Demography, Population Dynamics and Behavioural Ecology of Indian Flying Fox, *Pteropus giganteus*

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Under the supervision of

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This thesis is dedicated to the

Teachers

For their imperative advise, help, support and encouragement

DECLARATION

I hereby declare that the thesis entitled "**Demography, Population Dynamics and Behavioural Ecology of Indian Flying Fox, *Pteropus giganteus***" submitted by me for the degree of **Doctor of Philosophy** in **Applied Animal Science** is the result of my original work carried out under the guidance of **Dr. V. Elangovan,** Department of Applied Animal Sciences, Babasaheb Bhimrao Ambedkar University and it has not been submitted for the award of any degree, diploma, associateship of any University or Institution.

Place: Lucknow   Signature of candidate

Date: (Ram Kumar)

CERTIFICATE

This is to certify that the thesis titled "**Demography, Population Dynamics and Behavioural Ecology of Indian Flying Fox, *Pteropus giganteus***" submitted by **Mr. Ram Kumar** is an original research work and has not been previously submitted in part or full for the award of any other degree or diploma to this or any other university.

The thesis submitted to Babasaheb Bhimrao Ambedkar University Lucknow satisfies all the requirements as stipulated in the Doctor of Philosophy (Ph.D.) regulations – 1999 as amended in 2010 and it is fit for submission and evaluation for the award of the degree of Doctor of Philosophy of the University.

Date: Supervisor

Head of the Department

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LIST OF ABBREVIATIONS

°	–	Degree
°C	–	Degree Celsius
%	–	Percentage
cm	–	Centimeter
dbh	–	Diameter at breast height
df	–	Degree of freedom
h:m	–	Hour and minute
i.e.	–	that is
m	–	Meter
min	–	Minute
n	–	Number
SD	–	Standard deviation
sec	–	Second

INTRODUCTION

INTRODUCTION

The global diversity of vertebrate fauna comprises approximately 66,178 extant species. Further, species are highly diversified due to their habitation requirements and population abundance such as fishes (32,900 species), birds (10,425 species), reptiles (10,038 species), amphibians (7,302 species) and mammals (5,513 species) (Ceballos *et al.*, 2015) and among the mammalian group, bat contibutes more than 1300 species (Shi and Rabosky, 2015).

The global faunal diversity is known for its uniqueness, specialization, and characteristics. Presently, around 44% of the reported species are classified as nocturnal while diurnal are 26% and crepuscular or cathemeral mammals are 29% (Jones *et al.*, 2009). During photoperiodic phase, diurnal animals can identify based on their morphology, behaviour, and habitation. However nocturnal animals became active during dark hours and displays behavioural activities hence, they are generally avoided and least studies species. One such an amazing but neglected species are bats (Order: Chiroptera). Therefore, very few information is available on their habitat ecology, foraging behaviour, population dynamics and threat variables (Mildenstein *et al.*, 2005; Lacki *et al.*, 2007; Plowright *et al.*, 2011).

The most diverse order: Chiroptera evolved with several unique specializations such as well developed echolocation, highly sophisticated olfection, sustained flight adaptation, capturing of prey while flying, fly with larger fruits than body mass, passively hang upside down and cosmopolitan habitation (Kunz and Fenton, 2005). They are long-living, placental mammal and also known as the largest and true flying mammal in the world (Stier and Mildenstein, 2005). However, they share several characters, behaviour and life strategies with other animals (Hall and Richards, 2000).

There is a paucity of information available on the diversity of order Chiroptera. Therefore, it remains unclear how many species actually coexist in this species-rich assemblage because existing inventories are inadequate. However, because investigation and identification of new species are difficult, but collectively its number may extend up to many in a year (Fenton and Simmons, 2015). Around a decade back, the global diversity of bats was estimated as 1,100 (Simmons, 2005; Wilson and Reeder, 2005) then 1,117 (Srinivasulu *et al.*, 2010) and 1,232 species (Meyer *et al.*, 2011; Picard-Meyer *et al.*, 2014) but recently a new database reveals that there were more than 1300 species has been identified from the twenty different geographical location of the globe (Shi and Rabosky, 2015). Therefore, they maintained a remarkable position in mammalian community i.e. more than 20% of extant species (Wang *et al.*, 2011). Therefore, field biologist showed curiosity to investigate the natural history of bats.

The world's chiropteran fauna consists of two unequal sub-order i.e. the Megachiroptera (1 family) and the Microchiroptera (17 families) and they were immensely diverse in term of distribution and population size (Hutson and Mickleburgh, 2001; Wilson and Reeder, 2005). Historically, the distributional range of flying foxes ranges from East Indies to Australian Pacific Islands with the exception in the Antarctic and few other Oceanic Islands (Mickleburgh *et al.*, 2002). They are one of the major species contribute to mammalian diversity as they represent around 20% species richness in both Paleo and Neotropical region (Mickleburgh *et al.*, 2002). In term of species richness, around 75% of bats diversity are restricted with family Vespertilionidae, Pteropodidae, Phyllostomidae, Molossidae, Rhinolophidae and Hipposideridae while rest belongs to family Desmodontidae, Embalonuridae, Furipteridae, Megadermatidae, Mystacinidae, Myzopodidae, Natalidae, Noctilioidae, Nycteridae, Rhinopomodidae and Thyropteridae, (Shi and Rabosky, 2015). In Asian countries, a total of 123 species have been observed, among them, 14 species are frugivorous while 109 are reported as insectivorous bats (Wordley *et al.*, 2015).

Several studies have proven that bats are the keystone species and indigenous mammal for the ecological process in patchy and fragmented islands (Beggs and Wardle, 2006). The interaction of bats with foraging plants have considered as a very important component of the tropical ecosystems (Fleming, 2013). Throughout the globe, there were two families that have categoried as fruit-eating bats viz. Phyllostomidae and Pteropodidae (Kunz *et al.*, 2011).

In ecosystem, the flying foxes are categorically known as active pollinator and seed disperser. Ecologically and economically, fruit-eating bats have proven their importance in the Old World tropics, as they have a viable role in forest regeneration (Ingle, 2003; Nyhagen *et al.*, 2005). Fruit bats foraging on night blooming plants during night hours (Hall and Richards, 2000; Hodgkison *et al.*, 2004; Quesada *et al.*, 2004; Fleming *et al.*, 2009) and exchange pollen and disperse seeds between isolated and fragments islands and thus it helps in heterogeneity of tropical forests (Estrada and Coates-Estrada, 2002; Woinarski, 2004; Breed *et al.*, 2010).

Pteropodids are stringent phytophagy of fruits, nectars, leaves, shoots, buds, flowers and pollen (Utzurrum, 1995; Barclay, 2002; Singaravelan and Marimuthu, 2004). Due to their considerable feeding plasticity, they interacted with a wide hierarchy of plants diversity (Nakamoto *et al.*, 2015) and plays a fundamental role in the maintenance of ecological processes (Kunz *et al.*, 2011; Kasso and Balakrishnan, 2013). Generally, flying foxes prefer foraging on figs, bananas, palms, cashew, rambuttan, durian and breadfruit etc. (Deshpande and Kelkar, 2015). Hence, pollen and seed of several flowering, fruiting trees are transferred via chiropterophily thus the reproductive alteration facilitate ecological succession throughout their geographical ranges (Hodgkison *et al.*, 2003). Several studies confirmed that plants which are foraged by flying foxes have great medicinal and economic values (Singaravelan *et al.*, 2009). In terms of economic importance, a little investigation has been carried out so that the details of ecosystem services and economical contribution needs further investigation for systematic analysis (Pennisi *et al.*, 2004). As fruit bats are nomadic in foraging nature therefore, they actively engaged in the ecological process such as seed dispersal and pollination. Therefore, it was estimated that around 528 trees which belong to 64 families and 188 genera successfully maintained their diversity because of fruit bats (Kunz *et al.*, 2011; Kasso and Balakrishnan, 2013).

Pteropodidae bats (186 species and 42 genera) exhibits largest species richness in the order Chiroptera (Mickleburgh *et al.*, 1992; Simmons, 2005). The name “megabats” is abbreviated for them because of their body mass and wingspan. The flying foxes selected only well-exposed trees for roost because such trees are long lasting, spacious and mechanically stable however it also facilitates protection from predator, easier takeoff and landing room during flight (Granek, 2002; Gulraiz *et al.*, 2015). Some other parameters such as plants density, types of vegetation, urbanization and availability of flowering and fruiting trees are also associated with roost (Pierson and Rainey, 1992;

Kunz and Jones, 2000). Flying foxes aggregated as much as possible during reproductive periods at day camps but they entirely dependent on groove size and tree characteristics. Flying foxes select roost generally associated with some principally important factors such as aspect, slope, the presence of water bodies, and grove size (Granek, 2002; Hahn *et al.*, 2014). They generally occur close to human settlements and foraging on orchards, commercial crops and homestead garden as food resources. Some roosting colonies are long lasting even may retain for several decades (Hahn *et al.*, 2014).

Most of the *Pteropus* spp. are colonial, gathered from few hundreds to many thousands of individuals called camps. Particularly, *P. alecto* and *P. scapulatus* colonies size range from 500 ± 10,000 individuals even may increase more in a maternal colony are quite common (Vardon and Tidemann, 1997). *Pteropus alecto* selected roost in mangroves, monsoon, floodplain, rainforest, Melaleuca open-forests, woodland and open forest (Press *et al.*, 1995). The well-exposed trees have a significant role in food availability, social interaction, parturition, young rearing and protection (Lewis, 1996; Altringham and Senior, 2005).

The roosting sites of *Pteropus vampyrus* are reported in coconut groves, mangrove forests and primary forests (Kunz and Jones, 2000). Among them, the occurrence of roost sites is most frequent in mangrove forests and coconut groves due to abundance (Davis and Carter, 1962; Goodwin, 1979; Patterson *et al.*, 1996; Cryan, 2003). In some cases, *P. vampyrus* mutually share maternal colonies with *A. jubatus* (Stier and Mildenstein, 2005). In this regards, *P. giganteus* prefer roost in tropical and sub-tropical areas, generally near to coastal areas (Zhang *et al.*, 2010). The colonies size fluctuate seasonally but at the time of reproduction, they gathered as several hundred in a single roost (Krystufek, 2009; Sugita *et al.*, 2009).

Roost are the fundamental place for social interaction hence, its regular monitoring may provide qualitative information on threat and population trends and conservation initiatives can be implemented accordingly (Kingston, 2010). At the same time, the population size of the particular colony can be estimated through focal observation (O'Shea *et al.*, 2003). Generally, flying foxes don’t switch roost frequently and repeat year after year at the same geographical location (Fenton *et al.*, 1985; Chaverri *et al.*, 2007).

Flying foxes can travel around 3 – 166 km in a night for foraging (Roberts *et al.*, 2012) and several kilometers (~ 1500 km) during local migration and reproduction (Richter and Cumming, 2006). They are exemplary species as they have evolved with a proficient tool i.e. olfaction for food identification and diet selection. However, they select only dull, large, structurally protected (Bollen and Elsacker, 2002), aromatic or musky and freshly ripped fruits at foraging (Elangovan *et al.*, 2006). While foraging, they systematically bite on ripe fruits part, swallow only juicy contents and ejected fibrous portion as compact rinds (Nelson *et al.*, 2005). Meanwhile, few bats refuse seeds intact at feeding roost or dropped while flying and possibly it might help in the propagation of several plants in the fragmented and isolated areas. Though, it has a high impact on the socio-economic development of the local populations (Fujita and Tuttle, 1991).

In addition, flying foxes are adapted to travel for long distance with large fruits and also capable of retaining the mass of seed in the guts for longer periods (5.5 – 7.5 h) (Shilton *et al.*, 1999). Moreover, it has previously examined that the passed seeds from bats intestine have a strong germination power and viability than birds (Medellin and Gaona, 1999; Naranjo *et al.*, 2003). It has estimated that around 5% of fruits diversity and their 95% seeds are solely dispersed by frugivorous bats whereas birds and primates contribute merely 25% in their foraging territories (Medellin and Gaona, 1999). Therefore, fruit eating bats have a significant contribution to the seedlings establishment and forest regeneration (Fujita and Tuttle, 1991; Cox *et al.*, 1992).

The fruit bats exhibits several unique strategies and behaviour while foraging. Few of them, prefers earlier foraging (e.g. *Epomophorus gambianus*), few are at periphery (e.g. *Eidolon helvum*), lower canopy (e.g. *Cynopterus sphinx* and *Rousettus leschenaulti*), dense canopy (e.g. *Epomops franqueti*) (Marshall, 1983) while few are reported as postponed forager on the peripheral canopy (e.g. *Pteropus giganteus*) (Nathan *et al.*, 2009). Despite the foraging movements of *P. alecto* (Markus and Hall, 2004), feeding ecology of *P. rufus* (Bollen and Elsacker, 2002), odour based fruit selection of *P. pumilus* and *P. jagori* are well documented (Luft *et al.*, 2003).

Throughout the world, flying foxes are considered as a pest of commercial crop (Aziz *et al.*, 2016) but seed dispersal by them, boomed seed viability and also enhance the seed germination capacity (Djossa *et al.*, 2008; Helbig-Bonitz *et al.*, 2014; Baldwin and Whitehead, 2015). In this context, various studies suggested a fundamental difference between the foraging behaviour of bats and birds such as fruit bats prefer foraging on the fibrous fruits which may contain essential oils with hard rinds but generally birds mostly avoided such fruits while foraging (Galindo-González *et al.*, 2000; Bianconi *et al.*, 2007). Flying foxes systematically select and forage on freshly ripe fruits and drop food remnants underneath of feeding roost as ejected pellets. In some cases, they brought the entire fruits at their night roost. Accidentaly, it dropped on the flyway or sometimes reached up to the night roost (Muscarella and Fleming, 2007).

A study was conducted on the Ryukyu flying fox, *P*. *dasymallus* showed no apparent conflict with human dwellings (Lee *et al.*, 2009; Nakamoto *et al.*, 2009) while another study revealed a positive conflict with grove owner and *P*. *giganteus* in Myanmar. Further, it is also mentioned that *P*. *giganteus* accessed 24 plants as food amongst 13 fruits species also consuming by residing peoples (Win and Mya, 2015). The Rodrigues flying fox, *P*. *rodricensis* perceived as 36% damage of mango and lychee production in the Republic of Mauritius (Price, 2013). However, *P*. *giganteus* didn't prefer to forage on orchards or commercial crops and 30% of the lychee crop damage by birds while bats accessed only 9.5% (Mahmood-ul-Hassan *et al.*, 2010).

Flying foxes are large size and colonial species. Characteristically, noisy and open tree roost makes them more susceptible to threats such as hunting and roost harassment (Mickleburgh *et al.*, 2002; Mildenstein *et al.*, 2005). The population of *Pteropus* spp. is declining globally due to exponential growth of human population and ensuring food and house demands that are directly influencing the roost throughout their geographical ranges (Mildenstein *et al.*, 2005; Jung and Threlfall, 2016). Therefore, around half of the flying fox diversity are categorized as threatened by IUCN. In compression to other regions, a number of fruit bats have been reported from the Indian Ocean but many are higly threatened (Mickleburgh *et al.*, 2002).

Throughout the geographical ranges, the existence of flying fox colonies nearer to human dwelling have long practice for hunting. In Indonesia and Malaysia market, *Pteropus* spp. are tangibly hunted and sold as live or dead. In addition, *P*. *faunulus* hunted for medicinal properties, *P. cognatus* teeth used in necklaces, *P. tonganus* for recreation in Vanuatu hotels (Voigt and Kingston, 2016), *P. mariannus* in auspicious occasions (Mildenstein, 2012) and consumed as a delicious dish as having nutritional constituents (Mbete *et al.*, 2011). It is also consumed by nomadic and localities to whom meat might be expensive stuff (Jenkins and Racey, 2008) and sometimes in spiritual starvation (Goodman, 2006). The Chamorro community gathered at party and ceremonial time and happily enjoy the bush meat of the flying foxes. In several parts of the western Pacific Ocean, the Guam flying fox, *P. mariannus* boiled in coconut cream as such and had complete as an appetizing dish (Fahn *et al.*, 2011). Already, *P. tokudae* have been extinct and now *P. mariannus* listed as endangered. However, the prevalence of amyotrophic lateral sclerosis outbreak was recorded as 50 – 100 times higher in Chamorros peoples due to flying foxes consumption (Cox *et al.*, 2003).

It is strongly believed that the bush meat of flying foxes cures diverse ailments such as night blindness (Goodman, 2006), menstrual problems in mammalian females (Walker, 2005), rheumatoid arthritis (Jain *et al.*, 2008), healing of external injuries and cough (Ghosh, 2009), fever (Jaroli *et al.*, 2010), kidney stones (Tuladhar-Douglas, 2008), oil in rapid hair growth (Lohani, 2011) and still in several places, it is hunted simply and eaten just because of the pleasure while it also considered as one of a preferable dishes for the Chinese and Manadonese communities (Harrison *et al.*, 2011).

Since the threats factors are increased exponentially, particularly in Islands. In this context, several studies have been carried out to reveal the causation of threat factors. Concretely, they explore that habitat depletion and hunting pressure arose as dominant population destructor of flying foxes. Presently, the flying fox of the Palau, Chuuk and

Pohnpei islands faced the dramatic period for survivability, though, they have a fundamental role as guardian for the natural process in the tropical forests particularly in patchy habitats (Pierson and Rainey, 1992).

Recent studies reveal that flying foxes are facing large exposure to metallic contamination (Zukal *et al.*, 2015). It was argued that bats have longer life span than other species of similar body mass but higher level of roost fidelity, slow reproduction and long foraging movements, or even local migration during reproduction and harsh period showed lower level of extinction (Wilkinson and South, 2002; Barclay *et al.*, 2003; Golden, 2009). On average, a flying fox can live up to 40 years with suitable habitation (Jurgens and Prothero, 1987; Healy *et al.*, 2014) but highly sensitive to human disturbances or induced habitat changes and environmental stress (Parris and Hazell, 2005; Hayes and Loeb, 2007). Therefore, they strangely categorized as an ecological indicator of heavy metal and habitat quality (Kalcounis-Rueppell *et al.*, 2007; Zukal *et al.*, 2015).

Flying foxes are exposed to all seasonal changes directly hence, they became susceptible to climate change. Therefore, the viability of physical parameters particularly temperature causes fragile death of flying foxes. In the year 2002, the temperature was raised at 42.8 °C in Australian pacific region as a result, around 3,500 individuals died from the nine colonies. Further, the maternal colony of flying fox decline 5 – 6 % of the population due to hyperthermia but the mortality rate was recorded as higher in *P. alecto* (10 – 13%) while lesser in *P. poliocephalus* (>1%). The overall death frequency was estimated that the young ones (23 – 49%) and females (10 – 15%) was major sufferer than adult males (3%) (Welbergen *et al.*, 2008). Approximately 30,000 populations of flying-foxes (including 24,500 *P. poliocephalus*) decreased due to 19 similar outbreaks since 1989 – 2001 in the Australian pacific region (Eby and Lunney, 2002).

Sometimes the natural calamities (typhoons and cyclones) raise natural food resources. Due to cyclones, the colony size of *P. samoensis* and *P. tonganus* population decreases 80 – 90% in the Samoan islands (Shilton *et al.*, 2008). In addition, several Islands are major losses *Pteropus* population due to the occurrence of typhoons (2 – 4 times in a century) causes major depletion of roosting and foraging trees on which *Pteropus* exclusively relay (Esselstyn *et al.*, 2006). Moreover, many species of flying foxes have become threatened due to over hunting such as *P. aldabrensis* and *P. rodricensis* (Mickleburgh *et al.*, 2009), *P. tonganus* (Hamilton and Helgen, 2008), *P. samoensis* and *P. tonganus* (Brooke, 2001) and *P. mariannus* (Esselstyn *et al.*, 2006).

It was noticed that the IUCN Red List of Threatened species has mentioned *P. giganteus* as a Least Concerned species (Venkatesan, 2007; Dey *et al.*, 2013). It has been reported that about 48% population of *P. giganteus* decline from a single roosting site due to anthropogenic activities in Assam, India (Ali, 2010). Since few decade back, deforestation increased exponentially and species diversity decreased proportionally. The available database on the IUCN showed that species such as *P. tokudae*, *P. brunneus*, *P. pilosus* and *P. subniger* have gone extinct. A number of studies reveal that about half of the flying foxes diversity are threatened due to deforestation and anthropogenic causes. Due to the anthropogenic activities, the flying foxes population coerced to seasonal migration (Struebig *et al.*, 2007; Avgar *et al.*, 2013).

In tropical forest, habitat depletion are considered as the potential damaging factors for faunal diversity. Therefore, it is crucial to understand threat factors and effect on flying foxes. Therefore, various research suggested for species specific investigation for systematic conservation of threatened species (Myers *et al.*, 2000; Williams-Guillén *et al.*, 2016). However, a number of comparative studies have been carried on birds and mammals and they concretely suggested that the conservation initiatives have to start from slow reproducing and long living species within the confined area and biologically, it helps in the predation avoidance and estimation of threatened factors (Jones *et al.*, 2002).

As the population flying foxes are drastically declining in Paleotropic coordinates, hence they have received exclusive attention by world chiropterologist. Since few decades several studies have been carried out with special consideration of the conservation priorities of winged keepers of the forest (Marshall, 1983; Fujita and Tuttle, 1991; Wilson and Graham, 1992). Though, threatened number of bats species are boomed as the deforestation, urbanization and human population enhanced regionally (Mildenstein *et al.*, 2005). As a result, around the 25% of chiropteran diversity is threatened (O'Shea *et al.*, 2003; Kingston, 2010). As the present situation of chiropteran diversity has been reached at the remarkable position hence, some novel methods for effective conservation which have to be implemented into extensive field survey (Breed *et al.*, 2006). Further, it might be more reliable for minimizing the degree the habitat distraction throughout the habitation zones (Corlett, 2007; Rainho and Palmeirim, 2011). In addition, the effective conservation strategies of flying foxes can exaggerate the genetic variability through captive breeding and enhance the sustainability in natural conditions (O’Brien, 2005). In addition, the regular interaction with local masses as well as occasional visitors throughout their roosting site may help as the primary steps towards sustainable conservation managements.

REVIEW OF LITERATURE

Brooke *et al*. (2000) examined colonial and roosting behaviour of *Pteropus tongunus* and *P*. *samoensis* in American Samoa. Over the study period (10 years), two times natural hurricanes ruined at large scale of the roosting and foraging resources of studied flying foxes. Soon after hurricanes, *P*. *tongunus* showed local migration due to inaccessibility of roosting and foraging sources. They observed that some newly established diurnal colonies as patchy and scattered in unplanned coastal areas. Generally, primary forest was identified as most favourable roosting sites of *P*. *tongunus* and *P*. *samoensis*. A few clumped colonies of *P*. *tonganus* was identified due to regular hunting pressure.

Brooke (2001) observed diurnal activities and territorial behaviour of *Pteropus samoensis*. They investigated higher fidelity with regular roost while occasional roost displayed lesser but *P*. *samoensis* exhibited diurnal as well as nocturnal activities independently. The individuals of *P*. *samoensis* actively displayed territorial behaviour during foraging. During the territorial defense, they mainly exhibited few behavioural activities such as chase, wing flapping, screaming in front of intruders. Due to dense forest vegetation, the exact population estimation was not estimated but in most of the observations, females were noted as solitary with pups on shaded and foliage part of the roost tree while males are commonly observed either on tree top or peripheral canopy. They observed that the reproduction and mating behaviour was mostly recorded in the months of August – January. Apart from, they mentioned that the population size of *P*. *samoensis* consistently decreasing due to regular hunting.

Vardon *et al*. (2001) investigated the habitat suitability and distribution of *Pteropus alecto* and *P*. *scapulatus* in northern Australia. They demonstrated that both of flying foxes have different habitation criteria and distribution pattern and it significantly influenced by food availability, humidity and temperature. The roosting, foraging and reproduction of *P*. *alecto* and *P*. *scapulatus* are altered by habitat suitability. They typically maintained their roost in rainforests, woodlands, swamps, mangroves, and floodplain forests. The protection of available forest diversity may help to the conservation of *P*. *alecto* and *P*. *scapulatus*.

Bollen and Elsacker (2002) examined fruit choice and diet selection of *Pteropus rufus*. The fecal analysis showed that *P*. *rufus* prefer to forage on 40 types of available either flower or fruit and sometimes both (i.e. flowers and fruits). *Pteropus rufus* likely selected single and multiple of fruits while foraging and swallowed only juicy materials for the fulfillment of nutritional requirements. They swallowed tiny seeds with pulp and the gut passed seeds showed higher germination. They suggest that the active participation of *P*. *rufus* in the pollination and seed dispersal helps in the sustainable ecosystem function. Therefore, they considered *P*. *rufus* as highly valuable species and also recommended for conservation.

Brooke and Tschapka (2002) reported that flying foxes are the most threatened due to over hunting practices in Niue, an isolated island of South Pacific nation. They noticed that the massive hunting is significantly associated with the population reduction of flying foxes. They estimated that approximately 2040 and 4080 flying foxes are sampled as hunted in two successive survey period. The interactive session with 16 serial hunters reveals that around 1555 bats may shot in a year. The localities of Niue suggested that flying acts as a safe guard of natural resources.

Granek (2002) studied on the roost characteristics of *Pteropus livingstonii*. *Pteropus livingstonii* is one of the endemic, common and abundant flying foxes in the West Indian Ocean particularly in two islands viz. Moheli and Anjouan, Comoros. They studied the seasonal roosting pattern of *P. livingstonii* in dry and rainy seasons and population assessment respectively. They conducted a systematics field work to search out the new roost and recorded roost characteristics such as water proximity, aspect, slopes, and native tree was also identified. They reported *P. livingstonii* as highly abundant as it population was estimated around 2000 individuals but habitat requirement and roost characteristics of giant flying foxes are minimal studies in Moheli and Anjouan. Due to the longer practice of deforestation and roost harassment, this species became Critically Endangered. This study suggested that roost characteristics may be helpful in the formulation of conservation strategies to conserve *P. livingstonii* and its habitation.

Markus and Blackshow (2002) studied in the behavioural activities of *Pteropus alecto*. They observed the behavioural activities into two main phases. The first observation was based on the behavioural activities with reference to social interaction of single individual and second one was exclusively based on the mother-infant interaction. They estimated that generic activities such as vocalizations, grooming, sleeping and home flight were the predominant behavioural activities among diurnal activities. Further, they constructed an ethogram of behavioural activities which includes seventy four set of behaviour that mainly deals the individual, social and mother infants activities of *P*. *alecto*. They also suggested that the behavioural activities may helpful to conserve the flying fox basically where they are minimally studied and highly threatened.

Inaba *et al.* (2005) proposed conservation strategies through diet requirements of endemic flying fox, *Pteropus pselaphon* in the Ogasawara Islands, Japan. They reported that *P*. *pselaphon* primarily forage on flowers and fruits of 56 plants while a single family of insect was also recorded as opportunistic diet. They explained that *P*. *pselaphon* preferred only on the fresh flower and fruits and disperse their pollen and seeds in surrounding through foraging movement. They also suggested that *P*. *pselaphon* played a crucial role in ecological process particularly in roosting and foraging areas.

Mcdonald-Madden *et al*. (2005) examined the factors that crucially associated with foraging behaviour of *Pteropus poliocephalus*. They used stratified-random sampling technique for access the foraging criteria of *P*. *poliocephalus*. They covered 30 kilometers distance for investigating the colony distance, river, density, park, street, and availability foraging resource. *Pteropus poliocephalus* decreased foraging activities with increasing colony distance but food source and canopy cover are significantly related. They actively forage on the fragmented and patchy area where the probability of food abundance are comparatively higher. They suggested that *P*. *poliocephalus* preferred to forage in the grove than solitary plants.

Mildenstein *et al*. (2005) studied on habitat selection of *Pteropus vampyrus* and *Acerodon jubatus*. The endemic flying foxes of the forest at Subic Bay, Philippines have a great level of threat hence they conducted an extensive study to conserve them through habitat management. They used radio telemetry technique and covered around 14,000 hectare areas in the vegetative forest of Subic Bay, Philippines. They found that endemic flying foxes show higher preference to make roost in vegetative and riparian areas than agricultural areas. This study suggested for habitat management which may helpful in the conservation of *P*. *vampyrus* and *A. jubatus*.

Nyhagen *et al*. (2005) investigated diet composition and ecological services of *Pteropus niger*. They quantified diet composition and resource utilization through ejected pellets analysis. They found that *P*. *niger* mainly forage on flower (n = 2), fruits (n = 20) and leaves (n = 1). Apart from, eighteen plants species was estimated as pollen and each sample contains 2.2 mg pollen and their respective pollen load was quantified as 17.7 mg per bats. Therefore, they suggested *P*. *niger* act as active seed dispersal and pollination agent of foraging plants.

Welbergen (2006) exclusively studied the emergence behaviour of *Pteropus poliocephalus* with reference to predation risk, social context and foraging strategies. They found that emergence varied with predation risk while social context altered the foraging of *P*. *poliocephalus*. The emergence time of *P*. *poliocephalus* highly correlated with sunset pattern and cloud cover. They explained that the presence of predatory risk, *P*. *poliocephalus* exhibited postponed emergence while pregnant and lactating females exhibited preponed emergence due to higher energy budgets for milk production and neonate nursing. The novice neonate exhibited later emergence followed by mother and rest of the group members. The emergence of roost mates entirely dependent on the weather condition and breeding seasons. The sub-adults showed active emergence with perfect emergence pattern while mature males delayed emerge as they act as guardian until last female emergence of harem group which was made during breeding season.

Nakamoto *et al.* (2007) investigated the role of *Pteropus dasymallus* in seed dispersal and germination of *Ficus microcarpa*. *Ficus microcarpa* was mentioned as the most abundance and major constituents of *P*. *dasymallus* diet. Though, a number of fruits are highly varied between trees and seasons. This study reveals that gut passed seed of *F*. *microcarpa* showed higher germination frequency within short span than natural seeds. They suggested that enhancement in the seed viability significantly associated with the faunal reestablishment. Therefore, they mentioned that Orii's flying-fox is commonly known as a forest guardian.

Parsons *et al.* (2007) examined the diet composition of *Pteropus conspicillatus* through fecal analysis. They collected sample as pollen, pulp, tiny seeds and processed fruits from the four different geographical localities. Therefore, it showed that *P*. *conspicillatus* used a wide range of plants diversity in their diet. The ever dynamic nature of *P*. *conspicillatus* make fit into the almost all kind of available forest to avail their food resource and propagated their seedling in the surrounding areas. They mentioned that *P*. *conspicillatus* are one among major foraging species which altered rainforest diversity through valuable ecosystem services.

Shilton *et al*. (2008) examined the effect of short-term disturbances on the population of the most threatened flying fox species, *Pteropus conspicillatus*. They carried this study successively either period on cyclone phases i.e. before and after occurrence at each roost sites. Further, the pattern of re-distribution and response to cyclone was typically studied. The individuals of *P*. *conspicillatus* tenanted their roost on the same canopy trees after cyclone but in the pre-cyclone phases, they normally distributed on the canopies while after cyclone they randomly distributed or shifted roost at nearer grove. They found that cyclone causes great loss of *P*. *conspicillatus* population in compression to another phase of the study. Though, it caused great loos of roosting as well as foraging site and played a vital role in *P*. *conspicillatus* mortality. They suggested that the destruction of roosting and foraging resources due to cyclone altered the population size in north-east Queensland, Australia. They also reported six newly established diurnal roost after the cyclone.

Welbergen (2008) studied the effect of twilight on emergence behaviour of *Pteropus alecto* and *P*. *poliocephalus* in New South Wales, Australia. It confirmed that the emergence of flying foxes are highly influenced by twilight variation because it triggers the onset of emergence behaviour. Though, twilight is independent physical variable but it significantly altered by seasonal changes. It concluded that the availability of twilight caused narrow emergence on *P*. *poliocephalus* and broad emergence on *P*. *alecto*. Finally, result states that emergence behaviour of flying foxes are entirely dependent on twilight variation.

Lee *et al.* (2009) studied on distribution and resource utilization of *Pteropus dasymallu* in Japan. The most abundant population of *P*. *dasymallu* recorded from the village areas because of agricultural land provides ample roosting area and abundant food source. They suggested that higher population size is proportionally related to the frequency of anthropogenic causes. The solitary and lesser populated roost was recorded as more threatened (68%) than large and abundant (16.8%). They mentioned that random distribution of *P*. *dasymallu* in the islands was not significantly related to transect length but canopy height and cover positively related to the *P*. *dasymallu* population. They suggested that *P*. *dasymallu* primarily engaged in the seed dispersal and pollination because of foraging plasticity.

Nakamoto *et al.* (2009) used radio-tracking and direct observation method to study of pollination potential of *Pteropus dasymallus*. The foraging behaviour of *P*. *dasymallus* suggested that the food parts have morphological characteristics that attract bats for feeding and thus pollination of *Mucuna macrocarpa* and *Schima wallichii liukiuensis* are successfully sustained. They mentioned that dropping at foraging roost, flying with plucked fruit and defecation on flyway were observed frequently. They suggested that Orii's flying-fox travelled around 126 meters from the foraging sites. The movability and body size of the Orii's flying-fox suggested as potential pollinator and seed dispersing agent of feeding plants in the studied areas of Okinawa-Jima Islands.

Nathan *et al.* (2009) observed the foraging activities and behaviour of two sympatrically associated bats, *Cynopterus sphinx* and *Pteropus giganteus* in the southern part of India. During foraging period, an extensive observation was made to figure out the foraging strategies of the selected species on *Madhuca latifolia*. Indian short-nosed fruit bat, *C*. *sphinx* showed earlier foraging behaviour around lower most foliage of *M*. *latifolia* while Indian flying fox, *P*. *giganteus* generally prefer on the upper and peripheral branches. The foraging behaviour initiated with circle flight, screaming and landing on the lower and marginal canopy. They meticulously hold flower bunch, tore corolla and processed either on the foraging tree or at the feeding roost. They mentioned that the studied species swallowed only juicy contents while fibrous part spat out as rind. This study suggested that *C*. *sphinx* and *P*. *dasymallus giganteus* are well skilled to pollinate the *M*. *latifolia*.

Sugita *et al*. (2009) studied on shifting and roosting pattern of the Bonin flying foxes, *Pteropus pselaphon* during breeding seasons in Bonin Island, Japan. They used radio telemetry technique to investigate the shifting pattern of *P*. *pselaphon*. The individuals of *P*. *pselaphon* was observed as cluster during winter season while scattered during summer period. During summer, the colony existed on the solitary tree with nursing female and the population decreased up to 100 individuals in winter. The pattern of dispersal was categorized into three major group viz. multiple females with several males, multiple females with fewer males and few males and sub-adults of *P*. *pselaphon*. Though, *P*. *pselaphon* mates over the seasons but major numbers of copulation was observed during summer than winter. Hence, based on the neonates emergence and gestation period, they concluded that cluster formation in winter sited has a significant role in reproduction and colony stability.

Mahmood-Ul-Hassan *et al*. (2010) estimated the diet composition of the Indian flying fox, *Pteropus giganteus* in Pakistan. During the course of the study, they recorded 20 plants as a food source which belongs to 11 families. The result showed that *P*. *giganteus* mainly forage flower and fruit of available plants. They found that the analysis of ejected pellets and bolus samples showed that Moraceae (50.7%) was highly preferred food. Further, seasonal food preference showed significant among seasons such as winter (*Ficus retusa*, 27.5%), spring (*Ficus glomerata*, 30.9%), summer (*Psidium guajava*, 19.6%), and during autumn (*Diospyros peregrine*, 71.9%). Hence, they concluded that Indian flying fox, *P*. *giganteus* played a significant role in the ecosystem services such as seed dispersal and pollination in the study area of Pakistan.

Nakamoto *et al.* (2011) conducted study on the several main and associated islands in Japan to document the relationship between roost and population size of *Pteropus dasymallus*. They suggested that the distance between food source and roost act as roost determinant factor. However, a number of food plants and islands distance are not influenced population size. The trend of population increased with decreasing distance of food availability while decreased population with increasing distance in main islands. The emigration and immigration also have played as a key determinant in the population alteration of *P. inopinatus*. They suggested that population size of *P. inopinatus* highly variable due to availability and scarcity of food source and thus, the availability of food items trigger inter-islands movements.

Vendan and Kaleeswaran (2011) reported four roosting sites of *Pteropus giganteus* in Madurai, India. They found that the observed roosting colonies are highly diverse in term of their distribution and roosting pattern. They mentioned that among the observed colonies, most of the colonies used multiple of roost trees while single roost on discrete trees. They identified 21 saplings as the most preferred by *P. giganteus*. They found that the roosting sites have plentiful of food source but they preferred only on more feasible food sources such as *Anacardium occidentale, Borassus flabellifer, Madhuca indica, Nerium indicum, Phoenix dactylifera* and *Prosopis juliflora*. In addition, they suggested that *P. giganteus* have a significant participant in seed dispersal throughout the Madurai district.

Nakamoto *et al.* (2012) investigated the roost preference and habitation pattern of *Pteropus dasymallus* in urbanized and forest habitation. This study explained that the *P. dasymallus* exhibited its behavioural activities with respect to sunset and sunrise pattern.

This study suggested that 12:12 h dark and light pattern is significantly influenced the behavioural activities of *P*. *dasymallus*. The pattern and frequency of *P*. *dasymallus* behaviour are significantly altered with seasons. In the summer season, shorter night triggered earlier emergence while foraging movement decreases with the increasing food abundance. This study concretely suggested that the presence of food abundance, light-dark phase and human disturbance act as a key determinant for the behavioural activities, roost preference, and foraging of the *P*. *dasymallus*.

Toyama *et al.* (2012) examined the feeding behaviour and role of the *P*. *dasymallus* in the propagation of *Mucuna macrocarpa*. The captive *P*. *dasymallus* forage vigorously on the nectar and flower of *M*. *macrocarpa*. Though, they are perfect phytophagous but they meticulously tore sepal and petal to access the nectar of *M*. *macrocarpa*. The front or direct faced part was torn firstly and showed significantly higher opening of sepal and petals than rest of the possible angle. During opening of flower parts, an abundance of pollen load was recorded and concretely, it was recommended that the Orii's flying-fox act as primary pollinating agent of *M*. *macrocarpa*. This study suggested that *P*. *dasymallus* have a significant role in the propagation of *M*. *macrocarpa*.

Dey *et al*. (2013) recorded three diurnal roost sites of *Pteropus giganteus* in West Bengal, India. They reported that the composition of roost trees was varied among the studied colonies and they mainly occupied on the top of *Eucalyptus* spp., *Dalbergia latifolia*, *Tamarindus indica* and *Terminalia arjuna*. All the studied colonies were located nearer the water bodies perhaps fulfill the water requirements and also helpful for the optimal growth of plants which are the ultimate source of roosting and foraging of *P*.

giganteus. Further, they recorded behavioural activities of *P*. *giganteus* through binocular and visual observation with 30 minutes interval. The temperature and mating seasons positively associated with the individual aggregation. They were also collected fresh guano and ejected pellets for the investigation of the food composition, resource availability and utilization by *P*. *giganteus*. This study also explained that there were no apparent conflicts was noted throughout the study period but due to the deforestation, anthropogenic activities and regular nomadic disturbances, the population size of *P*. *giganteus* decreased drastically.

Maruthupandian and Marimuthu (2013) studied the copulatory behaviour of *Pteropus giganteus* under natural condition in the southern part of India. They extensively carried field work for 13 months to observe mating behaviour. They recorded mating behaviour during day hours under natural condition (n = 57). The males were actively involved in grooming their genital organ and approaching females for copulation. In continuation, female escaped from male gripping but male tried successively on single female until female become stable and allowed him for cunnilingus or vaginal licking. The continuous vaginal licking made the female for mating. In most of the case of cunnilingus, male successfully make mating pair with female and its duration ranged from 10 to 20 seconds. The correlation factor showed a positive relationship between pre-cunnilingus and copulation while negative with post-cunnilingus in the *P*. *giganteus*.

Sugita and Ueda (2013) studied the aggregation of *Pteropus pselaphon*. *Pteropus pselaphon* made a seasonal aggregation to avoid temperature effect during winter season though it showed a negative effect on aggregation. The results of this study suggested that they made their aggregation basically into three group such as sub-adults, adults and females. The aggregation size of *P*. *pselaphon* was varied with few females to several in a harem while males are observed as solitary among the group on the peripheral canopies. The results of this study suggested that the clustering of *P*. *pselaphon* help in worming and polygyny.

Tangavelou *et al*. (2013) reported that local peoples are actively involved in the conservation of the Indian flying fox, *Pteropus giganteus* even without any awareness campaign or chiropterologist initiatives. Hence, *P*. *giganteus* are not hunted even though, the fallen roost tree is not used in domestic because they believe that Goddess Kali punished them. In few other places, local community offers seasonal fruits to *P*. *giganteus* for the blessing of God for happiness. It is believed that the presence of roost sites of *P*. *giganteus* is the symbol of unrevealed or natural treasure. They also believed that diurnal roost protects grove owner and house guardian from the natural calamities. Apart from it, the authors conducted extensive conservation campaign in several places nearer to the maternal colonies of *P*. *giganteus*, to create awareness local mass for the conservation of *P*. *giganteus*.

Perveen and Rahman (2014) focused his study to access the role of *Pteropus giganteus* in seed dispersal and pollination which yielded socio-economic benefit to the local peoples in Pakistan. They found that the population size of *P*. *giganteus* fluctuated over the seasons but entirely dependent on resource availability which significantly altered by anthropogenic causes. The morphometric measurements of *P*. *giganteus* ranged as 174.10 ± 1.73 mm (forearm length) and 884 ± 18.17 mm (wingspan). Further, the results of this study suggested that *P*. *giganteus* forage on the wide range of plants.

Prasad *et al*. (2014) designed an exclusive study to examine the foraging behaviour and ecological importance of the Indian flying fox, *Pteropus giganteus*. They suggested that *P*. *giganteus* forage randomly on available flowering and fruiting trees but such trees are greatly associated with the biomedical values for human dwelling. For diet estimation and resource utilization, they conducted an extensive field work for accessing food source while ejected pellet analysis procedure was used for quantification. The identified food plant was correlated with market demands for the estimation of socio-economic contribution in local masses. *Pteropus giganteus* foraging plants species showed significant impact on the market values and physical life of human. They mainly prefer to forage on the commonly available plants such as *Anacardium occidentale*, *Areca catechu*, *Manilkara achras*, *Mangifera indica* and *Psidium gujava*. The ejected pellets analysis showed *P*. *giganteus* forage on various plants species such as *Anacardium occidentale*, *Anonna squamosa*, *Areca catechu*, *Artocarpus heterophillus*, *Basia latifolia*, *Ceiba pentandra*, *Cochlospermum religiosum*, *Cucurbita* species, *Ficus religiosa*, *Mangifera indica*, *Manilkara achras*, *Psidium guajava*, *Psychotria curviflora* and *Terminelia catappa*. *Ceiba pentandra* is famous for silky fiber while *Cochlospermum religiosum* known as gum producing plant. They suggested that the Indian flying fox, *Pteropus giganteus* have a significant impact on seedlings establishment of commercially and medicinally important plants species.

Ravon *et al*. (2014) explained that *Pteropus* spp. (Chiroptera: Pteropodidae) are globally known species for their ecological and economical contribution. In several forest, they are known as forest guardian because they actively involved in the pollen transfer and seed dispersing services. Unfortunately, the recent data of IUCN red list of threatened species categorized as near threatened (*P*. *vampyrus*), vulnerable (*P*. *lylei*) and least concern respectively (*P*. *hypomelanus*). Though, *P*. *vampyrus* and *P*. *lylei* are commonly distributed while *P*. *hypomelanus* are minimally investigated in Cambodian legislation. In term of conservation implementation, they designed a systematic survey program which helped in to the access the several new roost site, roosting pattern, population treads and obviously it enhanced conservation initiative of the Cambodian flying foxes.

Scanlon *et al*. (2014) measured the eco-values of flying foxes in the Fiji forest. This study suggested the conservation priorities for three Fiji flying foxes viz., *Notopteris macdonaldi*, *Pteropus samoensis* and *P*. *tonganus* based on their ecological services which yielded several benefits to local community. They collected around 500 ejected pellets as diet sample of *N*. *macdonaldi*, *P*. *samoensis*, and *P*. *tonganus* through random sampling method from the multiple locations in Fiji. They observed foraging resources contributes 75% plants as daily benefited while 42% plants are actively rotated their reproductive cycle because of flying foxes habitation and forging movements. Apart from, they also suggested that the conservation of flying foxes might be more powerful but it needed an exclusive adherence to diet and eco-benefits.

Stewart *et al.* (2014) analyzed a systematical interaction between the night blooming plants and fruit bats. They categorized blooming plants into three main group such as flower with nectar, flower without nectar and fruiting plants as a major food source for fruit bats. Further, the available plants are also categorized as either obligate pollinators (nectarivorous bats) or facultative pollinators (frugi-nectarivorous bats). They have conducted typical bats capturing method i.e. mist netting between 20:00 h – 22:00 h for both bats species such as nectarivorous (n = 179) and frugi-nectarivorous (n = 209). A typical foraging strategies may enhance the probability of pollination however it varied among the foraging groups. However, they mentioned that fruit bats have two different foraging guilds as a result, pollination and seed dispersal of forest plants successfully sustained hence, they significantly help in the regeneration of wild plants.

Tait *et al*. (2014) examined the effect and association of urbanization on *Pteropus conspicillatus* in Australia. This paper exclusively deals the habitat adaptation of *P*. *conspicillatus* as they mostly preferred their roost nearer to the human dwelling and home steady garden. They also mentioned that as long as urbanization exaggerated, the rate of conflict between flying foxes and humans has accelerated proportionally. Though, urban areas provide a productive shelter and habitation wealth to the *P*. *conspicillatus.* They concluded that *P*. *conspicillatus* adopted to sustain in fragmented areas where a maximum number of maternal roost was recorded. In addition, the outcome of this study suggested that urbanization have a significant impact on the colony size of *P*. *conspicillatus.* Thus, it was suggested that urbanization are a type of behavioural response rather than habitat loss of *P*. *conspicillatus* and might be helpful in the conservation and management initiatives of flying foxes.

Vyas and Upadhyay (2014) conducted extensive field survey to find the diurnal roost of *Pteropus giganteus* in Gujarat, India. They reported that *P*. *giganteus* generally aggregated on top of the larger trees. They found that the population of *P*. *giganteus* consists of neonates, sub-adults and mature individual of both sexes. This study reported a total of 182 larger trees as roost trees of *P*. *giganteus*. Apart from roosting population, they claimed that they reported first time as the largest roost tree across the Gujarat state and most probably in India.

Gulraiz *et al*. (2015) examined the roost characteristics and preference of *Pteropus giganteus*. They critically examined the roosting parameters into two maternal colonies of *P*. *giganteus* for a year at the Lahore, Pakistan. The result of this study was mentioned that the most abundant population of *P*. *giganteus* (*n* = 1052) was reported during breeding season while non-breeding supported fewer population size (*n* = 40). They reported that the abundance of roost trees was recorded at Jinnah (*n* = 4119) while Lalazar has very lesser roost trees (*n* = 90). The recorded roost trees showed a wide range of hierarchal diversity such as family, genera and species. They reported that the height of the roost ranged between 19.8 m (*Celtis australis*) to 7.5 m (*Dendrocalamus hamiltonii*) and dbh existed as 0.89 m (*Kigelia pinnata*) to 0.10 m (*Putranjiva roxburghii*). Further, 13.4 m height and 0.1 m dbh bearer trees like *P*. *roxburghii* recorded as most preferred roost tree while *Manilkara hexandra* which height was 14.4 m and dbh 0.24 m was explained as least preferred trees among the studied colony of *P*. *giganteus*. This study also demonstrated that water vicinity and trees characteristics are the key determinant factor which decides the roost preference of Indian flying fox, *P*. *giganteus*.

Oleksy *et al.* (2015) studied the feeding behaviour and movement pattern of the *Pteropus rufus*. They estimated that *P*. *rufus* can travel longer distance with average speeds of 9.13 m/s which indicated that they are the perfect nomadic species. They extensively used 86 nights observation and covered 58,000 hectares and estimated that the tagged females showed longer foraging movements (28.1 km) than male (26.7 km).

Due to gestation periods, female need more energy budgets hence cover longer foraging area. *Pteropus rufus* abundantly forage on the pollen and nectar of *Agave sisalana* while *Ficus grevei* fruits persist for longer. This study also suggested that the potential of foraging movements are directly associated with the ecological services of *P. rufus* such as seed dispersal and pollination and hence they have a significant role in the Madagascar forest regeneration.

Weber *et al.* (2015) studied about the foraging movements of the Lyle's flying fox, *Pteropus lylei*. They reported that *P. lylei* are made their roost in dense forests and also nearer to human dwelling perhaps home steady garden provided diverse food. Therefore, the conflict ratio between flying foxes and orchards owner are acclerated exponentially as a result, few species have been extinct while rest diversity is either threatened or on the verge of extinction. Keeping in the consideration of conservation priorities, they used highly sophisticated GPS tracking system for the analysis of foraging movement and behaviour of *P. lylei*. The tagged individuals of *P. lylei* frequently communicated during foraging and roosting period thereby it showed a higher level of fidelity. Though, *P. lylei* is the most mobile feeder but they showed a positive correlation with nearer food source. In this study, they also quantified that *P. lylei* substantially forages on native and exotic species (n = 34). They suggested that *P. lylei* have significant importance in the facilitation of ecological process while their conservation might be helpful in the propagation of various physical and biomedical important plants.

Baskaran *et al*. (2016) examined the effect of heat waves and rain on *Pteropus giganteus* under natural environments in the southern part of India. They also studied the pattern and frequency of behavioural activities of *P. giganteus* during the harsh period of summer and rainy days respectively. This study explained that *P*. *giganteus* made their roost on larger and taller trees therefore, they faced direct heat waves during hot days and ceased the behavioural activities accordingly. They reported that wild *P*. *giganteus* expend a lot of energy in behavioural activities hence alteration during adverse condition helps them for sustainability. It was the first observation which demonstrated that *P*. *giganteus* exhibited some unforeseen changes in the diurnal activities during ambient temperature and rainy time. At rainy times, they covered body by patagium and ceased all physical activities as a result, they retained on the same tree foliage until the rain stops. They explained that *P*. *giganteus* actively engaged in licking water drops from both sides of patagium and grooms the rest part of the body.

Neupane *et al*. (2016) reported that the population of Indian flying fox, *Pteropus giganteus* consistantly decreased due to electrocution, habitat alteration and human interference. Apart from, they summarized that hunting for bush meat is another major issue with *P*. *giganteus* at their roost sites. Therefore, authors have continuously made awareness campaign with residential and localities to make them aware about the conservation of Indian flying fox, *P*. *giganteus*.

Sugita (2016) reported first time homosexuality among the males of the Bonin flying fox, *Pteropus pselaphon*. During breeding season, individuals of *P*. *pselaphon* clustered as a well shape on the tree foliage. It was mentioned that the clustering of *P*. *pselaphon* consists of males and females and allogrooming among the roost mates are quite common. It confirmed that the grooming and licking of genital organs are occurred because of space scarcity while clustering. Laterally, the allogrooming of the same sex was firstly demonstrated as homosexuality in the *P*. *pselaphon.* The significance of the homosexuality in *P. pselaphon* was mainly associated with the reproductive fitness of males while it clustering on tree foliage facilitates thermoregulation, physical stability and social strength among the colony members.

Chen *et al.* (2017) empirically studied the contribution of pteropodid bats in regeneration and maintenance of plants diversity. In this study, they demonstrated that *Pteropus dasymallus* mainly forage on the freak fruiting trees (e.g. figs, 94.4%) than big bank or steady state food source. The analysis of isolated seeds from fecal pellets showed higher viability and germination power than natural seeds. This study also suggested that the *P. dasymallus* have a significant role in seed dispersal in patchy and isolated areas.

Javid *et al.* (2017) studied the dietary composition and seasonal variation in the diet selection of Indian flying fox, *Pteropus giganteus*. They collected dietary sample identified and quantified the nutritional contents. The proximity of food resources exists as 32 species from 23 genera which belong to 15 families. Further, they found that the selected plants species consist of 24 exotic and 8 native species while 13 fruits are commercially important and rest are wild species in Pakistan. This study demonstrated that ambient temperature (i.e. summer season), *P. giganteus* preferred to forage on the moist fruits. Through nutritional analysis, it was revealed that proteins, carbohydrates, and minerals are the major constituents of the *P. giganteus* diet during winter season while calcium and vitamins in the autumn season. Apart from the dietary estimation, they also studied the population dynamics and seasonal roost preference. They most abundant population was recorded on *Dalbergia sissoo* during summer (n = 425), *Kigelia pinnata* during spring (n = 270), *Celtis australis* during autumn (n = 374) and *Cedrela toona* during winter season (n = 330).

Vincenot *et al*. (2017) investigated the population trend of critically endangered, the Ryukyu flying fox, *Pteropus dasymallus* and also suggested viable conservation measures. *Pteropus dasymallus* is one of the common and native flying foxes of Japan, Philippines and Taiwan but recently, it was uplifted to critically endangered by IUCN threatened list. They estimated that hunting, anthropogenic causes, typhoons and localities attitude particularly farmers and grove owners are positively influenced the population of *P*. *dasymallus*. In addition, based on the decreasing population trend of *P*. *dasymallus*, they suggested viable initiatives for *P*. *dasymallus* conservation.

Chapter I

DISTRIBUTION AND ROOST SELECTION OF THE INDIAN FLYING FOX, *PTEROPUS GIGANTEUS*

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DISTRIBUTION AND ROOST SELECTION OF THE INDIAN FLYING FOX, *PTEROPUS GIGANTEUS*

INTRODUCTION

Flying foxes (Pteropodidae) constitute the largest genus of Megachiroptera, with 186 species distributed globally and among 86 species were recorded from Asian countries (Mildenstein *et al.*, 2005). Indian flying fox, *Pteropus giganteus* (Brunnich, 1782) is ubiquitously distributed in Asian region (Thomas *et al.*, 2013; Tsang, 2015; Kingston *et al.*, 2016). India categorized as a tropical country and exhibits a wide range of bat diversity in term of species richness. In India, approximately 120 bats species have been identified from the multiple locations. *Pteropus giganteus* has been reported from twenty six states while there was no information have found in very few states (Tsang, 2015).

In the recent decades, flying foxes have become a growing area in ecological studies. At the global scale, flying foxes are often considered as a viable participant of ecological functions. They chiefly propagate various plants species in accessible and inaccessible area through stringent eco-services, such as pollination and seed dispersal. In addition, because of their size, mobility and longevity make themselves as a difficult order to study. However, information regarding global diversity, distribution habitat characteristics of several species are largely unknown (Russ and Montgomery, 2002; Miller *et al.*, 2003; Loeb and O'keefe, 2006). As they hold such a unique and prominent position in the mammalian community therefore, field biologist and chiropterologist shows curious attention to find and evaluate the worthy contribution of flying foxes in the ecosystem (Warren and Witter, 2002; O'Shea and Bogan, 2003). Over all, the diversity, distribution and extant species richness of bats are ubiquitous but it positively altered by food availability and anthropogenic disturbances. Hence, these factors are critically associated with distribution, roost persistency and survival of bats (Willis and Brigham, 2004).

Flying foxes belong to one of the most primitive and diverse mammalian order in term of distribution which enables them to sustain into the several geographical regions (Simmons and Conway, 2003). The distribution of bats is influenced by evolutionary and environmental factors (Amengual *et al.*, 1997; Cox *et al.*, 2000). However, the interaction among either factor integrated with the sustainability and also primary step in the geographical analysis of bats distribution (Eick *et al.*, 2005; Monadjem *et al.*, 2010).

Most of the *Pteropus* spp. are endemic to Paleotropics (Corbet and Hill, 1991) and Indo-Pacific region (Rainey *et al.*, 1995; Nakamoto *et al.*, 2011); while very few species are recorded from temperate regions though it is well known for the richest faunal diversity than any other habitation premises in the planet (Harrison, 2005). Geographically, flying foxes cover a wide habitation range in most of the islands in the tropical belt as Madagascar in the west, Formosa in the north-east, and Samoa in the south-east, and also in the Malay Peninsula, and Australia (Pierson and Rainey, 1992; Hall and Richards, 2000). The maternal colonies of *P. alecto* typically maintained in the mangroves, monsoon, floodplain, rainforest, Melaleuca open-forests, woodland and open forest (Vardon and Tidemann, 1999; Vardon *et al.*, 2001). The roosting sites of *P.*

vampyrus are reported in primary forests, orchards and coconut groves (Rickart, 1993; Jones and Kunz, 2000).

Just because of evolutionary adaptation, flying foxes prefer roost on tall and emergent trees and assemble as many as thousands during day times for rest and social interaction. However, such type of aggregation during day hours called ‘camps’ (Markus and Blackshaw, 2002). They can be easily observed nearer to human habitation, arterial road, and water bodies. Some other non-roosting components which influenced roost selection significantly such as natural calamities, weather, anthropogenic load, forest density and vegetation (O’Brien *et al.*, 2007).

Pteropus spp. selected roost on the basis of topographical feature of trees but population aggregation is entirely dependent on the mechanical stability of roost trees (Pierson and Rainey, 1992; Kunz and Jones, 2000). The well exposed canopy of roost trees played a significant role in roosting suitability, predation sensitivity and social activities. *Ficus* trees are the most favoured roost trees of *Pteropus giganteus* however, they also prefer roost on *Eucalyptus* spp., *Mangifera indica* and *Tamarindus indica* (Vendan, 2003). In some cases, *P. vampyrus* mutually share maternal colonies with *A. jubatus* (Stier, 2003). Though, *Pteropus* stayed for longer period at the same roost site but food scarcity, reproduction, and harsh condition coerced them for short term migration, as a result, some unforeseen changes can be observed in the population size. In the case of *P. livingstonii*, the seasonal changes in colony size and roost switching are quite common between the rainy and dry weathers (Tidemann *et al.*, 1999).

The roosting ecology is a complex interaction of behavioural ecology as it actuate reproduction and survival of flying foxes (Kunz, 1982; Bell *et al.*, 1986). However, flying foxes systematically select only trees which are tall with wide canopy. The selection of appropriate roost exclusively associated with protection and flight feasibility. As it also considered as prime place of social activities particularly reproduction and young ones rearing (Richmond *et al.*, 1998). It was reported that the roost persistency is significantly associated with the reproduction (Kunz *et al.*, 2003).

Roost is the functional integer because bats spent most of the life span at roost. Hence, it is principally associated with the social activities (Wilkinson and South, 2002). Moreover, it acts as determinant factor for distribution and population size (Esselstyn *et al.*, 2004; Buden *et al.*, 2013). It was estimated that around 850 species of bats are either primarily or opportunistically depend on plants for their roost and food. Further, another study suggested that around 15 neotropical and 3 paleotropical bats are used more than 80 plants for roost (Kunz *et al.*, 1994). In this context, few other studies reveal that around 21 species i.e. Phyllostomidae bats (17 species), Pteropodidae (3 species) and Verspertilionidae (1 species) used a different part of the plant as roost (Dechmann *et al.*, 2005).

In this connection, several bats have been reported that they used different parts of the plants as roost such as *Cynopterus sphinx* and *Platyrrhinus helleri* chews palm leaves and make tent (Storz *et al.*, 2000), *Chalinolobus tuberculatus* roosting in the tree trunk (Kunz *et al.*, 2003). However, *Artibeus glaucus* generally chewed the basal or lateral leaf nerve for making roost in *Xanthosoma* plant (Ortega *et al.*, 2015). Further, few more bats species are also chewed the different parts of leaves such as midrib, veins, interconnected tissues and make roost in apical or conical shape such as *Artibeus phaeotis* (V-shaped tent), *Artibeus toltecus* (pyramid shaped tent), *Artibeus watsoni* (J-shaped tent) and

Uroderma bilobatum (inverted V-shaped tent) (Kunz *et al.*, 1994; Balasingh *et al.*, 1995; Ter Hofstede and Fenton, 2005).

Flying foxes roost selection are highly influenced by biotic, abiotic, and geographic factors (Granek, 2002). They occur close to human settlements and foraging on the nearer sources such as orchards, commercial crops and homestead garden (Hahn *et al.*, 2014). They select roost or retained maternal colonies generally associated with some crucially important factors such as aspect, slope, proximity to water, and mechanical stability of available trees (Palmer and Woinarski, 1999; Granek, 2002). Flying foxes are colonial species, therefore, they congregate from few dozens to several thousand on the tree top during day hours. Particularly, *P. alecto* and *P. scapulatus* colonies size range from 500 to 10,000 individuals even may increase more are quite common (Tidemann *et al.*, 1999). In term of bats diversity, India is known for its wealthy chiropteran diversity, as it harboured around 120 species and among them, 14 species are fruit bats. However, *P. giganteus*, *R. leschenaulti* and *C. sphinx* are most familiar fruit bats in India.

Flying foxes are the most common and familiar among bats and extensively studied throughout their habitation. A little information exists on habitat selection and utilization by Philippines giant fruit bat *P. vampyrus* and golden-crowned flying-fox *Acerodon jubatus* (Mildenstein *et al*., 2005), habitat characteristics of Livingstone's fruit bat *P. livingstonii* (Granek, 2002) and *P. giganteus* (Gulraiz *et al.*, 2015), and habitat selection of Indian flying fox *P. giganteus* (Hahn *et al.*, 2014) but there was no specific information available on roost tree characteristics and roost selection of *P. giganteus*. However, the availability of scientific contents on their distribution in Uttar Pradesh is scanty and obviously, it hampered conservation initiatives. Therefore, this study was aimed on the distribution, roost tree characteristics and roost selection of Indian flying fox, *Pteropus giganteus* in Uttar Pradesh.

MATERIALS AND METHODS

Study area

The study was carried out between Jan 2013 and Dec 2017 in rural, urban, semi-urban and developed areas in various districts of Uttar Pradesh such as Ambedkar Nagar (26°28'6.22"N; 82°41'29.55"E), Amroha (28°54'15.70"N; 78°28'1.61"E), Azamgarh (30°33'31.67"N; 75°50'25.17"E), Badaun (28° 7'47.80"N; 78°55'43.77"E), Baghpat (28°56'31.78"N; 77°13'34.12"E), Ballia (25°46'16.86"N; 84°10'30.59"E), Barabanki (26°59'43.82"N; 81°15'6.78"E), Bareilly (23° 0'30.61"N; 78°14'2.85"E), Basti (26°49'3.65"N; 82°45'47.93"E), Bijnor (29°22'20.79"N; 78° 8'9.05"E), Deoria (26°29'10.45"N; 83°47'1.76"E), Faizabad (26°46'23.69"N; 82° 8'38.99"E), Firozabad (27° 9'32.76"N; 78°23'44.73"E), Hardoi (27°23'54.58"N; 80° 7'54.13"E), Kanpur (26°26'59.72"N; 80°19'54.74"E), Kanpur Dehat (26°31'36.51"N; 79°49'46.96"E), Lakhimpur Kheri (27°56'56.66"N; 80°46'56.63"E), Lucknow (26°50'48.10"N; 80°56'46.20"E), Meerut (28°59'4.06"N; 28°59'4.06"N), Muzaffarnagar (29°28'21.58"N; 77°42'30.79"E), Pilibhit (28°35'0.56"N; 80° 0'31.59"E), Raebareli (26°14'4.31"N; 81°14'27.13"E), Saharanpur (29°58'1.48"N; 77°33'3.66"E), Siddharth Nagar (27°16'17.63"N; 82°49'15.51"E), Sitapur (27°35'2.05"N; 80°39'58.88"E), Sultanpur (26°50'48.10"N; 80°56'46.20"E) and Unnao (26°32'21.64"N; 80°29'16.15"E).

The information regarding roost sites of *P. giganteus* was collected from local places such as railway stations, bus stations, and local people. Based on the collected information, the survey was carried out and information like number of roost sites, population size and garden composition, distance of roost from the adjacent road, human habitation and water body were recorded. The geographical coordinates of all the recorded roost sites were assembled separately and an exclusive cartogram was constructed with the help of ArcGIS software (Version 10.2.2).

The tree characteristics such as diameter at breast height (dbh), tree height and canopy width of roost trees were recorded. The large, tall and wide canopy unoccupied trees located adjacent to the roost trees dbh (n = 53), height (n = 53) and canopy width (n = 53) were also measured precisely. Thereafter, the unoccupied large, tall and wide canopy trees, located adjacent to roost trees at least with a minimum dbh (39.7 cm), tree height (10.1 m) and canopy width (12.7 m) of selected trees were considered as non-roost trees also measured. The tree characteristics such as diameter at breast height (dbh), tree height and canopy width of roost trees were measured by following the American forests champion trees measuring guidelines handbook (Leverett and Bertolette, 2015). The population size of *P. giganteus* was estimated and correlated with the roost characteristics to ascertain the roost selection criteria.

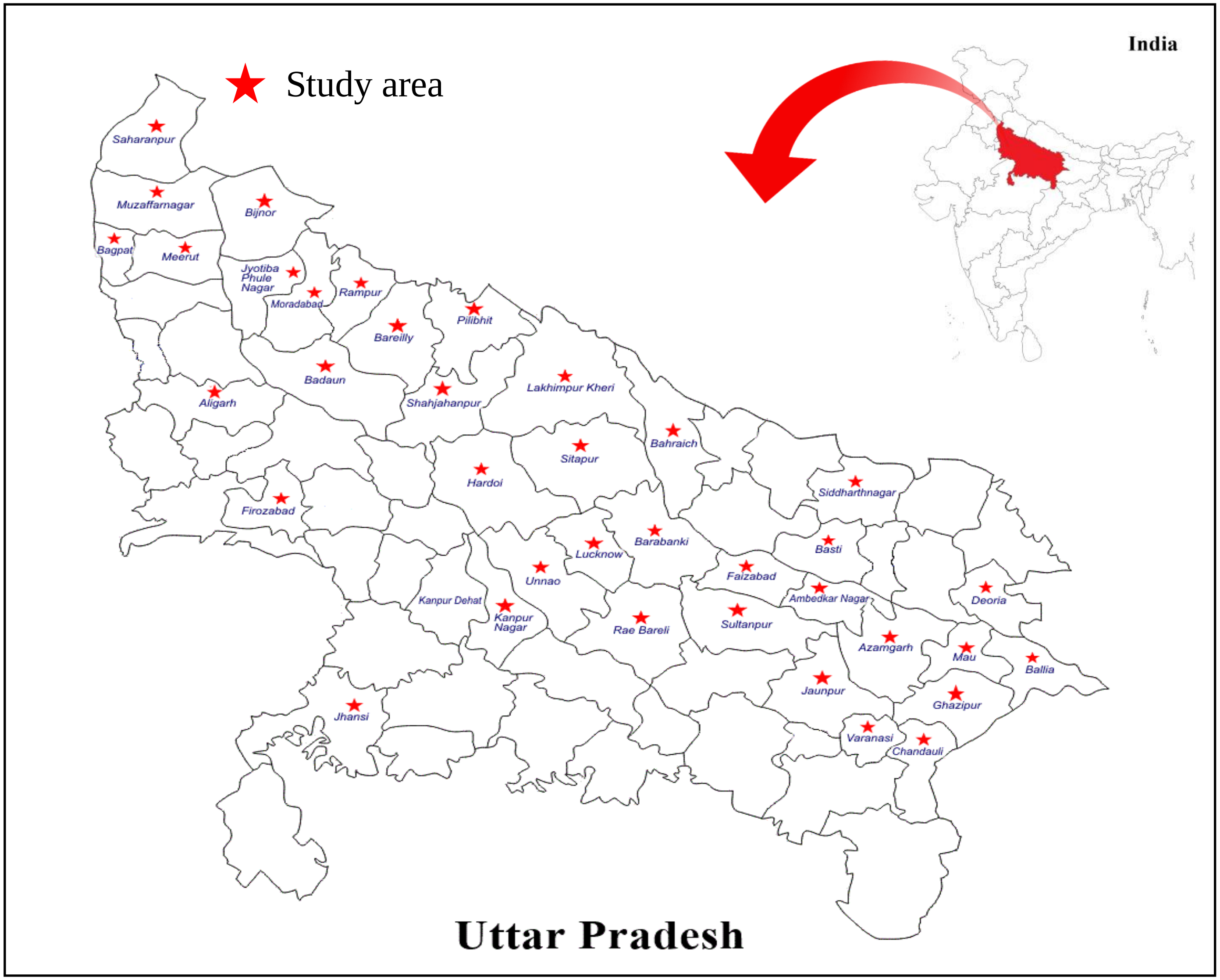

Figure 1.1. The distribution of *Pteropus giganteus* in the study area.

RESULTS

Indian flying fox, *Pteropus giganteus*

Phylum	:	Chordata
Subphylum	:	Vertebrata
Class	:	Mammalia
Order	:	Chiroptera
Suborder	:	Megachiroptera
Family	:	Pteropodidae
Genus	:	*Pteropus* (Brisson, 1762)
Species	:	*Pteropus giganteus* (Briinnich, 1782)

Colloquial name of *Pteropus giganteus* in the study districts are: Gadur (गागुर), Gaduri (गदुरी), Geedar (गीदड़), Chamgoder (चम्गोद्र) and Panchi (पँछी).

In the present study, a total of 84 roost sites of *Pteropus giganteus* was observed from the 34 districts of Uttar Pradesh, India (Figure 1.2 and Table 1.1). Among the observed roosts, a majority of *Pteropus* colonies was observed from the eastern region of Uttar Pradesh (70%) compared to western part (30%). However, in terms of population size, the colonies observed at a protected area in Kanpur harboured a maximum (1250). It shows that the location of colony offers a congenial environment by means of roosting wealth, food abundance and survivability. The population size of colonies ranged from 106 to 1250 individuals with an average population of 497 ± 270 (SD) individuals. Akin to population size, the number of roost trees per colony was also varied (6.0 ± 2.5 SD). Though the distribution of *P. giganteus* was widespread in Uttar Pradesh but the number of colonies varied among the districts from 1 to 7 colonies. The distribution and population size of *P. giganteus*, number of preferred roost trees and grove size were given in Table 1.1.

Plate 1.1. A glimpse of the dorsal (a) and ventral (b) view of the Indian flying fox, *Pteropus giganteus*.

Plate 1.2. The frontal view of the Indian flying fox, *Pteropus giganteus*.

Figure 1.2. ArcGIS based cartogram of the distribution of *Pteropus giganteus* in Uttar Pradesh.

Table 1.1. Distribution and average population size of *Pteropus giganteus* in the study area. The preferred roost trees (*codes of roost trees) along with number of colonies of *P. giganteus* with reference to average number of roost trees occupied and grove size observed in the study area.

Roosting sites	**GPS location**	**No. of colonies**	**Population ($\bar{x}$ ± SD)**	**Grove size**	**No. of roost trees**	**Roost trees***
Ambedkar Nagar	26°28'6.22"N; 82°41'29.55"E	6	359.6 ± 136.4	23.1 ± 13.8	6.0 ± 1.2	RT1, RT2, RT6, RT9, RT12, RT16, RT21 and RT23
Amroha	28°54'15.70"N; 78°28'1.61"E	1	750 ± 0	17 ± 0	5.0 ± 0	RT9, RT13, RT18 and RT21
Azamgarh	30°33'31.67"N; 75°50'25.17"E	3	607.0 ± 437.5	23.3 ± 7.6	4.6 ± 1.5	RT4, RT6, RT9, RT11, RT13 and RT20
Badaun	28° 7'47.80"N; 78°55'43.77"E	4	464.2 ± 108.5	35.0 ± 40.4	5.2 ± 1.7	RT1, RT2, RT9, RT11, RT13, RT16, RT19, RT21, RT25 and RT26
Baghpat	28°56'31.78"N; 77°13'34.12"E	1	250 ± 0	13 ± 0	3.0 ± 0	RT4, RT12 and RT20
Ballia	25°46'16.86"N; 84°10'30.59"E	4	426.7 ± 138.3	23.2 ± 13.7	5.0 ± 1.6	RT4, RT6, RT11, RT12, RT13, RT21 and RT25
Barabanki	26°59'43.82"N; 81°15'6.78"E	5	541.6 ± 269.4	32.0 ± 15.8	6.2 ± 2.4	RT4, RT6, RT7, RT10, RT11, RT13, RT18, RT19, RT21 and RT25

Bareilly	23° 0'30.61"N; 78°14'2.85"E	3	606.6 ± 517.3	45.6 ± 47.0	6.0 ± 3.6	RTRT11, RT13, RT18, RT21, RT23, RT26, RT27 and RT30
Basti	26°49'3.65"N; 82°45'47.93"E	2	575.0 ± 106.0	38.5 ± 2.1	7.5 ± 0.7	RT4, RT6, RT9, RT11, RT12, RT13 and RT25
Bijnor	29°22'20.79"N; 78° 8'9.05"E	5	586.2 ± 360.4	25.4 ± 15.4	8.6 ± 3.5	RT1, RT4, RT5, RT6, RT9, RT7, RT11, RT13, RT18, and RT21
Deoria	26°29'10.45"N; 83°47'1.76"E	2	537.5 ± 112.5	19.5 ± 3.5	5.5 ± 1.5	RT1, RT2, RT6, RT7, RT17 and RT20
Faizabad	26°46'23.69"N; 82° 8'38.99"E	7	453.4 ± 124.2	29.0 ± 17.8	6.4 ± 2.0	RT2, RT3, RT5, RT11, RT12, RT13, RT15, RT16, RT18, RT20, RT21, RT25 and RT26
Firozabad	27° 9'32.76"N; 78°23'44.73"E	1	450 ± 0	15 ± 0	5.0 ± 0	RT4, RT22 and RT23
Hardoi	27°23'54.58"N; 80° 7'54.13"E	1	395 ± 00	10 ± 00	7 ± 00	RT1, RT4, RT9 and RT25
Kanpur	26°26'59.72"N; 80°19'54.74"E	1	1250 ± 0	78 ± 0	15.0 ± 0	RT3, RT4, RT10, RT11, RT13, RT14, RT22 and RT23
Kanpur Dehat	6°31'36.51"N; 79°49'46.96"E	1	250 ± 00	19 ± 00	5 ± 00	RT4, RT11, RT13 and RT21

Lakhimpur Kheri	27°56'56.66"N; 80°46'56.63"E	3	466.7 ± 112.4	21.6 ± 6.2	6.6 ± 1.7	RT1, RT4, RT5, RT6, RT9, RT12, RT13, RT20 and RT25
Lucknow	26°50'48.10"N; 80°56'46.20"E	6	562.1 ± 424.5	49.1 ± 19.8	6.5 ± 4.3	RT3, RT4, RT6, RT8, RT9, RT11, RT13, RT15, RT20, RT23 and RT25
Meerut	28°59'4.06"N; 28°59'4.06"N	2	559.5 ± 252.1	18.6 ± 8.9	6.3 ± 2.0	RT8, RT11, RT13, RT21, RT23 and RT25
Muzaffarnagar	29°28'21.58"N; 77°42'30.79"E	1	1150 ± 0	7 ± 0	4 ± 0	RT6, RT11, RT13, RT20, RT28 and RT29
Pilibhit	28°35'0.56"N; 80° 0'31.59"E	5	513.0 ± 102.9	28.6 ± 23.3	5.6 ± 1.5	RT7, RT8, RT10, RT11, RT13, RT21, RT25 and RT26
Raebareli	26°14'4.31"N; 81°14'27.13"E	2	258.5 ± 8.5	18.5 ± 6.5	4.5 ± 1.5	RT4, RT13, RT21 and RT25
Saharanpur	29°58'1.48"N; 77°33'3.66"E	1	1225 ± 0	43 ± 0	10 ± 0	RT4, RT15, RT6, RT9 and RT13
Siddharth Nagar	27°16'17.63"N; 82°49'15.51"E	5	203.8 ± 79.5	16.0 ± 7.3	4.6 ± 1.3	RT4, RT9, RT10, RT11, RT13, RT18, RT21 and RT25
Sitapur	27°35'2.05"N; 80°39'58.88"E	3	555.6 ± 99.6	28.3 ± 20.2	6.3 ± 1.1	RT3 RT4, RT10, RT12, RT13 and RT21

Sultanpur	26°50'48.10"N; 80°56'46.20"E	5	396.0 ± 106.1	18.2 ± 5.4	4.6 ± 1.1	RT4, and RT5, RT9, RT6, RT11, RT13, RT21 and RT25
Unnao	26°32'21.64"N; 80°29'16.15"E	1	426 ± 0	4 ± 0	6.6 ± 0	RT11, RT13 and RT21

**Acacia nilotica* RT1, *Albizia lebbeck* RT2, *Alstonia scholaris* RT3, *Artocarpus integrifolia* RT4, *Artocarpus lakoocha* RT5, *Azadirachta indica* RT6, *Bamboo* spp. RT7, *Bassia latifolia* RT8, *Bombax ceiba* RT9, *Borassus flabellifer* RT10, *Cassia senna* RT11, *Dalbergia sissoo* RT12, *Delonix regia* RT13, *Eucalyptus* spp. RT14, *Ficus racemosa* RT15, *F. religiosa* RT16, *F. tinctoria* RT17, *F. virens* RT18, *F. benghalensis* RT19, *Grevillea robusta* RT20, *Holoptelea integrifolia* RT21, *Leucaena leucocephala* RT22, *Limonia acidissima* RT23, *Mangifera indica* RT24, *Neolamarckia cadamba* RT25, *Phoenix silvestris* RT26, *Polyalthia longifolia* RT27, *Prosopis juliflora* RT28, *Syzygium cumini* RT29 and *Terminalia arjuna* RT30.

Pteropus giganteus preferred to roost exclusively on larger trees such as *Acacia nilotica* Linn. (RT1), *Albizia lebbeck* Linn. (RT2), *Alstonia scholaris* Linn. (RT3), *Artocarpus integrifolia* Linn. (RT4), *Artocarpus lakoocha* Roxb. (RT5), *Azadirachta indica* A. Juss. (RT6), *Bamboo* spp. (RT7), *Bassia latifolia* Linn. (RT8), *Bombax ceiba* Linn. (RT9), *Borassus flabellifer* Linn. (RT10), *Cassia senna* Linn. (RT11), *Dalbergia sissoo* Roxb. (RT12), *Delonix regia* Hook. (RT13), *Eucalyptus* spp. (RT14), *Ficus racemosa* Roxb. (RT15), *F. religiosa* Linn. (RT16), *F. tinctoria* Bl. (RT17), *F. virens* Linn. (RT18), *F. benghalensis* Linn. (RT19), *Grevillea robusta* A. Cunn. (RT20), *Holoptelea integrifolia* Planch. (RT21), *Leucaena leucocephala* Lam. (RT22), *Limonia acidissima* Linn. (RT23), *Mangifera indica* Linn. (RT24), *Neolamarckia cadamba* Roxb. (RT25), *Phoenix silvestris* Roxb. (RT26), *Polyalthia longifolia* Sonn. (RT27), *Prosopis juliflora* Sw. (RT28), *Syzygium cumini* Linn. (RT29) and *Terminalia arjuna* Roxb. (RT30).

A total of 435 trees belonging to 30 species and 23 genera were used by *Pteropus giganteus* as roost trees and the number of roost trees used in a colony ranged from 3 to 15 according to the tree characteristics and grove size. *Pteropus giganteus* preferably occupied a large number of wide-canopy trees (71.4% trees) such as *F. benghalensis*, *F. racemosa*, *F. religiosa*, *F. virens*, *M. indica*, *S. cumini*, *B. latifolia*, *D. sissoo*, *D. regia* and *A. indica* while they occupied a few narrow-canopy trees (28.6% trees) like *Eucalyptus* spp., *T. arjuna* and *P. longifolia*. *Pteropus giganteus* seldom roosts in discrete trees, instead, the colonies were observed in groves with large number of trees. The population size of *P. giganteus* increased significantly with an increase in the number of roost trees (r = 0.841, $p < 0.001$, n = 68, Figure 1.3) and the number of roost trees in groves increased with increasing grove size (r = 0.619, $p < 0.001$, n = 68, Figure 1.4). Thus, the population size of *P. giganteus* is directly correlated to the grove size (r = 0.629, $p < 0.001$, n = 68, Figure 1.5).

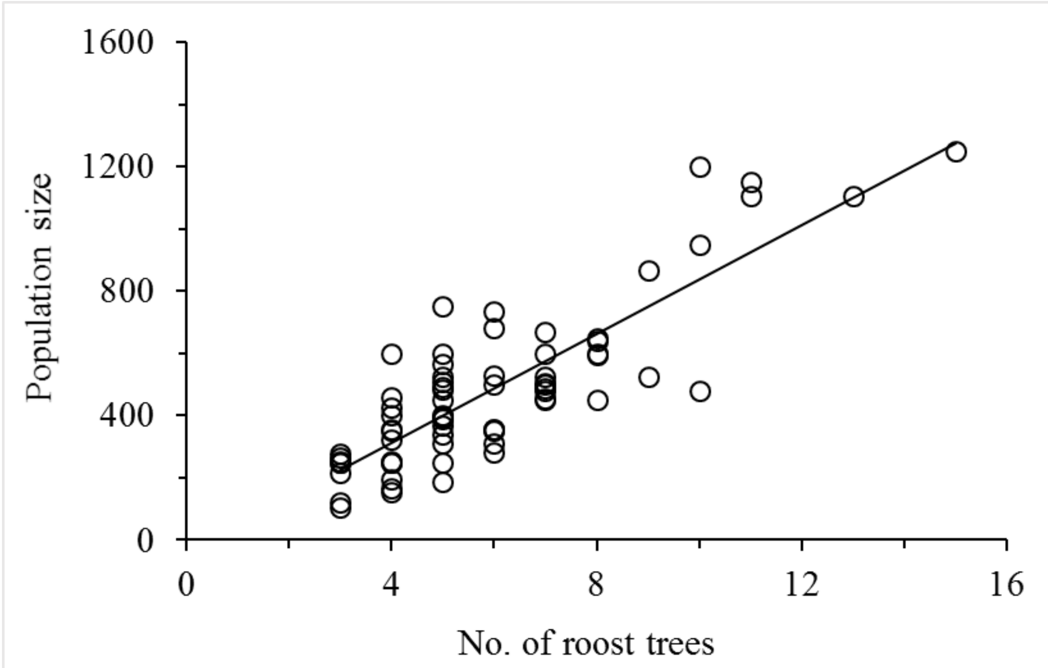

Figure 1.3. Shows the relation between the population size of *Pteropus giganteus* and number of roost trees.

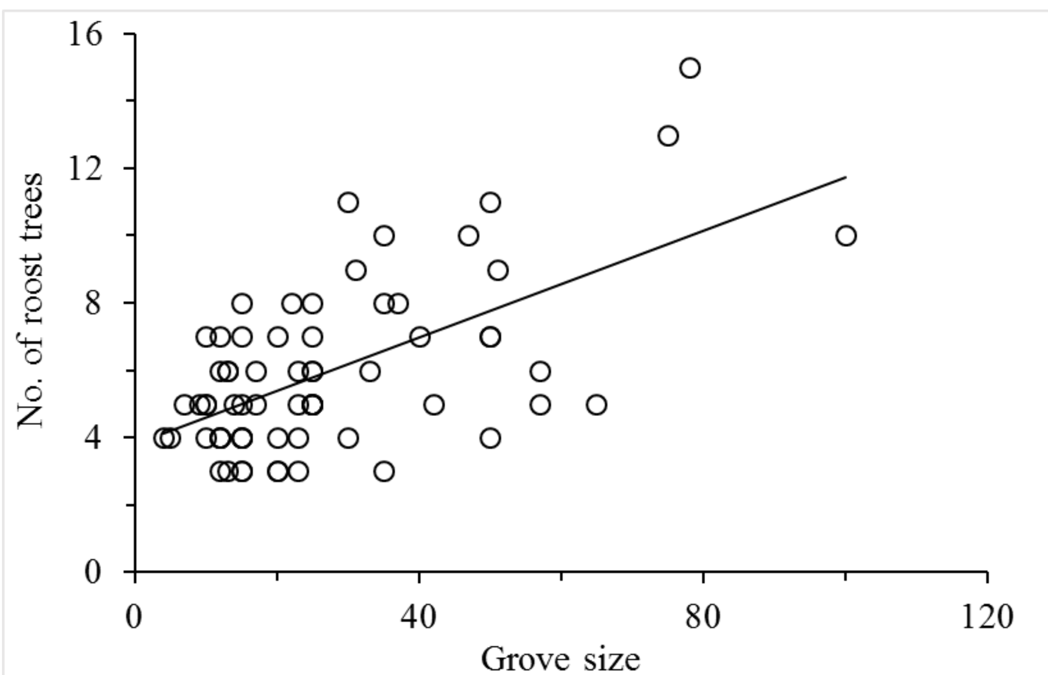

Figure 1.4. Shows the relation between grove size and number of roost trees.

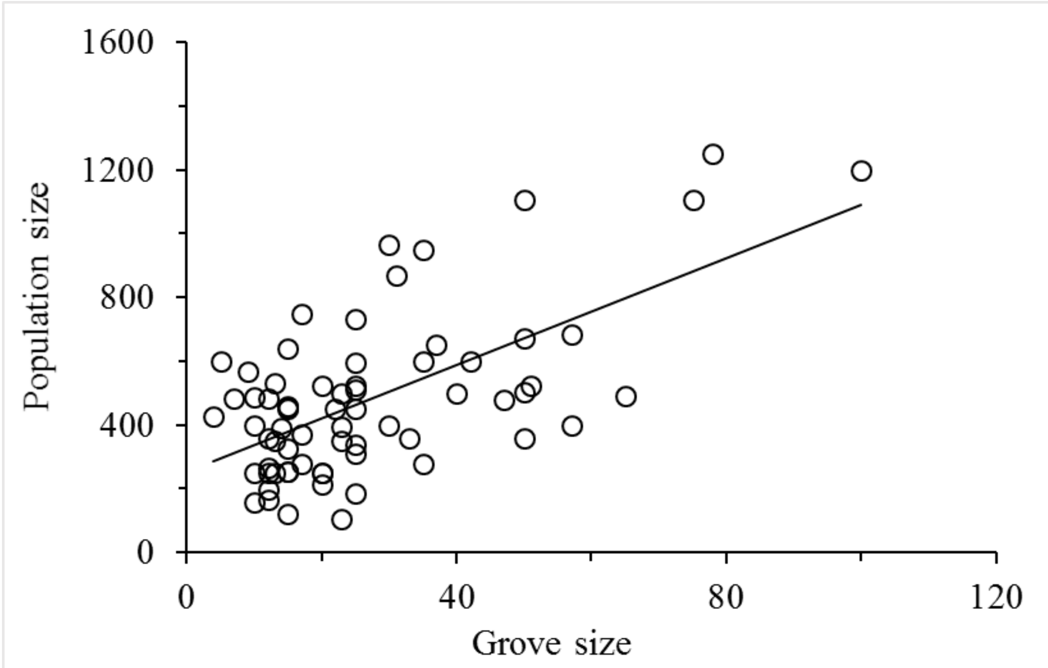

Figure 1.5. Shows the relation between the population size of *Pteropus giganteus* and grove size.

The tree characteristics of roosting and non-roosting tree such as dbh (t = 7.73, p < 0.001, df = 119), tree height (t = 8.29, p < 0.001, df = 119) and canopy width (t = 4.57, p < 0.001, df = 119) differed significantly. The roost characteristics such as dbh (r = 0.657, p < 0.001, n = 68, Figure 1.6), tree height (r = 0.530, p < 0.001, n = 68, Figure 1.7) and canopy width (r = 0.551, p < 0.001, n = 68, Figure 1.8) were positively correlated with the population size of *P. giganteus*.

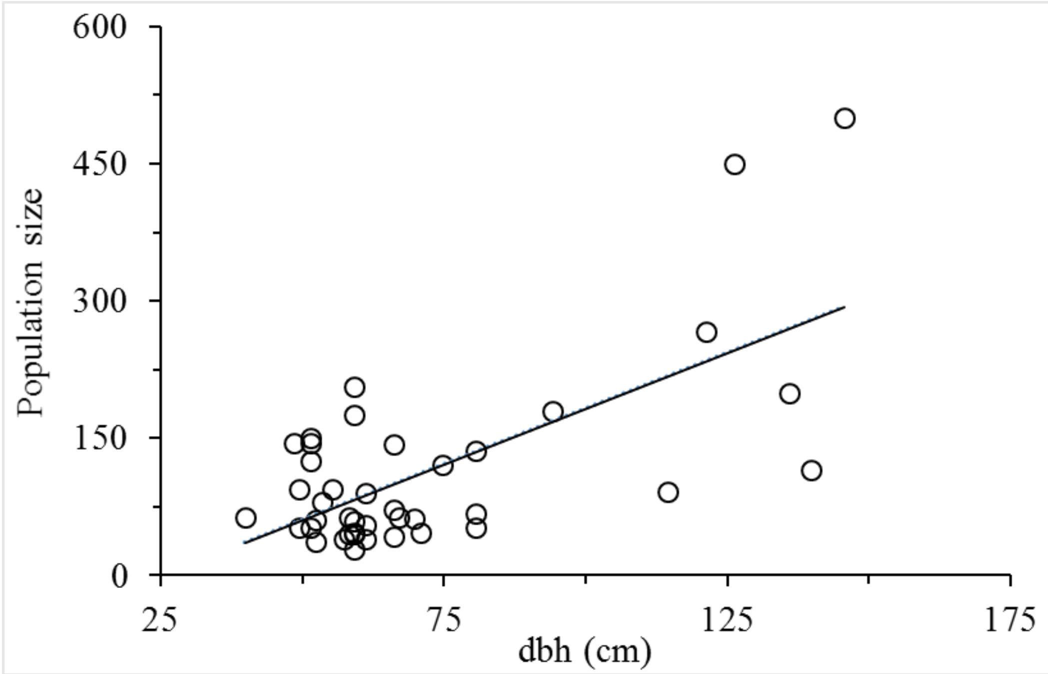

Figure 1.6. Effect of dbh on the population size of *Pteropus giganteus*.

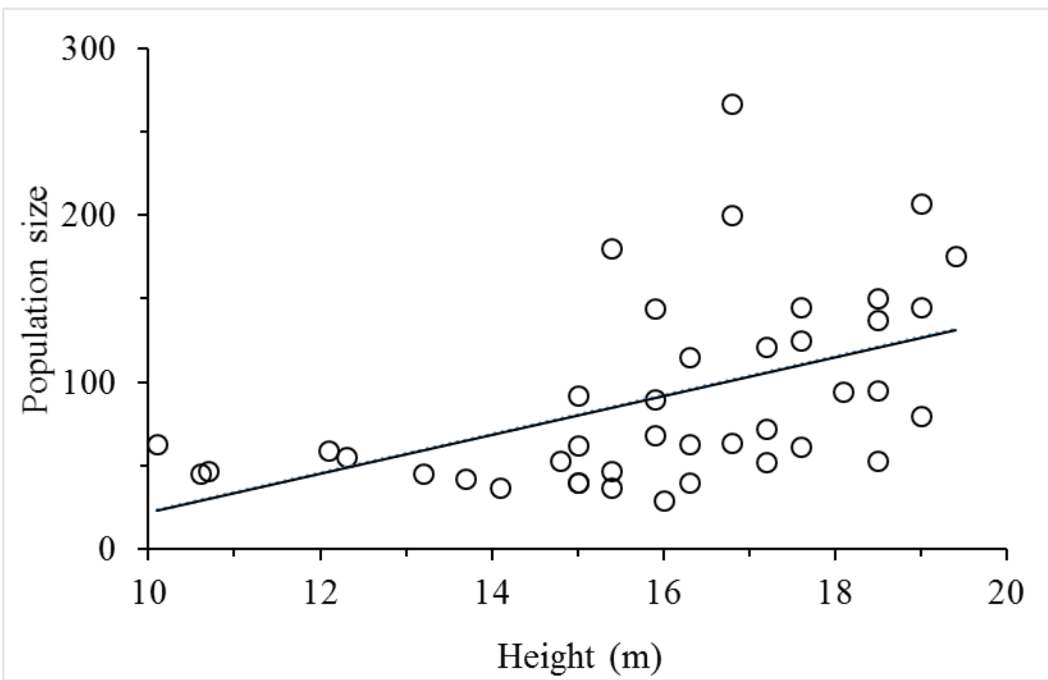

Figure 1.7. Effect of tree height on the population size of *Pteropus giganteus*.

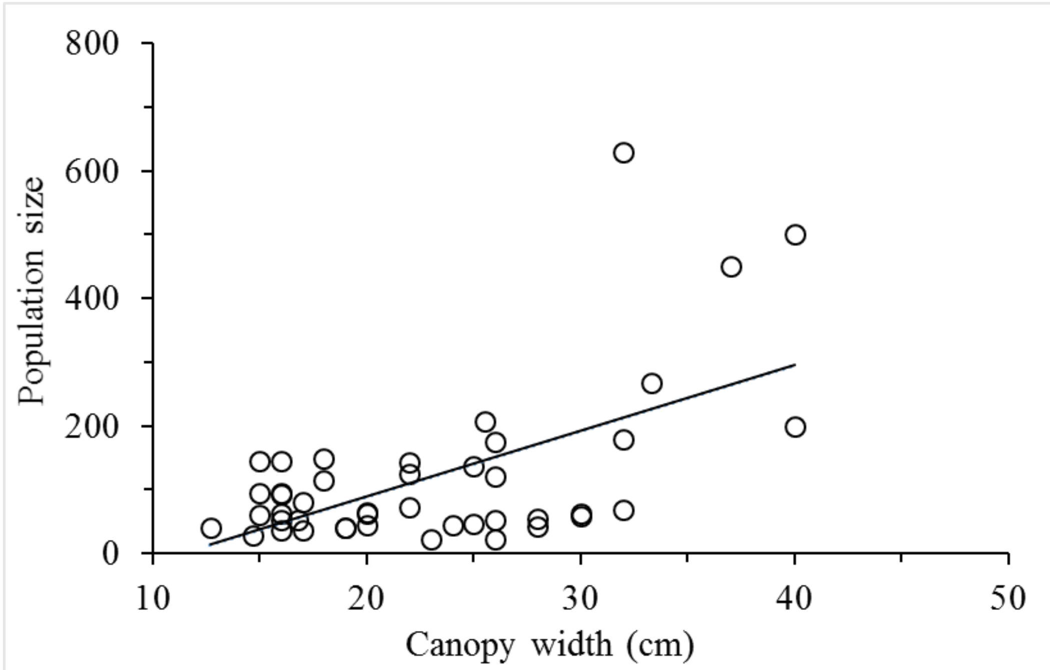

Figure 1.8. Effect canopy width on the population size of *Pteropus giganteus*.

In addition, the non-roost dependent features such as distance of roost from the adjacent road, human habitation and water body were also recorded. The average distance of roost from the adjacent road, water body and human habitation were 272 ± 240 m, 158 ± 183 m, and 302 ± 182 m, respectively. However, the non-roost dependant characteristics such as distance from the road (r = 0.080, n = 72), water body (r = 0.004, n = 72) and human habitation (r = 0.078, n = 72) did not influence the population size of *P. giganteus*.

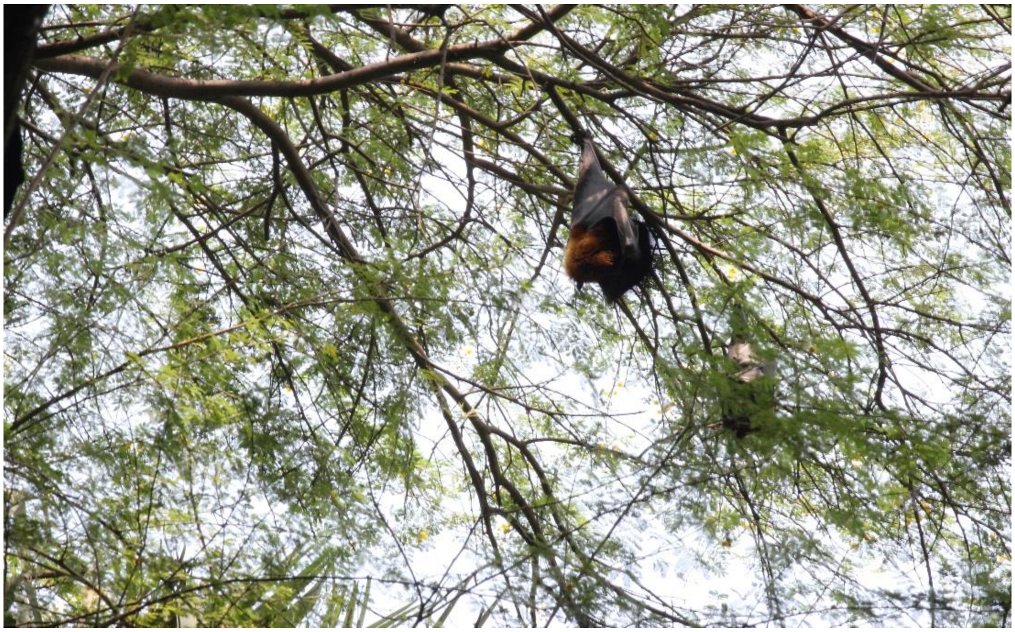

Plate 1.3. A diurnal roost of *Pteropus giganteus* on *Acacia nilotica* at Amova, Lucknow.

Plate 1.4. *Pteropus giganteus* roost on *Albizzia lebbek* at Kushumbha, Deoria.

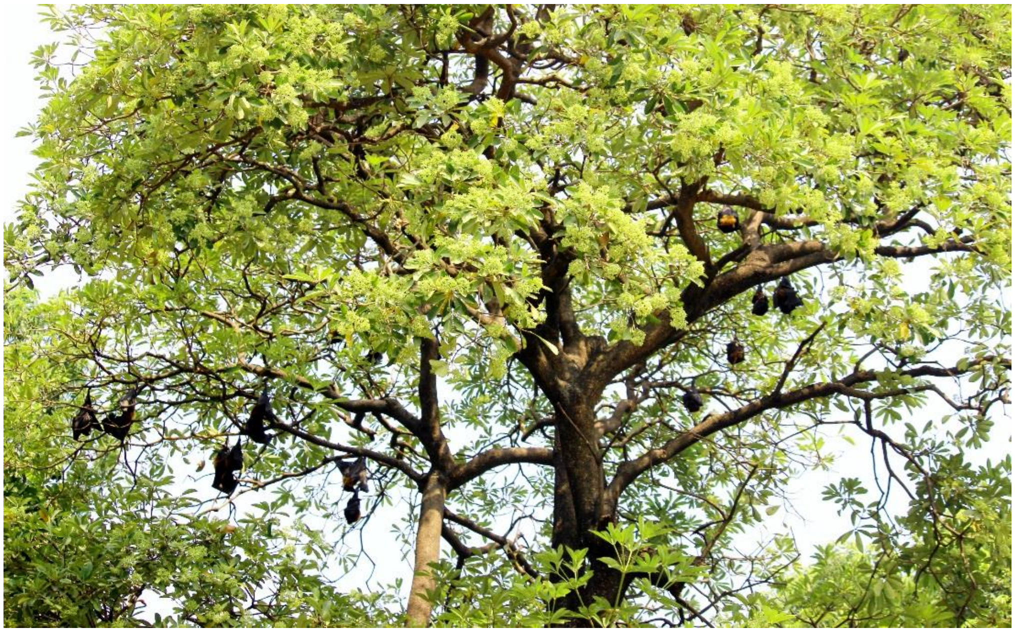

Plate 1.5. A maternal colony of *Pteropus giganteus* on *Alstonia scholaris* at Bisab Inter College, Bareilly.

Plate 1.6. A diurnal colony of *Pteropus giganteus* on *Artocarpus integrifolia* at Achelikhera, Lucknow.

Plate 1.7. A camp of *Pteropus giganteus* on *Azadirachta indica* at Company Bagh, Kanpur.

Plate 1.8. A maternal colony of *Pteropus giganteus* on Bamboo spp. at Gajraj Ka Purva, Ambedkar Nagar.

Plate 1.9. A maternal colony of *Pteropus giganteus* on *Bassia latifolia* at Achlikhera, Lucknow.

Plate 1.10. A diurnal roost of *Pteropus giganteus* on *Bombax ceiba* at Rudrapur, Deoria.

Plate 1.11. A summer roost of *Pteropus giganteus* on *Borassus flabellifer* at Amova, Lucknow.

Plate 1.12. A winter roost of *Pteropus giganteus* on *Cassia senna* at Company Bagh, Kanpur.

Plate 1.13. A diurnal colony of *Pteropus giganteus* on *Dalbergia sissoo* at Chaturipatti, Faizabad.

Plate 1.14. The individuals of *Pteropus giganteus* roosting on *Delonix regia* at Company Bagh, Kanpur.

Plate 1.15. A diurnal colony of *Pteropus giganteus* on *Eucalyptus* spp. at Maikpur, Bareilly.

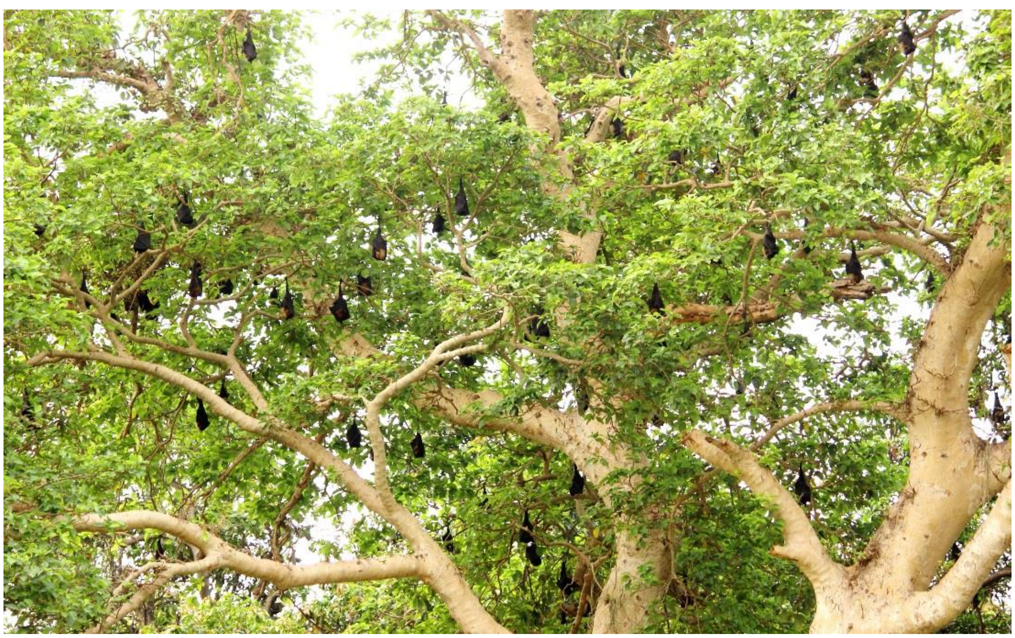

Plate 1.16. A roost of *Pteropus giganteus* on *Ficus racemosa* at Chathiya, Lakhimpur Kheri.

Plate 1.17. A summer camp of *Pteropus giganteus* on *Ficus religiosa* at Company Bagh, Kanpur.

Plate 1.18. A maternal colony of *Pteropus giganteus* on *Ficus tinctoria* at Noorpur Kabristan, Bijnor.

Plate 1.19. *Pteropus giganteus* roost on *Ficus virens* at Company Bagh, Kanpur.

Plate 1.20. A maternal colony of *Pteropus giganteus* on *Ficus benghalensis* at Government Inter College, Amroha.

Plate 1.21. A decade old maternal roost of *Pteropus giganteus* on *Grevillea robusta* at Indian Tobacco Company, Saharanpur.

Plate 1.22. A diurnal roost of *Pteropus giganteus* on *Holoptelea integrifolia* at Amova, Lucknow.

Plate 1.23. The individuals of *Pteropus giganteus* on *Leucaena Leucocephala* at Bhoyer, Basti.

Plate 1.24. A roost of *Pteropus giganteus* on *Limonia acidissima* at Amova, Lucknow.

Plate 1.25. A maternal roost of *Pteropus giganteus* on *Mangifera indica* at Nassulapur, Ambedkar Nagar.

Plate 1.26. A summer camp of *Pteropus giganteus* on *Phoenix silvestris* at Company Bagh, Kanpur.

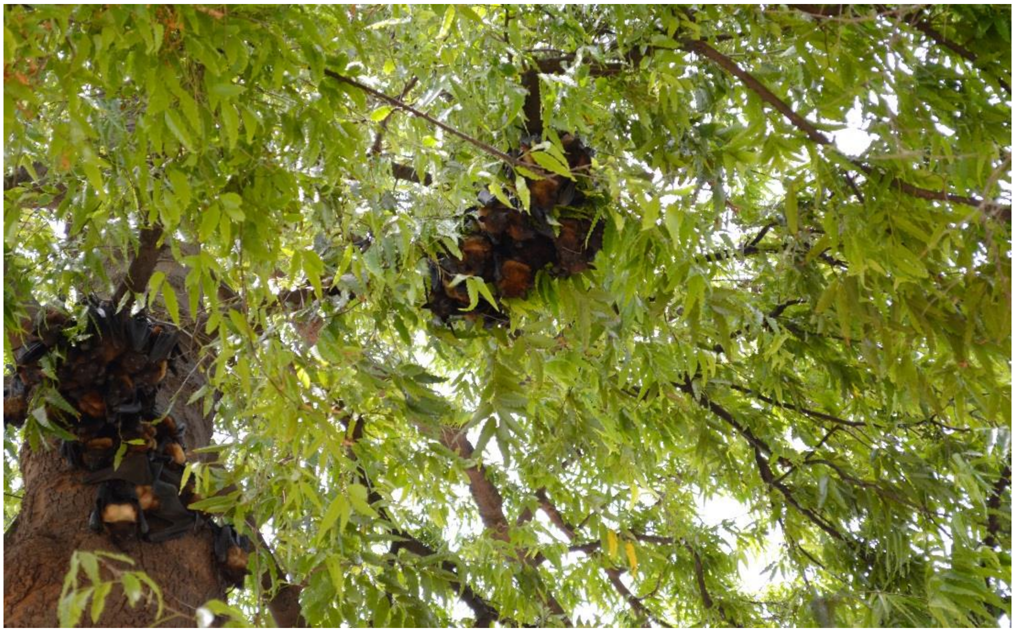

Plate 1.27. A diurnal colony of *Pteropus giganteus* on *Polyalthia longifolia* at Company Bagh, Kanpur.

Plate 1.28. A maternal colony of *Pteropus giganteus* on *Prosopis juliflora* at Sudamapur, Faizabad.

Plate 1.29. A maternal roost of *Pteropus giganteus* on *Syzygium cumini* at Teergawn, Sultanpur.

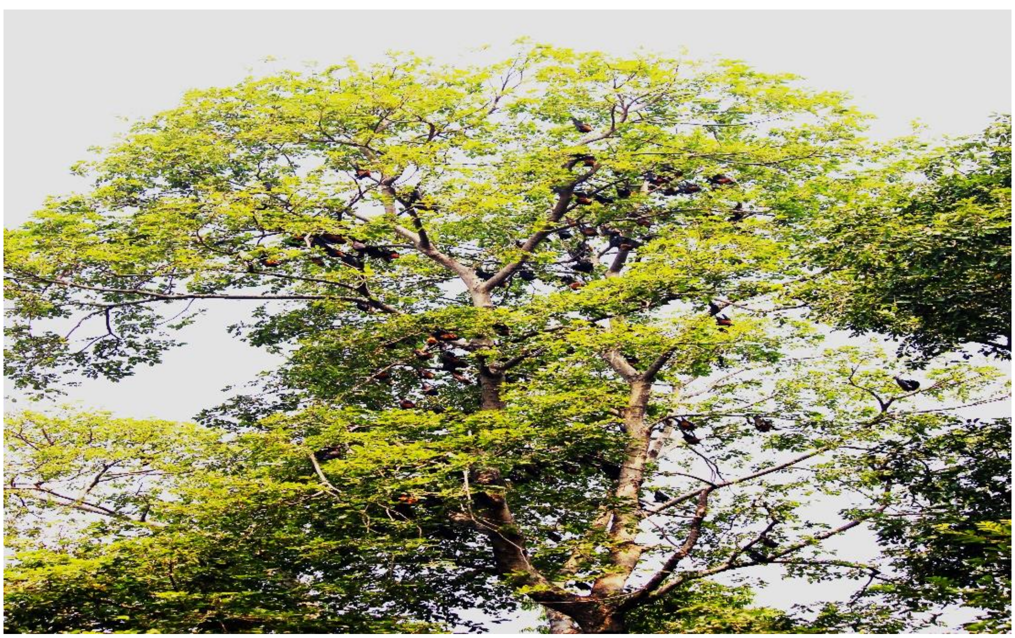

Plate 1.30. A diurnal colony of *Pteropus giganteus* on *Terminalia arjuna* at Bisab Inter College, Bareilly.

Plate 1.31. A summer roost of *Pteropus giganteus* on unidentified tree at Company Bagh Kanpur.

Plate 1.32. *Pteropus giganteus* roost on unidentified tree at Indian Tobacco Company, Saharanpur.

DISCUSSION

The results of present study showed that the distribution of *P. giganteus* was wide spread in Uttar Pradesh and the roost selection was influenced by roost tree characteristics such as dbh, height and canopy width of roost trees. It is obvious that the high dbh trees are long-lasting and sustainable for heavy rain, wind and drought, while more canopy width trees offer ample surface area for roosting and tall trees offer protection. In addition to the roost tree characteristics, the roost selection was favoured by the grove size that suggests *P. giganteus* preferred to roost in groves compared to discrete trees. The larger trees in groves provide many advantages to the bats like protection, thermoregulation, easy flight and suitable conditions for their reproductive behaviour. The observations of the present study substantiate the findings of earlier work that stated the roost selection was highly influenced by its use (Mildenstein *et al.*, 2005).

The roost trees chosen by bats had well spreaded canopy and out of reach to human and many predators. The selection of tall and wide canopy tree roosts by *P. giganteus* was also reported by a number of researchers e.g. *Acacia nilotica (Gulraiz et al., 2016)*, *Albizzia lebbek* (Gulraiz *et al.*, 2015; Baskaran *et al.*, 2016), *Alstonia scholaris* (Ali, 2010), *Azadirachta indica* (Vendan *et al.*, 2008), *Bassia latifolia* (Senthilkumar and Marimuthu, 2012), *Dalbergia sissoo* (Vyas and Upadhyay, 2014), *Eucalyptus* spp., (Gulraiz *et al.*, 2015), *Ficus racemosa* (Maruthupandian and Marimuthu, 2013), *Ficus benghalensis* (Chakravarthy and Girish, 2003), *Holoptelea integrifolia* (Suthari and Raju, 2012), *Mangifera indica* (Singaravelan *et al.*, 2009), *Polyalthia longifolia* (Caughlin *et al.*, 2012), *Syzygium cumini* (Tangavelou *et al.*, 2013) and *Terminalia arjuna* (Dey *et al.*, 2013).

The selection of wider canopy roost trees facilitates the flying foxes with more roosting area to fulfill their life history needs, especially reproduction. The topographic features of large and long-living trees in this observation support that *P. giganteus* not only availing protection but also gaining aerodynamic benefits such as easy take-off and landing as similar observations were also reported previously (Granek, 2002; Gulraiz *et al.*, 2015). The positive correlation between grove size and population size suggests that *P. giganteus* prefer to roost in large trees at larger groves that provide protection and suitability for their survival and reproduction. Thus, the population size positively correlated with the grove size. Though, the dbh, canopy width, and height varies among roost trees, the population size of *P. giganteus* was increased with increasing number of roost trees. It shows that the larger groves facilitate *P. giganteus* to maintain higher population density. The selection of larger and well-exposed trees was also reported by various studies (Vyas and Upadhyay, 2014; Elangovan and Kumar, 2015). The colonies were observed nearer to the non-roost dependent characters water bodies such as pond, lake, canal and river, human habitations and arterial road but it didn't influence significantly. It was also observed that *P. giganteus* drinks water from nearby water sources during day hours (personal observation). A number of researchers explained that *P. livingstonii* and *P. alecto* preferred to roost adjacent to water bodies as it facilitate water facilitates, humid environment thermal balance during hot seasons (Palmer and Woinarski, 1999; Welbergen *et al.*, 2008; Russo and Ancillotto, 2015) while human habitation offers a diverse food items which are possibly inaccessible in the natural forests (Hahn *et al.*, 2014). The results of this study reveal that *P. giganteus* selects tall trees with wider canopy width and dbh for survival and life history needs. Hence, the protection of larger trees which were reported in this study would help to conserve the habitat and thus the Indian flying fox, *P. giganteus*. Further, this study may contribute for future research on the distribution and conservation of *Pteropus giganteus* in Uttar Pradesh.

Chapter II

BEHAVIOURAL ECOLOGY OF THE INDIAN FLYING FOX, *PTEROPUS GIGANTEUS*

Chapter II

BEHAVIOURAL ECOLOGY OF THE INDIAN FLYING FOX, *PTEROPUS GIGANTEUS*

A. DIURNAL AND EMERGENCE BEHAVIOUR OF *PTEROPUS GIGANTEUS*

INTRODUCTION

Indian flying fox, *Pteropus giganteus* gregariously live at roosts during daytimes. The roosts are the fundamental site of interaction and exhibition of various behavioural activities between roost mates. The day roost is a typical platform which provides a congenial environment for social behaviour (Granek, 2002). Moreover, the selection of roost is a functional integer of behavioural activities as it provides ample roosting area which is associated with the diurnal activities, predation sensing, luminous scanning and aerodynamic advantages (Richmond *et al.*, 1998; Welbergen, 2006). Although various studies explained that the diurnal activities of flying foxes attracted a large number of regular and occasional visitor and it has a great role in the tourism (Walpole and Leader-Williams, 2002; Pennisi *et al.*, 2004). In addition, they eminently provide pollination and seed dispersal services that offer fitness in the ecological process (Fujita and Tuttle, 1991). Moreover, various plants are mainly dependent on flying foxes for their generation alteration. Hence, keeping them as a forest guardian, the behavioural activities of *P. giganteus* are principally required to understand for conservation implementation.

The emergence behaviour of *P. giganteus* considered as an interesting phase because it bifurcates the diurnal and nocturnal activities. The nocturnal behaviour of *P.*

giganteus begins with the emergence and ends with home flight. Though, the emergence behaviour of bats triggered by 12:12 h light-dark cycle but it is formally categorized as a predictable event (Erkert, 1982; Isaac and Marimuthu, 1993). Naturally, the emergence behaviour and pattern are greatly influenced by several climatic variables such as clouds, fog, moonlight (Welbergen, 2008), light intensity (Downs *et al.*, 2003), rain (Entwistle *et al.*, 1996), food availability (Lee and McCracken, 2001), predatory risk and age structure (Welbergen, 2006). Further, the pregnant and lactating females prepone their emergence than the rest of colony individuals (Duverge *et al.*, 2000).

In term of behavioural studies, flying foxes such as *Pteropus livingstonii* (Courts, 1996), *P. alecto* (Markus, 2002; Markus and Blackshaw, 2002), *P. poliocephalus* (Connell *et al.*, 2006), *Acerodon jubatus* are extensively studied in the Paleotropic regions (Hengjan *et al.*, 2017). However, a few more studies have been carried out on the emergence behavior of *Pteropus* suggest that the emergence was influenced by twilight in *P. alecto* and *P. poliocephalus* (Welbergen, 2008), predation risk, foraging needs, and social context in *P. poliocephalus* (Welbergen, 2006) and *P. giganteus* (Sudhakaran *et al.*, 2012) but there was no exclusive study on the effect of day length, sunset, and temperature on the emergence behaviour of the Indian flying fox, *Pteropus giganteus*. Therefore, the present study was aimed to fulfill the lacuna on emergence behaviour of *P. giganteus*.

MATERIALS AND METHODS

The present study was carried out between January 2013 – December 2015 in a colony of the Indian flying fox, *Pteropus giganteus* at the Northern Railway garden of Mohanlal Ganj (26°40'57.56''N; 80°59'1.49''E), Uttar Pradesh, India. The average day length and time of bat emergence during summer (March – June), monsoon (July – October) and winter (November – February) were recorded. The behaviour of bats at their roosts was observed from a vantage point at three different time periods, i.e. morning (6 – 8 h), mid-day (11 – 13 h) and pre-emergence (16 – 18 h). Activities such as screaming, grooming, sleeping, wing fanning and roost shifting were recorded throughout the study period. The physical data such as sunset, day length (duration between onset and offset of the sun), and temperature (ºC) were obtained from Indian Metrological Department. The time and number of bat emergence were recorded between the emergence of the first and last bat of the colony. The time of bat emergence was correlated with day length, sunset, and temperature. In addition, the time and duration of emergence were compared with different seasons.

RESULTS

The flying foxes were chosen tall and large *Eucalyptus* trees as their roost while a few trees of *Azadirachta indica*, *Dalbergia sissoo*, and *Ficus religiosa* were also present in the grove. The bats were occupied the well-exposed trees at the periphery of the large garden. The individuals of *P. giganteus* returned back to their roost before sunrise and they screamed continuously with short circle flights around their roost. They also switched their roosts to a couple of times before settling at a particular branch. Though, the bats spent a maximum of their day time for resting with folded wings, they were actively involved in various diurnal behaviours such as wing fanning (3%), grooming (6%), roost shifting (22%) and screaming (14%) until afternoon. However, they did not actively involve on wing fanning (8%), instead, they spent more time on grooming

(26%), roost shifting (20%) and screaming (19%) during pre-emergence hours (Figure 2.1).

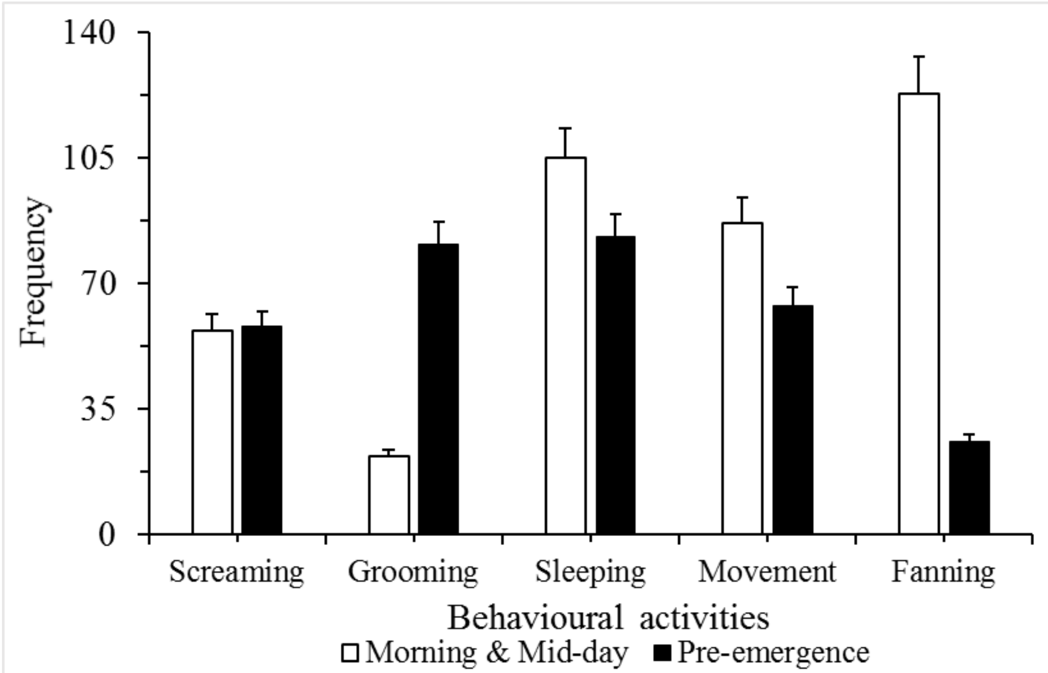

Figure 2.1. Diurnal and pre-emergence activities of *Pteropus giganteus* at the day roost.

Pteropus giganteus made a few circling flights around their roosts before emergence, presumably to assess the light and weather conditions for the emergence. The emergence was initiated by a few individuals which were occupied the peripheral canopy of the tree, followed by other individuals emerged from the roosts. An average bat emergence was observed 0:32 ± 0:10 h:m after the sunset. The time of peak emergence was varied throughout the year and seasons (Figure 2.2 a and b), and early emergence was observed during winter (17:30 – 18:37 h:m) than monsoon (18:37 – 20:04 h:m) and summer (18:38 – 19:46 h:m).

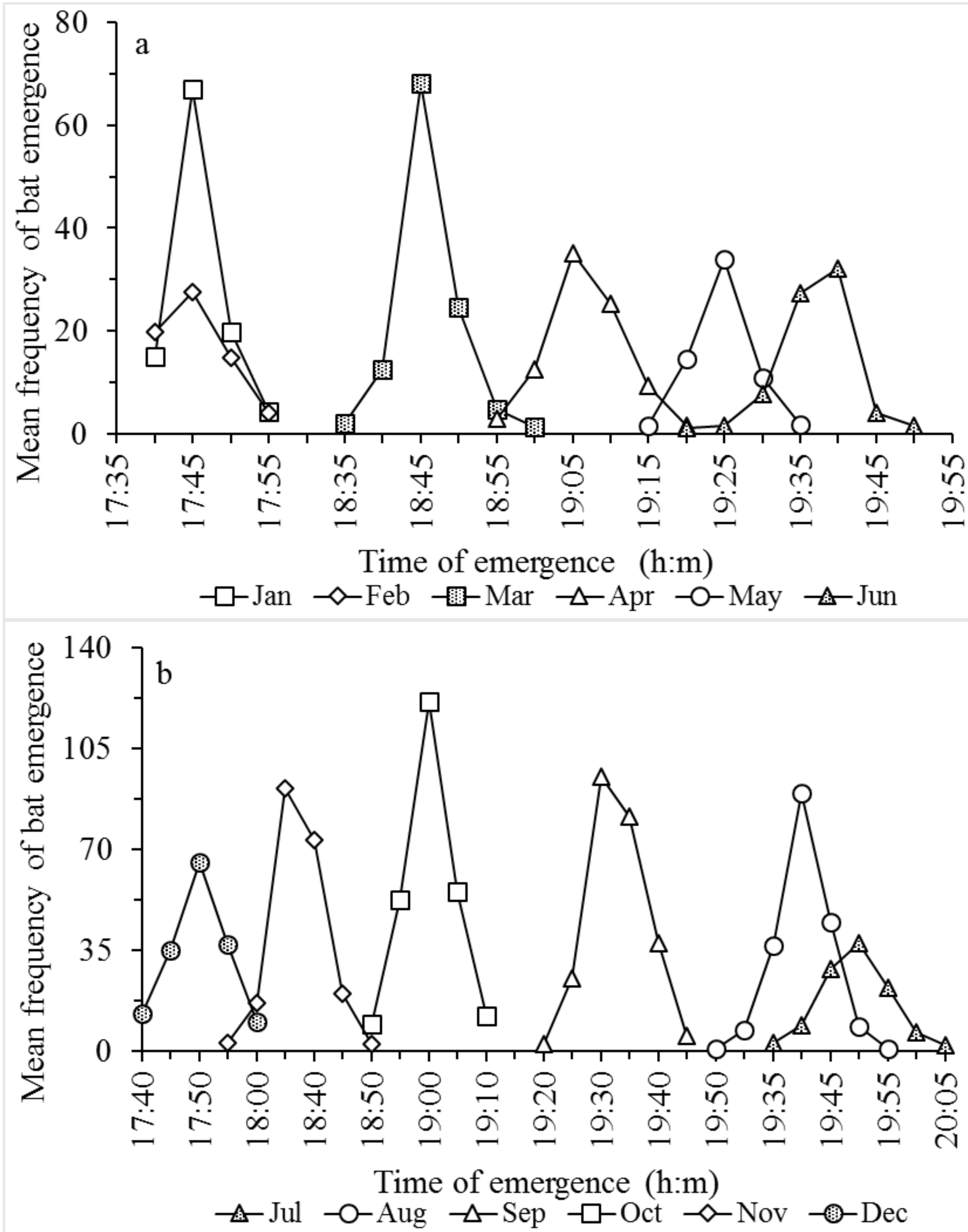

Figure 2.2. Mean frequency and emergence pattern of *Pteropus giganteus* over the study period (January 2013 to December 2015). a) Pattern of emergence from January to June, and b) Pattern of emergence from July to December.

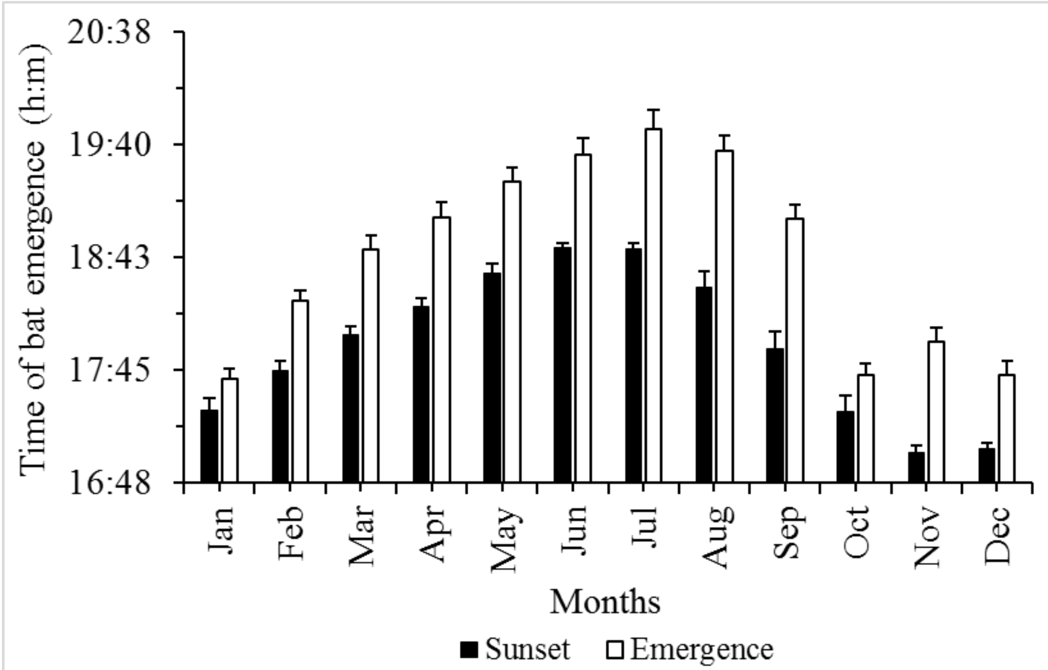

Figure 2.3. The effect of sunset on emergence time of *Pteropus giganteus* during summer (Mar – June), monsoon (Jul – Oct) and winter (Nov – Feb) seasons.

The time of bat emergence was highly correlated with the time of sunset (r = 0.952, n = 12, Figure 2.3) and day length (r = 0.889, n = 12). Similar to the time of sunset, the day length varied over seasons (12:04 ± 01:10 h:m), and the shortest day length (10:48 h:m) was observed during winter while longest day length (13:02 h:m) observed during the summer season. Though, the bats were altered their time of emergence according to the day length, i.e. shorter the day length, earlier the emergence and longer the day length, later the emergence. Thus, time of bat emergence was highly correlated with the duration of day length (r = 0.889, n = 12, Figure 2.4). Further, the duration of emergence spread over a short span during winter compared to other seasons. In addition to the time of sunset and day length, the temperature also influenced the time of emergence of *P. giganteus*. The bat emergence was delayed with increasing ambient temperature (r = 0.886, n = 36, Figure 2.5). The population of *P. giganteus* increased during monsoon season due to the aggregation of male individuals for reproduction and decreased steeply during summer and non-reproductive seasons possibly due to male dispersal (Figure 2.2 a and b).

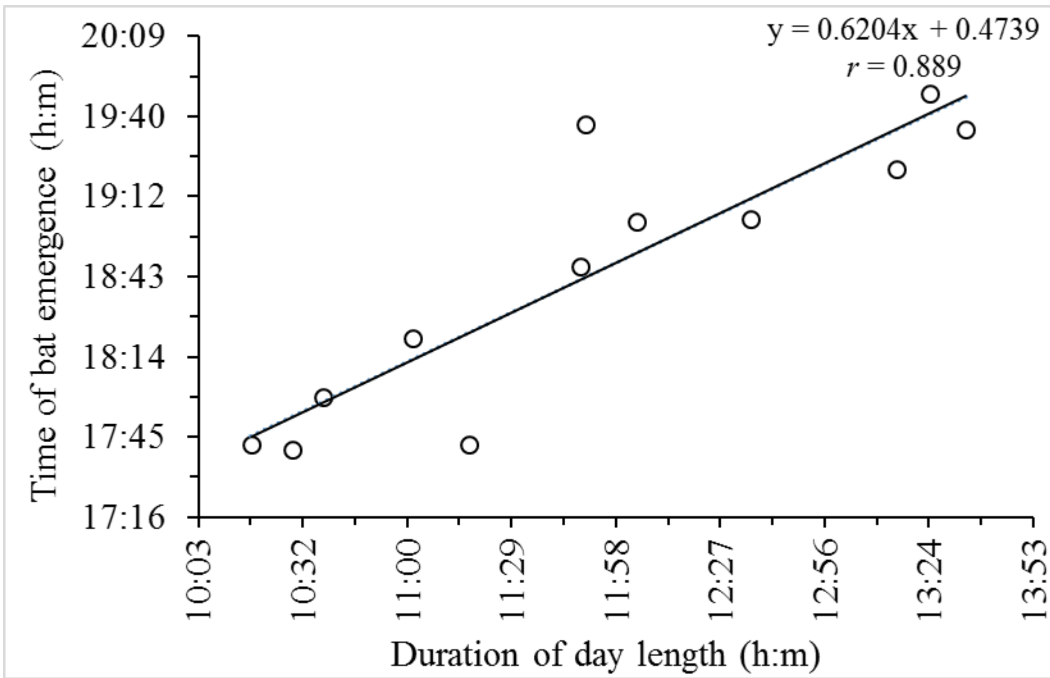

Figure 2.4. Effect of day length on the time of bat emergence. The increasing day length delayed the emergence time of *Pteropus giganteus*.

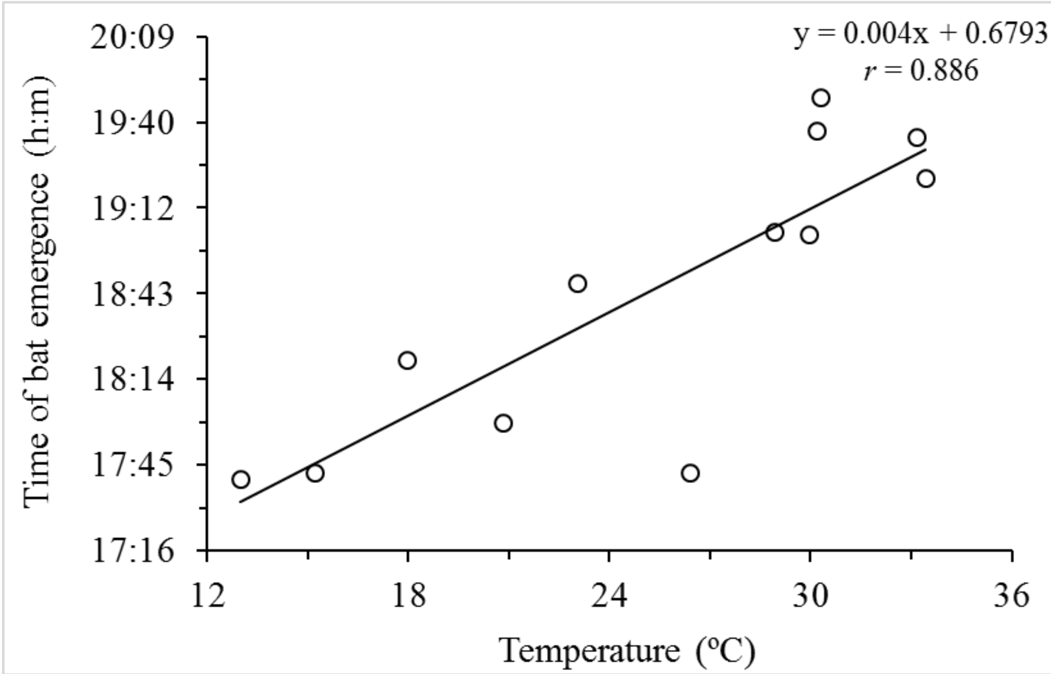

Figure 2.5. Effect of ambient temperature on the time of emergence of *Pteropus giganteus*.

DISCUSSION

The results of present study suggest that the individuals of *P. giganteus* emerged from their day roost around 30 min after the sunset. The bats exhibited pre-emergence activities such as wing stretching, squawking, grooming and short flight around the roosts possibly to advertise the time of emergence to the roost mates. The few individuals which were exhibited the pre-emergence behaviour might hold dominancy in the colony. The roost shifting behaviour of *P. giganteus* observed throughout the day hours associated with finding out the suitable foliage for roosting, thermoregulation and social interaction with the group members. Though, *P. giganteus* reproduces seasonally, the reproductive behaviour such as pair bonding, courting the females, licking the face and genitalia of females by males were observed throughout the year (Maruthupandian and Marimuthu, 2013; Sugita, 2016). The successful male undergone pair bonding and subsequently copulated with the females and the unsuccessful males kept on shifting the roost over the day. The roost shifting behaviour facilitates acquiring suitable foliage, social interaction, and reproduction in *Eptesicus fuscus* (Willis and Brigham, 2004). The wing fanning during sunny hours make them maintain thermoregulation with ambient temperature, *P. hypomelanus* increased wing fanning with increasing temperature while decreased with decreasing temperature (Ochoa-Acuña and Kunz, 1999). *Pteropus giganteus* altered their diurnal activities as they approached emergence time. They actively involved in wakeup, body worm up, sensing of weathers, and suitability of emergence. Grooming and wing stretching make them ready for emergence while vocalization synchronizes their wake up (Sudhakaran *et al.*, 2012). The bat emergence was entirely based on group size and their reproductive conditions, perhaps the males of larger groups emerge at the end (Welbergen, 2006). The lactating females of many species of bats prepone their emergence, like *Chaerephon pumila* (McWilliam, 1989), *Lasiurus cinereus* (Barclay, 1985), *Myotis velifer* (Jones and Rydell, 1994), and *Nyctalus noctula* (Jones, 1995).

Day length is an explicit feature of the environment that decide the behavioural activities. Nevertheless, the bats emerged after sunset but the duration of emergence varied among seasons. The early emergence was observed during winter (17:30 h:m), delayed emergence during summer adhered to the sunset. Thus, the sunset triggers the emergence of *P. giganteus*. However, the duration of emergence was near similar during summer (01:08 h:m) and winter (01:07 h:m) than the monsoon season (01:27 h:m). The long duration emergence during monsoon season corresponds to reproductive activities at the day roosts. Although, long dark hours available to bats during the winter season but the bats did not delay their emergence, instead they emerged soon after the sunset. The outcome of this study revealed that the time of emergence was absolutely based on time of sunset and thus yielded a correlation coefficient of r = 0.952. The emergence of *Pteropus* soon after the sunset was reported by various studies (Welbergen, 2006; Sudhakaran *et al.*, 2012). It was previously observed that several nontropical vertebrates altered their behaviour such as diurnal movement, foraging strategies, pelage pattern, and sleep duration according to day length (Heldmaier *et al.*, 1989; Sauter *et al.*, 2012). Though, the emergence was influenced by various physical factors, the time of sunset played a crucial role. Although, *P. giganteus* roosts in well-exposed trees over the day, the emergence occurred after sunset. Albeit, the ambient temperature also played a significant role in the emergence of *P. giganteus*. The emergence of *P. giganteus* was also determined by temperature as it was observed in *Tadarida brasiliensis* (Frick *et al.*, 2012).

The amiable environmental conditions during monsoon season favour reproduction of *P. giganteus* hence the aggregation increase the population size while segregation of individuals during non-reproductive seasons (summer and winter) declined the population size. It was reported that the population of *Pteropus* steeply decreased during non-breeding period (summer season) due to scanty food and sometimes local migration (Tidemann and Nelson, 2004a). Thus, the present study reveals that the emergence behaviour of the Indian flying fox, *Pteropus giganteus* influenced by the physical parameters such as day length, sunset, and temperature.

B. REPRODUCTIVE BEHAVIOUR OF *PTEROPUS GIGANTEUS*

INTRODUCTION

The order chiroptera represents one such an amazing diversity of 1300 extant paleotropical and neotropical species (Shi and Rabosky, 2015). However, inaccessible roosting nature makes them a typical species and hence very few studies have focused on the reproductive aspect of bats (Maruthupandian and Marimuthu, 2013). During reproductive seasons, flying foxes involved in various reproductive activities such as grooming of body parts and genital organ (Tan *et al.*, 2009; Maruthupandian and Marimuthu, 2013; Sugita, 2016). Indian flying fox, *Pteropus giganteus* roosting on tall trees which is almost faraway from eyesight. Hence, it is tough to observe the behavioural activities particularly the reproductive behaviour of *P. giganteus*. Presumably, it might be a reason for information scarcity on the reproductive behaviour of *P. giganteus*. Therefore, this study was carried out to investigate the reproductive behaviour of *Pteropus giganteus*.

MATERIALS AND METHODS

An extensive field observation was carried out between 2013 and 2016 during the reproductive seasons of *Pteropus giganteus* in a colony located at Nassulapur, Ambedkar Nagar district, Uttar Pradesh, India (26°32'40.81''N; 82°33'40.59''E). The individuals of *P. giganteus* were roosting on *Ficus benghalensis* (*n* = 1), *Azadirachta indica* (*n* = 1), *Mangifera indica* (*n* = 13) and *Ficus religiosa* (*n* = 1). The reproductive behaviour of *P. giganteus* was observed from a vantage point. In addition, the frequency, time and duration of copulations were observed. Further, the frequency of wing stretching, vulva licking, and grooming was observed through binocular and precisely recorded through stopwatch. The Pearson correlation (*r*) was applied to study the relationship between the duration of vulva licking and copulation.

RESULTS

After the home flight, the individuals of *P. giganteus* were actively engaged in roost alteration which facilitated them for finding suitable mates. The male bats made many circling flights around the roost and exhibited quadrapedal movement until finding a suitable mating partner. The bats have selected a few tree species such as *Ficus benghalensis* (n = 1), *Azadirachta indica* (n = 1), *Mangifera indica* (n = 13) and *Ficus religiosa* (n = 1). The roosting pattern of *P. giganteus* varied over reproductive season, a few individuals of *P. giganteus* were roosting at the base branches of the roost tree while reproductively active individuals observed at peripheral canopies. The reproductive activities of bats were observed from peripheral canopies rather than dense and leafy area. The reproductive behaviour of *P. giganteus* was varied over the reproductive season from July to November. The higher number of copulation was recorded during September (6.3 ± 5.7 SD) followed by October (3.3 ± 3.0 SD) while very few copulations were observed during July (1.2 ± 0.4 SD) and November (1.0 ± 0.5 SD, Figure 2.6).

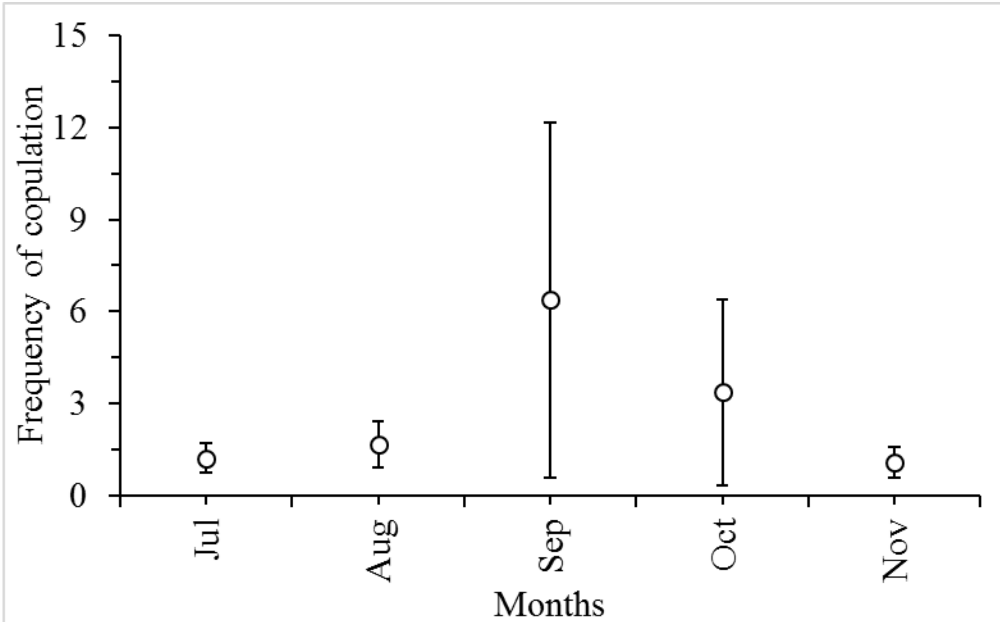

Figure 2.6. The frequency of copulation during the reproductive season of *Pteropus giganteus*.

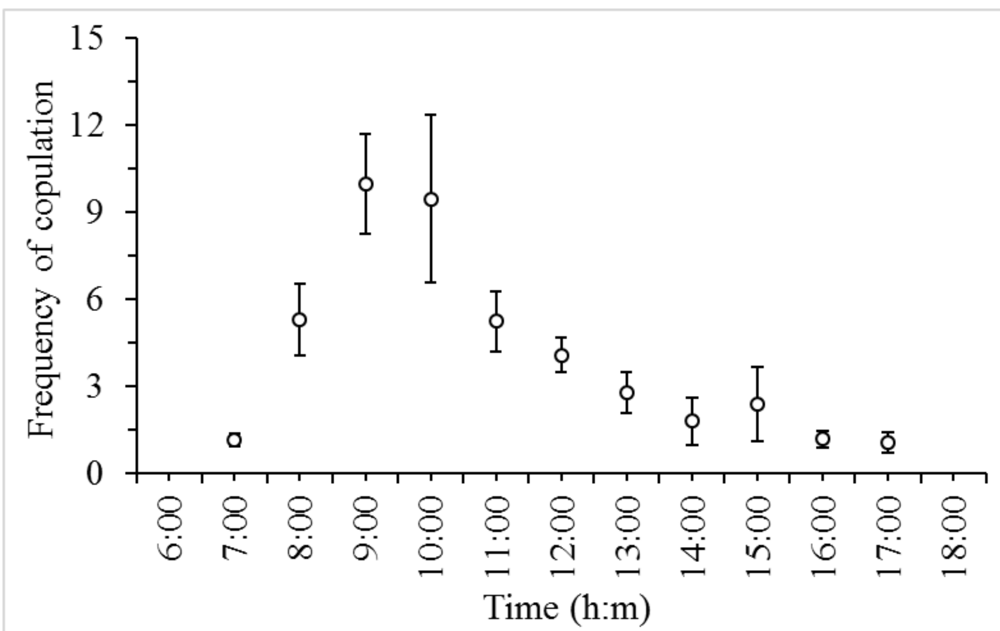

Figure 2.7. The pattern of reproductive activity of *Pteropus giganteus* during day hours.

Pteropus giganteus screams during copulation and they were more active during cloudy hours than sunny period. The male bats were very active and involved in courting of females mainly during forenoon (cloudy hours) than afternoon (Figure 2.7). As pre-copulation activity, the male bat approached a female and courted by stretching its wings. The male exhibited an average 16.2 ± 4.5 SD wing stretching and 65.5 ± 26.8 SD vocalization prior to copulation. The courting behaviour was associated with sexual potentiality of male and determine mate choice in *P. giganteus*. Once a male courted a female, the male engaged in vulva licking (36.3 ± 6.4 sec, n = 84, Plate 2.1a) before copulation. During the copulation, the male grips the female through claws and mouth and sometimes wraps by patagium. The duration of vulva licking by a male was directly proportional to the duration of copulation (r = 0.835, Figure 2.8). The copulation was observed from both dorsal and ventral side of the body (dorsal mounting in the Plate 2.1b). After the copulation, both the sexes were segregated from each other and settled for a while. They also engaged in grooming of genital organ, snout, and patagium for an average 50.3 ± 9.8 sec (Plate 2.1c). On various occasions, the potentially active male was exchanged the roost trees for exploring other mating opportunities while the female retained the same roost.

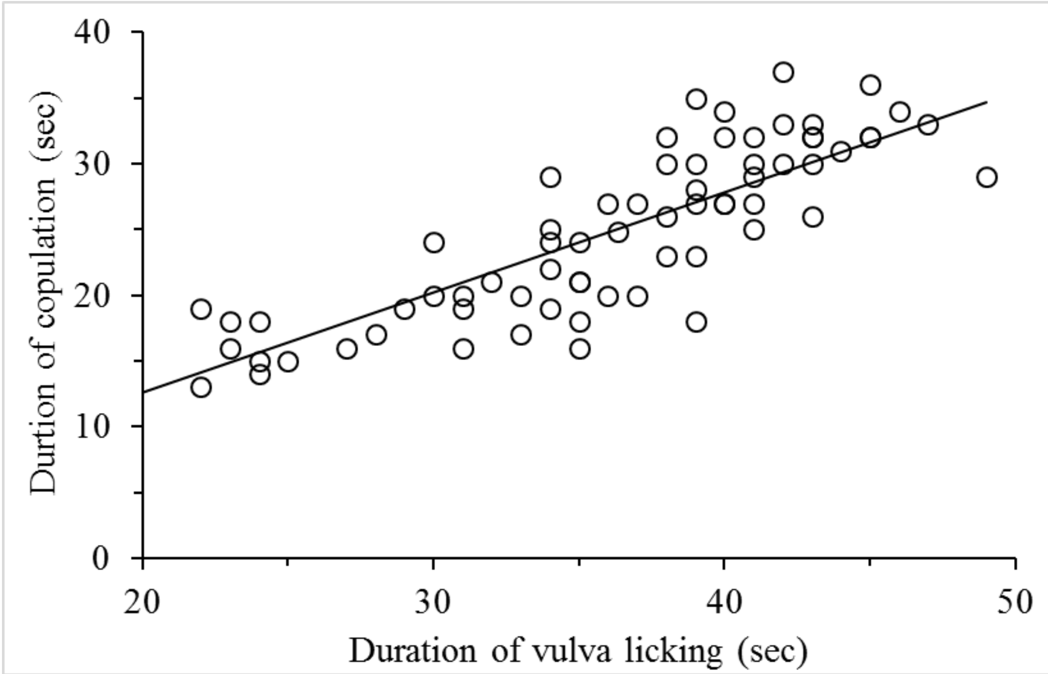

Figure 2.8. The effect of vulva licking on copulation duration of *Pteropus giganteus*.

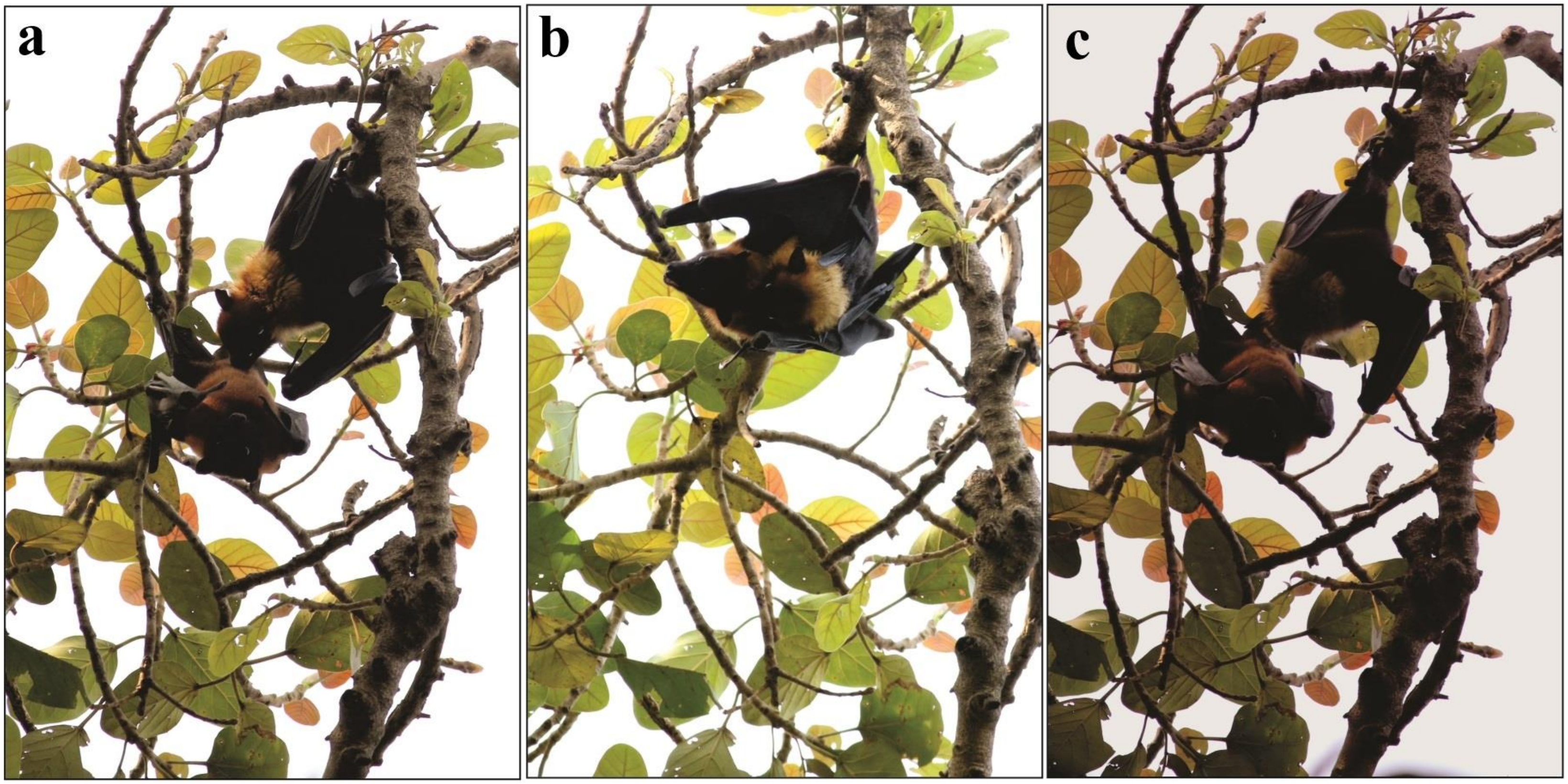

Plate 2.1. The reproductive activities of *Pteropus giganteus* during copulation such as vulva licking (a), dorsal mounting (b) and grooming of body organs after copulation (c).

DISCUSSION

In the present study, it was observed that the individuals of *P. giganteus* actively involved on copulation between July and November, while the peak copulation was observed during September. However, similar observation on the reproduction of *P. giganteus* was also reported by various studies (Mathur *et al.*, 2012; Maruthupandian and Marimuthu, 2013; Baki *et al.*, 2015). The high frequency of copulation observed at forenoon suggest the existence of pleasant weather and biologically active period than afternoon. It may also be a matter of physical fitness, as the bats accumulate higher energy after their home flight. Moreover, warm weather conditions favours reproduction and fetus development while hot and dry seasons inhibit the reproduction and even cause mortality in flying foxes (Welbergen *et al.*, 2008).

The exhibition of various behavioural activities such as wing stretching, vocalization and licking of genital region was commonly observed in this study. Generally, male stretches wings for demonstration of it potentiality and attracting the females. The pre-copulatory activities had a significant impact on the duration of copulation. It suggest that male spent more body energy in pre-mating activities than rest of the social activities. Therefore, the physical strength of male have a crucial role in reproductive behaviour (Kyogoku, 2015; Takakura and Fujii, 2015). It is obvious that the foreplay altered copulation and played a significant role in the reproductive aspects of bats (Tan *et al.*, 2009; Maruthupandian and Marimuthu, 2013; Sugita, 2016). In the present study, it was also observed that *P. giganteus* copulates from both dorsal and ventral sides. Though, dorsal and ventral copulation are well elaborated in flying foxes but still its need further investigation on the role of body plan in flying foxes reproduction (Maruthupandian and Marimuthu, 2013; Baki *et al.*, 2015).

The segregated mating partner grooms patagium, toes and genital organs independently which presumably enhanced reproductive fitness in *P. giganteus* (Maruthupandian and Marimuthu, 2013). The outcome of this study may pave various novel approaches on the reproduction of Indian flying fox, *Pteropus giganteus*.

Chapter III

POPULATION DYNAMICS OF THE INDIAN FLYING FOX, *PTEROPUS GIGANTEUS*

Chapter III

POPULATION DYNAMICS OF THE INDIAN FLYING FOX, *PTEROPUS GIGANTEUS*

INTRODUCTION

Indian flying fox, *Pteropus giganteus* is a sacred species in India (Marimuthu, 1988) and most persecuted bats in South Asia (Singaravelan *et al.*, 2009; Srinivasulu and Srinivasulu, 2012). Generally, *Pteropus* prefer sustained roost and it might be a reason for the selection of large and long living trees (Granek, 2002). Though, several bat species have reported that they made roost in different part of the plants such as *Cynopterus sphinx* and *Platyrrhinus helleri* chews palm leaves and make tent like roost (Storz *et al.*, 2000), *Chalinolobus tuberculatus* in tree trunk (Sedgeley and O'Donnell, 1999) but flying foxes are an exclusive fruit bats, make open roost on foliage. Therefore, flying foxes have directly faced all climatic changes. However, the ever changing pattern of climate influence flying foxes population and obviously, it hampered ecosystem services (Kremen *et al.*, 2007; Welbergen *et al.*, 2008).

In the natural condition, bats are categorically known as long living and slow reproducing mammal live in various geographical locations except in few islands and Antarctic regions (Barclay *et al.*, 2004; Srinivasulu *et al.*, 2010). Presumably, slow maturation caused a high level of threat and mortality, therefore, they considered as one of the most threatened group in mammalian taxa (Racey and Entwistle, 2000; Wilkinson and South, 2002).

Temperature plays a significant role in the population ecology of animals and phenology of plants (Walther *et al.*, 2002). Therefore, animals adjust their behaviour, migration, and reproduction with reference to temperature (Winkler *et al.*, 2014). In the natural history of bats, a couple of study have demonstrated that low temperature caused delay in sexual maturity and prolonged gestation while high temperature induces improper fetus development and even death of bats (Racey and Speakman, 1987; Lewis, 1993). It is a well elaborated concept in the behavioural ecology that temperature is a key factor which determines reproductive success in bats. In general, bats are resilient with little changes in weather and they alter life history trade accordingly (Frick *et al.*, 2010). However, slight change in temperature may not entertain much more by bats and as usual, they adjust diurnal, emergence and foraging activities while longer exposure of ambient temperature caused seasonal roost displacement and even fragile death in flying foxes (Welbergen *et al.*, 2008). Therefore, most of the temperate bats give birth to young ones and rearing them in spring to early summer. However, neonates access a wide range of food diversity and high level of survival and fecundity because of congenial environment. During pregnancy and lactation, female needs to be gain plentiful water and food stuff for proper fetus development and milk production. Therefore, lactating females maintain maternal roost for the survival of neonates (Racey and Speakman, 1987; Heideman, 2000). In temperate bats, reproduction during hot periods or water scanty are not viable for offspring hence, such pregnant female makes behavioural as well as physiological adaptation to spent more body energy in reproduction and parental investment. Therefore, they are facing a great level of extinction risk (Isaac, 2009).

Currently, there are a number of natural as well as anthropogenic factors playing major role in the population reduction in bats. However, a little is known about the influence of these variables at colony level but some other factors such as resource availability (Arlettaz *et al.*, 2017), hunting (Struebig *et al.*, 2007; Jenkins and Racey, 2008), natural predators (Welch and Leppanen, 2017), urbanization (Jung and Kalko, 2011), roost harassment (McClelland, 2009), and climate variability is collectively determines roost persistency (Rebelo *et al.*, 2010) and fidelity of bats (Lewis, 1995; Arlettaz *et al.*, 2001).

Since few decades back, the rate of habitat destruction and hunting exaggerated exponentially. Therefore, the population of *P. giganteus* declined dramatically (Venkatesan, 2007; Ali, 2010). Ali (2010) reported that around 48% of the population has been decreased due to anthropogenic activities nearer to the roost site in Assam. As a result, *P. giganteus* become threatened and listed as Least Concerned species (Singaravelan *et al.*, 2009). As the recent data indicated that the population dynamics of the most flying foxes are entirely faraway from the scientific investigation. Contextually, all together caused data deficient in the population ecology of flying foxes. In order to significant conservation initiatives of flying foxes, long term population studies need to be implemented at colony level for accessing the population trends. Therefore, the recent trend of scientific investigation particularly population aspects of flying foxes have become more venerable for sustain management (McConkey and Drake, 2006).

Although bats have significant importance in various ecological process and constitutes around 20% of mammalian fauna (Mickleburgh *et al.*, 2002; Schipper *et al.*, 2008) but the availability of information on demography, age structure, sex ratio and survivability of most bats are largely unknown (Purohit and Vyas, 2006). However, a number of researcher who solely carried investigation on the population ecology of bats such as *Tadarida brasiliensis* (Romano *et al.*, 1999), *Myotis lucifugus* (Frick *et al.*, 2010), *Eptesicus fuscus* (O'shea *et al.*, 2011), *Eidolon helvum* (Hayman *et al.*, 2012). The hypothesis of this study began with the fundamental question on the population ecology of *Pteropus giganteus* i.e. Does the population of *P. giganteus* fluctuated and why its need to be investigated ?. Though, these are quite a common question but when it falls with wild and nocturnal species which is staying in inaccessible areas. It was absolutely challenging to observe the population periodically and estimate the natural dynamism of *P. giganteus*. Keeping all the challenges collectively, the proposed study was carried out to investigate the population dynamics of Indian flying fox, *Pteropus giganteus*.

MATERIALS AND METHODS

A maternal roost of *Pteropus giganteus* at Mohanlal Ganj, Lucknow, Uttar Pradesh (26°40'57.56"N; 80°59'1.49"E) was extensively studied between Jan 2014 and Dec 2016. In the study site, *P. giganteus* were predominated on *Eucalyptus* trees while few other trees such as *Azadirachta indica*, *Dalbergia sissoo* and *Ficus religiosa* was observed as a seasonal roost. A visual count method was used for population estimation of *P. giganteus* while branch estimation, binocular and photography was extensively applied in inaccessible roost. During the study, the population of neonates, death, immigrant and emigrant was recorded. In addition, the physical parameters such as temperature (°C) and humidity (%) was measured using thermo-hygrometer in each consecutive day of the observation. Further, to ascertain the effect of temperature and humidity on the population of *Pteropus giganteus*, paired t-test was applied.

RESULTS

It was observed that the population of *Pteropus giganteus* fluctuated over the study period. The colony size of *P. giganteus* increased exponentially in reproductive season due to mass aggregation of immigrants (Aug – Nov, 449.8 ± 44.6 SD) and the most abundant population was recorded in the month of September (n = 1495, Figure 1). The individuals of adjacent roost sites such as Miranpur and Achelikhera were aggregated for availing mating opportunities. Thus, the population size of Miranpur and Achelikhera decreased steeply while Mohanlal Ganj increased during the reproductive season of *P. giganteus*. Due to the abundance of population size, the individuals roosting over the grove and colony was observed as noisy. The dispersal of migrant individuals during non-reproductive season caused dramatic changes in the population size of *P. giganteus* in May and June (220.3 ± 108.4 SD) while it stable in winter season (Nov, Dec, and Jan, 447.5 ± 90.2, Figure 3.1).

Other than neonates, the congenial roost and large grove attract immigrants to stay for avail reproductive opportunities. Thus, it might be a reason for population abundance in March and April (414 ± 138 SD). The dispersal of emigrant started with the end of breeding season hence, the population size of *P. giganteus* decrease drastically in summer season particularly in June (n = 211). The highest ambient temperature was recorded during June (42.4 °C) while lowest in January (4.9 °C) but the colony size decreases with increasing temperature and remains stable during low temperature due to pregnancy and harsh weather.

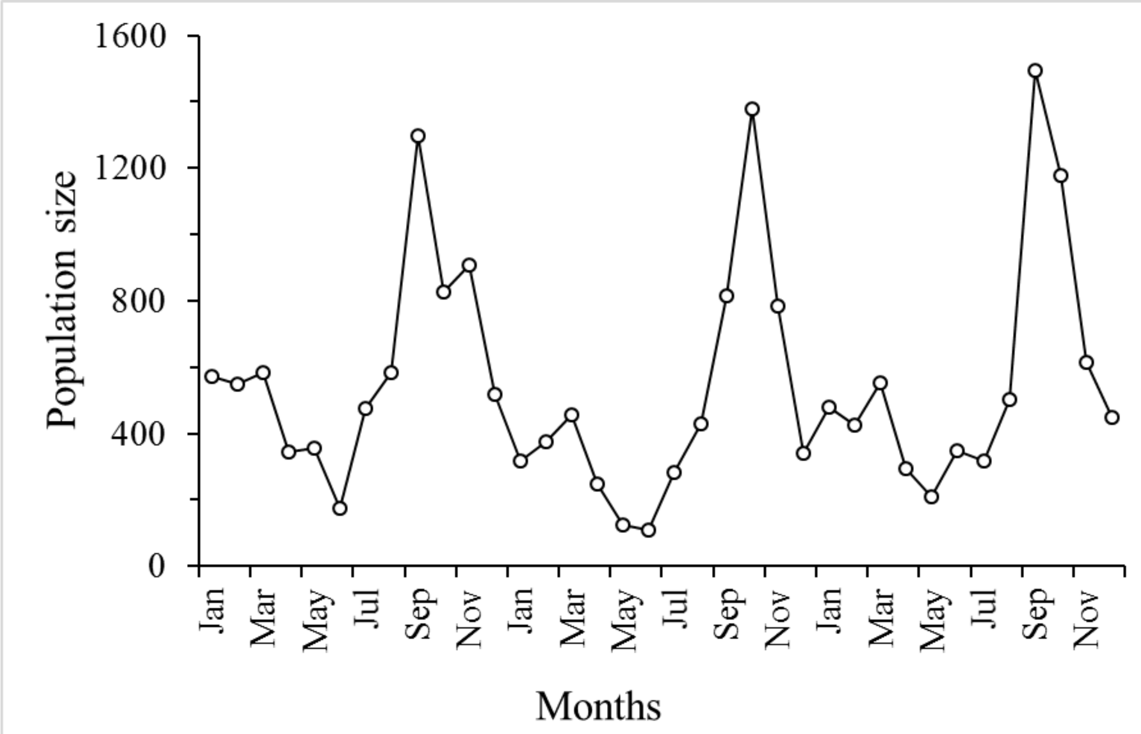

Figure 3.1. Population dynamics of the Indian flying fox, *Pteropus giganteus*.

Pteropus giganteus shifted roost from the canopy to trunk region and leafy area in the roost trees and also made a well shape cluster due to heat waves (Plate 3.1). However, it was also observed that a number of bats died due to high temperature and it was recorded from various roost sites of the study area (41.6 ± 36.6 SD). Due to heat shock, a huge number of *P. giganteus* died from the single roost in Kanpur (n = 84). Thus, it shows that temperature has a significant influence on the population of *P. giganteus* (t = 5.710, $p < 0.001$). The dead individuals were recorded from the ground (Plate 3.2) as well as different part of roost trees (Plate 3.3).

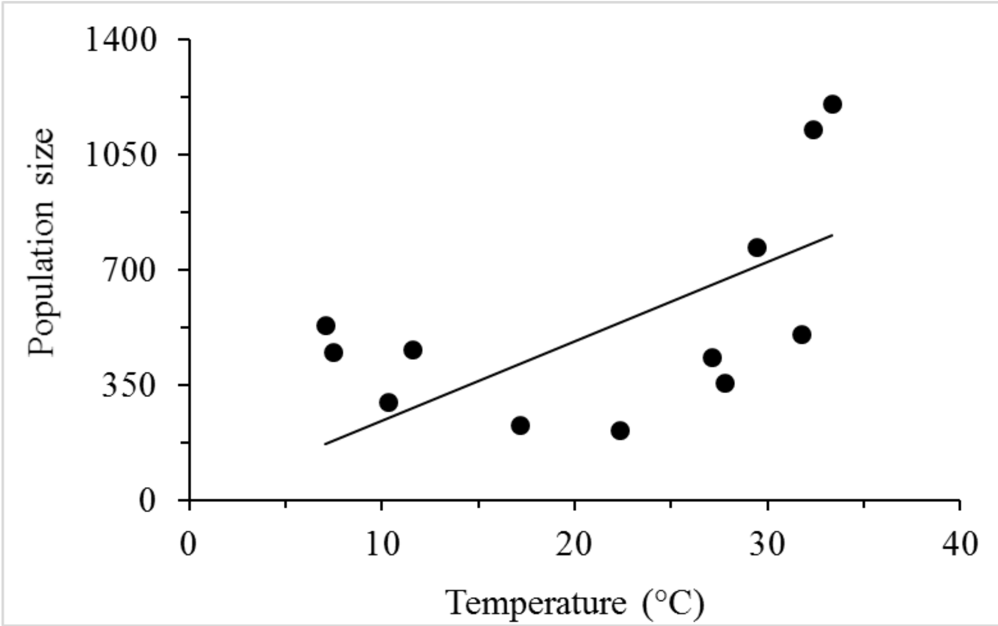

Figure 3.2. Effect of temperature on the population of *Pteropus giganteus*.

In addition, few other death cases were recorded during winter season particularly in foggy periods (Dec – Jan). Due to the long foraging movement, *P. giganteus* accidently contact in eclectic wire and a number of dead bats shock was recorded in Ambedkar Nagar (n = 4), Bareilly (n = 2), Faizabad (n = 7), Lucknow (n = 9, Plate 3.4), Shajahanpur (n = 2) and Sitapur districts (n = 2, Plate 3.5). Though humidity was highly varied over the study period but it facilitates a congenial environment for social interaction during reproductive season (Aug – Nov, 67.7 ± 16.1%), fetus development and parturition (Nov – Mar, 69.9 ± 9.2%). However, it also plays crucial role clustering of *P. giganteus* during summer season (48.3 ± 8.7%, t = 5.028, p > 0.001, Figure 3.3).

Plate 3.1 A well shape cluster of *Pteropus giganteus* during summer season.

Plate 3.2. A dead individual of *Pteropus giganteus* at roost site.

Plate 3.3. *Pteropus giganteus* died due to heat shock at the maternal roost.

Plate 3.4. *Pteropus giganteus* died due to electric shock at Vrindavan Yogna, Lucknow.

Plate 3.5. A died individual of *Pteropus giganteus* at Sitapur district.

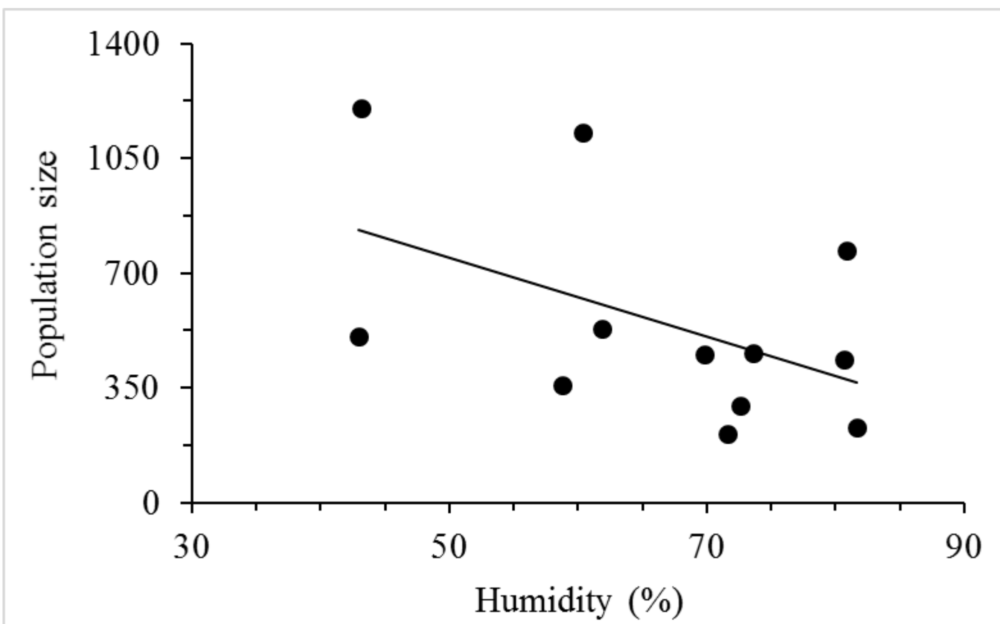

Figure 3.3. Effect of humidity on the population of *Pteropus giganteus*.

The parturition of *Pteropus giganteus* was observed in February, March and April. It was observed that *P. giganteus* gives single pup in a breeding cycle. The population of neonates was 39.0 ± 7.5 (SD). However, infants were exclusively cared by mother for 30 days, until they can roost and fly independently. It was also noticed that lactating mothers generally made solitary roost either at the peripheral branches or trunk region of the roost trees. The lactating females were actively engaged in neonate grooming and nourishing (Plate 3.6).

Plate 3.6. Mother carrying pup at the roost tree.

Plate 3.7. A newly parturient female along with pup at the maternal roost.

DISCUSSION

The present study address the population dynamics of Indian flying fox, *Pteropus giganteus*. The individuals of *P. giganteus* exhibited seasonal variation in population during reproductive season. Hence, the population size of *P. giganteus* increased dramatically due to gathering of immigrants possibly male individuals for availing mating opportunities and colony size decreased at the end of mating season due to the dispersal of emigrants. Thus, reproductive season have a significant role in the aggregation and segregation of flying foxes population (Sugita *et al.*, 2009; Mathur *et al.*, 2012; Sugita and Ueda, 2013).

In non-reproductive season, population slightly increased due to the addition of neonates and presence of few immigrants possibly large grove size attract them for roosting along with the residential population of *P. giganteus*. During summer season, camp decreased due to the dispersal of emigrant population. Moreover, temperature also raised in summer season, particularly in May and June. Hence, *P. giganteus* alter roosting position and make a well shape cluster at trunk and leafy area for thermal balance. However, alteration of roosting area during mating and cluster formation due to temperature has widely reported (Ochoa-Acuña and Kunz, 1999; Sugita *et al.*, 2009; Sugita and Ueda, 2013). The ambient temperature caused mortality of sub-adult and adults of *P. giganteus* hence population size decreases with increasing temperature as it was reported previously in *Pteropus alecto* and *P. poliocephalus* (Welbergen *et al.*, 2008). The study area has ample of roosting wealth and climatic extreme. The presence of water bodies near to the roost provide humid environment and also helps in thermal balance to the bats and it enhances survivability and reproductive fitness of bats (McCain, 2007; Sherwin *et al.*, 2013). *Pteropus giganteus* are adapted to travel long foraging distance within the short span but due to invisibility in foggy nights, they accidentally get trapped into electric wire and a number of dead bats were recorded. However, the accidental death of *P. giganteus* due to electric shock has widely reported in various studies (Chakravarthy and Girish, 2003; Ali, 2010).

The individuals of *Pteropus giganteus* gives birth in the spring season. The spring season provides food abundance and also minimizes foraging movement, maximize resource utilization and it enhances parental investment (Welbergen, 2006; McCain, 2007). In initial weeks of birth, neonates attached with mother and mother generally prefers solitary roost due to intraspecific conflict. The neonates are cared by mother until they roost independently. A study suggested that the neonate of *P. alecto* were closely attached with mother until they can fly and hang upside down freely (Markus and Blackshaw, 2002). Thus, this study shows that the population of *P. giganteus* fluctuated over the study period. The congenial temperature and humid environment during parturition support neonatal survivability.

Chapter IV

FORAGING BEHAVIOUR OF THE INDIAN FLYING FOX, *PTEROPUS GIGANTEUS*

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FORAGING BEHAVIOUR OF THE INDIAN FLYING FOX, *PTEROPUS GIGANTEUS*

INTRODUCTION

Flying foxes are successfully reproducing in Paleotropic region for a number of reason such as food abundance and habitation wealth and eventually both are associated with plant diversity. Therefore, plants play a significant role in the natural history of flying foxes. Flying foxes exclusively feed on part of plants such as bark, buds, flowers, fruits, leaves, nectar and pollen as a results, the process of pollination and seed dispersal are successfully sustained in the ecosystem (Marshall, 1983; Fujita and Tuttle, 1991; Banack, 1998).

Flying foxes have a proficient tool i.e. sustainable flight which allows them to cover long distance within a short period during foraging and reproduction (Eby, 1991; Palmer and Woinarski, 1999). Flying foxes can travel more than 1500 kilometers during migration (Tidemann and Nelson, 2004b; Richter and Cumming, 2006) while 3 – 166 kilometers in a foraging night (Roberts *et al.*, 2012). Forest regeneration and establishment process of several rainforests are entirely dependent on flying foxes movement (Kunz *et al.*, 2011; Kasso and Balakrishnan, 2013). It has estimated that around 5% of ripe fruits and 95% seeds are dispersed by frugivorous bats while birds and primates contribute around 25% in their feeding and habitat territories (Lobova *et al.*, 2003). Further, a few studies suggested that fruit bats are the only species which are able to fly with larger fruit and defecate at feeding, flyway or camps (Charles-Dominique, 1986).

In Asian coordinates, fruit bats are categorized as most abundant seed dispersing and pollinating agent followed by birds and non-flying mammals (Cox *et al.*, 1991; Corlett and Hau, 2000). Approximately 98 – 99% of the tropical plants and 30% of bat fauna are either primarily or opportunistically dependent on each other hence, they help in the rotation of reproductive cycle of various night blooming plants (Wunderle, 1997; Bollen *et al.*, 2004). Recently, few studies conducted in tropical forests mentioned that bats and birds are the widely engaged in the forest re-establishment between isolated and fragmented areas and enhance plants diversity (Terborgh *et al.*, 2002; Jordano *et al.*, 2011).

Flying foxes are entirely different from birds as they have well developed eyesight, olfactory system, and cranial arrangements. Their eyesight has an exclusive role in social behaviour and olfaction and it immensely associated with diet selection (Elangovan *et al.*, 2006; Zhang *et al.*, 2014). The fruit bats differentiates diet on the basis of fruit colour and odour thus it categorized as a diet selection critera. Fruit bats are exemplary species as they select large, structurally protected and dull colour fruits like yellow, orange, green and brown while birds prefer without hard protective and bright colour fruits such as red, black, blue and purple (Bollen and Elsacker, 2002). The diet of fruit bats is qualitatively classified as aromatic or musky in odour while birds prefer generally odourless (Elangovan *et al.*, 2006). Furthermore, fruit characteristics like shape, size, arrangement and position attract bats for foraging (Kalko and Condon, 1998; Hodgkison *et al.*, 2007).

The foraging ecology of phytophagous bats begin with the interaction of bats with food plants and it also has a prime role in the analysis of resource availability and utilization (Banack, 1998). The foraging behaviour of fruit bats is crucially associated with diet composition (Stier and Mildenstein, 2005; Nakamoto *et al.*, 2007), foraging resources (Fujita and Tuttle, 1991; Elangovan *et al.*, 1999; Elangovan and Marimuthu, 2001), fruit hardness (Aguirre *et al.*, 2003), nutritional requirements (Nelson *et al.*, 2000; Soto-Centeno *et al.*, 2014) and olfaction (Kalko and Condon, 1998; Elangovan *et al.*, 2006).

Flying foxes (Genus: *Pteropus*) are well known for their mobile feeding habits and forage on a wide range of plants but they are specialist in terms of their diet selection (Tan *et al.*, 1998; Elangovan *et al.*, 2001). In most of the study, it was explained that they select generally fresh and ripe fruits for foraging. While foraging, they meticulously remove epicarp of fruits, swallowed only juicy contents from pulp and ejected the fibrous portion as a compact fibrous rinds called ejected pellets (Nelson *et al.*, 2005). Flying foxes are generally foraging and carrying fruits around 20 to 200 meters from their feeding sites and process it solitary but small frugivorous bats like *Cynopterus sphinx* like to forage at foraging site (Nathan *et al.*, 2009).

Flying foxes are exclusive chiropterochoric fruit eating bats. They are group feeder hence intraspecific conflicts during foraging time are widely reported (Robbins, 2004; Nakamoto *et al.*, 2007). Moreover, they follow a specific territorial strategy and also exhibited various behaviours such as chasing, biting, kicking, vocalization, and wing flapping and sometimes possessive attack on intruder (Brooke, 2001; Singaravelan and Marimuthu, 2008). *Pteropus samoensis* became more possessive while the time of foraging, especially when they unable to pluck chosen fruit such as *Artocarpus ultilis* and *Pteropus vampyrus* actively defense the flowers of *Durio zibethinus* from other bats species (Nyhagen *et al.*, 2005). The fruit bats alter foraging behaviour and preference based on the resource availability and duration. They generally prefer to visit regularly on steady grove with a mass of population but very few individuals like to visit near to freaky fruiting orchards. However, the bag bang trees attract a large number of bats for foraging though it duration is predictable (Elangovan *et al.*, 1999; Srinivasulu and Srinivasulu, 2002; Hodgkison *et al.*, 2004; Kunz and Fenton, 2005).

The group foraging behaviour is well documented for the members of Phyllostomidae and Pteropodidae family (Meyer *et al.*, 2005). *Artibeus iamaicensis* and *Phyllostomus hastatus* are the phyllostomid frugivorous bats have reported group flyer at the time of foraging. In Pteropodid bats, group feeding is a global phenomenon. It was previously studied that few members of the Pteropodidae family such as *Pteropus giganteus*, *Rousettus leschenaultia* and *Cynopterus sphinx* have been noted as a group feeder (Nathan *et al.*, 2009). The group foraging habits are entirely influenced by the availability of foraging resource (Bonaccorso *et al.*, 2007; Hodgkison *et al.*, 2013). Globally, the short-tailed fruit bat prefers solitary foraging hence, they availed the available foraging sources within the short span of periods (Thies and Kalko, 2004).

The initiation of foraging movements attached with emergence time. As they emerge and follow foraging path randomly however, availability of seasonal food sources plays a key role in the pattern of foraging movement (Goldingay, 1990). It was explained that few fruit bats are solitary feeder and many are group feeder but solitary foraging bats have very less camp size, high predation risk, difficulty in the searching out of new foraging site, and very important, pledge to social interaction (Elangovan *et al.*, 1999). Another study explained that group foraging habit of flying foxes offers them to avail many foraging resources around the foraging sites (Weber *et al.*, 2015). However, subadults are more curious to forage independently and thus they visited surrounding areas of foraging sites to scan the availability of other sites. Therefore, group foraging habits of fruit bats have a significant impact on social behaviour and ecological services (Balasingh *et al.*, 1995; Giannini and Kalko, 2004).

Fruit bats have an exemplary adaptation in term of their diet selection but they consistently visit same grove since flowering to rotten periods. They are adapted to iterate foraging strategies which enhance pollination and seed dispersal probability, therefore, they are also defined as a forest guardian (Nyhagen *et al.*, 2005; Muscarella and Fleming, 2007). It is a well-established and known fact that the chiropterophilous plants have evolved with a specific morphological and phenological adaptation particularly in floral arrangements which attract bats for foraging. As usual, frugivorous bats exclusively chose only fibrous part of the selected fruits because of high energy demands and in turn, it reduce intestinal mechanism and enhance digestion (Lee and Houston, 1993).

In order to explain the feeding habits of fruit bats, various studies explained that fruits type and size determine the diet selection and foraging behaviour of fruit bats. The body mass of fruit bats are proportionally related to the biting force and also play a fundamental role in tearing and processing of fruits while foraging (Aguirre *et al.*, 2002). They prefer to forage on soften fruits but their cranial orientation is morphologically adapted to tear hard coat and process at feeding and night roost (Dumont *et al.*, 2003). The foraging strategies and biting force increased with increasing of body weight such as

Syconycteris australis are an average 18 g is exclusive nectar feeder (Winkelmann *et al.*, 2000). *Paranyctimene raptor* (27 g) and *Nyctimene albiventer* (31 g) forage on soft, fleshy and fibrous fruits (Dumont and O'neal, 2004), *Dobsonia minor* (77 g) forage on slightly hard fruit (Hall and Richards, 2000; Bonaccorso *et al.*, 2002) while *Pteropus conspicillatus* (814 g) mainly dependent on a wide range of large and hard coated fruits (Winkelmann *et al.*, 2000). The bites on the soft fruits are an easier task for bats but in case of hard coated fruits, it needs physical, morphological and behavioural adaptations for optimum performance (Dumont *et al.*, 2003). Another study documented that the biting force was introduced on foraging items varied between bite position and angle. The highest biting forces have been reported at the time of unilateral bites while lower most at unilateral shallow and further moderate at the time of the bilateral bite and shallow (Santana, 2015).

Though, resource utilization particularly temporal and spatial activities are well elaborated in Paleotropic bats (Elangovan *et al.*, 1999). The co-existence of two bats species have a special foraging adaptation at different strata followed by their choice of canopy, height and width of the foraging tree (Nathan *et al.*, 2009). They mutually avoid the foraging conflict with other bats either by spatially or temporally. In term of foraging behaviour, studies suggested that *Epomophorus gambianus* displayed earlier foraging than *Rousettus aegyptiacus* while in case of foraging preference, *Eidolon helvum* select peripheral canopies and *Epomops franqueti* feeds in dense foliage (Marshall, 1983). However, it is physiological mandate of bats that they have to gain optimum nutrients for various life sterategies particularly in flight performance, social activities and reproductive fitness (Stewart *et al.*, 2014).

In term of geographical area, Uttar Pradesh categorized as fourth largest state of India, covering 243,286 km² and have a wide range of biodiversity. A little work has been carried out on the resource availabilty and foraging ecology of bats in Uttar Pradesh (Mathur *et al.*, 2014) but the availability of information on food resource and foraging behaviour of Indian flying fox, *Pteropus giganteus* is scanty. Therefore, the present study was carried out to elaborate about the food resources and foraging behaviour of Indian flying fox, *Pteropus giganteus* in Uttar Pradesh.

MATERIALS AND METHODS

The study was carried out from January 2013 to December 2017 in various districts of Uttar Pradesh. An extensive field survey was carried out to observe the diversity of food resources. The foraging site of *P. giganteus* was identified through visual observation, defecation, fruits dropping, ejected pellets and tooth marks in unprocessed fruits. The foraging observation was made from 18:00 h – 06:00 h over the study period. The presence of street and high-mast lights provide ample light intensity to observe the behavioural activities of *P. giganteus* but sometimes redfiltred torch was also used particularly when light was either absent or scanty. A pilot study was carried out in an orchard from the very 1st bat settled till the last flew from the foraging site. Moreover, each tree was visited periodically to access the bats population with respect to time periods (30 m interval). For foraging, the observation was carried out by visual and digital recording (Canon EOS Rebel T3i) places underneath the canopy with minimum hindrance (in order to keep them in minimum disturbance). Further, the duration of behavioural activities such as circling flight, vocalization, chasing and wing flapping of *P. giganteus* was precisely recorded by stopwatch.

In addition, the tree specific foraging behaviour of *Pteropus giganteus* was also investigated at various foraging sites. The characteristics of foraging trees such as diameter at breast height (dbh), height and canopy width was measured substantially. The Pearson correlation was applied to find the relationship between behavioural activities during foraging. The student unpaired ‘t’ test was also applied for comparing the mean differences between foraging behaviour and tree characteristics such dbh, tree height and canopy width.

RESULTS

Food resources and seasonal food preference of *Pteropus giganteus*

The study area has a wide range of plant diversity as a results, *Pteropus giganteus* is privileged by abundant food resources. A total of 20 food resources were identified which belonging to 13 families (Table 1). However, the available food resources are varied seasonally hence, it offer a wide range of diet selection and alteration of foraging behaviour accordingly (Table 4.2).

During the study period, the presence of *Pteropus giganteus* around the flowering and fruiting tree was observed at various occasion. However, *P. giganteus* actively forage on selective plants such as *Ficus benghalensis*, *F. religiosa*, *F. racemosa*, *F. virens*, *Psidium guajava*, *Syzygium cumini* and *Neolamarckia cadamba* possibly due to the abundance in the study area. In order to foraging preference, *P. giganteus* prefer to forage on steady food items because of higher maturation synchrony and longer persistency. Apart from, due to the mobile foraging habit, *P. giganteus* opportunistically visit nearer orchards for scanning and social interaction.

Table 4.1. Food preference of *Pteropus giganteus* and dietary parts of food plants.

FAMILY	SPECIES	BUD	LEAVES	FLOWER	FRUITS
ANACARDIACEAE	*Mangifera indica*	–	–	–	+
ANNONACEAE	*Annona squamosal*	–	–	–	+
ANNONACEAE	*Polyalthia longifolia*	–	–	–	+
BOMBACACEAE	*Ceiba pentandra*	–	–	+	–
CAESALPINIACEAE	*Cassia fistula*	–	–	+	–
CARICACEAE	*Carica papaya*	–	–	–	+
COMBRETACEAE	*Terminalia catappa*	–	–	+	+
FABACEAE	*Albizia lebbeck*	–	–	+	–
	Prosopis juliflora	–	–	+	–
	Pithecellobium dulce	–	–	+	–
MELIACEAE	*Azadirachta indica*	–	–	–	+
MORACEAE	*Artocarpus integrifolia*	+	–	+	–
	Ficus benghalensis	–	+	–	+
	Ficus religiosa	–	+	–	+
	Ficus racemosa	–	+	–	+
	Ficus virens	–	–	–	+
MUSACEAE	*Musa paradisiaca*	–	–	–	+
MYRTACEAE	*Psidium guajava*	–	–	+	+
	Syzygium cumini	–	–	–	+
RUBIACEAE	*Neolamarckia cadamba*	–	–	–	+

Table 4.2. Seasonal variation in the food availability of *Pteropus giganteus*.

Species	**Seasons**											
	Spring			Summer			Autum			Winter		
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Albizia lebbeck	–	+	+	–	–	–	–	–	–	+	+	–
Annona squamosal	–	–	–	–	–	–	+	+	+	–	–	–
Artocarpus integrifolia	–	–	+	–	–	–	–	–	–	+	+	+
Azadirachta indica	+	+	+	+	+	+	–	–	–	–	–	–
Carica papaya	+	+	–	–	+	+	+	–	–	–	–	+
Cassia fistula	–	–	+	+	+	–	–	–	–	–	–	–
Ceiba pentandra	+	+	–	–	–	–	–	–	–	–	+	+
Ficus benghalensis	+	+	+	–	–	+	+	+	+	–	–	+
Ficus racemosa	–	–	–	–	+	+	+	–	–	+	+	+
Ficus religiosa	+	+	+	–	–	+	+	+	–	–	–	–
Ficus virens	+	+	+	–	–	+	+	+	+	–	–	+
Mangifera indica	+	+	+	+	–	–	–	–	–	–	–	–
Musa paradisiaca	+	+	+	–	–	+	+	+	–	–	–	–
Pithecellobium dulce	–	+	+	+	+	–	–	–	–	+	–	–
Polyalthia longifolia	+	+	+	–	–	–	–	–	–	–	–	–
Prosopis juliflora	–	–	–	–	–	+	+	+	–	–	–	–
Psidium guajava	+	+	+	–	+	+	+	–	+	+	+	–
Syzygium cumini	+	+	+	+	+	–	–	–	–	–	–	–
Terminalia catappa	–	–	–	–	–	–	–	+	+	+	–	–
Neolamarckia cadamba	+	–	–	–	–	–	+	+	+	+	+	+

Plate 4.1. An individual of *Pteropus giganteus* roosting on *Ficus benghalensis*.

The foraging of *Pteropus giganteus* were quite common in the grove of *Psidium guajava* while they opportunistically visited for a couple of day on the flower of *Musa paradisiaca* and fruit of *Annona squamosa*.

Foraging behaviour of Indian flying fox, *Pteropus giganteus*

The individuals of *Pteropus giganteus* started to arrive in the grove at 19:04 ± 0:29 h:m. In the beginning, only few individuals arrived in the foraging site but within a couple of minutes, the population size increased dramatically. It shows that the number of *P*. *giganteus* visit increases with time in pre-midnight while decreases with time periods in post-midnight (Figure 4.1). It was observed that *Pteropus giganteus* actively engaged in the circling flight over the fruiting trees for scanning the foraging suitability and food availability (17.5 ± 12.6 SD, Plate 4.3). They highest circling flight was recorded at 20:00 h:m but once they involved in the foraging activities, the frequency decrease steeply

(Figure 4.2). It was observed that *P. giganteus* land on the peripheral canopy on foraging trees. They partially closed wings while landing and found suitable fruits.

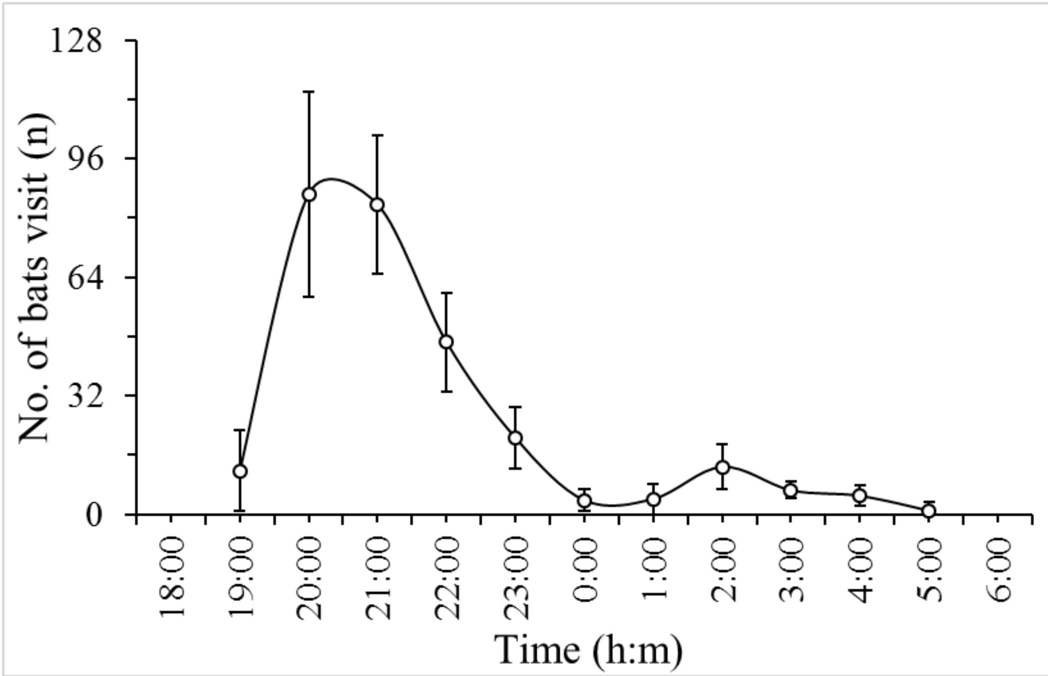

Figure 4.1. Mean number of bats visit during foraging.

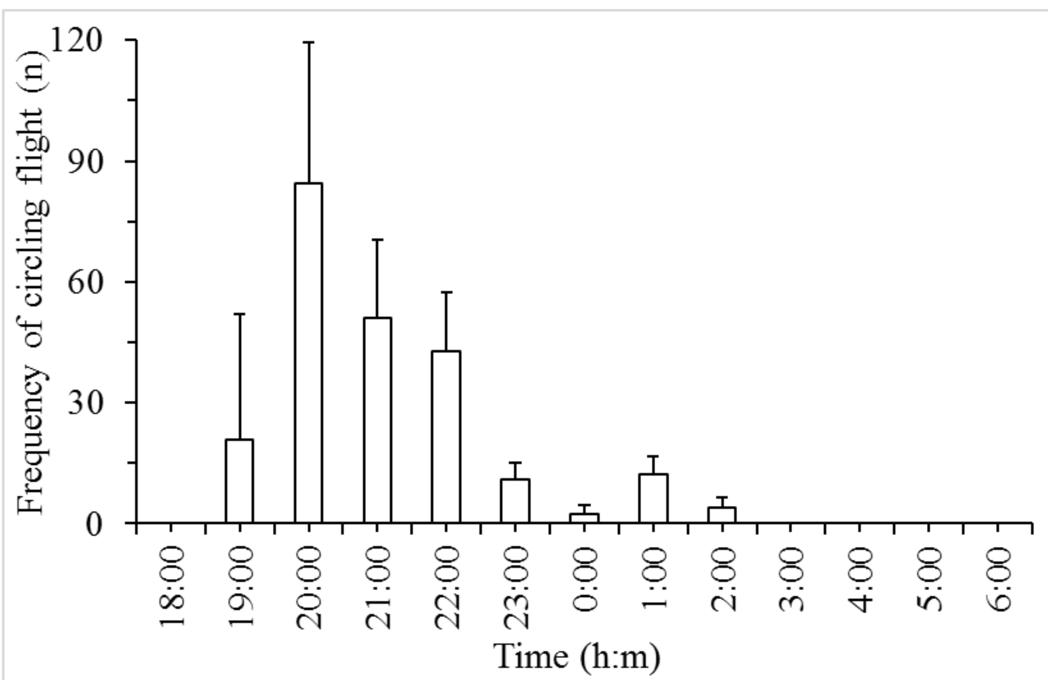

Figure 4.2. Frequency of circling flight during foraging.

Plate 4.2. Circling flight of *Pteropus giganteus* at foraging site.

Pteropus giganteus senses the fruit conditions though its snout possibly olfaction and hold the selected fruit with the help of their thumb and claws. Further, biting starts from the soft part of fruit for 23.1 ± 3.9 sec until buccal cavity fill up with sufficient amount of bolus. As chewing is initiated (35.4 ± 6.1 sec), the succulent portion of the bolus sucked and spitted out the fibrous portion as rinds (Plate 4.7). During each foraging bout, biting and chewing was uniformly observed therefore it might be a reason of strong relationship ($r = 0.891$, $p < 0.001$, Figure 4.3).

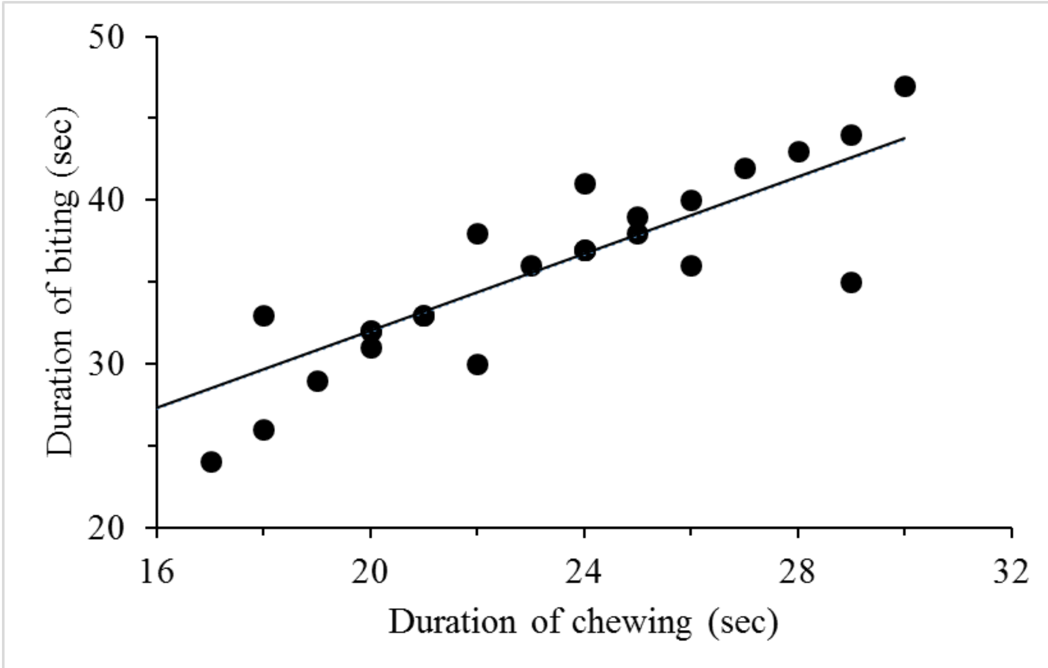

Figure 4.3. Shows relationship between biting and chewing during foraging.

In addition, it was observed that *Pteropus giganteus* preferred foraging at peripheral canopies instead dense foliage. However, they shifted and also changed foraging canopies due to intraspecific conflict. As a result, such individuals exhibit vocalization (7.0 ± 6.9 SD) and also making circling flight around the foraging trees (17.5 ± 12.6 SD). Therefore, a significant relationship was found between vocalization and circling flight (r = 0.801, p < 0.001, Figure 4.4). They mostly hold fruits in abdomen region with the help of toes and respond intruder through vocalization. However, they dropped marked and semi-processed or unprocessed fruits underneath and near to feeding roost accidently (Plate 4.8 and 4.9).

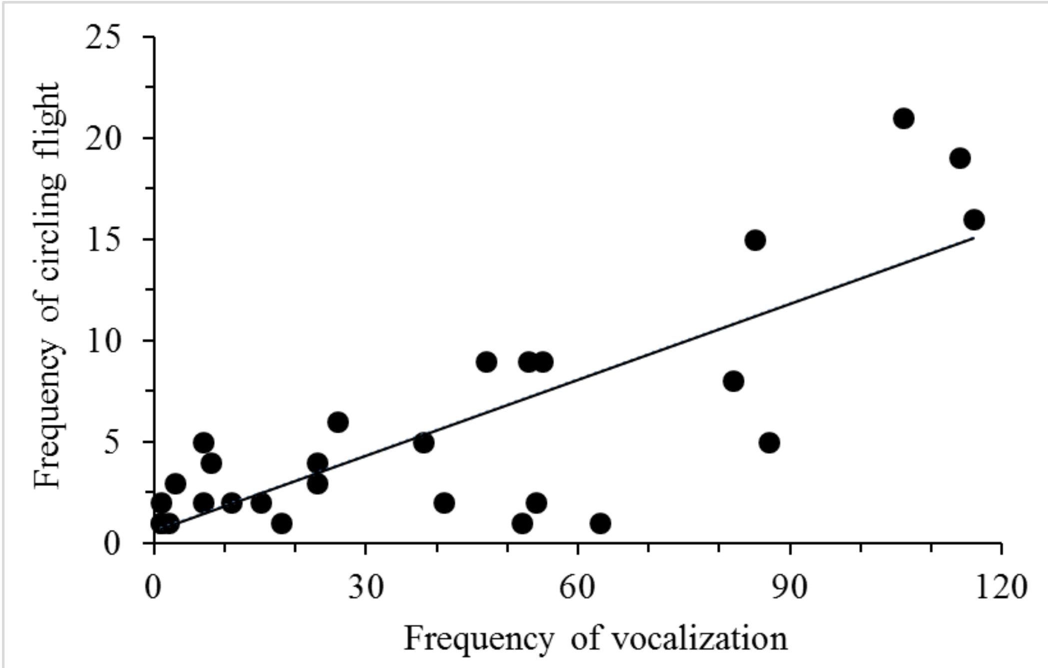

Figure 4.4. Shows frequency of circling flight and vocalization during foraging.

Plate 4.3. *Pteropus giganteus* exhibits quadrupedal movement during food selection.

Plate 4.4. *Pteropus giganteus* foraging on *Neolamarckia cadamba* fruits.

Plate 4.5. A glimpse of peripheral foraging habit of *Pteropus giganteus*.

Plate 4.6. Ejected pellets of *Neolamarckia cadamba* fruits at feeding roost of *Pteropus giganteus*.

Plate 4.7. The collected ejected pullets of *Pteropus giganteus* from the foraging site.

Plate 4.8. Fruit remnant of *Pteropus giganteus* underneath the foraging site.

Plate 4.9. *Psidium guajava* remnant collected from the foraging site of *Pteropus giganteus*.

Plate 4.10. The accumulation of food remnants and guano of *Pteropus giganteus* at diurnal roost.

Further, the results of tree characteristics of foraging trees suggested that the taller tree height (10.4 ± 1.6 m, $t = 4.559$, $p < 0.001$) and wider canopy width (9.6 ± 1.2 m, $t = 4.711$, $p < 0.001$) offers feasibility of tree selection, fruits scanning and social interaction but dbh have no substantial role in the foraging behaviour of *P*. *giganteus* (34.1 ± 4.5 cm, $t = 0.054$, $p > 0.05$). In this context, the results of correlation matrix also suggested that the tree height and canopy width are the key feature which attracts *P*. *giganteus* for foraging while dbh have no relationship with the number of bats visit during foraging (Table 4.3).

Table 4.3. Shows correlation matrix between the number of bats and dbh, height and canopy of foraging trees.

	Population	**Dbh**	**Height**	**Canopy width**
Population	1			
Dbh	-0.0237	1		
Height	0.0165	0.9285	1	
Canopy width	0.0874	0.8446	0.8673	1

DISCUSSION

In the present study, it was found that the study area of Uttar Pradesh has a wide range of resource availability and presumably it might be a reason of sustainability of Indian flying fox, *Pteropus giganteus* in Uttar Pradesh. Therefore, they reproduce and maintains roost for many decades. It was noticed that *P. giganteus* are mobile feeder hence, they altered foraging sites based on the food availability. Moreover, the dynamic and opportunistic foraging nature of *P. giganteus* was reported by various studies (Mahmood-ul-Hassan *et al.*, 2010; Javid *et al.,* 2017). The study area have plentiful of food resources but *Ficus benghalensis*, *F. religiosa*, *F. racemosa*, *F. virens*, *Psidium guajava*, *Syzygium cumini*, and *Neolamarckia cadamba* were identified as major part of *P. giganteus* diet. A study conducted in the southern region of India explained that *P. giganteus* systematically foraging on steady foraging resources (Sudhakaran and Doss, 2012).

In the preliminary phase of foraging behaviour, the arrived individuals made few circling flight for short period to scan food availability, foraging suitability and predation risk but the number of bats arrival enhanced within short period. However, foraging suitability and predation risk was well documented in *Carollia perspicillata* (Fleming and Heithaus, 1986) and *Pteropus poliocephalus* (Welbergen, 2006). Due to the nocturnal foraging habit, they maintained foraging group through circling flight and vocalization therefore, it play a major role in emergence, foraging, home flight and social organization of flying foxes (Welbergen, 2006).

The large body size of *P*. *giganteus* needs a spacious canopy for easier landing and takeoff therefore foraging on the peripheral and resilient foliage of resource trees. Hence, they significantly altered foraging behaviour based on the tree characteristics. Generally, wider and spacious canopy harboured a number of fruits. As a result, *P*. *giganteus* may avail a largre number of fruits within the short span and it also facilitates flight suitability during foraging. *Pteropus giganteus* typically used visual acuity and olfaction in diet selection. However, the ability of diet selection through visual acuity and olfaction was evantually reported in *Glossophaga soricina* (Winter *et al.*, 2003), *Ptenochirus jagori* and *Pteropus pumilus* (Luft *et al.*, 2003), *Cynopterus sphinx* (Elangovan *et al.*, 2006) and *Rousettus leschenaulti* (Tang *et al.*, 2007).

The spacious canopy and reliable foliage of foraging trees provide an easier flight room and amiable condition for foraging and social activities. The foraging activities of *P*. *giganteus* were mainly recorded around the peripheral canopies instead of dense foliage. Nathan *et al*. (2009) suggested that the common Indian fruit bats such as *Cynopterus sphinx* prefer foraging on lower canopy while *P*. *giganteus* around the upper and marginal canopy of *Madhuca latifolia*. Foraging trees are topographically suitable and mechanically stable hence, *P*. *giganteus* comparatively preferred foraging on it fruits than other available foraging sources. Tree characteristics particularly height and canopy width attract large population for foraging. It was previously reported that the canopy shape and tree height are significantly influenced the foraging behaviour of bats such as *Eptesicus fuscus* and *Lasiurus cinereus* (Menzel *et al.*, 2005) and also birds like *Dendroica caerulescens*, *Setophaga ruticilla* and *Dendroica virens* (Whelan, 2001). Therefore, the present study suggests that the study area have ample of food resources. As a result, *Pteropus giganteus* is privileged by a wide range of resource utilization. Further, the tree characteristics of foraging trees attract *P*. *giganteus* for foraging and may have substaintail role in the foraging and social hehaviour of Indian flying fox, *Pteropus giganteus*.

SUMMARY

SUMMARY

A total of 84 roost sites of *P. giganteus* was observed from the 34 districts of Uttar Pradesh. *Pteropus giganteus* independently roosts on larger trees such as *Acacia nilotica* Linn., *Albizia lebbeck* Linn., *Alstonia scholaris* Linn., *Artocarpus integrifolia* Linn., *Artocarpus lakoocha* Roxb., *Azadirachta indica* A. Juss., *Bamboo* spp., *Bassia latifolia* Linn., *Bombax ceiba* Linn., *Borassus flabellifer* Linn., *Cassia senna* Linn., *Dalbergia sissoo* Roxb., *Delonix regia* Hook., *Eucalyptus* spp., *Ficus racemosa* Roxb., *F. religiosa* Linn., *F. tinctoria* Bl., *F. virens* Linn., *F. benghalensis* Linn., *Grevillea robusta* A. Cunn., *Holoptelea integrifolia* Planch., *Leucaena leucocephala* Lam., *Limonia acidissima* Linn., *Mangifera indica* Linn., *Neolamarckia cadamba* Roxb., *Phoenix silvestris* Roxb., *Polyalthia longifolia* Sonn., *Prosopis juliflora* Sw., *Syzygium cumini* Linn. and *Terminalia arjuna* Roxb.

Pteropus giganteus prefers to occupy a large number of wide-canopy trees (71.4% trees) such as *F. benghalensis*, *F. racemosa*, *F. religiosa*, *F. virens*, *M. indica*, *S. cumini*, *B. latifolia*, *D. sissoo*, *D. regia* and *A. indica* while they occupied a few narrow-canopy trees (28.6% trees) like *Eucalyptus* spp., *T. arjuna* and *P. longifolia*. *Pteropus giganteus* seldom roosts in discrete trees, instead the colonies were observed in groves with a large number of trees.

The results of present study showed that the distribution of *P. giganteus* was wide spread and roost selection was influenced by roost tree characteristics such as dbh, height and canopy width of roost trees. The roost trees chosen by bats had wide canopy and out of reach to human and predators. The selection of wider canopy roost trees provides

ample of roosting area to fulfill their life history needs especially reproduction. The topographic feature of large and long living trees provide many advantages to the bats like protection, thermoregulation, aerodynamic benefits such as easy take-off and landing and suitable conditions for their reproductive behaviour.

The colonies were observed nearer to the non-roost dependent characters water bodies such as pond, lake, canal and river, human habitations and arterial road but it didn't influence significantly. Further, it was also observed that *P*. *giganteus* drinks water nearby water sources during day hours. Roost adjacent to water bodies provides water facilitates, humid environment and thermal balance during hot seasons while human habitation offers diverse food items which are possibly inaccessible in the natural forests.

During day times, the individuals of *P*. *giganteus* actively involved in various diurnal behaviours such as wing fanning (3%), grooming (6%), roost shifting (22%) and screaming (14%) until afternoon. However, they did not actively involve on wing fanning (8%), instead, they spent more time on grooming (26%), roost shifting (20%) and screaming (19%) during pre-emergence hours.

Bat emergence was recorded from the vantage point while time and number of bat emergence were recorded between the emergence of the first to the last bat in the colony. They actively involved in body worm up, sensing of weather and suitability of emergence. Grooming and wing stretching make them ready for emergence while vocalization synchronizes their wake up. *Pteropus gigantesus* makes a few circling flights around their roosts before emergence, presumably to assess the light intensity and predation risk.

The emergence was initiated by a few individuals which were occupied the peripheral canopy of the tree, followed by other individuals emerged from the roosts. An average bat emergence was observed 0:32 ± 0:10 h:m after the sunset. The time of peak emergence was varied throughout the year and seasons. The emergence behaviour of *P. giganteus* was observed during winter (17:30 – 18:37 h:m) than monsoon (18:37 – 20:04 h:m) and summer (18:38 – 19:46 h:m).

The emergence of bat was entirely based on group size and their reproductive conditions, perhaps lactating females exhibit prepone emergence while males at the end. The shortest day length was observed during winter (10:48 h:m) while longest day length observed during the summer season (13:02 h:m). Hence, bats altered their time of emergence according to the day length, i.e. shorter the day length, earlier the emergence and longer the day length, later the emergence.

After the home flight, the individuals of *P. giganteus* were actively engaged in roost alteration which facilitated them for finding suitable mates. The male bats made many circling flights around the roost and exhibited quadrapedal movement until finding a suitable mating partner. The reproductive behaviour such as pair bonding, courting the females, licking the face and genitalia of females by males were observed throughout the year. The successful male undergone pair bonding and subsequently copulated with the females and the unsuccessful males kept on shifting the roost over the day. The segregated mating partner grooms patagium, toes and genital organs independently which presumably enhanced reproductive fitness in *P. giganteus*.

A visual count method was used for the estimation of population size of *P. giganteus* while branch estimation, binocular and photographic method was extensively applied in inaccessible roost. The population size of *P*. *giganteus* increased dramatically due to gathering of immigrants during reproductive season possibly male individuals for availing mating opportunities and colony size decreases proportionally at the end of mating season due to the dispersal of emigrants. It was observed that the population of *P*. *giganteus* fluctuated over the study period. The colony size of *P*. *giganteus* increased exponentially during reproductive season due to aggregation of immigrants (Aug – Nov) and the most abundant population was recorded in the month of September (n = 1495). Due to the abundance of population size, the individuals roosting over the grove and colony was observed as noisy. The dispersal of migrant individuals during non-reproductive season caused dramatic changes in the population size of *P*. *giganteus* even population decline in May and June whereas it stable in winter season.

Throughout the study period, the highest ambient temperature was recorded in June (42.4 °C) and lowest in January (4.9 °C) but the colony size decreased with increasing temperature in summer season and remains stable during winter season because of pregnancy.

During ambient temperature, *P*. *giganteus* shifted roost from canopy to trunk and leafy area and made a well shape cluster due to heat waves. However, it also observed that a number of bats died due to heat shock and it was recorded from the various roosts. An unforeseen death case of *P*. *giganteus* observed from a colony in Kanpur (n = 84). During foggy nights, a number of dead bats were observed from Ambedkar Nagar, Bareliey, Faizabad, Lucknow, Shajahanpur and Sitapur districts.

It was observed that *P*. *giganteus* gives single pup in a reproductive season. However, pups were exclusively cared by mother for a couple of days until they can roost and fly independently. It was also noticed that pups carrying mother generally made solitary roost either at the peripheral branch or trunk region of the roost trees. The lactating females actively involved in wing fanning during sunny hours which make them maintain thermoregulation with ambient temperature.

It was found that the study area of Uttar Pradesh has a wide range of resource availability and presumably it might be a reason that *P. giganteus* reproduces and maintains maternal colonies for many decades. It was noticed that *P. giganteus* are the mobile feeder hence, they altered foraging sites based on the food availability. However, *P. giganteus* actively forage on selective plants such as *Ficus benghalensis*, *F. religiosa*, *F. racemosa*, *F. virens*, *Psidium guajava*, *Syzygium cumini* and *Neolamarckia cadamba* due to the abundance in the study area.

The individuals of *P. giganteus* started to arrive in the grove at 19:04 ± 0:29 h:m. In the beginning, only a few individuals arrive at the foraging site but within a couple of minutes, the population size increased dramatically. *Pteropus giganteus* actively engaged in the circling flight over the fruiting trees for scanning for food availability, foraging suitability and predation risk. They highest circling flight was recorded at 20:00 h:m but once they involved in the foraging, the frequency of circling flight decreased steeply. The number of circling flight was higher in pre-midnight than post-midnight.

It was observed that *P. giganteus* forages on the upper and peripheral canopy of the tree. They start biting until buccal cavity fills up with sufficient amount of bolus. As chewing is initiated, the succulent portion of the bolus is sucked and spitted out the fibrous portion as rinds.

The characteristics of foraging trees were measured and the result suggests that tree height and canopy width have a significant role as it offers feasibility of resource identification, fruits scanning and social interaction while dbh have no substantial role in the foraging behaviour of *P. giganteus*.

The outcome of this study may pave various novel approaches on the behavioural and population ecology of *P. giganteus*. Further, the protection of larger trees which were reported in this study would help to conserve the habitat and thus the Indian flying fox, *Pteropus giganteus* in Uttar Pradesh.

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LITERATURE CITED

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An Update on Distribution of the Indian Flying Fox, *Pteropus giganteus* in Uttar Pradesh, India

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ABSTRACT

As a viable key stone species, *Pteropus giganteus* provides ecological sustainability and considered as sacred species in India. An extensive field survey was carried out in 34 districts of Uttar Pradesh and found a total of 84 colonies of *P. giganteus*. Though, *P. giganteus* showed ubiquitous distribution in Uttar Pradesh but the eastern region harboured more colonies (70%) than the western part of Uttar Pradesh (30%). The colonies of *P. giganteus* was predominantly observed adjacent to human habitation (49%) and water bodies (41%). The bats have chosen large, tall and long lasting trees belonging to 30 species. The widespread distribution of *P. giganteus* in Uttar Pradesh is possibly due to the occurrence of decade old trees which provide suitability for their existence. This study provides an exclusive draft on the distribution of *Pteropus giganteus* which can be used substantially in future research.

Key words *Distribution*, *Pteropus giganteus*, *Roost trees*, *Conservation*

At the global scale, flying foxes are often considered as a viable participant of ecological functions. They chiefly propagate various plants species in accessible and inaccessible area through stringent eco-services, such as pollination and seed dispersal (Fujita and Tuttle, 1991). Flying foxes are the most common and familiar among bats and extensively studied. Unfortunately, the availability of scientific contents on their distribution in Uttar Pradesh is scanty and obviously, it has hampered conservation initiatives. In India, a little information on the distribution of the Indian flying fox, *Pteropus giganteus* is available (Marimuthu, 1988; Dey *et al.*, 2013). Several studies have also incorporated substantial information on the distribution of *P. giganteus* particularly in southern India (Deshpande, 2012; Senthilkumar and Marimuthu, 2012; Kumar *et al.*, 2016), however a scanty information is available from Uttar Pradesh. Therefore, we were tried to draw a preliminary draft on the distribution of *P. giganteus* in Uttar Pradesh.

MATERIALS AND METHODS

The study was carried out for a period of three years (Jan 2013 – Dec 2016) in various districts of Uttar Pradesh such as Ambedkar Nagar (26°28'6.22"N; 82°41'29.55"E), Amroha (28°54'15.70"N; 78°28'1.61"E), Azamgarh (30°33'31.67"N; 75°50'25.17"E), Badaun (28° 7'47.80"N; 78°55'43.77"E), Baghpat (28°56'31.78"N; 77°13'34.12"E), Ballia (25°46'16.86"N; 84°10'30.59"E), Barabanki (26°59'43.82"N; 81°15'6.78"E), Bareilly (23° 0'30.61"N; 78°14'2.85"E), Basti (26°49'3.65"N; 82°45'47.93"E), Bijnor (29°22'20.79"N; 78° 8'9.05"E), Deoria (26°29'10.45"N; 83°47'1.76"E), Faizabad (26°46'23.69"N; 82° 8'38.99"E), Firozabad (27° 9'32.76"N; 78°23'44.73"E), Hardoi (27°23'54.58"N; 80° 7'54.13"E), Kanpur (26°26'59.72"N; 80°19'54.74"E), Kanpur Dehat (26°31'36.51"N; 79°49'46.96"E), Lakhimpur Kheri (27°56'56.66"N; 80°46'56.63"E), Lucknow (26°50'48.10"N; 80°56'46.20"E), Meerut (28°59'4.06"N; 28°59'4.06"N), Muzaffarnagar (29°28'21.58"N; 77°42'30.79"E), Pilibhit (28°35'0.56"N; 80° 0'31.59"E), Raebareli (26°14'4.31"N; 81°14'27.13"E), Saharanpur (29°58'1.48"N; 77°33'3.66"E), Siddharth Nagar (27°16'17.63"N; 82°49'15.51"E), Sitapur (27°35'2.05"N; 80°39'58.88"E), Sultanpur (26°50'48.10"N; 80°56'46.20"E) and Unnao (26°32'21.64"N; 80°29'16.15"E). The field survey was carried out at various locations of eastern and western regions of Uttar Pradesh. The information regarding roost sites of *P. giganteus* was collected from local places such as railway stations, bus stations, and local people. Based on the collected information, the survey was carried out and information such as colony location, number of roost sites, population size and garden composition were recorded precisely. The geographical coordinates of all the recorded roost sites were assembled separately and an exclusive cartogram was constructed with the help of ArcGIS software (Version 10.2.2).

RESULTS AND DISCUSSION

In the present study, a total of 84 roost sites of *P. giganteus* was observed from the 34 districts of Uttar Pradesh, India (Fig.1, Table 1). Among the observed roosts, a majority of *Pteropus* colonies was observed from the eastern region of Uttar Pradesh (70%) compared to western part (30%). However, in terms of population size, the colonies observed at a protected area in Kanpur harboured a maximum (1250). It shows that the location of colony offers a congenial environment by means of roosting wealth, food abundance and survivability. A highest number of colonies was observed in Faizabad (n = 7) followed by Ambedkar Nagar (n = 6) and Lucknow districts (n = 6). However, the average population size of Faizabad, Ambedkar Nagar and Lucknow (458.3 ± 228.4 SD) was relatively lesser than Kanpur population.

Pteropus giganteus preferred to roost exclusively on

Fig. 1. ArcGIS based cartogram of *Pteropus giganteus* roosting sites in Uttar Pradesh. The distribution of *Pteropus giganteus* was marked by ArcGIS Explorer for ready and future references.

larger trees such as *Acacia nilotica* Linn. (RT1), *Albizia lebbeck* Linn. (RT2), *Alstonia scholaris* Linn. (RT3), *Artocarpus integrifolia* Linn. (RT4), *Artocarpus lakoocha* Roxb. (RT5), *Azadirachta indica* A. Juss. (RT6), *Bamboo* spp. (RT7), *Bassia latifolia* Linn. (RT8), *Bombax ceiba* Linn. (RT9), *Borassus flabellifer* Linn. (RT10), *Cassia senna* Linn. (RT11), *Dalbergia sissoo* Roxb. (RT12), *Delonix regia* Hook. (RT13), *Eucalyptus* spp. (RT14), *Ficus racemosa* Roxb. (RT15), *F. religiosa* Linn. (RT16), *F. tinctoria* Bl. (RT17), *F. virens* Linn. (RT18), *F. benghalensis* Linn. (RT19), *Grevillea robusta* A. Cunn. (RT20), *Holoptelea integrifolia* Planch. (RT21), *Leucaena leucocephala* Lam. (RT22), *Limonia acidissima* Linn. (RT23), *Mangifera indica* Linn. (RT24), *Neolamarckia cadamba* Roxb. (RT25), *Phoenix silvestris* Roxb. (RT26), *Polyalthia longifolia* Sonn. (RT27), *Prosopis juliflora* Sw. (RT28), *Syzygium cumini* Linn. (RT29) and *Terminalia arjuna* Roxb. (RT30) (Fig. 2a – d).

The roost trees chosen by bats had well spreaded canopy and out of reach to human and many predators. The selection of tall and wide canopy tree roosts by *P. giganteus* was also reported by a number of researchers e.g. *Acacia nilotica* (Gulraiz *et al.*, 2016), *Albizzia lebbek* (Gulraiz *et al.*, 2015; Baskaran *et al.*, 2016), *Alstonia scholaris* (Ali, 2010), *Azadirachta indica* (Vendan *et al.*, 2008), *Bassia latifolia* (Senthilkumar and Marimuthu, 2012), *Dalbergia sissoo* (Vyas and Upadhyay, 2014), *Eucalyptus* sp., (Gulraiz *et al.*, 2015), *Ficus racemosa* (Maruthupandian and Marimuthu, 2013), *Ficus benghalensis* (Chakravarthy and Girish, 2003), *Holoptelea integrifolia* (Suthari and Raju, 2012), *Mangifera indica* (Singaravelan *et al.*, 2009), *Polyalthia longifolia* (Caughlin *et al.*, 2012), *Syzygium cumini* (Tangavelou *et al.*, 2013) and *Terminalia arjuna* (Dey et al., 2013).

The colonies were observed nearer to water bodies such as pond, lake, canal and river (41%) and human habitations (49%). It was also observed that *P. giganteus* drinks water from nearby water sources during day hours (personal observation). A number of researchers explained that the proximity to water facilitates water requirement and thermal balance during hot seasons (Welbergen *et al.*, 2008; Russo and Ancillotto, 2015) while human habitation offers a diverse food items which are possibly inaccessible in the natural forests (Hahn *et al.*, 2014).

Hence, the conservation of large and wide canopy trees may provide roosting and foraging wealth to *P. giganteus* for proper ecological functioning. Further, this study may contribute for future research on the distribution and conservation of *Pteropus giganteus* in Uttar Pradesh.

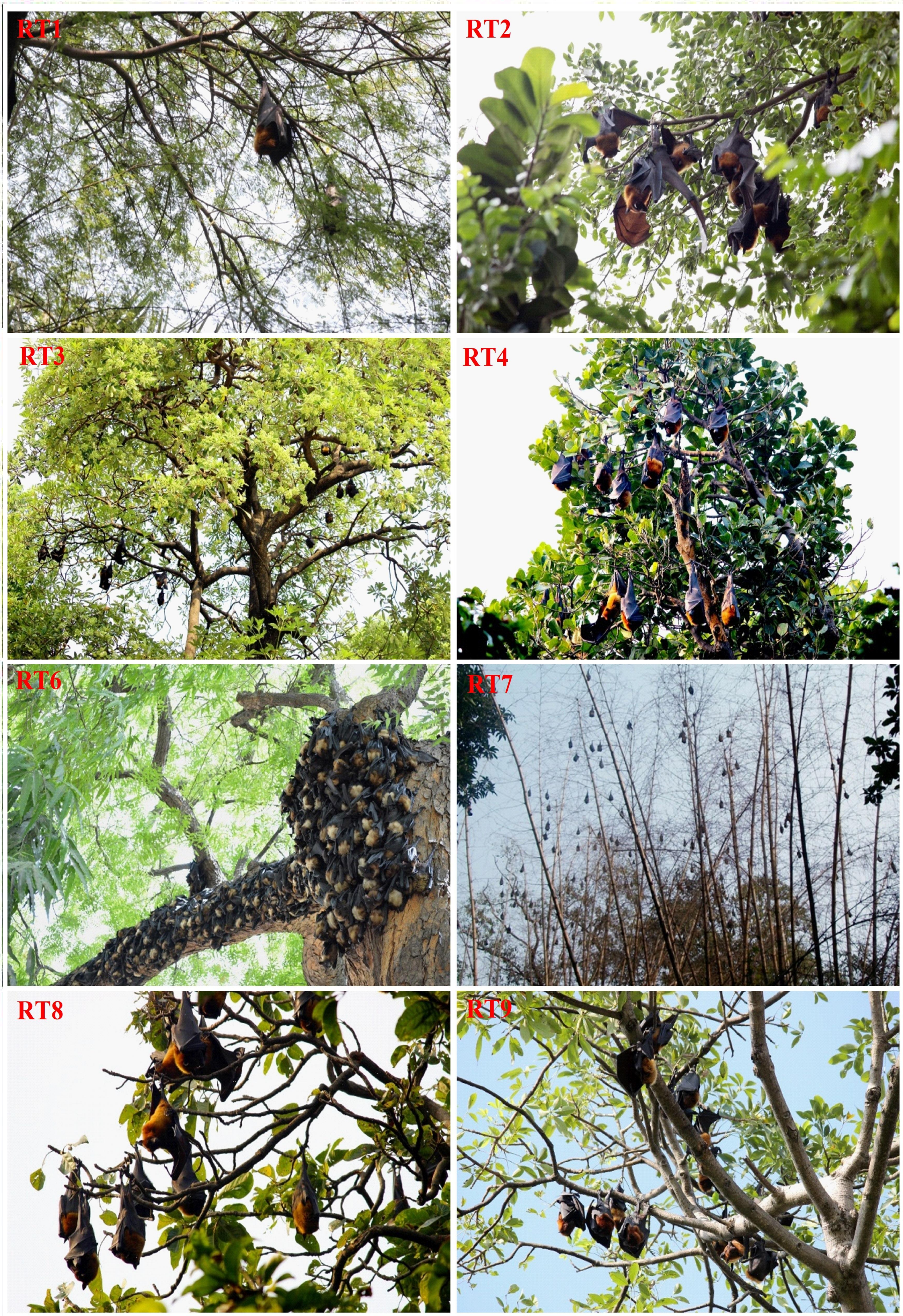

Fig.2a. Details about the roost trees (RT 1 – 9) of *Pteropus giganteus* in study area.

Fig.2b. Details about the roost trees (RT 10 – 17) of *Pteropus giganteus* in study area.

Fig.2c. Details about the roost trees (RT 18 – 26) of *Pteropus giganteus* in study area.

Fig.2d. Details about the roost trees (RT 27 – 30) of *Pteropus giganteus* in study area.

Table 1. Distribution and average population size of *Pteropus giganteus* in the study area. The preferred roost trees along with number of colonies of *P. giganteus* with reference to the geographical coordinates of the study area.

Roosting sites	GPS coordinate	No. of colonies	Population ($\bar{x}$ ± SD)	Roost trees*
Ambedkar Nagar	26°28'6.22"N; 82°41'29.55"E	6	359.6 ± 136.4	RT1, RT2, RT6, RT9, RT12, RT16, RT21 and RT23
Amroha	28°54'15.70"N; 78°28'1.61"E	1	750 ± 0	RT9, RT13, RT18 and RT21
Azamgarh	30°33'31.67"N; 75°50'25.17"E	3	607.0 ± 437.5	RT4, RT6, RT9, RT11, RT13 and RT20
Badaun	28° 7'47.80"N; 78°55'43.77"E	4	464.2 ± 108.5	RT1, RT2, RT9, RT11, RT13, RT16, RT19, RT21, RT25 and RT26
Baghpat	28°56'31.78"N; 77°13'34.12"E	1	250 ± 0	RT4, RT12 and RT20
Ballia	25°46'16.86"N; 84°10'30.59"E	4	426.7 ± 138.3	RT4, RT6, RT11, RT12, RT13, RT21 and RT25
Barabanki	26°59'43.82"N; 81°15'6.78"E	5	541.6 ± 269.4	RT4, RT6, RT7, RT10, RT11, RT13, RT18, RT19, RT21 and RT25
Bareilly	23° 0'30.61"N; 78°14'2.85"E	3	606.6 ± 517.3	RTRT11, RT13, RT18, RT21, RT23, RT26, RT27 and RT30
Basti	26°49'3.65"N; 82°45'47.93"E	2	575.0 ± 106.0	RT4, RT6, RT9, RT11, RT12, RT13 and RT25
Bijnor	29°22'20.79"N; 78° 8'9.05"E	5	586.2 ± 360.4	RT1, RT4, RT5, RT6, RT9, RT7, RT11, RT13, RT18, and RT21

Roosting sites	GPS coordinate	No. of colonies	Population ($\bar{x} \pm$ SD)	Roost trees*
Deoria	26°29'10.45"N; 83°47'1.76"E	2	537.5 ± 112.5	RT1, RT2, RT6, RT7, RT17 and RT20
Faizabad	26°46'23.69"N; 82° 8'38.99"E	7	453.4 ± 124.2	RT2, RT3, RT5, RT11, RT12, RT13, RT15, RT16, RT18, RT20, RT21, RT25 and RT26
Firozabad	27° 9'32.76"N; 78°23'44.73"E	1	450 ± 0	RT4, RT22 and RT23
Hardoi	27°23'54.58"N; 80° 7'54.13"E	1	395 ± 0	RT1, RT4, RT9 and RT25
Kanpur	26°26'59.72"N; 80°19'54.74"E	1	1250 ± 0	RT3, RT4, RT10, RT11, RT13, RT14, RT22 and RT23
Kanpur Dehat	26°31'36.51"N; 79°49'46.96"E	1	250 ± 0	RT4, RT11, RT13 and RT21
Lakhimpur Kheri	27°56'56.66"N; 80°46'56.63"E	3	466.7 ± 112.4	RT1, RT4, RT5, RT6, RT9, RT12, RT13, RT20 and RT25
Lucknow	26°50'48.10"N; 80°56'46.20"E	6	562.1 ± 424.5	RT3, RT4, RT6, RT8, RT9, RT11, RT13, RT15, RT20, RT23 and RT25
Meerut	28°59'4.06"N; 28°59'4.06"N	2	559.5 ± 252.1	RT8, RT11, RT13, RT21, RT23 and RT25
Muzaffarnagar	29°28'21.58"N; 77°42'30.79"E	1	1150 ± 0	RT6, RT11, RT13, RT20, RT28 and RT29
Pilibhit	28°35'0.56"N; 80° 0'31.59"E	5	513.0 ± 102.9	RT7, RT8, RT10, RT11, RT13, RT21, RT25 and RT26
Raebareli	26°14'4.31"N; 81°14'27.13"E	2	258.5 ± 8.5	RT4, RT13, RT21 and RT25
Saharanpur	29°58'1.48"N; 77°33'3.66"E	1	1225 ± 0	RT4, RT15, RT6, RT9 and RT13
Siddharth Nagar	27°16'17.63"N; 82°49'15.51"E	5	203.8 ± 79.5	RT4, RT9, RT10, RT11, RT13, RT18, RT21 and RT25
Sitapur	27°35'2.05"N; 80°39'58.88"E	3	555.6 ± 99.6	RT3 RT4, RT10, RT12, RT13 and RT21
Sultanpur	26°50'48.10"N; 80°56'46.20"E	5	396.0 ± 106.1	RT4, and RT5, RT9, RT6, RT11, RT13, RT21 and RT25
Unnao	26°32'21.64"N; 80°29'16.15"E	1	426 ± 0	RT11, RT13 and RT21

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RESEARCH ARTICLE.........

Diurnal reproductive behaviour of Indian flying fox, *Pteropus giganteus*

RAM KUMAR, DEEP NARAYAN PRASAD AND **VADAMALAI ELANGOVAN**

ABSTRACT...... The reproductive behaviour of Indian flying fox, *Pteropus giganteus* was observed at a maternity colony situated in Ambedkar Nagar district of Uttar Pradesh, India. The behavioural activities of *P. giganteus*at pre- and post-copulation period was observed. The bats were actively involved in copulation form July to November,however the frequency of copulation was higher during September. Although, bats were engaged on reproductive activities over the day but intensive copulation was observed during the forenoon than afternoonhours. The bats chosen the peripheral and open canopies for copulation than leafy and dense area. The male individuals consistently courted the females by stretching their wings, licking vulva and producing vocal sounds. The observation on vulva licking showed a significant relationship with duration and frequency of copulation. Hence, the finding of this study may use substantially in further studies with reference to reproductive aspects of bats biology.

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KEY WORDS...... Copulatory behaviour, *Pteropus giganteus*, Reproductive season, Roost site selection

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INTRODUCTION...

The order chiropterare present an amazing biodiversity of about1300 species identified form various geographical regions (Shi and Rabosky, 2015). The inaccessible roost height makes them a typical taxa and hence, very fewer studies have been carried out on various aspects of bats (Maruthupandian and Marimuthu, 2013). During reproductive seasons, flying foxes are actively involved in various reproductive activities (Tan *et al*., 2009; Maruthupandian and Marimuthu, 2013 and Sugita, 2016). Therefore, this study was aimed to observe and quantify the reproductive behaviour of Indian flying fox, *Pteropus giganteus* in Uttar Pradesh.

RESEARCH METHODS....................................

An extensive field observation was carried out between 2013 and 2016 during the reproductive seasons of *Pteropus giganteus* in a colony located at Nassulapur, Ambedkar Nagar district, Uttar Pradesh, India (26°32'40.81"N; 82°33'40.59"E). The individuals of *P.*

giganteus were roosting on *Ficusbenghalensis* (n = 1), *Azadirachta indica* (n = 1), *Mangifera indica* (n = 13) and *Ficus religiosa* (n = 1). The reproductive behaviour of *P. giganteus* was observed from a vantage point. In addition, the frequency, time and duration of copulations were observed. Further, the frequency of wing stretching, vulva licking, and grooming was observed through binocular and precisely recorded through stopwatch. The pearson correlation (r) was applied to study the relationship between the duration of vulva licking and copulation.

RESEARCH FINDINGS AND ANALYSIS...........

After the home flight, the individuals of *P. giganteus* were actively engaged in roost alteration which facilitated them finding suitable mates.The male batsmade many circling flights around the roost and exhibited quadrapedal movement until finding a suitable mating partner. The bats have selected a few tree species such as *Ficusbenghalensis* (n = 1), *Azadirachta indica* (n = 1), *Mangifera indica* (n = 13) and *Ficus religiosa* (n = 1). The roosting pattern of *P. giganteus* varied over reproductive season, a few individuals of *P. giganteus* were roosting at the base branches of the roost tree while reproductively active individuals observed at peripheral canopies. Hence, the reproductively active bats were observed from peripheral canopies rather than dense and leafy area. The reproductive behaviour of *P. giganteus* was varied over the reproductive season from July to November. The higher number of copulation was recorded during September (6.3 ± 5.7 SD) followed by October (3.3 ± 3.0 SD) while very few copulations were observed during July (1.2 ± 0.4 SD) and November (1.0 ± 0.5 SD, Fig. 1a).

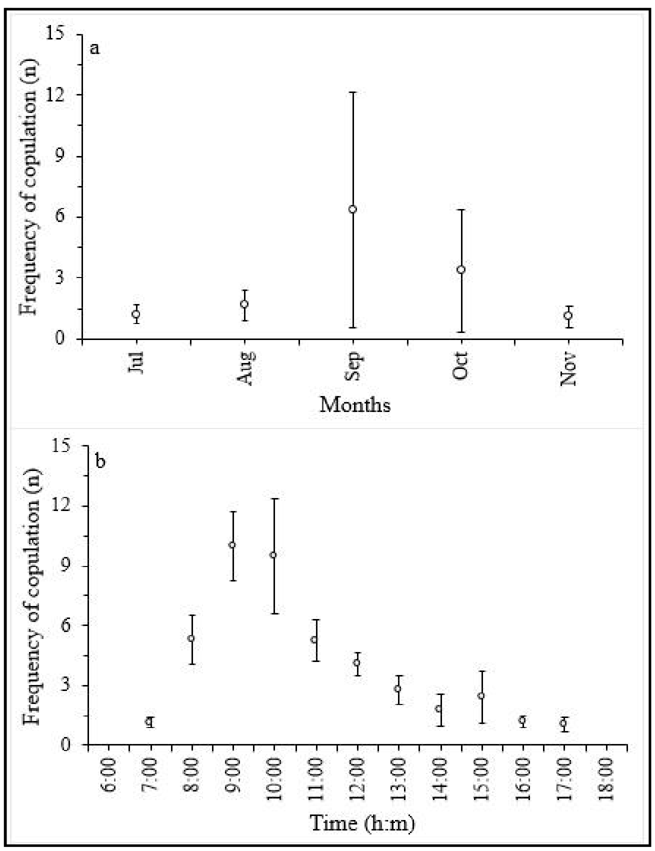

Fig.1(a): The frequency of copulation during the reproductive season of *Pteropus giganteus* and (b) : The pattern of reproductive activity of *Pteropus giganteus* at roostduring day hours

The bats made loud screams during copulation and they were more active during cloudy hours than sunnyperiod. The male bats were very active and involved in courting of females mainly during forenoon (cloudy hours) than afternoon (sunny hours, Fig. 1b). As pre-copulation activity, the malebat approacheda female and courted by stretching its wings. The male exhibited an average 16.2 ± 4.5 SD wing stretching and 65.5 ± 26.8 S D vocalization prior to copulation. The courting behaviour is associated with sexual potentiality of male and determine mate choice in *P. giganteus*. Once a male courted a female, the male engaged in vulva licking (36.32 ± 6.48 sec, *n* = 84, Fig. 2a) before copulation. During the copulation, the male gripsthe female through claws and mouth and sometimes wraps by patagium. The duration of vulva licking by a male was directly proportional to the duration and frequency of copulation (*r* = 0.835, Fig. 3). The copulation was observed from both dorsal and ventral side of the body (dorsal mountingin Fig. 2b). After the copulation, both the sexes were segregated from each other and settled for a while. They also engaged in grooming of genital organ, snout and patagium for an average 50.34 ± 9.84 sec (Fig. 2c). On various occasions, the potentially active male was exchanged the roost trees for exploring other mating opportunities while the female retained the same roost.

In the present, it was observed that the individuals of *P. giganteus* actively involved on copulation between July and November, while the peak copulation was observed during September (Mathur *et al.*, 2012; Maruthupandian and Marimuthu, 2013 and Baki *et al.*, 2015). The high frequency of copulation observed at

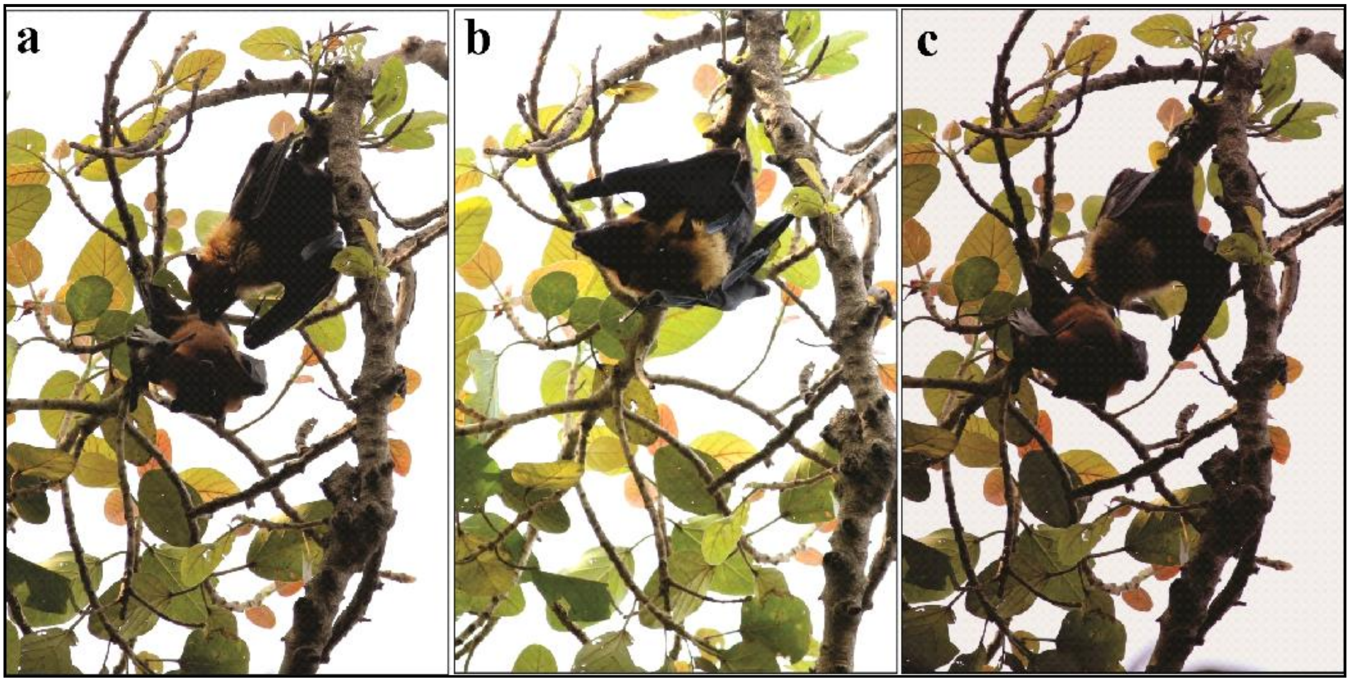

Fig. 2(a): Showed the reporductive activities of *Pteropus giganteus* during copulation such as vulva licking, (b) dorsal mounting and (c) grooming of body organs after copulation

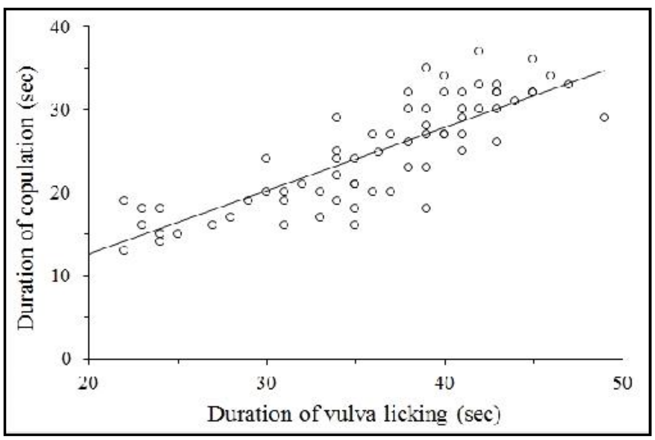

Fig. 3: The effect of vulva lickingon copulation duration of *Pteropus giganteus*

forenoon suggest the existence of pleasant weather and biologically active period than afternoon. It may also be a matter of physical fitness, as the bats accumulate higher energy after their home flight. Moreover, warm weather conditions favours reproduction and fetus development while hot and dry seasons inhibit the reproduction and even cause mortality in flying foxes (Welbergen *et al*., 2008).

The exhibition of various behavioural activities such as wing stretching, vocalization and licking of genital region was commonly observed in this study. Generally, male stretches wings for demonstration of it potentiality and attracting the females. The pre-copulatory activities had a significant impact on the duration of copulation. It suggest that male spent more body energy in pre-mating activities than rest of the social activities. Therefore, the physical strength of male have a crucial role in reproductive behaviour (Kyogoku, 2015 and Takakura and Fujii, 2015). It is obvious that the foreplay altered copulation and played a significant role in the reproductive aspects of bats (Tan *et al*., 2009; Maruthupandian and Marimuthu, 2013 and Sugita, 2016). In the present study, it was also observed that *P*. *giganteus* copulates from both dorsal and ventral sides. Though body plan during copulation is the matter of change but it was not estimated that which axis is more viable however, copulation form both axis (e.g. dorsal and ventral) are well elaborated in various studies (Mathur *et al*., 2012; Maruthupandian and Marimuthu, 2013 and Baki *et al*., 2015).

The segregated mating partner grooms patagium, toes and genital organs independently which presumably provide enhanced reproductive fitness in *P*. *giganteus* (Maruthupandian and Marimuthu, 2013). The outcome of this study may pave various novel approaches on reproductive of *P. giganteus*.

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crop (HYPERLINK \l "_ENREF_321" \o "Ullio, 2002 #54" Ullio, 2002 ; HYPERLINK \l "_ENREF_336" \o "Wanger, 2014 #55" Wanger et al., 2014 ; HYPERLINK \l "_ENREF_13" \o "Aziz, 2016 #297" Aziz et al., 2016) but seed dispersal by them, boomed seed viability and also enhance the seed germination capacity (HYPERLINK \l "_ENREF_63" \o "Djossa, 2008 #81" Djossa et al., 2008 ; HYPERLINK \l "_ENREF_97" \o "Galindo-González, 2009 #78" Galindo-González et al., 2009 ; HYPERLINK \l "_ENREF_125" \o "Helbig-Bonitz, 2014 #82" Helbig-Bonitz et al., 2014 ; HYPERLINK \l "_ENREF_16" \o "Baldwin, 2015 #83" Baldwin and Whitehead, 2015) . In this context, various studies suggested a fundamental difference between the foraging behaviour of bats and birds such as fruit bats prefer foraging on the fibrous fruits which may contain essential oils with hard rinds but generally birds mostly avoided such fruits while foraging (HYPERLINK \l "_ENREF_98" \o "Galindo-González, 2000 #223" Galindo-González et al., 2000 ; HYPERLINK \l "_ENREF_27" \o "Bianconi, 2007 #86" Bianconi et al., 2007) . Flying foxes systematically select and forage on freshly ripe fruits and drop food remnants underneath of feeding roost as ejected pellets. In some cases, they brought the entire fruits at their night roost. Accidentally, it dropped on the flyway or sometimes reached up to the night roost (HYPERLINK \l "_ENREF_217" \o "Muscarella, 2007 #30" Muscarella and Fleming, 2007) .

A study was conducted on the Ryukyu flying fox, P. dasymallus showed no apparent conflict with human dwellings (HYPERLINK \l "_ENREF_178" \o "Lee, 2009 #87" Lee et al., 2009 ; HYPERLINK \l "_ENREF_220" \o "Nakamoto, 2009 #104" Nakamoto et al., 2009)

while another study revealed a positive conflict with grove owner and P. giganteus in Myanmar. Further, it is also mentioned that P. giganteus accessed 24 plants as food amongst 13 fruits species also consuming by residing peoples (