

Quantitative method of research was applied and the study was field and laboratory-based. Random Block Design (RBD) was used and eight colonies were selected for the study. The study was conducted from December 2016 to November 2017.

Study site and description of the study area

Swayambhunath is cultural and religious site located at 27042'24" N and 85017'24" E geographic coordinates in the Northwest of Kathmandu Valley. Known as "self-existent one" the stupa sits atop a hill and stands as a symbol of the religious harmony prevailing in Nepal since the place is equally important shrine for both Hindus and Buddhists in the country. This area has also been listed in the World Heritage Site by UNESCO in 1979.

Generally temperate type of climate with mean temperature of 21 degrees and average annual rainfall of 1377 mm (61%), summer having a lot of rainfall and dry winter is found in this region. This region remains dry for 152 days of a year. UV-index of this area is 4 (internet).

Ranging at an altitude of 1350m to 1405m, the area has moderate climate and so is the vegetation i.e. sub-tropical flora. Needlewood (*Schima wallichii)*, Pine (*Pinus roxburghii)*, Wild Himalayan Pear (*Pyrus pashia)* and ground layers like Sticky snakeroot (*Eupatorium adenophorum*, Lantana (*Lantana camara)*, Malabar nut (*Justica adhatoda)* are found as the principle vegetation of this area (Ranjitkar and Chaulagain 2004).

The study was carried out in the apiaries of Tribhuvan University, Natural History Museum, Swayambhu, Kathmandu. The coordinates are 27.71460 N and 85.2878'E (Internet).

Natural History Museum of Nepal is located near the World Heritage site of Swayambhunath, Kathmandu, Nepal. It was established in 1975 A.D.

An apiary was set up for Smart Bees Project (collaborative project between Länderinstitutfür Bienenkunde (LIB), Hohen Neuendorfe.V., Germany and Natural History Museum, Tribhuvan University, Swayambhu, Kathmandu, Nepal). The apiary had the hives of *A. cerana* and *A. mellifera*. Hornet invasion turned out to be one of the serious problems in the site during the implementation of the project. With the purpose of finding the variety of hornets invading the bee hives as well as for pesticide-free controlling of the pest population, the traps were kept in the apiaries.

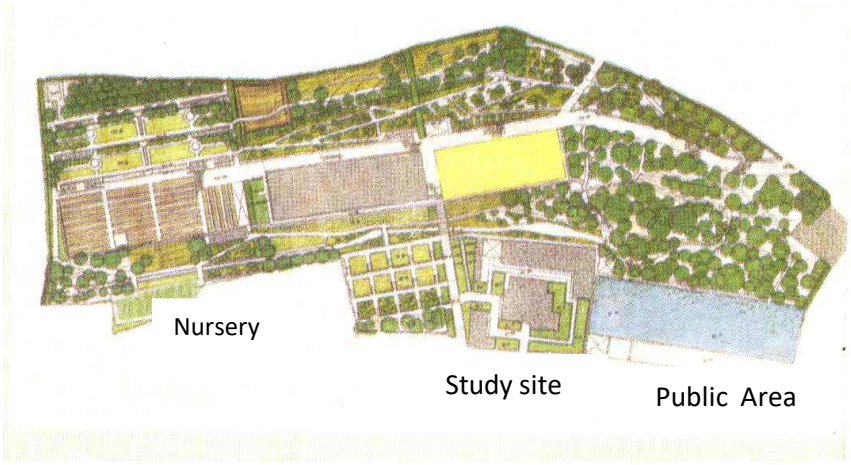

Figure 2: Map of study area

Preparation of the trap

Locally available plastic bottles were used to collect hornets/wasps population at study site. Plastic bottles measuring 25 cm in length, 10 cm to 15cm in wide and having two inlets (2.2 cm diameter) in just opposite postures were used as the frame of the trap in which bait was filled. The traps were designed in such a way that the hornets could enter but could not get out through them and thus get trapped. In the middle of the bottle lid, two small holes were made to insert a thread with which the trap was hung in the appropriate place.

Trap setup

Two traps made from locally available plastic bottles (25 cm) were placed near eight hives. In every seven days, new trap of same bait composition (mixture of locally made beverage (Raksi), water, honey, egg, orange, banana and sugar) were replaced in the bottles hung at the branches of trees near the colonies. Traps were randomly placed at a height of 1.5 m. Altogether 84 times bait placement was done during the study period. In each replacement of the fresh bait, the hornets attracted and caught in the traps were collected and counted (average/trap/week).

In addition, wooden bat was used to kill the individuals of hornet foraging near and around the apiaries as a mechanical control and the number was recorded as well. Temperature and humidity were also recorded by using thermo-hygrometer.

Specimen collection and storage

Average number of hornets fell per trap per week was calculated. Screened traps were also used as control in this study.

Thereafter collected specimens were transferred to the laboratory of Natural History Museum, Swayambhu, Kathmandu and preserved for identification.

Enumeration and identification

After transferring the specimens to the laboratory, the species were identified using identification key provided in the book Fauna of British India, Hymenoptera, Vol. I).

Preservation of the specimens

The specimens were mounted using entomological pin in insect box and preserved.

Data analysis

Diversity indices were analysed by calculating Simpson's Diversity Index, Shannon Diversity Index and Evenness index by using the formula in Excel spreadsheet 2010. Chi-square test and one way ANNOVA was done and a p-value of 0.05 was considered statistically significant.

Following formulae were applied for the calculation of diversity indices:

1. For Simpson's diversity index (http://www.statisticshowto.com/simpsons-diversity-index/)

$$D = 1 - \frac{\Sigma n(n-1)}{N(N-1)}$$

Where :

- n= number of individuals of each species
- N= total number of species of individuals of all species

The range is from 0 to 1, where:

- High score (close to 1) indicate high diversity
- Low score (close to 0) indicate low diversity

2. For Shannon-weaver diversity index

(http://biology.kenyon.edu/courses/bio/229/diversity.pdf)

$H' = -\Sigma P_i \ln P_i$

Where, $P_i = n/N$

ln= Natural log

3. For Evenness Index (Zhang et. al 2012)

Evenness (J)= H/ (ln S)

Where, H= Shannon diversity index

ln = Natural log

S = Species richness

Study design

The whole process and procedures of the study is summarized in the following flowchart:

Flowchart of the study design

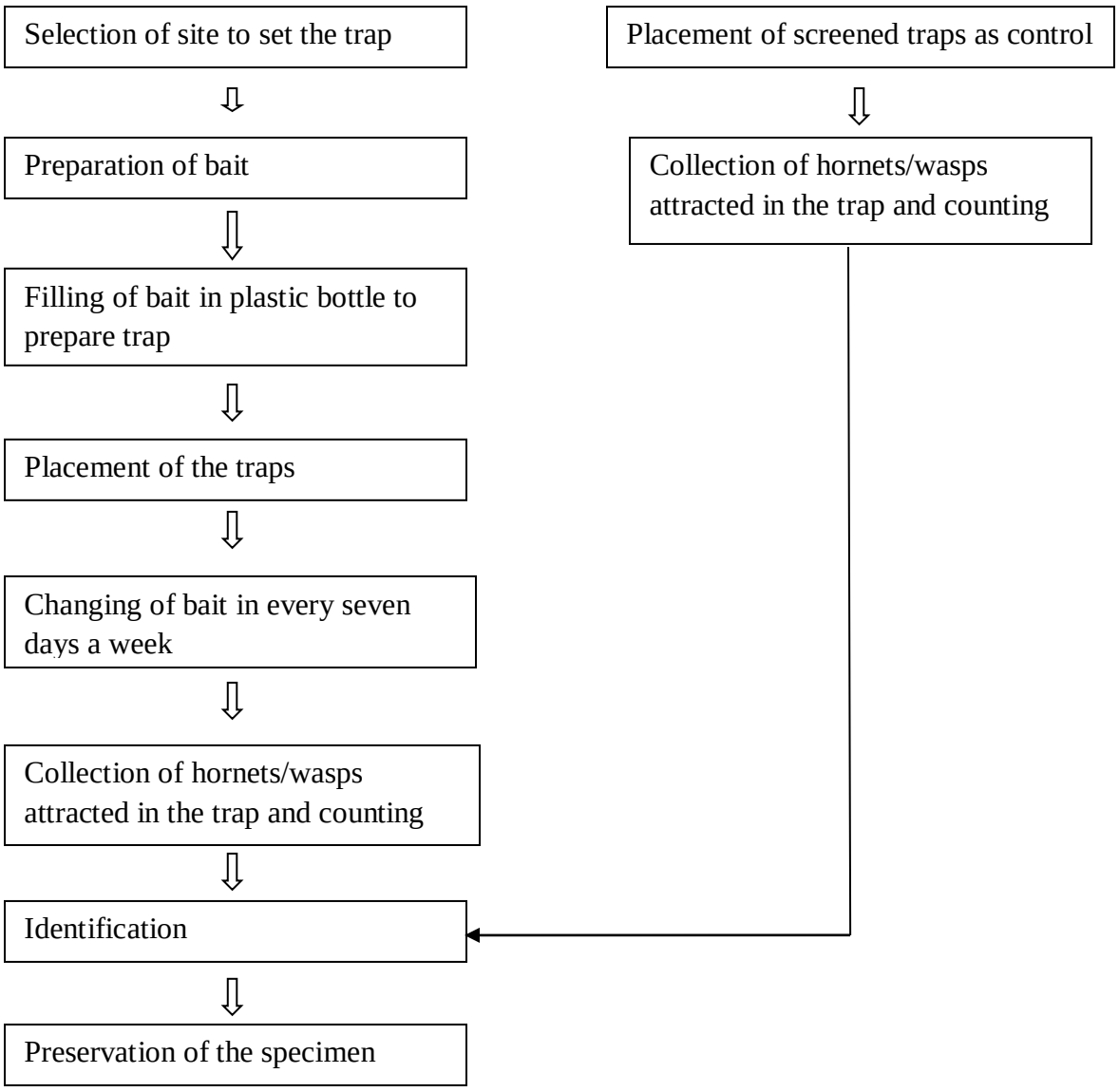

Figure 3: Flow-chart of study design

CHAPR IV: RESULTS

4.1 Total number of Hornets

Table 2: Species-wise occurrence of hornets at Natural History Museum apiary

Species	*V. velutina*	*V. basalis*	*V. tropica*	*V. orientalis*	*V. magnifica*
Number	951	122	5	3	1

Of the five species of hornets viz. *V. velutina* L., *V. basalis* S., *V. tropica* S., *V. orientalis* S. and *V. magnifica* S. recorded invading *A. cerana* and *A. mellifera* colonies of Natural History Museum Premises, Swayambhu, Kathmandu. *V. velutina* was found in the largest number (951) during the whole period of this study followed by *V. basalis* (122) and *V. tropica* (5), *V. orientalis* (3) and *V. magnifica* (1) (Table 2).

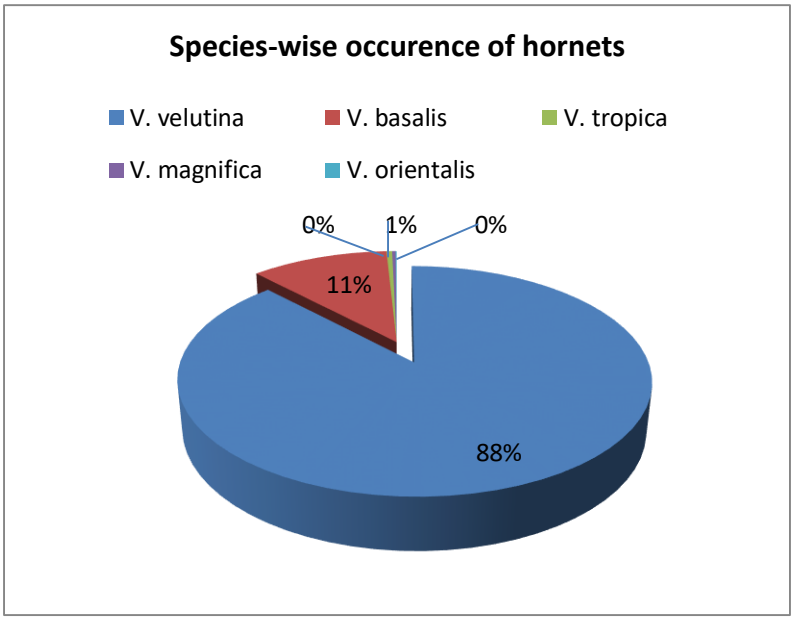

Figure 4: Species-wise hornet occurrence at the Natural History Museum apiary

In percentage, the occurrence of *V. magnifica* was found to be highest (88%) whereas two species (*V. tropica* and *V. orientalis*) were observed in a few number (near to 0%) (Figure 4).

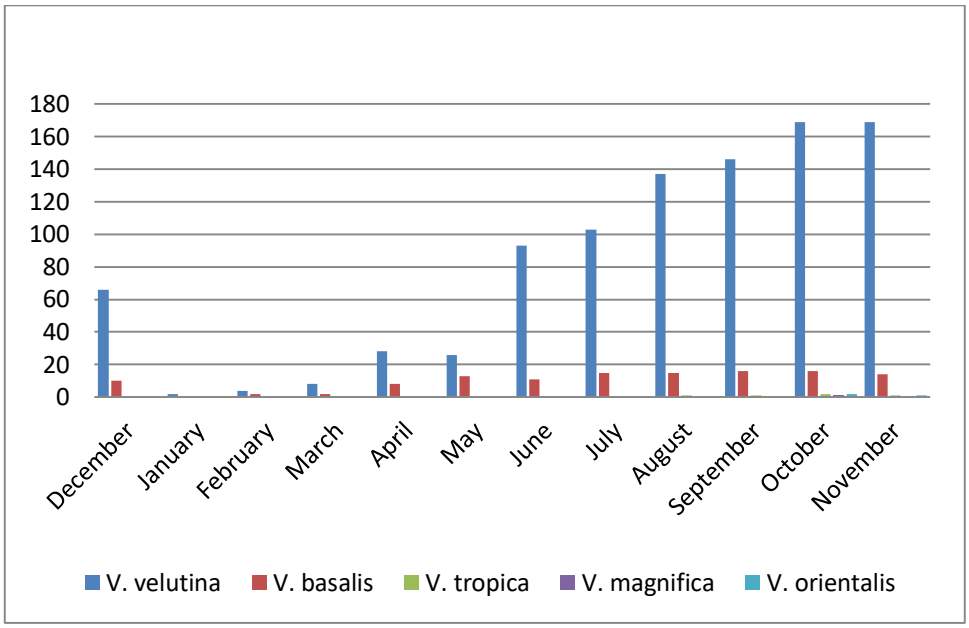

Figure 5: Species wise occurrence of hornets at the Natural History Museum apiary

Similarly, *V. velutina* was the species of the highest occurrence followed by *V. basalis* almost in all months of the study period. *V. tropica*, *V. orientalis* and *V. magnifica* made lower occurrence whereas *V. magnifica* made the least (Figure 5).

Table 3: Monthly average occurrence of hornets at Natural History Museum apiary site.

Month	December	January	February	March	April	May	June	July	August	September	October	November
Average	9.5±1.5	0.25 ±0.25	0.75± 0.25	1.25± 0.829	4.5±1.06	4.875± 0.739	13.25± 2.304	14.875 ±0.544	19.25± 1.03	20.625± 1.916	23.75±1.920	23.125± 0.892

The average occurrence of hornets was highest in the month of October (23.75±1.920) followed by November (23.125±0.892) and September (20.625±1.916) and the lowest invasion occurred in the month of January (0.25±0.25) followed by February (0.75±0.25) and March (1.25±0.829). (Table 3).

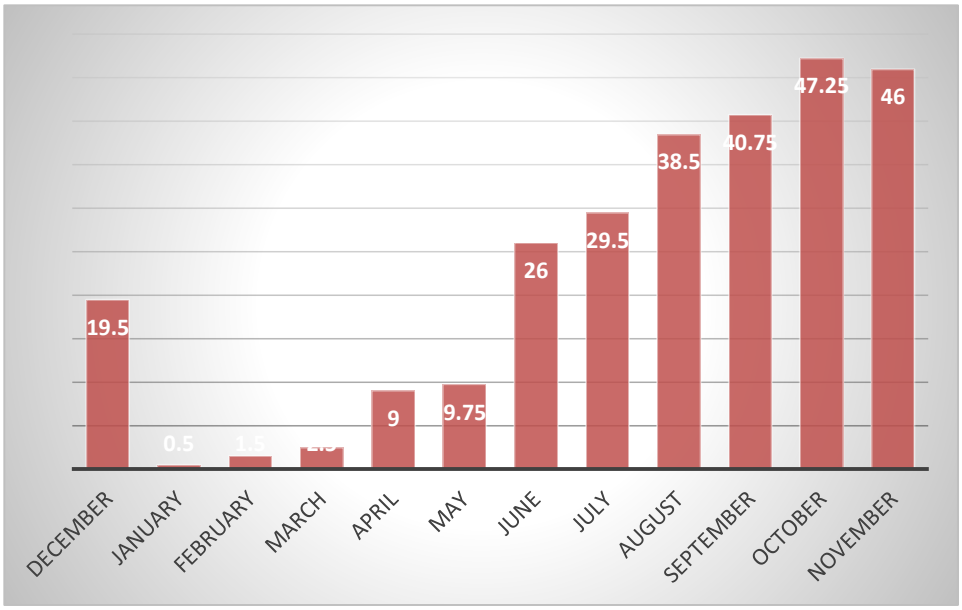

Figure 6 : Monthly average occurrence of hornets at Natural History Museum apiary

Monthly average occurrence of hornets was statistically significant with p-value 0.87592465 (11, 59) at 0.05 level of significance. There was a swift decrease from the month of December to January (Figure 5).

Table 4: Weekly average occurrence of hornets throughout the study period

Month	Occurrence of hornets			
	1st Week	2nd Week	3rd Week	4th Week
December	7±1.5	10±1.5	10±1.5	11±1.5
January	0.5±0.25	0.5±0.25	0	0
February	0.5±0.25	0.5±0.25	1±0.25	1±0.25
March	2.5±0.829	1.5±0.829	0.5±0.829	0.5±0.829
April	3±1.06	4±1.06	5.5±1.06	5.5±1.06
May	4±0.739	4.5±0.739	5±0.739	6±0.739
June	10.5±2.304	11.5±2.304	14.5±2.304	15.5±2.304
July	15.5±0.544	15±0.544	14.5±0.544	14±0.544
August	19.5±1.03	17.5±1.03	19.5±1.03	20±1.03
September	19±1.916	18.5±1.916	21.5±1.916	22.5±1.916
October	23±1.920	23±1.920	22±1.920	26.5±1.920
November	22.5±0.892	24±0.892	24±0.892	21.5±0.892

Weekly average occurrence of hornets during this study period showed that the occurrence was highest in October and lowest in January (Table 4).

4.2 Diversity indices of the hornets

Table 5: Diversity indices of hornets at Natural History Museum apiary.

Species name	Simpson index	Shannon-weaver diversity index	Evenness index
Hornets (5 species)	0.214	0.39611	0.246

The Simpson diversity index (D), Shannon-Weaver diversity index (H') and Evenness index (E) of the hornets occurrence in the apiaries as fallen in the trap were 0.214, 0.39611 and 0.246 respectively (Table 5).

CHAPTER V: DISCUSSION

Vespa velutina (951) was the most abundant hornet predating the honeybee colonies of Natural History Museum, Swayambhu, Kathmandu followed by *V. basalis* during the study period of December 2016 to November 2017. The least occurrence was *V. magnifica* followed by *V. orientalis*. Results from the present study is similar to the study of Shah and Shah (1991) who observed *V. velutina* as the serious pest of honeybees in Kashmir but contradicts with the study of Abrol and Kakroo (1998) who noticed *V .orientalis a*s the most abundant and serious enemy of honeybees. Also the findings of the present study coincide with the study of Bista et al. (2020) who found four species of hornets (*V. velutina* L. *V. basalis* S., *V. tropica* S. and *V. mandarina* S.) predating the honey bee colonies at two locations of rural and forest areas of mid-hill in Lalitpur district. Further the present study differs in having *V. orientali s*and *V. magnifica* while they had *V. mandarina* as other predators of the honeybee. Bista (2011), had reported seven species (*V. analis, V. basalis, V. mandarina, V. tropica, V. affinis, V.orientalis* and *V. velutina*) from a survey conducted around the eastern and central parts of Nepal and Kafle (2012) reported six species (*V. affinis, V. basalis, V. mandarina, V. orientalis, V. tropica* and *V. velutina*) as chief predators of honeybees in different parts of Nepal (Bista 2020).

Highest occurrence of hornets in this study occurred in the month of October during which colony expands and least occurrence occurred in January where hornets undergo over-wintering. But the study of Bista et al. (2020) showed the highest incidence in mid-November (62.01%) and early-November (53.49%) at rural and forest locations in 2016/2017. In 2017/2018 the highest incidence was on early November (70.27%) at rural area and mid-November (58.62%) for the apiaries near forest area i.e. the incidence is highest in the month of November. Their study reported the least incidence in the spring and summer.

The observation of the present study, however, coincides with the observation that was carried out in the DiarbNegm, Sharkia governorate and Meat Ghamr Region, El-Dakhlia Governorate, Egypt, during 2012, 2013, where the monthly average numbers for catching of *V. orientalis* adults were recorded highest in October followed by September and November. But this study opposes the results shown from the study of Abrol and Kakroo (1998) who

found the peak predatory activity during July to September (as mentioned in Bhatta 2005). Another study carried out at Bhatkyapati-12 and Tyangla-3, Kirtipur Municipality under apiary and filed condition during July, 2004 to September, 2004, showed the highest incidence and percentage of predation in September (Bhatta and Tamrakar 2008).

The present study found the Simpson index to be 0.214 close to 0 reflecting sparsely diverse hornet community of the study site (apiary of the Natural History Museum). Here, we the Shannon-Weaver diversity is less than 1.5 (0.39611) indicates the less diverse community of the study site both in terms of number of individuals and species. The present study found the evenness of the study area to be 0.246 (close to 0) implying that the species diversity was less even. Therefore, low diversity index of the hornets in the present study suggests low species prevalence in Natural History Museum premises and the low evenness index suggests high interspecific difference in the occurrence of hornets.

Likewise, average monthly occurrence of the hornets showed positive correlation with the temperature and humidity i.e. with the increasing temperature and humidity, hornets also increased and vice-versa may be due to their physiology and lifecycle which is affected directly by the periodic change in temperature and humidity.

Since, hornets showed high affinity to locally prepared bait, it turned out to be useful in attracting a number of individuals in present study. Similarly, Bhatta and Tamrakar (2008) found the baits of rotten fish and pear as the best attractants for the management of predatory hornets because they attracted highest number of individuals and lowest number of honeybees followed by chicken bait.

CHAPTER VI: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Five species of hornets (*V. velutina* L.¸ *V. basalis* Smith, *V. tropica* Smith, *V. orientalis* Smith and *V. magnifica* Smith) were found as predators in the apiaries of Natural History Museum in the during the study period of year 2016 and 2017. Of them *V .velutina* was the most common invader whereas *V. magnifica* the least. Another common species attacking the honeybee colonies was *V. basalis*. The highest number of individuals of the hornets occurred in the month of October followed by November and September and the lowest invasion occurred in the month of January followed by February and March. Monthly average occurrence of hornets was found significant statistically.

The present study showed that species distribution in the community was less diverse with less abundance of the individuals of each species and the distribution was also less even i.e low diversity and low evenness was found in the study.

The results of the present study highlights the importance of seasonal occurrence and diversity of hornets attacking honeybee colonies pointing out necessity of a well-coordinated and environment-friendly control plans and operations as soon as possible for the entire hornet-invaded parts of Nepal since re-invasion is always possible from the adjacent areas.

6.2 Recommendations

Based on the present study, following recommendations can be made:

1. A detailed study on seasonal fluctuation of hornet population in and around apiaries can be done.
2. Studies associated with the meteorological factors can also be studied.
3. The number of traps should be increased to collect higher number of hornets. Trapping hornet workers to protect apiaries can be achieved by using lure traps in their vicinity. Hornets can be trapped using food baits (carbohydrates or proteins). Those traps can be used for monitoring as well.
4. A local preventative such as capturing and killing individuals' foraging in the vicinity of the apiary or flying in front of their hives can be effective.
5. Protective action against hornet's attack by narrowing the hive entrance can mitigate the predation process.
6. Removal of hornet nests in the vicinity of apiaries either chemically or mechanically insecticides or biocide gas like sulphur dioxide injected in the nest can minimize the damage.
7. Depriving hornets and their brood from their major food source may also limit population size.
8. Queen trapping can be performed before and/or after hibernation.
9. Resistant honeybee colonies should be selected.

REFERENCES

Abrol, D. P and Kakroo, S. K. 1989. Pests, predators and pathogens of honeybee, *Apis cerana* in Jammu, India. Indian Bee Journal **60:** 15-19.

Abdelaal, A.A.A and El-Defrawy, B.M. 2014. Efficacy of New Designed Traps for Controlling the oriental hornet (*Vespa orientalis*) in Egyptian apiaries and its measurements. International Journal of Advanced Research: 1-1.

Adhlakha, R. L., Sharma, O. P. and Dhaliwal, H. S. 1974. Hornets as serious enemies of honeybees. Farmer and Parliament **13:** 25.

Ahmed, M. 2021. Effectiveness of baited traps for controlling Oriental hornet *Vespa orientalis* (Hymenoptera: Vespidae) in Sohag Governorate apiaries.

Akre, R. D. and Davis, H.G. 1978. Biology and pest status of venomous hornets. Ann. Rev. Entomol., **23**: 215-238.

Ayasse, M., Paxton, R., and Tango, J. 2001. Mating behavior and chemical communication in the order Hymenoptera **46(1):** 31-78. Annual review of entomology.

Arca, M., Mougel. F., Guillemoud, T., Dupas, S., Rome. Q. and Perrard, A. et al. 2015. Reconstructing the invasion and the demographic history of the yellow-legged hornet, *Vespa velutina,* in Europe. Biological invasions **17**: 2357-2371.

Archer, M. E. 1998. Taxonomy, distribution and nesting biology of *Vespa orientalis* L. (Hymenoptera: Vespidae). Entomologist's Monthly Magazine **138:** 45-51.

Batra, S.W.T. 1980. Sexual behavior and pheromones in the European hornet, *Vespa crabro germana* (Hymenoptera: Vespidae). J. Kans. Entomol. Soc. **53:** 461-69.

Beekman, M. and Ratnieks, F.L. 2000. Long-range foraging by the honey bee, *Apis mellifera* L. Functional Ecology 2000 **14:** 490-496.

Beggs, J. 2001. The ecological consequences of social wasps (*Vespula* spp.) invading an ecosystem that has an abundant carbohydrate resource. ResearchGate **99(1)**: 17-28.

besttimetovisit.com.sg/Nepal/swayambhu_2961358

Bhatta, C.P. 2005. Flying Predators of Honeybees and its Management in Different Apiaries of Kathmandu Valley

Bingham, C.T. 1897. The Fauna of British India. Hymenoptera Vol-1, 400-407.

Botha, J.J.C. 1970. About enemies of bees in South Africa. Gleanings in Bee Culture, 98:100-103.

Braganca. 2019. Patterns of *Vespa velutina* invasion in western Iberia and Italy as revealed by mitochondrial and microsatellite markers, Ges *Vespa*: sustainable management strategies of Vespa velutina (POSEUR-03-2215-FC-000008).

Burgett, M. and Akratanakul P. 1982.Predation on the Western honey bee, *Apis mellifera* L., by the hornet, *Vespa tropica* (L.). Psyche 89: 347–350.

CABI.org. http://www.cabi.org>isc/datasheet. *Vespa velutina* (Asian hornet)- accessed on 7 February, 2020.

Chan, K.L. 1972. The Hornets of Singapore: their identification biology and control. Singapore Medical Journal.Vol 13.**4**: 178-187

Chantawannakul, P.,de Guzman, L.I. and Li, J. et al. 2016. Parasites, pathogens and pests of honeybees in Asia, Apidologie 47, 301-324. https:// doi.org/10.1007/s/13592-015-0407-5.

Choi. M. B., Martin, S.J. and Lee, J.W. 2012. Distribution, spread and impact of the invasive hornet *Vespa velutina* in South Korea, Journal of Asia-Pacific Entomology.

Crane, E. (1999).The world history of beekeeping and honey hunting. Gerald Duckworth & Co, Ltd, London

Dave, M.L. 1943. Hornets. Indian Bee J., 5:127,131.

Dejong, D. 1979. Social hornets, enemies of Honeybees. Am. Bee J., 119:505-507.

en.wikipedia.org>wiki>Diversity_index

Gandheker, S.S. 1959. Some common bee enemies in India. Gleannings in Bee culture, 87:360-362, 363.

Gulati, R and Kaushik, H.D. 2004. Enemies of Honeybees and their Management-A Review: 192-192

Higo, K. 1983. Mass trapping of *Vespa xanthocarpa* in the apiary. Honeybee Sci., 4:123-126.

Hirschfelder, H. 1952. Control of the bee killer wasps.GermanyAnz.Shadlingsk., 25: 122-123.

https://en.wikipedia.org/wiki/Black-bellied_hornet

Ibrahim, M.M.,Mazeed, M.M. 1967. Studies on the oriental hornet; *Vespa orientalis* F. Agric.Res. Rev., Cairo, **45**:163-180.

Ishay J. 1964. Observations sur la biologie de la guêpeorientale *Vespa orientalis* F. Insectes Sociaux **11**: 193–206.

Ishay, J.S., Perna, B.,Hochberg, Y. and Goldstein, M. 1979. The effect of hornet venom on the photoelectric properties of hornet cuticle: Toxicon **17**: 407-411.

Islam, N., Iftikhar, F. and Mahmood. R. 2015. Seasonal Variation in Hornet's spp. and Efficiency of Different Traps as a Tool for Control **2(6):** 223-230. American Journal of Agricultural Science.

Ken, T. and Wang, J.M. 2004. Reduction of foraging activity by *A. cerana* colonies attacked by *Vespa velutina*. Journal of Bee **2**: 7–9.

Ken, T., Hepburn, H.R., Radloff, S.E., Yusheng, Y., Yiqiu, L., Danyin, Z. and Neumann, P. 2005. Heat-balling wasps by honeybees. Naturwissenschaften **92**: 492–495.

Kloft, W. and Schneider, P. 1969. Gruppenverteidigungsverthalten bei wildbenden Beinen (*Apis cerana* F.) in Afghanistan (Group defensive behavior in *Apis cerana* F. living wild in Afghanistan). *Naataaxrwissenschaften,* **56:** 219.

Koeniger N., Koeniger G. and Mardan, M. 1994. Mimicking a honeybee queen? *Vespa affinisindo sinensis* Perez 1910 hunts drones of *Apis cerana* F. 1973. Ethology **98**: 149–153.

Koeniger N., Koeniger G., Gries M., Tingek, S. and Kelitu, A. 1996.Observations on colony defense of *Apis noluensis* Tingek, Koeniger and Koeniger, 1996, and predatory behavior of the hornet, *Vespa multimaculata* Perez, 1910.Apidologie 27: 341–352.

Kshirasagar, K.K. 1971. A hornet trap to control predatory hornet in apiary. Indian Bee J., 33:56-58.

Kshirasagar, K.K. and Mahindre, D.B. 1975. Some notes on predatory hornets. Indian Bee J., 37(1/4): 4-9.

Longo, S. 1980. The Control of hornets that are injurious to honeybee colonies (In Italian). La difesa dale Vespa. Apicalt.Mod. 71:109-112.

Martin, S. J. 1995. Hornets (Hymenoptera:Vespinae) of Malayan Nature Jaournal **49:** 71-82.

Matsuura, M. and Yamane, S.K. 1990. Biology of the Vespine wasps. Berlin: Springer.

Matsuura, M. and Sakagami, S.F. 1973. A bionomic sketch of the giant hornet, *Vespa mandarina*, a serious pest for Japanese apiculture.Journal of the Faculty of Science. Hokkaido University 19: 125–162.

Matsuura, M. 1988. Ecological study on Vespine hornets (Hymenoptera: Vespidae) attacking honeybee colonies. Seasonal changes in the frequency of visits to apiaries by Vespine hornets and damage inflicted, especially in the absence of artificial protection. Appl. Entom. Zool., 23:428-440.

Mohammad, A.F. and Yasser, I. 2009. The Serious Effects of the Dangerous Insect Predator (*Vespa orientalis* L.) on Honeybee colonies in Giza Governorate. 4th Conference on Recent Technologies in Agriculture, 2009. 58-59. Reasearch Gate.

Mollet, T. and Torre, C. de la 2006. *Vespa velutina.* The Asian Hornet. Bulletin technique Agricole **33(4):** 203-208.

Monceau, K., Bonnard,O. and Thirey, D. 2013. *Vespa velutina*:a new invasive predator of honeybees in Europe, Springer-Verlag Berlin Heidelberg 2013:1-2

Morse, R.A. 1978. Comb Honey Production. Wicwas Press, New York.

Morse, R.A. and Nowogrodzki, R. 1990. Honeybee Pests, Predators and Diseases (2nd Edition).Cornell University Press.Ithaca and London. Pp. 156-177.

Munawar, M.S. and Camphor, E.S.W. 2004. Studies onpopulation trends of *Vespa* spp. predacious on Honeybee colonies in Pakistan. apimondia.com/en/component/easyfolderlistingpro/

Muzaffar. N. and Ahmad, R. 1986. Studies on hornets attacking honeybees in Pakistan. Pakistan J. Agric.Res., 7:59-63.

Okada, I. 1980. Trapping giant hornets on sticky paper. Honeybee Science.,1:24-25.

Oldroyd, B. and Wongsiri, S. 2006. Asian Honey Bees. Bibliovault OAI Repository, the University of Sikago Press.

Ono M., Igarashi T., Ohno E. and Sasaki M. 1995.Unusual thermal defense by a honeybee against mass attack by hornets. Nature 377: 334–336.

Ono M., Okada I. and Sasaki M. 1987. Heat production by balling in the Japanese honeybee *Apis cerana japonica* as a defensive behavior against the hornet *Vespa simillima xanthoptera* (Hymenoptera: Vespidae). Experientia 43: 1031–1032.

Papachristoforou A., Rortais A., Zafeiridou G., Theophilidis G., Garnery L., Thrasyvoulou A. & Arnold G. 2007. Smothered to death: hornets asphyxiated by honeybees. Current Biology 17: 795–796.

Papachristoforou A., Sueur J., Rortais A., Angelopoulos S., Thrasyvoulou A. & Arnold G. 2008. High frequency sounds produced by Cyprian honeybees *Apis mellifera cypria* when confronting their predator, the Oriental hornet *Vespa orientalis*. Apidologie 39: 468–474.

Pokharel, S. 2008. The Ecological Problems and Possible Solutions of Beekeeping in Hills and Terai of Chitwan, Nepal. The Journal of Agriculture and Environment vol **9.**

Ranabhat, N. B. and Tamrakar, A.S. 2008. Study on seasonal activity of predatory wasps attacking honeybee *Apis cerana* Fab. colonies in southern belt of Kaski district, Nepal. Journal of Natural History Museum **23(1) :** 125-128.

Rahman, A. and Rahman, S. 1995. Efficacy of certain feeding attractants against predatory hornet (*Vespa magnifica* L.). Plant Health, 1:66-68.

Ranjitkar, S. and Chaulagain, B. 2004. Diversity and Conservation Practices in the Swayambhunath Hillock. Proceedings of IV National Conference on Science and Technology: 771-773.

Rivnay, E. and Bitinsky-Salz, H. 1949. The oriental hornet (Vespula *orientalis* L.,): Its biology in Israel. Bulletin of Agricultural Research Station, Rehovot, 52.

Robinet, C. Suppo, C and Darrouzet, E. 2016. Rapid spread of the invasive Yellow-legged hornet in France; the role of human mediated dispersal and effects of control measures. Journal of Applied Ecology **52:** 205-215. https://doi.org./101111/1365-2664.12724.

Rye, B. 1986. Hornets Control for beekeepers. Australian Bee Journal **67**:14-16.

Sauvard, D. Imbault, V, Darrouzet, E. 2018. Flight capabilities of yellow-legged hornet (*Vespa velutina nigrothorax*, Hymenoptera: Vespidae) workers from an invasive population in Europe PLosONE **13(6):** e019897. https://doi.org/10.1371/journal. Pone 0198597.

Shah, F.A. and Shah.T.A. 1991.*Vespa velutina*, a serious pest of Honeybees in Kashmir. Bee Wld., 72:161-164.

Sharma, O.P., Thakur, A.K. and Garg. R. 1985. Control of hornets attacking bee colonies. Indian Bee J., 47: 21-24.

Sharma, P.L.; Dogra, G.S.; Mishra, R.C. 1979.Evaluation of methods of control of predatory hornets, *Vespa* spp. in apiaries. Indian Bee J., 41: 10-16.

Singh S. 1962. Beekeeping in India. New Delhi: Council of Agricultural Research.

Sugahara, M. and Sakamoto, F. 2009. Heat and carbon dioxide generated by honeybees jointly act to kill hornets. Naturwissenschaften **96:** 1133-1136. https://doi.org.10.1007/s00114-009-0575-0.

Tan K., Radloff S.E., LI J.J., Hepburn H.R., Yang M.X., Zhang L.J. & Neumann P. 2007. Beehawking by the wasp, *Vespa velutina*, on the honeybees *Apis cerana* and *A. mellifera*. Naturwissenschaften **94**: 469–472.

Thakur, S.S. and Kashyap, N.P. 1996. Hornet control by lure trap in an apiary. Insect Environ.,**2**: 6-7.

National Academies Press, Chapter 2: Satus of Pollinators, 34-36. Nap.edu/read/11761/chapter 4#36. accessed on 25 January 2021.

vanEngelsdorp, D., Meixner, M.D. (2010) A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. J InvertebrPathol **103**, S80–S95

Wafa A.K. 1956.Ecological investigations on the activity of the oriental hornet, *Vespa orientalis*. Bulletin of the Faculty of Agriculture – University of Cairo 103: 1–35.

Wafa, A.K.;EI Borolossy, F.F.;Charkawi, S.G. 1968. Studies on *Vespa orientalis* F. Bull.Ent. Soc.Egypt, 11:9-27.

Walton, G. and Reid, G. M. 1976. The 1975 New Zealand European hornet survey. New Zealand Beekeeper **38(2):** 26-30.

Wang, J. D., Zhang, W. H., Wang, Y. M. and Long, H. R. 1985. Biological study on several kinds of hornet spread upon honeybees and their control. J. Fujian Agric. Coll. **14:** 43-51.

Williams, G.R., Tarpy, D.R., Vanengelsdorp, D., Chauzat, M.P., Cox-Foster, D.L., Delaplane, K.S., Neumann, P., Pettis, J.S., Rogers, R.E.L., Shutler, D. (2010) Colony Collapse Disorder in context. Bioessays **32**, 845–846

Williams, P.H. 1983, Social Hornets (Hymenoptera: Vespidae) from North West India. Entmologists' Monthly, 119:193-197.

www.countrysideinfo.co.uk>simpsons

APPENDIX 1

Weekly occurrence of hornets in the bait

Month	Occurrence of hornets				
	1st week	2nd week	3rd week	4th week	Monthly total
December	14	20	20	22	76
January	1	1	0	0	2
February	1	1	2	2	6
March	5	[1]	1	1	10
April	6	8	11	11	36
May	8	9	10	12	39
June	21	23	29	31	104
July	31	30	29	28	118
August	39	35	39	40	153
September	38	37	43	45	163
October	46	46	44	53	190
November	45	48	48	43	185
Total					1082

APPENDIX 2

Monthly species wise occurrence in the bait

Species / Month	*V. velutina*	*V. basalis*	*V. tropica*	*V. orientalis*	*V. magnifica*
December	66	10	0	0	0
January	2	0	0	0	0
February	4	2	0	0	0
March	8	2	0	0	0
April	28	8	0	0	0
May	26	13	0	0	0
June	93	11	0	0	0
July	103	15	0	0	0
August	137	15	1	0	0
September	146	16	2	0	0
October	169	16	1	2	1
November	169	14	1	1	0
Total	951	122	5	3	1

APPENDIX 3

Monthly average humidity and temperature recorded during the study period.

Month	Humidity (%)	Temperature (Celsius)
December	72	13
January	68	11
February	66	14
March	66	16
April	61	21
May	72	22
June	76	24
July	84	24
August	86	24
September	80	24
October	74	21
November	73	16

APPENDIX 4

Photographs of hornets collected from the study

Photograph 1: *Vespa velutina*

Photograph 2: *Vespa basalis*

Photograph 3: *Vespa tropica*

Photograph 4: *Vespa orientalis*

Photograph 5: *Vespa magnifica*

APPENDIX 5

Photographs of apiary and study activities

Photograph 6: Apiary at Natural History Museum, premises, Swayambhu, Kathmandu, Nepal

Photograph 7: Preparation of the bait

Photograph 8: Trap setting

Photograph 9: Collection and storage of hornets

Photograph 10: Pinning and preservation of the species