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Assessment of hornet (*Vespa* spp.) predation on European honeybee (*Apis mellifera* L.) apiary at sub-tropical plain areas of Parasi district, Nepal

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Abstract
The predatory hornets have become one of the major limiting factors for commercial beekeeping. So, its incidence and predation rates were investigated at two different locations of sub-tropical plain areas of Parasi district, Nepal during five major hornet active months for 2016 and 2017. Observations were carried out on five *Apis mellifera* L. colonies, where the number of hornet and honeybee captured by hornet were assessed at three different times of the day for three continuous minutes every fortnightly. During the study periods, five major hornet species *Vespa velutina* Lepeletier, *V. bicolor* Fab., *V. basalis* Smith, *V. tropica* (Lin.) and *V. mandarina* Smith were observed. The hornet incidence varied significantly between different dates and locations, while between the years it was non-significant. The incidences as well as the predation rates were low during summer and early-autumn of both year but gradually increased to its peak in the autumn season during 2016, while during 2017, the predation rate increased to its maximum during autumn season. The predation rate was observed highest during early-November (50.44%) and mid-November (46.88%) at forest and rural areas, respectively during 2016. Likewise in 2017, the maximum predation at both locations occurred during early-November (43.75 and 55.65% at rural and forest area). Both the incidence and predation by hornet was comparatively more at forest locations with some exceptions. The hornet incidence and its predation rates were positively correlated and highly significant; while it was negatively correlated with rainfall during both years. For the sustainable management approach against predatory hornets its biological, ecological and behavioral aspects on honeybee apiary have to be well understood.

Keywords: Beekeeping, *Apis mellifera* L., *Vespa* spp., incidence, predation, locations

1. Introduction
Beekeeping is a cultural heritage in Nepal, practiced since ancient times. It is an exclusive non-land based activity that has offered various advantages in terms of cash generation, nutritious food as well as development of sustainable agriculture through pollination services. Nepal is rich in honeybee diversity with five different species found at different altitudes. The indigenous honeybee species, *Apis cerana* Fab. is dominant at hilly regions whereas the exotic honeybee, *Apis mellifera* Lin. is mostly concentrated at sub-tropical plains. The other species, *Apis laboriosa* Smith, *Apis dorsata* Fab. and *Apis florea* Fab. are found in wild condition; however honey and other hive products are also being extracted from these wild species [1, 2, 3]. The modern beekeeping in Nepal was initiated around mid-seventies with the introduction of moveable frame hives to rear *A. cerana* [4]. But, the actual process of commercialization in beekeeping started with the introduction of European honeybee, *Apis mellifera* Lin., officially introduced in April, 1994 [5].

The beekeeping practices, nowadays, are gradually shifting from subsistence level to commercialization. Due to high demand of honey and other hive products, inside the country and abroad, many organizations are involved in different capacities. The continuous support from government in co-operative and private sector has encouraged this profession throughout the country. Apart from this, some commercial beekeeping firms have established themselves with total input facilities ranging from construction of hives to production of hive products, processing and marketing. These types of involvement from private and co-operative sector have preceded the beekeeping business towards commercialization with *A. mellifera*. The *A. mellifera* have high honey hoarding capacity ranging from 30-35 kg as stationary beekeeping and more than 100 kg as migratory beekeeping [6, 7], which is related with abundance of quality

honeybee flora. Cultivation of different honey producing crops and presence of natural forest throughout the country have augmented cultivation of this species and process of commercialization; where the beekeepers migrate their colonies during the flowering period around agricultural, horticultural and forest areas in collective approach. On the other hand, these places are also the natural habitat of various honeybee predators, prominent among them is the predatory hornets, *Vespa* spp. (Hymenoptera: Vespidae) [2, 7, 8, 9].

Hornets are predatory carnivorous insects, and feed their brood mainly with animal proteins (insects, pieces from fresh or spoiled meat, etc.) while the adults rely on carbohydrates (nectar, honeydew, ripe fruits, etc.). Honeybee colonies constitute places where the hornets can find the best combination of animal proteins (adults or brood) as well as carbohydrates (nectar and honey). They often lay siege to the hive, enter and rob brood and honey, causing serious damage resulting destruction of the bee colony [10, 11]. Many species of hornet are considered as major enemies of honeybees possessing serious threat to the beekeeping industry especially in migratory beekeeping. The genus *Vespa*, largest of the social hornets, is physically capable of preying on honeybees with ease. A persistent hornet attack weakens the colonies while a serious attack results in absconding or devastation of honeybee colonies. Considering the fact that a single hornet of *Vespa magnifica* Smith killed more than 2000 honeybees per hour at a hive entrance [12], this species could prove to be the most dangerous to beekeeping. Several species of hornets have been recorded from Nepal and elsewhere [7] has described that most troublesome among insects for bee colonies are the hornets and accounted the devastation of 32 colonies in 1968 at Sundarijal area of Kathmandu district. Even beekeepers had to change their foraging area due the constant attack of hornet species on honeybees at Kaski, Nepal [13].

In some of the major colony migration sites of Nepal, the honeybees are severely affected due to the attack of different species of hornets resulting in the depletion of colony strength and economically discouraging the beekeepers [14, Per. com. A. Shukla, Author obvs.]. The beekeepers in these areas are compelled to employ persons to protect from hornet attack increasing their cost of production. The other practices followed for the management of hornet menace are, nest destruction, flapping the hornet, use of poison baits, etc., but all of these practices increased the production cost with no stable solution. Also, the hornets, being one of the prominent members of agro-ecological system should be cautiously handled. The mass destruction of this organism may have negative impact on ecosystem. So for the sustainable management, detail study on various aspects of hornet is required, which seems to be lacking in Nepalese context. Study on the diversity and abundance of hornets at the beekeeping pocket areas, its predating biology, foraging behavior are the basic means to develop the sustainable management techniques.

2. Materials and Methods

2.1 Hornet diversity

This study was carried out at beekeepers' apiaries at two locations of sub-tropical plain areas of Parasi district, Nepal. The first location was at Sunwal, Sunwal Municipality-4 (134-masl; N-27°36.38" and E-083°38.28") regarded as Parasi rural area and the second location was at Godaha, Devdaha Municipality-7 (162-masl; N-27°39.49" and E-083°34.17") regarded as Parasi forest area.

Sunwal area as Parasi rural location is near to the settlement areas with enough open places and running water. This location is accessible for transport, so migration of colonies is common during autumn and winter seasons. *A. mellifera* is the dominant cultivated honeybee species with presence of few feral *A. cerana* colonies. Mustard, maize, buckwheat, agricultural crops, horticultural trees, ornamental plants and plantation trees are major honeybee floras available around these areas. The second site, Godaha as Parasi forest location is covered by natural forest from north and west. *A. mellifera* is the major honeybee species maintained while few farmers also rear *A. cerana* colonies. Feral *A. cerana* colonies are also observed. Apart from the available floras of rural areas, the horticultural and plantation trees are more common along with forest floras nearby.

The hornet species were collected using insect sweep net and were dry preserved for further identification at Entomology Division, Nepal Agricultural Research Council (NARC), Khumaltar, Lalitpur, Nepal.

2.2 Hornet incidence and predation

This study was carried out for five hornet active months per year (July to November) for two years, 2016 and 2017 following methods mentioned by Ranabhat and Tamrakar, 2008 [13]. Five colonies each at two locations were randomly selected from the apiaries and managed throughout the study period following good beekeeping practices. Five honeybee frames containing at least three frames with brood, honey and pollen were selected for each colony. Observation was made on two aspects at each experimental colony: the number of hornets attacking the honeybees, and the number of honeybees caught by the hornets. Only the information on hornets hovering around the colonies was collected, the hornet passing by the colony or not performing the predatory position was not taken into consideration.

The number of hornets visiting the experimental colonies and the number of honeybees caught by the hornets were recorded following sight count method at five honeybee colonies during three different time periods of the day (9:00 to 9:30 AM, 12:00 noon to 12:30 PM and 15:00 to 15:30 PM) for three continuous minutes every fortnightly. The weather parameters (Maximum and minimum temperature in ^{o}C, relative humidity of 12 noon in percentage and rainfall in mm) of the observation dates were collected from meteorological observatory (110-masl; N-27°28.05.5" and E-083°47.10") of Semari, Parasi district from Department of Hydrology and Meteorology, Nepal.

2.3 Data processing and statistical analysis

The data were square root transformed wherever necessary. The capture rate (CR) by hornet, the defensive efficiency (DE) of colonies against hornet and the total predation of honeybees per day (PD) by the hornet was assessed following calculations given by Ibrahim, 2009 [15]. ANOVA was performed to compare the mean incidences of predatory hornets and their predation rate at different dates, year and location and their interactions. Means of the hornet incidence and predatory efficiency were using Tukey's Studentized Range Test (HSD) at 0.05 significance level. Relation between different weather parameters with hornet incidence and predation were established using Pearson's coefficient (P=<0.05%) (SPSS 16.0, SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

3.1 Hornet (Hymenoptera: Vespidae) diversity at study area

A total of five species of hornets were encountered around the honeybee apiary at both locations of Parasi district during 2016-2017, they were: the yellow-legged hornet, *Vespa velutina* Lepeletier, 1836; black-bellied hornet, *Vespa basalis* Smith, 1852; black shield hornet, *Vespa bicolor* Fabricius, 1787; greater banded hornet, *Vespa tropica* (Linnaeus, 1758) and Asian giant hornet, *Vespa mandarinia* Smith, 1852. Apart from this the oriental hornet, *Vespa orientalis* Linnaeus, 1771 and yellow-vented hornet, *V. analis* Fabricius, 1775 were also found but in few number. The *V. orientalis* was observed at both locations whereas *V. analis* was present only at the forest location. *V. velutina* was observed throughout the year, while other species were found during latter observation dates. The *V. velutina* found at these areas were further classified as *V. velutina auraria*, as per its thorax pigmentation [16].

Almost all beekeepers have reported hornet predation as problematic to the colonies, but still few studies have been conducted in Nepal regarding the predation of hornet on honeybees [13] reported four species of hornets (*V. velutina*, *V. bicolor*, *V. tropica* and *V. basalis*) preying on honeybee, *A. cerana* at three VDCs (Kristi Nachne Chour, Nirmal Pokhari and Pumdi Bhumdi) of Kaski district of Nepal during August 2003 to July 2004. Among these hornet species, *V. velutina* and *V. bicolor* were the most abundant and observed throughout the year [4, 7] stated *V. basilis*, *V. orientalis*, *V. mandarina*, *V. affinis*, *V. velutina* and *V. tropica* as the most troublesome among insects for bee colonies in different parts of Nepal. He also reported other wasp species *Vespula germanica* Fab., *Vespula vulgaris* Lin., *Philanthus triangulum diadema* (Fab.) and *Polistes hebraeus* (Fab.) as problematic to honeybees. The joint survey conducted by Nepal Agricultural Research Council (NARC), Nepal and Muséum National d'histoire Naturelle (MNHN), France around the honeybee apiary at eastern and central parts of Nepal during 2011 revealed seven species of *Vespa* as, *V. analis*, *V. basalis*, *V. mandarinia*, *V. tropica*, *V. affinis*, *V. orientalis* and *V. velutina* [17]. A general survey on different ecological problems of beekeeping accomplished by [14] in the hills and terai of Chitwan district, Nepal during 2004 found five species of hornets (*V. orientalis*, *V. cincta*, *V. ducalis* and *V. basalis*) among which *V. ducalis* and *V. basalis* were reported as major predators. Recent study conducted on hornet incidence and predation at mid-hill areas of Lalitpur district, Nepal reported four major (*V. velutina*, *V. basalis*, *V. tropica*, *V. mandarina)* and one minor species (*V. analis)* of hornets predating at *A. mellifera* apiaries [18].

Hornets are the largest known social wasps in the family Vespidae. Under genus Vespa, twenty-three extant species and seven more fossil species are recognized worldwide till now [19]. Most of these species are distributed in Asia, with highest diversity found in northern Indo-Malaya region. Among these, sixteen species are found in Indian subcontinent [20]. In Nepal, different studies reported the presence of eleven species of genus *Vespa*, they are: *Vespa affinis* Linnaeus, 1764; *Vespa analis* Fabricius, 1775; *Vespa basalis* Smith, 1852; *Vespa bicolor* Fabricius, 1787; *Vespa ducalis* Smith, 1852; *Vespa fumida* van der Vecht, 1959; *Vespa mandarinia* Smith, 1852; *Vespa orientalis* Linnaeus, 1771; *Vespa tropica* (Linnaeus, 1758); *Vespa velutina* Lepeletier, 1836 and *Vespa vivax* Smith, 1870 [7, 17, 21, 22, 16] also reported five forms of the genus *Vespa* from central Himalaya region of Nepal as *V. analis nigrans*, *V. mandarinia magnifica*, *V. tropica haematodes*, *V. basalis* and *V. velutina auraria*.

3.2 Incidence and honeybees caught by predatory hornets

The hornet incidence and average predation percentage by hornet in honeybees was studied for five hornet active months (July to November) for two years. The hornet incidence at honeybee apiary significantly varied among different dates ($F_{9, 200}$=119.1014, p=<0.001), different between the years ($F_{1, 200}$=5.667, p=0.0.018). Between interactions of different variables, the year with date ($F_{9, 200}$=13.29, p=<0.001) was highly significant while year with location ($F_{1, 200}$=0.003, p=0.0.956), date with location ($F_{9, 200}$ =1.84, p=0.0.065) and year, date and location ($F_{9, 200}$=0.0.0605, p=0.791) were not significant (Table 1, Fig. 1 & 2).

Table 1: Mean incidence and predation percentage of hornet in *A. mellifera* apiaries at rural and forest locations of sub-tropical plain areas in Parasi district during 2016 and 2017

S. No.	Observation dates	Mean incidence (No.) (±SE) (n=20 colonies)	Average predation (%) (±SE) (n=20 colonies)
1	Early – July	17.634 ± 0.855 ef	9.00 ± 0.303 e
2	Mid – July	22.985 ± 1.273 de	10.10 ±1.106 de
3	Early – August	24.150 ± 0.979 de	10.30 ± 0.647 de
4	Mid – August	10.458 ± 1.965 f	8.05 ± 0.827 e
5	Early – September	28.005 ± 0.977 cd	14.95 ± 1.335 cd
6	Mid – September	35.372 ± 2.129 bc	25.10 ± 0.340 b
7	Early – October	37.113 ± 2.103 abc	40.20 ± 1.720 a
8	Mid – October	38.697 ± 1.826 ab	39.60 ± 0.969 a
9	Early – November	45.945 ± 1.284 a	19.95 ± 1.211 bc
10	Mid – November	45.656 ± 0.625 ab	9.15 ± 1.620 e
	Year	0.74 ^{ns}	0.018 ^{ns}
	Date	<0.001**	<0.001**
	Location	<0.001**	<0.001**
	Year x Date	<0.001**	<0.001**
	Year x Location	0.167^{ns}	0.95 ^{ns}
	Date x Location	0.4 ^{ns}	0.065 ^{ns}
	Year x Date x Location	0.89 ^{ns}	0.79 ^{ns}

Data comprised of two year, two locations and observation taken fortnightly during five hornet active months. Same letter for mean incidence are not significantly difference ($P \leq .005$). ** = highly significant, *=significant, ns = non-significant

The incidence of hornet was found somewhat similar during entire summer period and up to early autumn season in 2016. Thereafter the incidence increased to reach its highest during the month of October. The population of hornet thereafter decreased abruptly during early winter season. The maximum number of hornet population was observed during mid-October (Fig. 1) at both rural (37.40) and forest (44.20) locations. The peak period of hornet incidence at both locations were recorded on the October observation dates. Although two small peaks were also observed during mid-July and mid-August, the average population was far lower than that of mid-October observation date. The rainfall during early-August to mid-September observation dates were in increasing trend which may be the cause of slight decrease in average hornet incidence during early-August and early-September observation dates.

The incidence of hornet population at both locations of Parasi district during 2016 fluctuated in similar trend during all observation dates. However, during the entire period, the average hornet population at forest location was slightly higher than that of rural location, except in early-September where the population was little bit higher at rural location (12.20 in rural and 11.80 at forest locations).

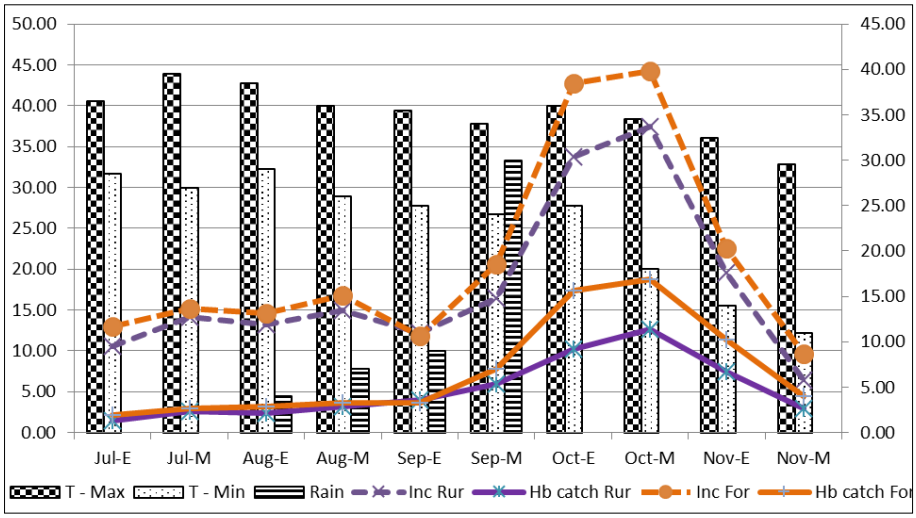

Fig 1: Incidence and honeybees caught by predatory hornets around honeybee apiary at rural and forest areas of sub-tropical plain areas of Parasi district, 2016 [Values of Rural and Forest in primary axis; T-max, T-min and Rain in secondary axis; T-Max= Maximum temperature (°C), T-Min= Minimum temperature (°C), Rain=Rainfall (mm); E=Start of month, M=Mid of month; Inc=Incidence of hornet, Hb catch=Honeybee caught by hornet, Rur= Rural and For= forest locations].

The average number of honeybees caught around the apiary by predatory hornet was observed low during the early observation dates that gradually increased reaching its peak during October mid, 2016. The predation rate slowly grew up from July to early September and then it instantly increased to reach its highest peak during the month of October, thereafter it began to decrease. The highest number of honeybees caught by the hornets was observed during mid-October (18.80 in forest and 12.60 in rural areas) observation dates at both locations of Parasi district (Fig. 1). The average number of honeybees caught by the hornet was proportionally similar with the hornet incidence around the apiary. As that of hornet incidence number, the rate of honeybees catch was also higher at the forest locations during entire observations dates except during the early-September.

The average hornet incidence around honeybee apiary in 2017 was to some extent similar from early-July to early-August observation dates, then the population of hornet decreased on mid-August; thereafter the population abruptly increased up to October, which again declined during November. The lowest population of hornet was noticed on mid-August (3.40 at rural and 3.20 at forest area) at both locations, while the highest incidence was observed on early-October (38.80 at rural and 45.40 at forest area) (Fig. 2). The peak period of hornet visit was found on the month of October at both locations, similar to that of 2016. Also a small peak was also observed during early-August in 2017. The hornet incidence during 2017 at both locations occurred in similar trend in most of the observation dates, except during early-November where the population was much lower at rural area. In the course of observation, the average hornet number was slightly higher at the forest location during the peak incidence periods, however during the early observation dates the number of average hornet was higher at rural area.

The study conducted at Kaski district, Nepal by [13] revealed the attack of hornet on honeybee colonies from June-July to September-October. Similarly, [18] investigated hornet incidence for two years at Lalitpur district, Nepal and concluded that the population was low in early spring and summer that gradually increased with the highest peak in October and November. The studies carried out in India, in the similar environment as of our study, also are in accordance with the present findings [23] at Punjab, India reported that the hornets visited *A. mellifera* colonies from July to December, with peak population in August and October. Likewise, the maximum incidences of hornets on *A. mellifera* colonies were observed during October to November in southern regions of India [24]. The result on seasonal incidence of hornet, *V. velutina*, the exotic invasive pest in France, made by [11] and [25] is also equivalent to our findings that the hornet activity was observed from July to December, with its peak activity during September and October.

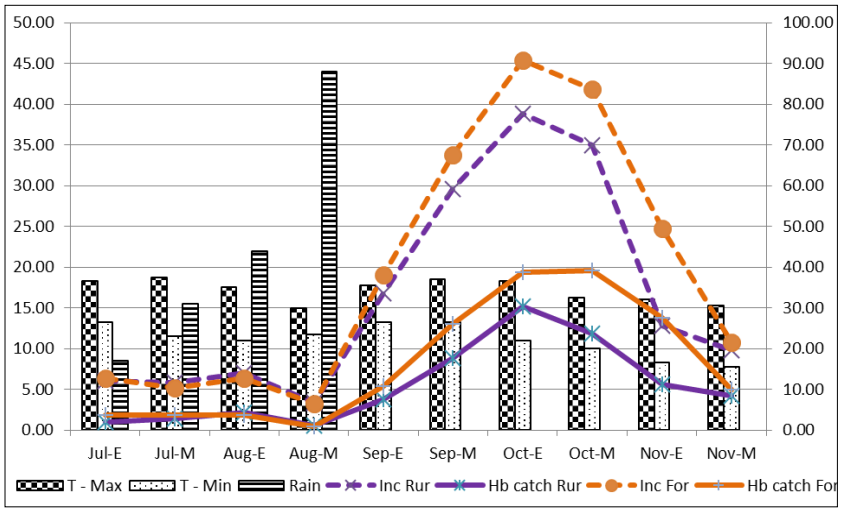

Fig 2: Incidence and honeybees caught by predatory hornets around honeybee apiary at rural and forest areas of sub-tropical plain areas of Parasi district, 2017 [Values of Rural and Forest mention in primary axis; T-max, T-min and Rain in secondary axis; T-Max= Maximum temperature (°C), T-Min= Minimum temperature (°C), Rain=Rainfall (mm); E=Start of month, M=Mid of month; Inc=Incidence of hornet, Hb catch=Honeybee caught by hornet, Rur= Rural and For= forest locations].

The average number of hornet and the honeybees caught during 2017 at both study locations are observed in similar proportion, that is higher the number of hornets, higher is the honeybees caught during all observation dates. The honeybees preyed upon by the hornet were lower during the summer and early autumn seasons, while it was highest during the late autumn (October observation dates). The maximum honeybee catch was observed on early-October (15.20) at rural and mid-October (19.60) at forest areas (Fig. 2). The lowest hornet incidence as well as honeybee catch persisted on mid-August at both locations, which might be due to prevalence of high rainfall (87.90 mm). In comparison to rural area, the honeybee catch was higher at the forest locations throughout the observation dates, except on the month of August, where it was slightly lower.

The average hornet incidence was substantially lower during summer and late autumn seasons in 2017, whereas the hornet number was observed slightly higher during early and mid-autumn seasons in 2017. Similar trend was observed on honeybee catch by the hornet, which was proportionate with hornet incidence. The lower number of hornet during 2017 might be due to the occurrence of rainfall during summer and early autumn seasons. The peak period of incidence and honeybee catch by the hornet was observed in the month of October during both years; while two small peaks of average number of hornet were found in 2016 and only one in 2017. Many authors in their studies have concluded maximum hornet incidences during autumn season [7, 11, 13, 18, 23, 24, 26, 27, 28, 29]. This statement matches in accordance with the biology and ecology of predatory hornet species encountered around the study areas.

The annual cycle of Asian hornets begins with single mated queens emerging from hibernation during early spring seasons and start building new foundation nests, where she starts to rear her first generation brood. This period is termed as "queen colony phase", and its success depends upon the ability of "foundress" queen to prey the animal protein for her brood [28]. After the first generation brood emerged and the colony strength increased throughout the summer season reaching to peak during autumn and early winter season. During these periods, the hornet colony needs sufficient number of animal protein as food and the honeybee colonies are the appropriate place [10, 11, 28]. Our findings also exhibited the major peak period of hornet incidence and preying of honeybees during autumn season ranging from early-September to November and from mid-August to November in 2016 and 2017, respectively. In spite of this, one small peak period of hornet incidences in 2017 and two peaks in 2016 were observed resembling with the biology of hornet at the studied locations (Fig. 1 & 2).

3.3 Relation between hornet incidences with weather parameters

The foraging activities of hornet are influenced by the prevailing weather parameters, especially the maximum and minimum temperature, humidity, wind speed and rainfall. The average number of hornet around honeybee apiary at both locations were found positively correlated with maximum temperature and negatively correlated with minimum temperature indicating the foraging frequency of hornet limited in low temperature and intensified with the increased temperature. Likewise the hornet population was positively correlated with relative humidity but negatively correlated with rainfall (Table 2). During the high rainfall (87.90 mm) on mid-August, 2017 observation day, the average hornet number was in minimum number (Fig. 2). Similar result regarding correlation between hornet, *V. velutina* incidence with temperature and relative humidity was noticed by [24] at southern region of India [30] also found positive correlation between number of *V. velutina* as well as *V. mandariana* honey bees with temperature and relative humidity. The correlation studies with similar weather parameters conducted at Lalitpur district, Nepal showed negative correlation with rainfall but positive with maximum and minimum temperatures [18].

Table 2: Pearson's correlation of hornet incidence with weather parameters at two locations of sub-tropical plain areas in Parasi district, 2016-2017

Particulars	Rural area	Forest area
Maximum Temperature (°C)	0.167 (0.482)	0.092 (0.698)
Minimum Temperature (°C)	-0.031 (0.896)	-0.101 (0.672)
Relative Humidity (%)	0.014 (0.954)	0.001 (0.995)
Rainfall (mm)	-0.399 (0.081)	-0.414 (0.069)

Data in parenthesis represents a probability value (P=<0.05%)

3.4 Percentage predation by hornet on honeybees

The total predation rates by hornet in honeybees were studied for five hornet active months (July to November) for two years. The predation rates at honeybee apiary were not significantly different between the years ($F_{1,\ 200}$=0.109, p=0.742) but were highly significant at different dates ($F_{9,\ 200}$=27.327, p=<0.001) and two locations ($F_{1,\ 200}$=15.128, p=<0.001) in Parasi district (Table 1, Fig. 3 & 4). Similarly, the hornet predation showed different interactions between year and location ($F_{1,\ 200}$=1.924, p=0.167), date and location ($F_{9,\ 200}$=1.054, p=0.40) and year, dates and locations ($F_{9,\ 200}$=0.470, p= 0.893) which were not significantly different, however the year and date interaction was highly significant ($F_{9,\ 200}$=4.089, p=<0.001) (Table 1, Fig. 3 & 4).

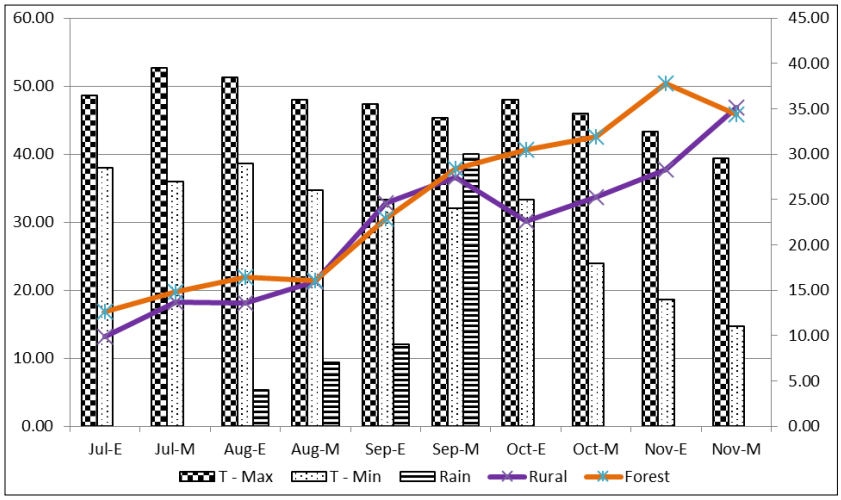

Fig 3: Percentage predation by hornet on honeybees during hornet active period around honeybee apiary at rural and forest sub-tropical plain areas in Parasi district, 2016 [Values of Rural and Forest locations mention in primary axis; T-max, T-min and Rain in secondary axis; T-Max= Maximum temperature (°C), T-Min= Minimum temperature (°C), Rain=Rainfall (mm); E=Start of month, M=Mid of month]

As the trend of the population fluctuation of hornet during different observation dates, the predation percentages also exhibited in similar trend. The predation rate during early days increased gradually then after mid-August, it intensified to the maximum level in 2016. The highest predation percentage was observed in early-November (50.44%) at forest location and in mid-November (46.88%) at rural location (Fig. 3). At forest location a small decrease in the predation trend was observed in mid-August (21.43%), while at the rural area two declines were found [early-August (18.18%) and early-October (30.18%)]. Similar trend was observed in 2017, where the predation percentage was low during the earlier observation dates and maximum during later period. The highest predation by hornet on honeybees was observed in early-November in 2017 at both rural (43.75%) and forest (55.65%) locations (Fig. 4). As that of 2016, the decline in predation rate was observed once at the forest location [mid-August (12.50%)] while it was two at the rural area [mid-August (17.65%) and mid-October (33.71%)] in 2017.

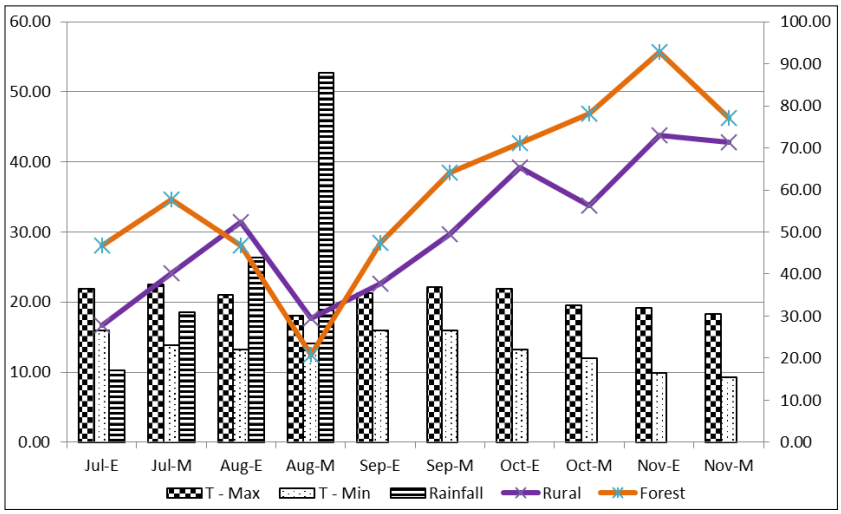

Fig 4: Percentage predation by hornet on honeybees during hornet active period around honeybee apiary at rural and forest sub-tropical plain areas in Parasi district, 2017 [Values of Rural and Forest locations mention in primary axis; T-max, T-min and Rain in secondary axis; T-Max= Maximum temperature (°C), T-Min= Minimum temperature (°C), Rain=Rainfall (mm); E=Start of month, M=Mid of month]

During both years, the predation rate was low during the early observation dates which raised to reach maximum in later dates. The maximum predation percentage was found highest during the month of November during both years and at both locations. The average predation percentage was observed comparatively higher at forest areas than that of rural areas. During 2016, the predation rate was higher in early-September (32.79%) and in mid-November (46.88%) at rural

location, likewise during 2017 it was higher in early-August (31.43%) and mid-August (17.65%) observation dates, while during the rest of the period it was higher at forest location. The average predation percentage increased progressively in 2016 but in 2017, the predation growth trend decreased in early-August (at forest area) and mid-August (at both locations) observation dates. This decline in average predation percentage was due to heavy rainfall during these two observation dates. The study conducted at mid-hills of Lalitpur district, Nepal also summarizes similar results as the maximum predation was in mid-November (62.07%) and in early-November (53.49%) at rural and forest locations, respectively during 2016/017. Also during the year 2017/018, the highest predation was in early-November (70.27%) at rural area while it was in mid-November (58.62%) in the apiaries near the forest area. The population of hornet was higher at the forest areas which is also in accordance with the present results [18].

3.5 Relation between hornet predation with weather parameters

Table 3: Pearson's correlation of hornet predation with weather parameters and hornet incidence at two locations of sub-tropical plain areas in Parasi district

Particulars	Rural area	Forest area
Maximum Temperature (°C)	-0.028 (0.906)	-0.094 (0.695)
Minimum Temperature (°C)	-0.256 (0.276)	-0.306 (0.189)
Relative Humidity (%)	0.073 (0.758)	0.055 (0.817)
Rainfall (mm)	-0.363 (0.116)	-0.376 (0.102)
Hornet Incidence	0.718** (<0.001)	0.656** (0.002)

Data in parenthesis represents a probability value (P=<0.05%)

The weather factors are highly related with the hornet predation on honeybees around the apiary. Both maximum and minimum temperatures were found negatively correlated with the predation rate by hornet (Table 3) featuring that hornet activity for predation was high at optimum temperature range. Negative correlation was also observed with rainfall pattern which highlights that the percentage of honeybee catch by the hornet was low during high rainfall. This fact was evident in 2017 in our study, where the predation rate was lower on August mid observation dates because of maximum rainfall. Irrespective of this, the average predation percentage was positively correlated with relative humidity and the hornet incidence. The average number of hornet visit to the apiary was highly significant with hornet predation rate which was obvious especially during the later observation dates. The results of similar study conducted at rural and forest location of Lalitpur district, Nepal was observed identical on the correlation with entire weather parameters. The correlation between hornet incidence and the predation rate at Lalitpur district was positive and highly significant [18].

3.6 Capture rate and pre day predation by hornet on honeybees

Table 4: Average hornet capture rate (CR), average predation per day (PD) and honeybee defensive efficiency (DE) during hornet active period around honeybee apiary at two locations of Parasi district during 2016-2017

Observation dates	Parasi Rural			Parasi Forest		
	CR	PD	DE	CR	PD	DE
July, Early	14.94	1.20	85.06	22.52	2.00	77.48
July, Mid	21.22	2.00	78.78	27.18	2.40	72.82
August, Early	24.81	2.30	75.19	25.02	2.50	74.98
August, Mid	19.49	1.90	80.51	16.96	2.00	83.04
September, Early	27.70	3.90	72.30	29.46	4.50	70.54
September, Mid	33.16	7.40	66.84	38.16	10.40	61.84
October, Early	34.68	12.70	65.32	41.69	18.40	58.31
October, Mid	33.70	12.20	66.30	44.71	19.20	55.29
November, Early	40.75	6.50	59.25	53.04	12.60	46.96
November, Mid	44.87	3.60	55.13	46.06	4.70	53.94

[CR= Hornet capture rate in %, PD= Average predation per day in no., DE= Honeybee defensive efficiency in %]

The honeybees capture rate by predatory hornet was observed in growing trend during the observation period at both locations. The average capture rate was 14.94% in early-July which reached at its peak (44.87%) in mid-November, 2016 (Table 4). Similar trend was found in 2017, where the average capture percentage in early-July was 22.52% that increased to reach its peak in early-November (53.04%). Among the two locations, the honeybee capture percentage was comparatively higher at forest areas during entire observation dates, except in mid-August. The per day average predation rate by hornet was also lower at early observation dates, which reached its maximum in the month of October and slightly decreased in November at both locations. The maximum predation was observed in early-October (12.70) at rural location and in mid-October (19.20) at forest location. The average predation per day was observed comparatively higher at the forest area than at rural location during the entire observation dates. In contrast to the capture rate by hornet, the honeybee defensive efficiency was better at early observation dates which continuously decreased during the latter days.

The increment in hornet preying on honeybees seems to be governed by two major factors: the hornet biology and weather parameters. Mild temperature and relative humidity without rainfall as well as number of hornet nests around the honeybee apiary induced the incidence and predation rate by hornet on honeybees. The summer time of our study areas coincides with the “queen colony phase” as mentioned by [28] where the queen hornet searches for animal prey for her first

generation brood rearing. Thereafter during early autumn and up to beginning of winter seasons, after the emergence of first generation brood the number of hornet and size of the hornet nest begin to expand demanding more animal proteins [26] also presumed that the attempts by hornets to attack honeybee colonies are numerous and frequent, particularly at the end of the season (September to December) when the production of new queens makes high demands on hornet workers [11] also elucidated similar biological facts of hornets and explained the predation pressure from early July to late October. The predation percentage in our study ranged from 13.21 to 21.33% at rural location and 16.92 to 21.43% at forest areas during summer time which reached its maximum up to 43.75 at rural area to 55.65% in forest locations during autumn season (Fig. 3 and 4). These evidences are further supported by the prey spectrum analysis of hornet nests [29] in their study compared the prey spectrum in hornet nest and revealed its preference on hymenopteran insects, as honeybees contains 37%, common wasps (18%) as well as other pollinators: the hoverflies (Syrphidae) and necrophagous Diptera, such as carrion and house flies (34%). Similarly, [27] while examining the food pellets (n=235) inside the hornet nest found predominant presence of honeybees (84.8%), fragments of various insects (11.7%) and vertebrate flesh (3.5%).

The predation rate by the hornets during the early observation dates was comparatively low at both locations, which gradually increased and reached its peak during the month of October (Table 3). The study done by [23] at Punjab, similar that of our study environment, reported the maximum hornet visit on *A. mellifera* apiary from July to December with peak population during August to October ranging the number of hornets caught from 18 to 74 [31] Found the peak period of hornet attack was during August to September and number of hornet on an average ranged from 0.10 to 13.58 per day in Kashmir, India. In our study, during July start observation date the average predation per day was 1.20 and 2.00, respectively at rural and forest locations. This figure increased to reach its maximum in early-October (12.70) at rural area and in mid-October (19.20) at forest location. Although the rate of predation increased from early spring to late autumn, during most of the observation dates the hornet attack was not always successful. But still, the hornets visited continuously around the apiaries throughout the day [27] in France have found that the hornet needs in an average of four trails to catch one honeybee during its peak predation period.

4. Conclusion

Nowadays the beekeeping profession has been challenged by many factors, most likely due to the combination of many stresses as, endo- and exo-parasites, different pests, shortage of quality flora and fragmentation, injudicious use of pesticides, weather change, etc. The apprehension of hornet predation has created an additional stress especially at the migration sites which has negatively affected the commercialization process of beekeeping in Nepal. The presence of hornet around the apiary itself has adverse impact on colony foraging activity and also need to deploy many honeybees for safeguarding the colonies. It has been observed that the maximum incidences of predatory hornets occurs during July to November, where the highest predation exists from September early to November mid, which is one of the major periods of honey harvesting at sub-tropical plain areas of Nepal. So a sustainable management approach has to be developed at this stage including various biological, ecological and behavioral aspects of hornet on honeybee apiary.

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6. References

1. Verma LR. Beekeeping in Integrated Mountain Development-Economic and Scientific Perspectives. Oxford and IBH Publishing, New Delhi, India, 1990, 367.
2. Aryal S, Thapa R, Jung C. An overview of beekeeping economy and its constraints in Nepal. Journal of Apiculture. 2015; 30(3):135-142.
3. Bista S, Lakhey PB. Honeybee and plant resources: Diversity, availability and significance for beekeeping in Nepal. In: Joshi BK, KC HB, Acharya AK. (Editors). Conservation and Utilization of Agricultural Plant Genetic Resources in Nepal. Proceedings of the 2nd National Workshop, 22-23 May 2017, Dhulikhel: National Agriculture Genetic Resource Center, Fruit Development Directorate, Department of Agriculture and Ministry of Agricultural Development, Kathmandu, Nepal, 2017, 423-445.
4. Kafle GP. Salient Features of Beekeeping in Nepal. In: Verma LR. (Editor), Honeybees in Mountain Agriculture. Oxford & IBH Publishing, New Delhi, India, 1992, 8-274.
5. Bista S, Shivakoti GP. Major constraints and management practices in the performance of *Apis cerana* F. and *Apis mellifera* L. in Kathmandu valley. In: Manandhar HK, Shrestha CL, Shrestha RK, Pradhan SM. (Editors). Advances in Agricultural Research in Nepal, Proceedings of the 1st Society of Agricultural Scientists, Nepal Convention, March 29-31, 1999, Kathmandu, Society of Agricultural Scientists (SAS), Nepal, 2001, 190-194.
6. BDS (Bee Development Section). Annual Progress Report. Bee Development Section, Godawari, Nepal, 2002, 47.
7. Kafle GP. Bees and beekeeping [Mauri Tatha Mauripalan (In Nepali language)]. Api-Net Nepal, Sanepa, Lalitpur, Nepal, 2012, 294+9.
8. Ahmad F, Joshi SR, Gurung MB. The Himalayan cliff bee *Apis laboriosa* and the honey hunters of Kaski: indigenous honeybees of the Himalayas. Vol. 1, ICIMOD, Kathmandu, Nepal, 2003, 52.
9. Bista S, Aryal S, Paneru RB, Giri YP. Performance study of European honeybee *Apis mellifera* L. on different management practices. In: Proceedings of 4th National Conference on Science and Technology, 23-26 March 2004. Nepal Academy of Science and Technology, Lalitpur, Nepal, Nepal, 2004, 535-541.
10. Shah FA, Shah TA. *Vespa velutina*, a serious pest of honey bees in Kashmir. Bee World. 1991; 72(4):161-164.
11. Monceau K, Arca M, Lepretre L, Mougel F, Bonnard O,

Silvain JF *et al*. Native prey and invasive predator patterns of foraging activity: the case of the yellow-legged hornet predation at European honeybee hives. PLOS ONE. 2013; 8(6):e66492.
12. Thakur SS, Kashayp NP. Hornet control by lure trap in an apiary. Insect Environment. 1996; 2:6-7.
13. Ranabhat NB, Tamrakar AS. 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. 2008; 23:125-128.
14. Pokhrel S. The ecological problems and possible solutions of beekeeping in hills and terai of Chitwan, Nepal. The Journal of Agriculture and Environment. 2008; 9:23-33.
15. Ibrahim YYM. Evaluation of defensive behavior of honeybee (*Apis mellifera* L.) colonies against the attacking of oriental hornet (*Vespa orientalis* L.). Ph.D. Thesis submitted to Faculty of Agriculture, Cairo University, Egypt, 2009.
16. Yamane S. On the genus *Vespa* (Hymenoptera: Vespidae) from Nepal. Kontyu, Tokyo. 1974; 1:29-39.
17. Bista S, Dangi N. Insect taxonomy studies in Nepal: Present status, existing problems and its future strategy. In: Joshi SL, Thapa RB, Bista S. (Editors). Proceedings of Workshop, Review and Strategy Development of Entomological Research Works in Nepal, Vol. 2, 04-06 March 2012. Entomology Division, Nepal Agricultural Research Council, Khumaltar, Nepal, 2012, 125-144.
18. Bista S, Thapa RB, Pradhan KCSB, Ghimire YN, Aryal S. Incidence and predation rate of hornet (*Vespa* spp.) on European honeybee (*Apis mellifera* L.) apiary at mid-hill areas of Lalitpur district, Nepal. Journal of Agriculture and Natural Resources. 2020; 3(1):117-132.
19. Carpenter JM, Kojima J. Checklist of the species in the subfamily Vespinae (Insecta: Hymenoptera: Vespidae). Natural History Bulletin of Ibaraki University. 1997; 1:51-92.
20. Kumar PG, Mazumdar PC, Pham P. New records of hornet wasps of the genus *Vespa* Linnaeus (Hymenoptera: Vespidae) from Indian states and Bangladesh. Records of Zoological Survey of India. 2015; 115(2):215-219.
21. Archer ME. Vespine wasps of the world. Siri Scientific Press, Manchester, UK, 2012.
22. Thapa VK. Insect Diversity in Nepal, 2015-1097.
23. Brar HS, Gatoria GAS, Ihaji HS, Chahal S. Seasonal infestation of *Galleriea mellonella* and population of *Vespa orientalis* in *Apis mellifera* apiaries in Punjap. Indian Journal of Ecology. 1985; 12(1):109-112.
24. Nagaraja N, Rajagopal D. Pests and predators of European foulbrood honeybee, *Apis mellifera ligustica* Spin. In Karnataka, India. Indian Bee Journal. 2003; 65:120-127.
25. Villemant C, Muller F, Rome Q, Perrard A, Barbet-Massin M, Jiguet F. Estimating the potential range expansion and environmental impact of the invasive bee-hawking hornet, *Vespa velutina nigrithorax*. In: Silico Bees, CRC Press. James Devillers, Boca Raton, FL, USA, 2014, 269-287.
26. Matsuura M, Yamane S. Biology of the vespine wasps. Berlin, Germany: Springer Verlag, 1990, xix+323.
27. Perrard A, Haxaire J, Rortais A, Villemant C. Observations on the colony activity of the Asian hornet *Vespa velutina* Lepeletier 1836 (Hymenoptera: Vespidae: Vespinae) in France. Annales de la Société Entomologique de France. 2009; 45(1):119-127.
28. Archer ME. The queen colony phase of vespine wasps (Hymenoptera, Vespidae). Insect Societies. 2010; 57:133-145.
29. Villemant C, Barbet-Massin M, Perrard A, Muller F, Gargominy O, Jiguet F *et al*. Predicting the invasion risk by the alien bee-hawking yellow-legged hornet *Vespa velutina nigrithorax* across Europe and other continents with niche models. Biological Conservation. 2011; 144(9):2142-2150.
30. Sharma V, Mattu VK. Bioecological studies on *Vespa* species in honeybee colonies of Himachal Pradesh, India. American Multidisciplinary International Research Journal. 2014; 2:14-15.
31. Abrol DP, Karroo SK. Studies on seasonal activity and control of predatory wasps attacking honeybee colonies. Indian Bee Journal. 1998; 60(1):15-19.