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RESEARCH ARTICLE

Avenue Plantations as Biodiversity Havens: A Case Study of Population Status of the Indian Flying Fox, *Pteropus giganteus* Brunnich, 1782 and Implications for Its Conservation in the Urban Megacity, Delhi, India

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Abstract This study provides the primary information about the population of *Pteropus giganteus*, a mega fruit-bat, having a permanent roost in avenue plantations of Delhi, India. These avenue plantations of Lutyens' Delhi have a variety of tree species which serve as habitats for both roosting and foraging of fruit-eating bats, *P. giganteus*. These avenue trees comprise of species like *Terminalia arjuna, Ficus microcarpa, Syzigium cumini, Polyalthia longifolia* and *Putranjiva roxburghii*. The Indian flying fox (*P. giganteus*) was observed roosting on nine species of avenue trees in Delhi in the present study, which was undertaken for a period of 3 years from April 2014 to June 2017. In this study period, the peak colony size was observed in May, 2014 (1660 individuals). The flying foxes use 9 species of avenue trees for roosting, where the largest colony size was observed on *T. arjuna*. This zone is the only roosting location of the Indian flying fox in Delhi, which plays an important role in seed dispersal and pollination. The colony size was largest during the spring-summer months which showed a gradual decrease with the decline in temperature during winters. Although, year round *T. arjuna* had the maximum number of individuals from the colony whereas *Cassia fistula, Delonix regia* and *Bombax ceiba* had the least. The result provides the scope for an uncharismatic species beyond protected area and organismal biology, towards linkages of functional landscapes and urban ecosystem services. With proper monitoring, this area has huge potential to be converted into a 'Conserved Roosting site' of *P. giganteus.*

Keywords Avenue plantations · Trees · Fruit-bat (*Pteropus giganteus*) · Population · Roost · Conservation · Delhi

Introduction

Bats belong to the order Chiroptera, which constitutes of the only mammals to have evolved with the mechanism of true flight. This order is the most diverse order after Rodentia (Srinivasulu and Srinivasulu 2001; Fenton and Simmons 2014). Among the countries representing South Asia, India has more than 90% of the total bat diversity of this region, with about 125 species of bats belonging to 8 families that have been reported from the country (Srinivasulu et al. 2010; Saikia et al. 2017; Senacha and Dookia 2013; Thong et al. 2018). There exists a huge research gap relating to the research studies on bats of Delhi. Very few studies have been undertaken after the independence of India, on this group of mammals (Brosset 1962a, b, c; Sinha and Sati 1997; Srinivasulu and Srinivasulu 2007; Mishra and Dookia 2015). According to the latest studies (Srinivasulu and Srinivasulu 2007; Dookia and Mishra 2018), Delhi has 14 species of bats out of which 3 are frugivorous species whereas 11 are insectivorous. The Indian Flying Fox, *Pteropus giganteus*, is the biggest and most conspicuous of all fruit bats in India and also one of the largest bats in the world (Mathur et al. 2012).

This particular bat species, roosts on avenue trees in Central Delhi, called the Lutyens' Bungalow Zone (LBZ), which has plenty of old and well-canopied trees on both sides of the road (Krishen 2006). This is the only roosting

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location of the species in Delhi. Flying foxes use a total of 9 species of avenue trees for roosting in Delhi. The LBZ, is an area of very high security pertaining to the residences of important persons in the political hierarchy of the country. Delhi, being the capital city, has an immaculately planned infrastructure where greenspaces, both natural and plantations, have been given their due importance, although the fringes of the city have been losing their greens to the rapid urban growth. The forest cover alone constitutes 20.22 per cent of the total 1483.01 sq. km. geographical area and comprises 6.94 sq. km. very dense forest, 57.15 sq. km. moderately dense forest and 124.68 sq. km. open forest (FSI 2015).

This study focused on documenting the colony size of *P. giganteus* in Delhi. Traditionally, population is defined as a group of individuals of a single species that inhabits a specific area during a specified period of time (Kunz et al. 2009). As most bat species are highly mobile, colony type may vary seasonally based on different life-history stages such as during maternity, transient, swarming and hibernating periods (Kunz et al. 2009). A large scattered roost is present in central Delhi on huge trees planted along the roadside. The Indian Flying Fox belongs to the family Pteropodidae and the suborder Yinpterochiroptera. Family Pteropodidae consists of 43 genera and about 165 species which are distributed throughout the world (Teeling et al. 2005). There are 14 species of fruit bats belonging to 8 genera, found in the Indian subcontinent (Bates and Harrison 1997). On the global scale, the conservation status of the Indian flying fox is assessed as 'Least Concern'. It is one of the most persecuted bats in South Asia and was listed as Vermin under Schedule V of the Indian Wildlife (Protection) Act 1972 (Molur 2008; Singaravelan et al. 2009). This classification has since been rectified and the Indian Flying Fox has been moved up to Schedule IV of the Indian Wildlife (Protection) Act 1972. This study provides baseline information about the roosting of this species in Delhi which will be beneficial for its future conservation management.

Materials and Methods

Study Area

This study was carried in the capital city of India, Delhi. There is only one roosting location of Indian flying fox in the metropolitan city. The colony sites fall in the New Delhi district known as the Lutyens' Bungalow Zone (LBZ) (Fig. 1). The bats roost on large avenue trees which are planted alongside the wide roads in Lutyens' Delhi (Fig. 2). Avenue plantation has long been practiced for the aesthetic value, purpose of shade, control of soil erosion and for its economic use plant products. Avenue tree plantations in New Delhi were planned in the early 20th century, when the imperial capital of British India was shifted from Calcutta to Delhi in 1912. The British New Delhi is often called Lutyens' Delhi after Sir Edwin Lutyens, the architect associated with the grand plan of designing the new capital city. This zone is known as the Lutyens' Bungalow Zone and is the most prominent, properly planned and high security area of the Indian capital city. While selecting tree species to be planted along roadside avenues, the planners and horticulturists under Sir Lutyens selected species of evergreen and few deciduous trees. But, due to the semi-arid and dry weather in Delhi many species are seen bare in the autumn months. These trees in the LBZ, include both the native trees and the species planted during the British regime more than 100 years ago. Every road has specific tree species are planted alongside which is shown in Fig. 3.

Data Collection

A preliminary opportunistic reconnaissance survey of the location was done in February 2014. Direct Roost Count (Kunz et al. 2009) was followed to collect primary data on the population (colony size) and the roosting tree species from April 2014 to June 2017. Direct Counts were done several times instead of counting just once on every visit. Flying foxes are known to have both single roosts where large congregations occur on a single tree and scattered roosts where the individuals roost on various trees in a specific area. This particular roost was scattered on 48 trees belonging to nine species. Tree estimation method (Molur et al. 2005), where the number of bats are counted on a tree and then multiplied by the number of trees was avoided because some trees had numbers as high as 600 and some as low as 10. Hence the method of Direct Counts was followed. The observations were made with the help of high resolution binoculars and camera. The site was regularly visited each month starting from April 2014. The survey was conducted during the day time starting at 9 in the morning and ended just before dusk (as per the season) as the bats then set out to forage for the night. On each visit the number of individuals was counted on each tree and summed up to determine the colony size. The total number of trees which had bat roosts was counted along with the taking down the tree species name. Microclimatic variables like temperature and humidity were recorded during each visit.

Data Analysis

The information regarding colony size, tree species, tree numbers and microclimatic parameters and compiled in

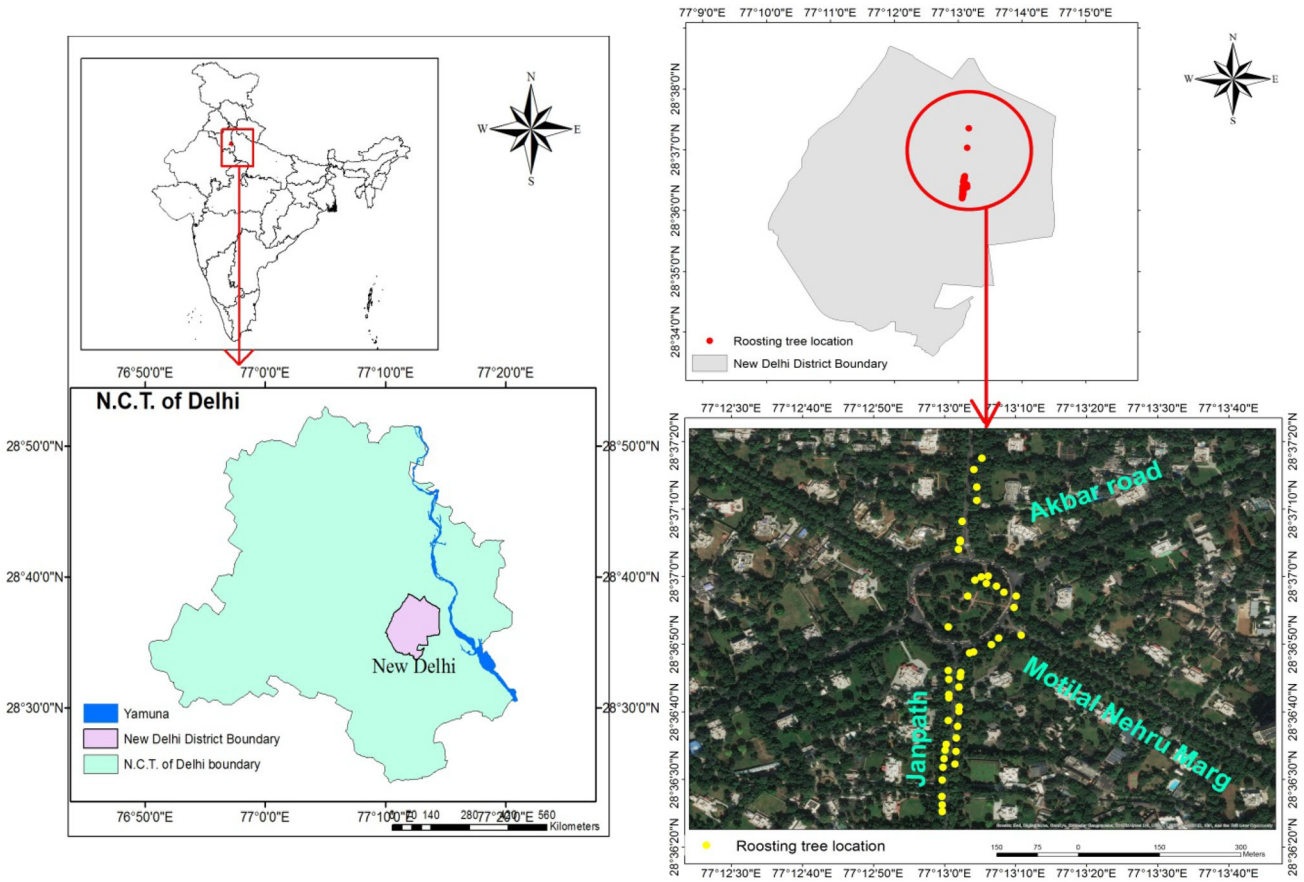


Fig. 1 Location of the roosting colony of *Pteropus giganteus* in Delhi, India

MS-Excel followed by data analysis and interpretation. Statistical Package for the Social Sciences version 20.0 (SPSS 2007) software was used for data analysis. Since the data did not follow a normal distribution, non-parametric

tests were used to analyze the data. Number of bats were expressed as mean, median and standard deviation and compared across the tree types and years using Kruskal–Wallis test. This was done to check the tree species that was most and least favored by the bats for roosting. The data was analyzed using the average value of each primary unit, in this case the number of bats, to avoid temporal pseudo-replication. Hence, the bats were expressed as mean, median and standard deviation. Spearman's Rank correlation coefficient was used to analyze the association of number of bats with temperature and humidity. Spearman's Rho is a non-parametric test for measuring the strength of association between two variables where the value of the correlation coefficient $\mathbf{r_s = 1}$, means a perfect positive correlation and the value $\mathbf{r_s = -1}$ means a perfect negative correlation. An alpha level of 5% was taken along with a 95% confidence interval i.e. any p value less than 0.05 was considered significant.

Results

Habitat Characteristics

The avenue trees in Lutyens' Delhi consist of 8 mainline species which are planted along major roads and 9 less common species confined mostly to single avenues (Table 1). Mainline tree species refer to trees that are planted along all major avenues. Jamun (*Syzigium cumini*), Arjun (*Terminalia arjuna*) and Neem (*Azadirachta indica*) are the most common and successful avenue trees planted on almost all major roads of Lutyens' Delhi (Fig. 3).

Pteropus giganteus uses 48 avenue trees belonging to nine species for roosting (Table 2). With p value < 0.001, the tree species has a significant association with the number of bats. While *T. arjuna* was the most favoured species for roosting with the maximum number of bats counted in every season, *Bombax ceiba* and *Cassia fistula* were the least favoured with the minimum number of individuals (Fig. 4). The average number of bats counted during each month for the 3 years study period is shown in Fig. 5. Janpath, which is almost a pure Arjuna avenue, is the most common road with the maximum number of bat

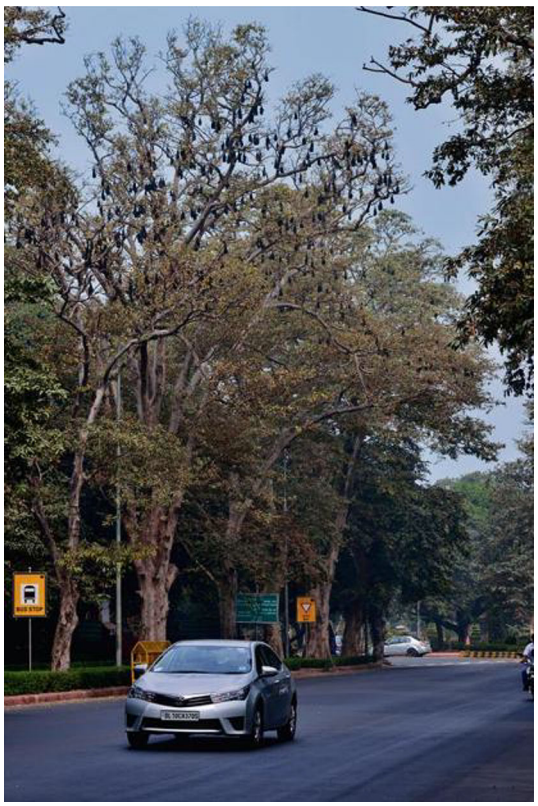


Fig. 2 Flying fox roosting on *Terminalia arjuna* tree, a part of the large roost, on Janpath

population on almost every Arjuna tree. Healthy population of bats was observed on some *Haplophragma* trees on Janpath and inside few bungalows. Adjacent roads like Motilal Nehru Marg and Akbar road have fewer bats on Putranjiva, Jamun and Ashoka trees. While surveying, it was observed that 25 trees of *T. arjuna* are used by bats for roosting, whereas only 1 tree each of *Delonix regia*, *B. ceiba* and *Cassia fistula* species had bats roosting. There was no significant variation in number of bats across the years of study.

Colony Size

The counts were conducted monthly beginning from April 2014 to June 2017. The corresponding temperature and relative humidity were also recorded simultaneously. The colony size varied considerably in the study area. During the study period, the peak population was observed in May 2014 (1660 ± 175.3 individuals) and lowest number of individuals was recorded in January 2017 (400 ± 54.9 individuals), with a clear trend of seasonal variation in the average number of individuals (Fig. 5). *Terminalia arjuna* was the most densely populated tree year round with the maximum number of bats counted on one tree at a time was 600 ± 143.76. *Cassia fistula*, *D. regia* and *B. ceiba* were equally least populated with the maximum number of bats counted on one tree of each of these species at a time being 18 ± 7.27. The standard error of mean is calculated to avoid bias as bats are highly mobile organisms and the counts were conducted more than once during each visit.

Effect of Microclimatic Parameters (Temperature and Humidity) on the Colony Size of *P. giganteus*

The association of temperature and humidity with the number of bats was calculated using Spearman's Rho. There was a considerable seasonal variation in the total number of bats that was recorded. The maximum numbers of bats were counted in the spring-summer season when the temperature ranged between 25 and 40 °C. With the approach of the colder winter months, the numbers gradually started to decrease. The minimum numbers were observed in the temperature range of 5–10 °C. The factors affecting the decreasing number of bats with temperature are not clearly established, but there are no reports of hibernation of Indian flying fox from the country.

With p value < 0.001 there was a significant positive correlation between number of bats and temperature (Fig. 6). However, at **0.191** the Spearman's Rho correlation coefficient ($\mathbf{r_{s)}}$ was weak.

With 0.636 as p value, humidity had no positive correlation with the number of bats (Fig. 7). Observations were randomly distributed along the relative humidity ranging from 40 to 85%. The Spearman's Rho in this case was $\mathbf{r_s = -\ 0.026}$.

Discussion

Habitat Characteristics

The population of *P. giganteus* has been found roosting in multiple tree species (Dookia and Tak 2004; Chakravarthy and Yeshwant 2008; Bhatnagar and Salvi 2011; Senthikumar and Marimuthu 2012; Dey et al. 2013; Manandhar et al. 2017). The present study shows that the flying fox roosted in 9 species of trees in Delhi. *Terminalia arjuna* was the most preferred tree species for roosting with 25 individual trees of the species being used as roosts by bats. Since, this is the first comprehensive study of roosting characteristics of *P. giganteus* from Delhi, it is not known what tree species were favoured by the bats in Delhi in the past. The avenue trees in the Lutyens' Bungalow Zone (LBZ) were the only roosting location of flying fox in Delhi. The major avenues occupied by the bats in the area are Janpath, intersection of Motilal Nehru road and Janpath, intersection of Akbar road and Janpath and the roundabout at Windsor circle. Though after dusk, the bats

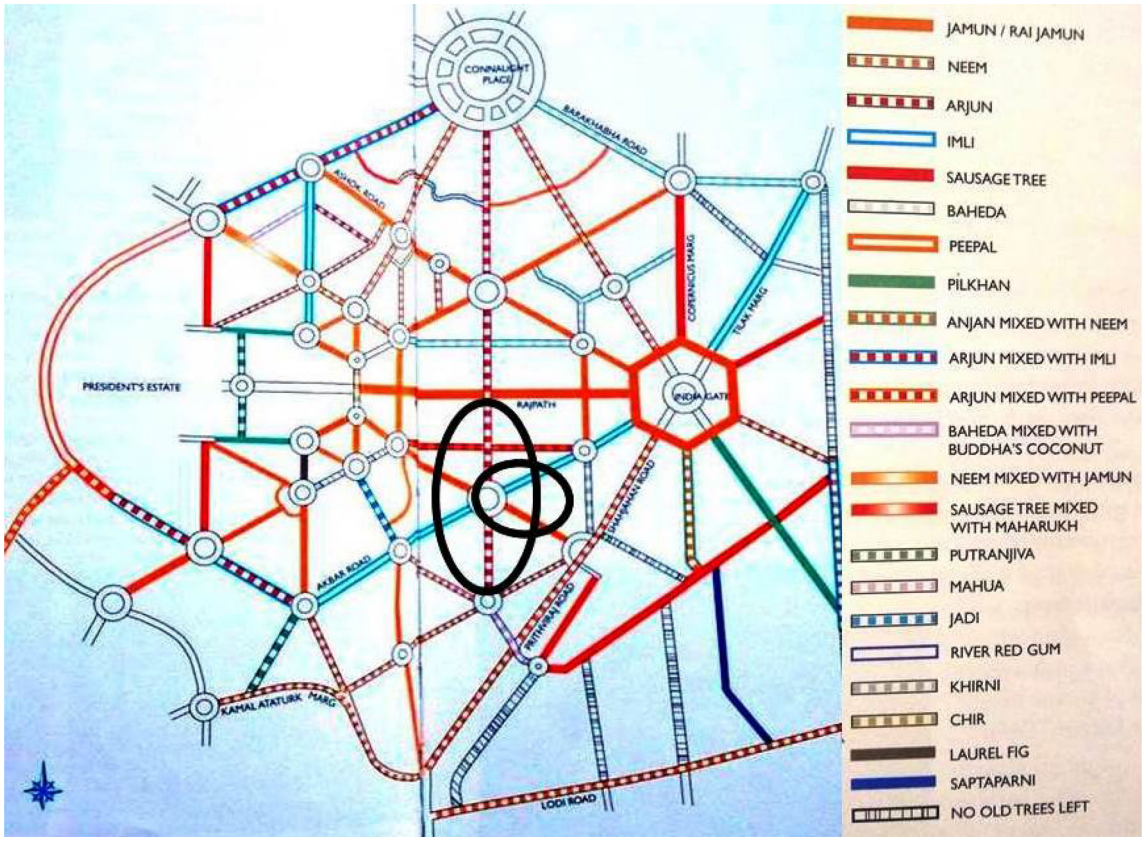


Fig. 3 The detailed avenue roads of Lutyens' Delhi depicting the names of the trees planted alongside them. The black circles show the avenues with the Flying Fox roosts. *Map source* Krishen (2006)

have been spotted flying in many locations all over Delhi including Connaught place, Kamala Nehru ridge, Yamuna Biodiversity park, Central ridge, Sunder Nursery and Southern ridge, but that was just in search of fruiting trees available for foraging. Bats were seen consuming the fruits of Arjun (*T. arjuna*), Jamun (*S. cumini*), Date Palm (*Phoenix dactylifera*), Putranjiva (*Putranjiva roxburghii*) and Peepal (*Ficus religiosa*) at multiple occasions after dusk. The fruits of Arjun, Jamun and Putranjiva were also consumed occasionally during the day while the bats rested in the roost. The bats slept and lazed for most of the time during the day with flapping and stretching their wings occasionally. The use of camera to inspect the roost was often limited as the area falls under a 'Restricted photography' zone. With the onset of summer and the temperature often crossing 40 °C, the bats were frequently seen sticking their tongue out for perspiration. During heavy rain and foggy or partly cloudy weather, the bats were observed to be sleeping. The same behavior of the Indian flying fox was also reported from Kathmandu Valley, Nepal (Manandhar et al. 2017). Behavioural data was not collected for this study and these are just occasional mentions that were very commonly observed.

Colony Size

The bats occupied 48 trees of 9 different species for roosting, suggesting that this is a scattered roost. The number of individuals fluctuated significantly between summer and winter months and there also was a variation in the number of roost trees used with the colony size. The pattern of fluctuation was similar for each year over the course of the 3-year study. An increased number of individuals were observed from the months of April to October. As the temperatures started dipping with the onset of November, the number of bats also decreased simultaneously. This suggests the possible local migration of flying foxes to the roost and also away from the roost. But, nothing is known about the original location of these migrating bats or the reason behind their migration. The flying-fox family (Pteropodidae) consists of many highly mobile species capable of long and strong flight but little is known about the pattern of their migration (Roberts et al. 2012). Migratory bats are among the most poorly understood of migratory taxa, with relatively little information available on their behavior and ecology during migration as is suggested from previous studies (Mickleburgh et al. 2002; Holland and Wikelski 2009). The seasonal

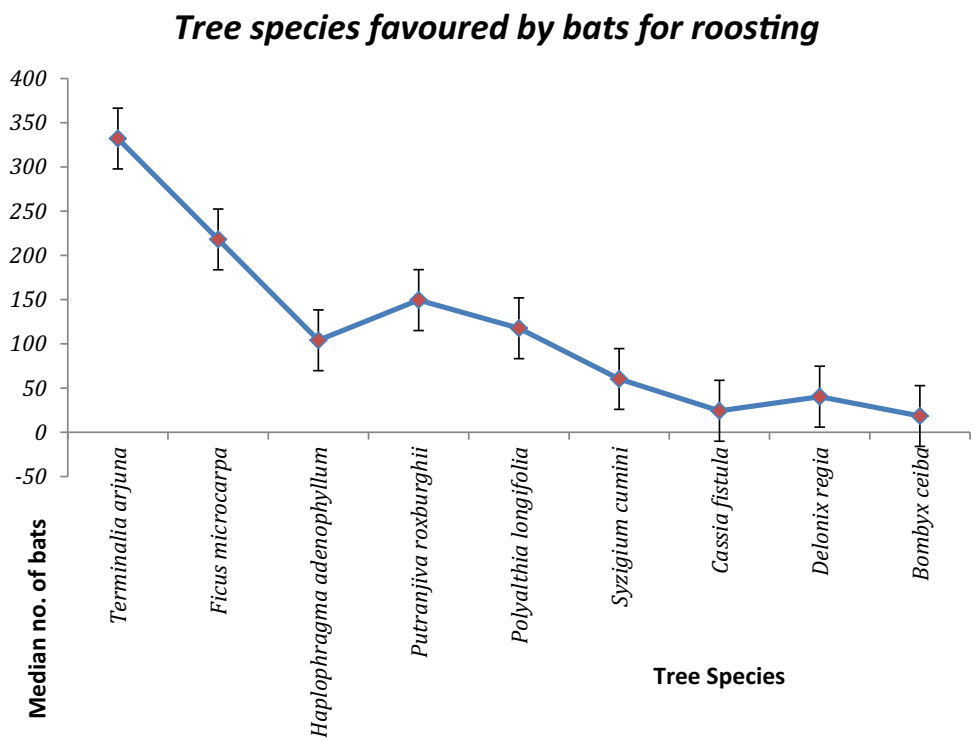
Table 1 Avenue tree species planted in Delhi and their location

S. no.	Tree species	Common name	Location
Mainline species			
1.	*Syzigium cumini*	Jamun	Tughlak road, Rajaji Marg, Tyagraj, M.L. Nehru marg, Ferozshah road, Sunehri bagh road
2.	*Azadirachta indica*	Neem	Safdarjung road, Lodhi road, Prithviraj road, Ashok road
3.	*Terminalia arjuna*	Arjun	Janpath, Akbar road, Tilak marg, Pandit Pant marg, Mother Teresa marg
4.	*Kigelia africana*	Sausage tree	S. Bharati marg, Humayun road, Amrita Shergill marg, Copernicus marg
5.	*Terminalia bellirica*	Baheda	Barakhamba road, Sikandra road, Rajendra Prasad road
6.	*Ficus religiosa*	Peepal	Baba Kharak Singh marg, Mandir marg
7.	*Ficus virens*	Pilkhan	Zakir Hussain road, Dalhousie road
8.	*Tamarindus indica*	Imli	Akbar road, Tilak road, Pandit Pant marg
Less common species			
1.	*Putranjiva roxburghii*	Putranjiva	Racecourse road, M.L. Nehru road
2.	*Madhuca longifolia*	Mahua	Southend road
3.	*Ficus amplissima*	Jadi	Krishna Menon marg
4.	*Eucalyptus camaldulensis*	River red gum	Tolstoy marg
5.	*Manilkara hexandra*	Khirni	Maulana Azad road, Man Singh road
6.	*Ailanthus excels*	Maharukh	Copernicus marg
7.	*Pterygota alata*	Buddha's coconut	Bishambhar Das marg
8.	*Hardwickia binata*	Anjan	Pandara road, Maulana Azad marg
9.	*Ficus microcarpa*	Laurel fig	Windsor circle roundabout, Rajaji marg

Table 2 Tree species used by *Pteropus giganteus* for roosting in Delhi

S. no.	Tree species	Common name	No. of trees with bat roosts	Location	No. of bats (Mean ± SD)
1.	*Terminalia arjuna*	Arjun	25	Janpath	332.16 ± 143.76
2.	*Ficus microcarpa*	Laurel fig	7	Windsor circle	218.11 ± 88.03
3.	*Haplophragma adenophyllum*	Katsagon	4	Janpath	104.05 ± 41.26
4.	*Putranjiva roxburghii*	Putranjiva	4	Motilal Nehru marg	149.46 ± 69.52
5.	*Polyalthia longifolia*	Ashok	3	M.L. Nehru Marg	117.57 ± 55.60
6.	*Syzigium cumini*	Jamun	2	M.L. Nehru/ Sunehri Bagh Road	60.27 ± 23.15
7.	*Cassia fistula*	Amaltas	1	Akbar Road	24.32 ± 13.85
8.	*Delonix regia*	Gulmohar	1	Intersection of Janpath and Akbar road	40.27 ± 17.71
9.	*Bombax ceiba*	Semal	1	Windsor circle	18.38 ± 7.27

availability and non-availability of food resources might also be the reason behind the migration of tropical bat species (Burland and Wilmer 2001). Very few bats remained in the roost during the months of December and January. This may be attributed to the extreme cold weather in Delhi when temperature often falls below 3 °C. Owing to the semi-arid climatic conditions in Delhi, the trees shed their leaves and go bare during late winters, which the bats might not prefer as dense foliage of the tree is lost. *Terminalia arjuna* is most favoured by the bats for roosting. This is a massive tree with a broad, oval crown and very dense foliage. This is one of the largest trees lining New Delhi's avenues and the height of its canopy from the ground is easily the highest among all avenue trees. This is a deciduous tree, but the leaves shed for a short period towards mid April and are renewed in late April or May. The fruits ripen and drop between February and June.



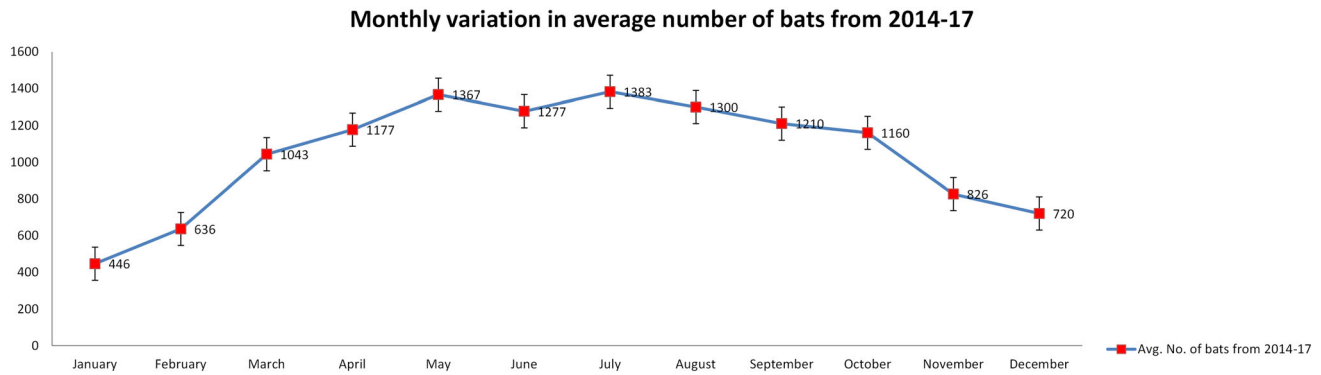


Fig. 4 Comparison of favourable tree species for roosting with the number of bats

Fig. 5 Seasonal variation in average number of bats during the study period

Absence of Factors Influencing Threats to the Species

Ongoing habitat loss due to anthropogenic pressures and the lack of conservation efforts are the most crucial threats to the survival of bats (Molur 2008). Fortunately, this roost in the avenue plantations of Central Delhi does not face much threat in the name of habitat loss. Since, these avenue trees were planted more than a century ago by the British, they stand strong and erect at the present day. The entire area has well-planned colonial bungalows and there appears no immediate threat in the near future under any urban development or renovation plan.

There are no high-tension electricity wires in the vicinity which reduces the chances of electrocution as is common in many parts of India (Rajeshkumar et al. 2013; Kumar and Kanojia 2015). In South-East Asia, nearly one quarter of Fruit Bat (Pteropodidae) species are projected to become globally extinct by the end of the 21st century, with Flying Foxes of the genera *Pteropus* and *Acerodon* being particularly at risk (Lane et al. 2006). In many parts of South-east Asia, the hunting of Flying Foxes as bush-meat and for their perceived medicinal properties is causing a significant decline in numbers (Mickleburgh et al. 2009; Mildenstein et al. 2016). Hunting of bats is not practiced in Delhi and hence is not a threat. But, the air quality of Delhi is degrading at an alarming rate with

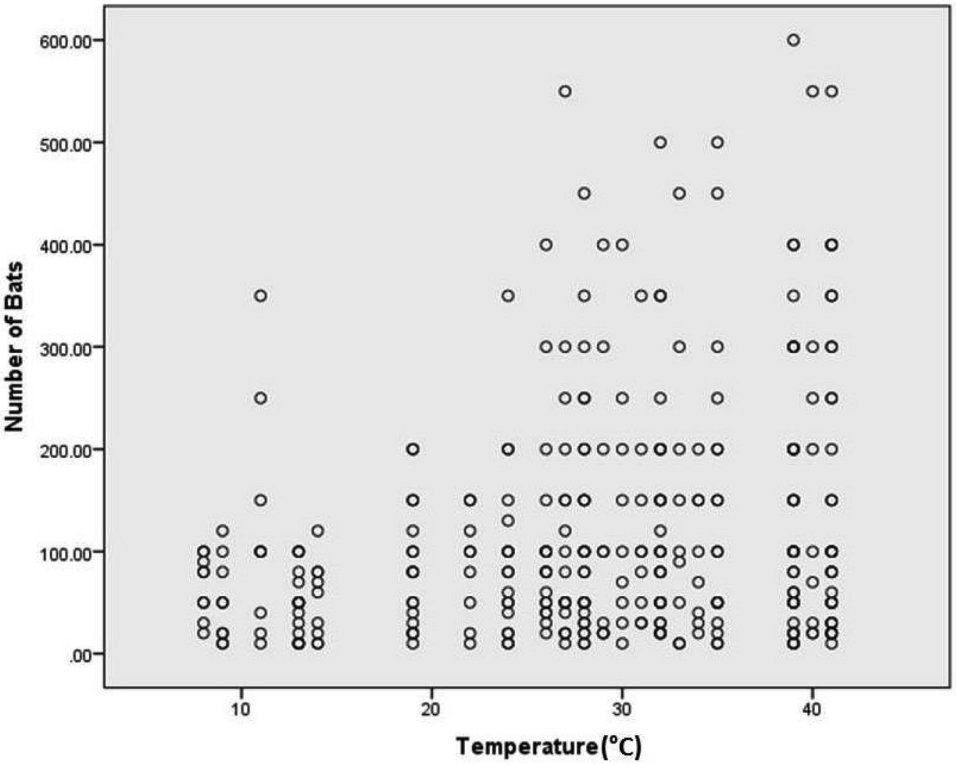


Fig. 6 Variation in number of bats with the change in temperature. The dots represent the number of observations made at the corresponding temperature

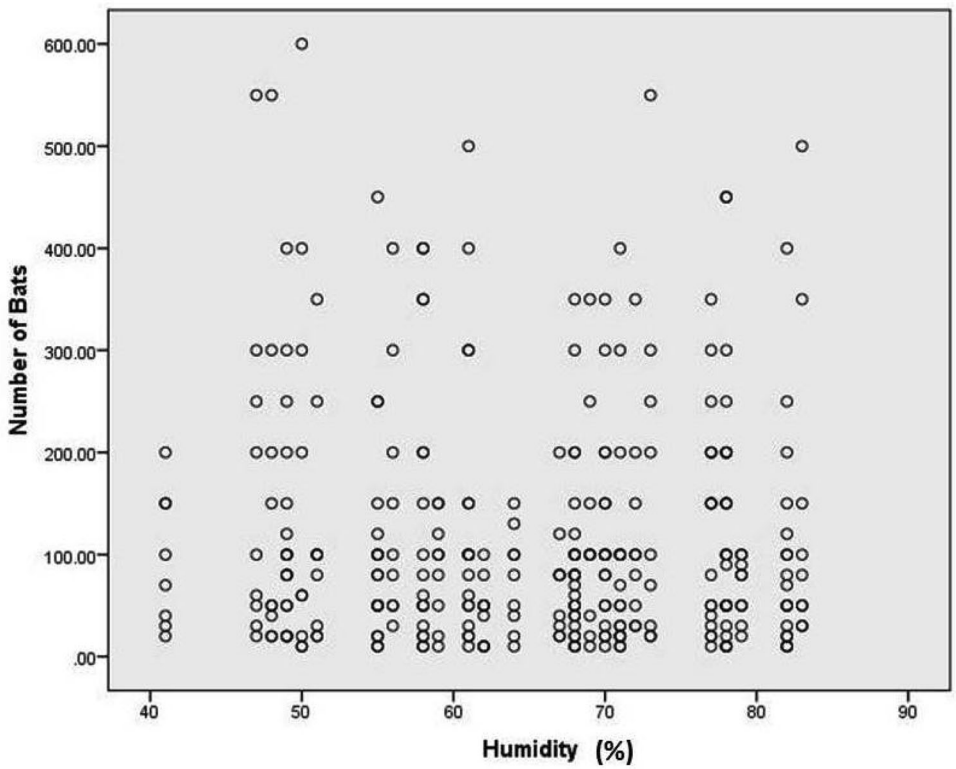


Fig. 7 Variation in number of bats with the change in humidity. The dots represent the number of observations made at the corresponding humidity

pollution levels rising to severe limits. Urbanization in the city and its fringes in exponentially increasing leading to concrete and vehicular, air and sound pollution which are unfriendly for bats and resident birds. Even if the roost trees are left undisturbed, if the roosting environment deteriorates, it will pose a serious threat to the survival of the Indian flying fox.

Implications for the Conservation of *P. giganteus* in the Avenue Plantations of Delhi

Trees in urban system provide a variety of ecosystem services including biodiversity conservation, removal of atmospheric pollutants, oxygen generation, noise reduction, mitigation of urban heat island effect, microclimate regulation, stabilization of soil, groundwater recharge, prevention of soil erosion and carbon sequestration (Bolund and Hunhammar 1999).Trees also have the potential to make a marked improvement on air quality by absorbing carbon dioxide and other pollutants. These avenue trees which were planted by the British with meticulous planning contribute significantly in increasing the urban greenspaces in Delhi, which are the most important indicators of a sustainable city. A recent study (Bhalla and Bhattacharya 2015) found that there were a total of 125 different tree species in Lutyens' Delhi in the present day scenario. In the recent past, a large scale tree felling order for infrastructure development was opposed and stopped by urban residents of Lutyens' Delhi.

The fact that *P. giganteus* roosts on these avenue trees should be given its due importance owing to the numerous ecosystem services provided by these bats. Almost all over India, fruit-bats, specially the Indian flying foxes are the most persecuted bat species because of the damage they cause to fruit orchards. Due to lack of proper knowledge, common people are not aware that flying foxes are responsible for pollination and seed dispersal of many fruiting tree species and the beneficial role of such bats and the ecological services they provide has not been considered significant (Singaravelan et al. 2009). Delhi has a healthy population of tree species like *Kigelia africana*, *Haplophragma adenophyllum* and *Crescentia cujete* that are specifically pollinated by fruit-bats. But, the persecutions associated with it led the Indian flying fox to be listed as Vermin under Schedule V of the Indian Wildlife (Protection) Act, 1972, which was recently rectified and the species was moved up to Schedule IV. Unlike other small mammals, fruit bats usually give birth to a single young (occasionally two, such as *Eonycteris)*, either once (e.g. *P. giganteus*) or twice (e.g. *R. leschenaultii* and *C. sphinx*) per year (Singaravelan et al. 2009). If the fruit bats of India are not protected, their populations will be drastically affected because of their low reproductive rate.

Since little is known about the fruit-eating pteropodid species of India, detailed long-term studies on their distribution, foraging and other behavior are the need of the time. The Lutyens' Bungalow Zone supports dense population of tree species favored by *P. giganteus* for roosting and foraging. Given the healthy population of the bats roosting on the avenue trees, the area has huge potential to be protected as a 'Conserved Roosting Site' or 'Special Conservation Site' for the Indian flying fox which will help create awareness about the species among citizens.

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Author Contributions RM carried out the field work for the study including data collection and analysis. RM prepared the manuscript. SD and PB revised the manuscript.

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Compliance with Ethical Standards

Conflict of interest The authors declare no conflicts of interest.

Human and Animal Rights This article does not contain any studies with human participants or animals performed by any of the authors. The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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