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Roost Preference in Three Species of Pteropodid Bats in Tirunelveli and Tenkasi, Tamilnadu, South India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Roost preference, roosting ecology and roost resource partitioning of megachiropteran bats in the plains of Tirunelveli and Tenkasi districts of Tamilnadu, South India, were investigated from January 2021 to December 2022. Three species of megachiropterans bats namely *Pteropus medius*, *Cynopterus sphinx* and *Rosettus leschanaulti* were recorded in the study area. *P. medius* roosts in open foliage on trees like *Terminalia arjuna* (46.90%), *Samanea saman* (13.53%), *Ficus religiosa* (12.09%), *Ficus benghalensis* (5.27%), *Bassia latifolia* (5.04%), *Tamarindus indica* (4.89%), *Sygium cumini* (4.71%), *Manjifera Indica* (2.32%), *Thespesia populnea* (1.93%), *Pongamia pinnata* (1.38%), *Pithecellobium dulce* (0.90%), *Albizia lebbeck* (0.74%), and *Azadirachta indica* (0.23%). *C. sphinx* roosts in *Borassus flabellifer* (68.55%), *Polyalthia longifolia* (25.90%) and *Pritchardia pacifica*

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(5.54%). Generally, the native trees are preferred by these bats as the favorite roost. *R. leschanaulti* prefers temples (56.52%), water wells (18.53%), stone buildings (17.16%) and abandoned houses (7.78%). Diversity measures with regard to Margalef index, Berger Parker index and Evenness index, comparatively; higher values were reported in *C. sphinx* (9.433), *R. leschanaulti* (0.270) and *C. sphinx* (0.925) respectively. The distribution pattern and roost preference of megachiropteran bats reveal that these bat species serve as bio-indicator of the agricultural landscape in the wetland ecosystem. It is evident that these three symbiotic bat species exhibit roost preference, and roost resources partitioning in the study area.

Keywords: Megachiropteran bat; habitat preference; water bodies; agriculture fields; species diversity; roost resource partitioning.

1. INTRODUCTION

According to modern taxonomy (which is based on molecular genetic data) the order Chiroptera is divided into two suborders i.e., Yinpterochiroptera and Yangochiroptera [1]. The suborder Yinpterochiropteran includes all the fruit bats that live in the old World tropics and subtropics but are not found in North and South America, except the Egyptian fruit bat of Europe [2]. Five microbat families such as Rhinopomatidae, Rhinolophidae, Hipposideridae, Craseonycteridae, and Megadermatidae are also included in this newly proposed suborder [3]. The remaining families of microbats are grouped under the suborder Yangochiroptera which include the bats that were previously grouped as Yinochiroptera. Yinpterochiropteran bats are herbivores and they depend on vision as well as smell detection capability to find foods [4]. The Yangochiropteran bats rely on laryngeal echolocation system to navigate. The Indian subcontinent is the home of 119 different species of bats belonging to 8 families and 3 genera [5] Chiropterans are found in almost every part of India [6,7]. The species *Latidens salimalii* (Salim Ali's fruit bat) are found in Madurai district of Tamil Nadu and *Otomops wroughtonii* (Wroughton's free-tailed bat) found in Belgaum of Karnataka. They are the only two Indian bat species that are listed in Schedule I of the Wildlife (Protection) Act of India, 1972 [8]. Apart from these *Pteropus medius*, *Rosettus leschanaulti* and *Cynopterus sphinx* are widly distributed in Tirunelveli and Tenkasi districts, playing a vital role in the ecosystem where they live as pollinators and seed dispersers [9].

Ecosystem services are the benefits obtained from the environment that increases human well-being. Economic valuation is conducted by measuring the human welfare gains or losses that result from changes in the provision of ecosystem services. Bats have long been postulated to play important roles in arthropod suppression, seed dispersal, and pollination; however, only recently these ecosystem services began to be thoroughly evaluated [10]. Distribution, survey and ecological studies are found to be important, because they not only bring out knowledge about the diversity of bat fauna but also reveal the habit and habitat requirements of bats [11]. Distributional and habitat studies would help to evaluate the species richness and dominance in the area which will be helpful in developing strategies for conservation of animals. Species richness is a measure used as an indicator of diversity of animals. Kunz reported that the richness and diversity of bats depend on the availability of food sources and identical roost sources [12].

Diversity, habitat preference and distribution of bats in human settlement such as undisturbed ancient temples, stone building and a variety of trees are studied [13-15]. In South Asia, several species of frugivorous bats use temples and trees as roosting sites [5,16]. In South India, numerous very old (>400y) temples dot the landscape and form important bat habitats [17,18]. In the present study, the primary reason for the habitat selection of frugivorous bats roosting near the pond, river, irrigation channel and agricultural fields is due to the availability of food and water resources. The main objectives of the study are to survey the megachiropteran bats, to find the most preferred roost areas of *P. medius C. sphinx*, and *R. leschenaulti*, and to observe the factors which insist the bats to select particular roosting areas in Tirunelveli and Tenkasi districts.

2. MATERIALS AND METHODS

2.1 Study Area

Tirunelveli: The total geographical area of the district is 3876.06 sq. km. The district is

surrounded by the State of Kerala, Gulf of Mannar and the districts of Virudhunagar, Thoothukudi, Tenkasi and Kanniyakumari. It lies between Lat 8.7139° N, Long 77.7567° E of the Northern latitude and 77°.17' and 77°.97' of Eastern longitude. The lifeline of the district is River Tamirabarani. It feeds the district and quenches the thirst of the residents of Tirunelveli and Tuticorin district too and it also supplies drinking water to Virudunagar district. The district has 2 revenue divisions consisting of 8 taluks, 31 firkas, 9 development blocks, 370 revenue villages and 199 village panchayats. The district is blessed with the Western Ghats, from which all the perennial rivers flow and drain towards the east. The surface water of the district is drained into the major river basin viz., Thamirabarani, Vaippar, Nambiar and Hanuman Nathi. The other streams which are seasonal in nature, Servallar, Manimuthar, Ramanathi, Pachaiyar, Chithar and Uppodai drain into the Tamirabarani river. The sources of irrigation are canal, tank and well, which cover the area of 154246 hectares. Among the total area irrigated, well irrigation covers 71307 hectares, tanks cover 55545 hectares and canals cover 27394 hectares during a year. Agriculture plays a vital role in the district's economy. The total cropped area is 206858 hectares, which is 30.61% of the total area. Out of total cultivated area of 206858 hectares, 31771 hectares were sown more than once.

Tenkasi: Tenkasi is one of the most significant places in South Tamilnadu. The District lies between 08º43'50''N to 09º24'30''N Latitude, 77º07'58''E to 77º52'15''E Longitude and has an area extent of 2916 sq.km. Tenkasi has 2 revenue divisions, which comprise of 8 revenue taluks, 30 revenue firkas and 246 revenue villages. The district is nourished by two major rivers namely Chittar and Anumanadhi, because of which agriculture flourishes in this area. More than 65% of the population is engaged in agriculture and related activities. Water sources such as Gundar, Adavinayinar, Karupanadhi and Ramanadhi dam along with more than 800 tanks succour irrigation. The waterfalls formed by the rivers attract a lot of tourists to the district. The famous Coutrallam falls situated in the river Chittar is well known across the state. The water from this falls is believed to have medicinal properties. It is also called "Spa of South India".

Study animal: The Indian flying fox *Pteropus medius*, (formerly *Pteropus giganteus*), also known as the greater Indian fruit bat, is native to the Indian subcontinent. It is one of the largest populated bats in the world. It is black in back and lightly streaked with grey, a pale, yellow-brown mantle. It has large eyes, simple ears, and no facial ornamentation, with a body mass of 0.6 - 1.6 kg, and wingspan 1.2-1.5 m (Bates and Harrison., 1997). Its preferred roosting spots are open tree, roosting in treetops of large trees. It is nocturnal and it feeds mainly on ripe fruits, such as mangoes, bananas, and nectar of flowers. The benefits of its pollination and seed propagation often outweigh the impacts of its fruit consumption. Most flying foxes that have been studied are moderately or strongly colonial [19]. Perhaps some of them form colonies that contain from a few hundred to millions of individuals [20]. It is reported that about 24,480 individuals of Indian flying fox, the largest known aggregation, were found in Peradeniya Botanical Gardens, Srilanka [21].

The Indian greater short-nosed fruit bat, *Cynopterus sphinx* is a common plant-visiting bat that occurs throughout the Indo-Malayan region and roosts solitarily or in small groups in the foliage [22]. The ears and wing bones of *C. sphinx* are edged in white. Lower cheek teeth are rounded without accessory cusps. The wingspan of the adult is about 48 cm. Juveniles are lighter than adults. Average forearm length is 70.2 mm [5]. It weighs about 40 -70 g and lives in small clusters of about 3-30 individuals [23,24]. These bats are known to alter different types of foliage to construct tents and attract females [25]. They typically nest high in palm trees. The bats chew the fronds of the palms to construct fairly simple tents and also construct tents by closely interweaving the leaves and twigs of creeping vines which cover buildings, but such nests are constructed only when palms are not available. The behaviours of tent construction [26] reproduction [25] and foraging [27] are widely studied.

The bat, *Rousettus leschenaulti* is frugivorous, grey - brown in colour, distributed all over India and most of the Southeast Asian countries [5]. These bats live in caves, historical monuments, wells, mines, deserted buildings, temples and unused tunnels [5,28,29]. A colony of *R. leschenaulti* can range from as low as 2-3 individuals to several thousand bats [28, 29]. The behaviour of post-partum pregnancy [30] development of the vomeronasal organ [31] postnatal growth, age estimation with development of foraging behavior [32] wing morphology and flight performance [29], entrainment and phase shifts [33] echolocation

signals [34], olfaction and vision [35], food and foraging preferences [36] roosting habits and seasonal variation in the diet [33], morphological characters [37], roosting ecology and distribution [38] are extensively studied in this species.

Field Survey: The survey of megachiropteran bats was done from January 2021 to December 2022 in the plains of Tirunelveli and Tenkasi districts. Based on the survey and local enquiries from the people, it is found that bat roosts were located and periodic visits were made during daytime. Three species of megachiropteran bats namely *Pteropus medius*, *Cynopterus sphinx* and *Rosettus leschanaulti* were identified roosting on trees, old stone buildings, abandoned houses, ancient temples and wells. The number of bats on each roosting tree was counted by direct roost count method [39] and it is regarded as the abundance or colony size of bats. Counting of the bats was done mostly by naked eye and, whenever needed, binocular was used (Olympus 10×50 DPS I Field 6.5°). The height of the trees was measured with the help of Haga altimeter. The GPS-coordinates of each site were recorded using GPS Map Camera version 1.4.15. The bat count on each tree was recorded by taking a consensus of observers' (3 members) estimates. The survey of *C. sphinx*, which live in the tent roost of *Borassus flabellifer*, *Polyalthia longifolia* and *Pichardia pacifica* trees at 20 feet height, were inspected by reflecting sunlight into their openings with a mirror [40]. Various parameters of the roosting trees were also recorded to study the roost tree preferences of *P. medius*. The trees used for roosting by *P. medius* and *C. sphinx* were identified at the species level and the related tree parameters were also recorded including their origin (native/exotic), colony size (solitary, harem, and total number of individuals) Girth at Breast Height (GBH), tree height and crown width. Stone buildings, temples and water wells were preferred by *R. leschenaulti* and the parameters like height/depth, area of spread were also recorded for their roosts. Bats were identified using the keys provided by Bates and Harrison [5].

2.2 Data Analysis

The marked bat roosting areas were analyzed using GIS Software (Spatial Reference Arc-GIS 10.2: WGS 1984 Datum: WGS 1984 Map units: Degree) (Plate 1). The data were interpreted for the three bat species in terms of species richness (Margalef index), species dominance (Berger Parker Index) and evenness (Evenness index), calculated for all the three pteropodid bats of the study area, were measured by PAST 4.03 (Table 5).

3. RESULTS

A survey of bat roosts was conducted at 16 taluks in 109 places of Tirunelveli and Tenkasi districts from January 2021 to December 2022. Three bat species named *Rousettus leschanulti*, *Cynopterus sphinx*, and *Pteropus medius* of three genera (*Rousettus, Cynopterus, Pteropus*), which belongs to the sub order megachiroptera and family Pteropodidae, were identified and observed in this survey. Among 109 roosts, 15 roosts were occupied by *R. leschanulti* (14.67%), 65 roosts were occupied by *C. sphinx* (59.63%) and 29 roosts were occupied by *P. medius* (25.68%).

3.1 Distribution of Indian flying fox, *Pteropus medius*

Totally 29 roosts were found ranging from 26 to 640 individuals choose large, top and safe places for their dwelling. It is identified that *P. medius* found in open foliage roosts on trees *Terminalia arjuna* (46.90%), *Samanea saman* (13.53%), *Ficus religiosa* (12.09%), *Ficus benghalensis* (5.27%), *Bassia latifolia* (5.04%), *Tamarindus indica* (4.89%), *Sygium cumini* (4.71%), *Manjifera indica* (2.32%), *Thespesia populnea* (1.93%), *Pongamia pinnata* (1.38%), *Pithecellobium dulce* (0.90%), *Albizia lebbeck* (0.74%), and *Azadirachta indica* (0.23%) (Table 1, Table 4 and Fig. 1). The tallest tree roost preference of *P. Medius* is *T. arjuna* (115 ft) and the shortest is *P. Pinnata* (15 ft). The roost parameters (Height, GBH, and CW) origin (Native or Exotic) were measured and tabulated in Table 1. *P. medius* prefers mostly native in the study zone. *T. arjuna,* a native offers highly populated roost because of its height, 115 ft.

This species of bats were identified in 65 roosts on *Borassus flabellifer*, *Polyalthiya logifolia* and *Pritchardia pacifica*. The distribution of roost for *C. sphinx* species in the study area are tabulated (Table 2, Table 4 and Fig. 1) revealing roost parameters (Height, GBH, and CW) origin (Native or Exotic) and colony size (solitary, harem and total number of individuals). *C. sphinx* preferred native trees to exotic trees for roosting. Especially in *B. flabellifer*, tree bats were found large in number (71.71%) because it is suitable for their livelihood, creating a tent like model using palm leaves and a number ranging from 4 to 23 bats.

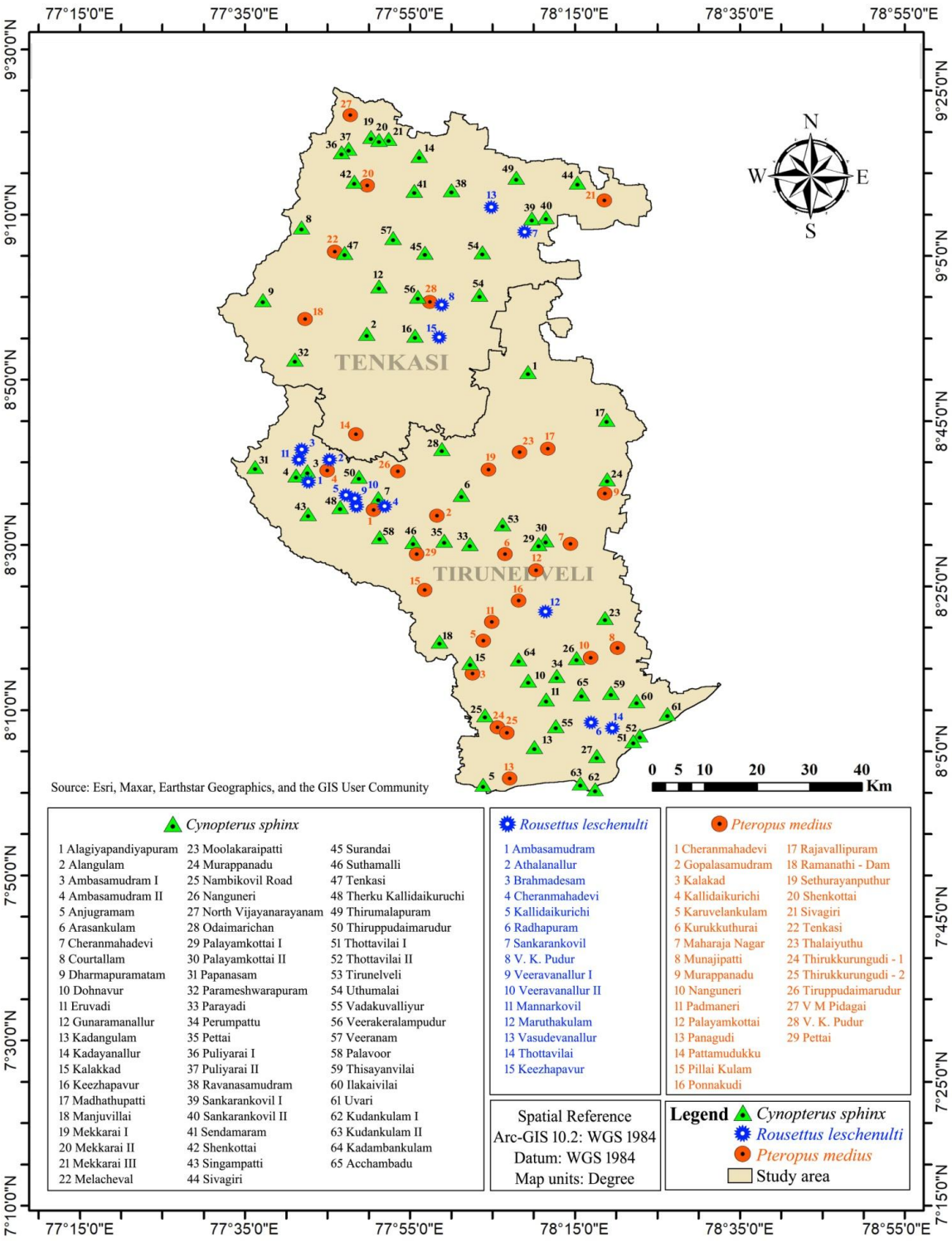


Plate 1. Distribution of Pteropodidae bats in tirunelveli Tenkasi district

Table 1. Distribution and Roost Preference of the Indian Flying Fox, *Pteropus medius*

S.No	Place	GPS Coordinate	Details of Roost Preference							Topography
			No of Trees	Name of the Tree Species	Bat Population Size Per Tree	Tree Height (Ft)	Girth at Breast Height (GBH) (Cm)	Crown Width in (Ft)	Origin	
1	Cheranmahadevi	N 8.847500° E 77.654724°	2	*Terminalia arjuna*	63	78	284	64	N	HRA/AF/HC/NP
					57	55	251	69		
2	Gopalasamudram	N 8.807225° E 77.716321°	1	*Syzygium cumini*	350	73	291	58	N	AF/NP/R/VA
3	Kalakad	N 8.667580° E 77.743611°	3	*Terminalia arjuna*	79	85	196	59	N	HC/AF/R/HRA
					213	80	313	62		
					208	90	336	66		
4	Kallidaikurichi	N 8.773055° E 77.530285°	3	*Bassia latifolia*	73	64	188	64	N	HC/AF/RWB/R
				Samanea saman	121	73	222	71	E	
				Tamarindus indica	96	67	181	55	E	
5	Karuvelankulam	N 8.695655° E 77.724255°	2	*Syzygium cumini*	163	70	266	69	N	NP/VA/AF
				Ficus benghalensis	121	82	248	58	N	
6	Kurukkuthurai	N 8.757272° E 77.895335°	1	*Terminalia arjuna*	640	110	339	73	N	HC/AF/R/HRA
7	Maharaja Nagar	N 8.796396° E 77.884166°	1	*Samanea saman*	173	73	295	68	E	HC/HRA
8	Munajipatti	N 8.683611° E 77.960833°	1	*Tamarindus indica*	256	80	267	59	E	AF/NP/RWB/VA
9	Murappanadu	N 8.951761° E 78.08354°	3	*Terminalia arjuna*	73	88	182	63	N	R/AF/VA/R
				Ficus religiosa	120	79	243	69	N	
				Terminalia arjuna	57	78	152	61	N	
10	Nanguneri	N 8.627262° E 77.737252°	2	*Terminalia arjuna*	220	90	329	57	N	NP/HC/HRA
					186	90	216	64		
11	Padmaneri	N 8.713823° E 77.602717°	1	*Ficus religiosa*	297	75	394	75	N	AF/VA/NP/R
12	Palayamkottai	N 8.770557° E 77.751491°	1	*Ficus benghalensis*	220	65	451	73	N	HC/HRA
13	Panagudi	N 8.457517° E	1	*Terminalia arjuna*	196	70	289	65	N	HRA/HC/AF/NP

S.No	Place	GPS Coordinate	Details of Roost Preference							Topography
			No of Trees	Name of the Tree Species	Bat Population Size Per Tree	Tree Height (Ft)	Girth at Breast Height (GBH) (Cm)	Crown Width in (Ft)	Origin	
		77.780277°								
14	Pattamudukku	N 8.865257° E 77.565643°	2	*Terminalia arjuna*	123	85	312	71	N	RWB/AF/NP/VA
				Bassia latifolia	142	82	287	66	N	
15	Pillai Kulam	N 8.806944° E 77.795277°	1	*Mangifera indica*	253	95	254	59	N	VA/NP/AF
16	Ponnakudi	N 8.782586° E 77.885833°	2	*Thespesia populnea*	210	65	298	63	E	NP/VA/AF
				Ficus benghalensis	233	70	342	69	N	
17	Rajavallipuram	N 8.817282° E 77.784722°	3	*Terminalia arjuna*	63	90	296	55	N	R/AF/NP/VA
					156	115	344	67		
					45	70	241	73		
18	Ramanathi - Dam	N 8.952975° E 77.38719°	2	*Samanea saman*	470	105	236	60	E	RWB/VA/AF/R
				Samanea saman	376	105	254	66	E	
19	Sethurayanputhur	N 8.882576° E 77.898611°	4	*Ficus religiosa*	371	20	336	71	N	MA
				Pongamia pinnata	151	15	274	64	N	
				Azadirachta indica	26	30	219	49	N	
				Tamarindus indica	73	25	248	44	E	
20	Shenkottai	N 9.221135° E 77.846521°	3	*Tamarindus indica*	532	110	294	52	E	HRA/AF/RWB/NP/HC
					346	110	288	48		
				Samanea saman	114	95	312	57	E	
21	Sivagiri	N 9.460833° E 77.446388°	4	*Terminalia arjuna*	465	105	421	67	N	HC/HRA/AF/NP
				Bassia latifolia	123	87	369	59	N	
				Samanea saman	218	90	294	65	E	
				Azadirachta indica	33	75	241	54	N	
22	Tenkasi	N 9.056246° E 77.553593°	1	*Terminalia arjuna*	377	65	279	71	N	HC/RWB/AF/HRA
23	Thalaiyuthu	N 8.961388° E 77.907538°	3	*Pithecellobium dulce*	98	70	214	54	E	HRA/HC
				Albizia lebbeck	81	70	276	64	E	
				Tamarindus indica	74	86	254	57	E	
24	Thirukkurungudi - I	N 8.478055° E 77.608611°	2	*Terminalia arjuna*	117	90	299	68	N	HRA/HC/AF/RWB/NP
				Ficus religiosa	86	85	355	62	N	
25	Thirukkurungudi - II	N 8.509166° E	1	*Ficus religiosa*	174	65	384	70	N	

S.No	Place	GPS Coordinate	Details of Roost Preference							Topography
			No of Trees	Name of the Tree Species	Bat Population Size Per Tree	Tree Height (Ft)	Girth at Breast Height (GBH) (Cm)	Crown Width in (Ft)	Origin	
		77.618611°								
26	Tiruppudaimarudur	N 8.893433° E 77.729474°	1	*Terminalia arjuna*	386	75	285	73	N	AF/RWB/VA/AF
27	V M Pidagai	N 8.703868° E 77.252877°	1	*Bassia latifolia*	210	80	268	66		RWB/NP/AF
28	V. K. Pudur	N 9.188358° E 77.695775°	3	*Terminalia arjuna*	166 210 122	70 87 65	354 395 377	69 71 66	N	R/HC/NP/AF
29	Pettai	N 8.721537° E 77.657245°	1	*Ficus religiosa*	137	67	389	71	N	HC/HRA

Topography: NP – Nearby Pond, RWB - Running Water Bodies, HRA - Human Residential Area, MA - Mining Area, VA - Village Area, HC - Heart of the City, AF - Agriculture Field, HA - Hills Area
Origin: N - Native, E - Exotic Distribution of Greater short-nosed Indian fruit bat, Cynopterus sphinx

Table 2. Distribution and roost preference of the greater short-nosed indian fruit bat, *Cynopterus sphinx*

S.No	Location	Gps Coordinates	Roost Characteristics				Colony Size				Topography
			Name of the Tree Species	Roost Height in (Ft)	Girth at Breast Height (GBH) (Cm)	Crown Width in (Ft)	Origin	Solitary	Harem	Total Number of Individuals	
1	Alagiyapandiyapuram	N 8.911498° E 77.647614°	*Borassus flabellifer*	15	102	8	N	3	8	13	VA/AF/NP/R
2	Alangulam	N 8.867655° E 77.494549°	*Borassus flabellifer*	23	96	5	N	1	3	7	HC/HRA
3	Ambasamudram - I	N 8.775838° E 77.398149°	*Borassus flabellifer*	12	111	7	N	1	2	4	HRA/HC/AF/R/NP
4	Ambasamudram - II	N 8.705514° E 77.440766°	*Polyalthia longifolia*	17	87	5	N	2	5	16	
5	Anjugramam	N 8.149961° E 77.576098°	*Polyalthia longifolia*	20	117	3.5	N	3	2	11	AF/NP
6	Arasankulam	N 8.711624° E 77.565272°	*Borassus flabellifer*	10	136	6	N	1	6	18	AF/NP/VA
7	Cheranmahadevi	N 8.683446° E 77.565291°	*Polyalthia longifolia*	21	112	3.5	N	5	2	10	AF/HC/NP/HRA
8	Courtallam	N 8.900464° E 77.296688°	*Pritchardia pacifica*	15	93	4.5	E	1	5	9	HA/HC/HRA
9	Dharmapuramatam	N 8.800198° E 77.322383°	*Polyalthia longifolia*	20	99	3	N	2	7	13	VA/AF/NP
10	Dohnavur	N 8.465268° E 77.575726°	*Borassus flabellifer*	25	117	6.5	N	4	4	21	AF/NP/VA
11	Eruvadi	N 8.441388° E 77.605276°	*Borassus flabellifer*	23	107	8	N	2	6	11	HRA/RWB
12	Gunaramanallur	N 8.943022° E 77.334371°	*Polyalthia longifolia*	21	141	5	N	2	2	6	AF/NP/VA
13	Kadangulam	N 8.493853° E 77.773155°	*Borassus flabellifer*	12	127	7.5	N	3	5	15	NP/VA/AF
14	Kadayanallur	N 9.078672° E 77.346385°	*Polyalthia longifolia*	16	106	2	N	4	3	10	HA/HC/HRA
15	Kalakkad	N 8.515173° E 77.554488°	*Polyalthia longifolia*	17	81	3.5	N	1	3	9	HC/AF/R/HRA
16	Keezhapavur	N 8.907472° E 77.396835°	*Borassus flabellifer*	15	114	6	N	5	6	22	VA/AF/NP
17	Madhathupatti	N 9.132358° E	*Borassus flabellifer*	20	126	6	N	1	4	19	NP/VA/AF

S.No	Location	Gps Coordinates	Roost Characteristics				Colony Size				Topography
			Name of the Tree Species	Roost Height in (Ft)	Girth at Breast Height (GBH) (Cm)	Crown Width in (Ft)	Origin	Solitary	Harem	Total Number of Individuals	
		77.427704°									
18	Manjuvillai	N 8.542091° E 77.527985°	*Polyalthia longifolia*	13	86	4	N	1	3	8	HA/VA/AF/NP/RWB
19	Mekkarai - I	N 9.064493° E 77.215533°	*Borassus flabellifer*	18	116	6	N	1	5	16	HA/HRA
20	Mekkarai - II	N 9.064522° E 77.214525°	*Polyalthia longifolia*	10	132	4	N	1	5	12	
21	Mekkarai - III	N 9.064493° E 77.215513°	*Pritchardia pacifica*	21	83	4	E	3	6	20	
22	Melacheval	N 8.658444° E 77.629755°	*Borassus flabellifer*	23	119	6	N	2	4	11	AF/NP/VA
23	Moolakaraipatti	N 8.575443° E 77.773013°	*Borassus flabellifer*	18	132	7	N	3	3	8	VA/AF/NP
24	Murappanadu	N 8.580874° E 77.773841°	*Borassus flabellifer*	13	116	7	N	1	8	11	R/AF/RWB/VA
25	Nambikovil Road	N 8.435408° E 77.535511°	*Borassus flabellifer*	20	156	5	N	3	4	15	HA/AF/RWB/NP
26	Nanguneri	N 8.493117° E 77.650025°	*Polyalthia longifolia*	15	111	5	N	3	2	10	NP/HC/HRA
27	North Vijayanarayanam	N 8.414379° E 77.790948°	*Borassus flabellifer*	23	137	5	N	3	2	9	VA/AF/NP
28	Odaimarichan	N 8.794123° E 77.531242°	*Borassus flabellifer*	17	167	5	N	1	6	12	VA/AF
29	Palayamkottai - I	N 8.721167° E 77.742321°	*Borassus flabellifer*	12	135	6	N	2	4	22	HC/HRA/NP/AF
30	Palayamkottai - II	N 8.727332° E 77.727228°	*Borassus flabellifer*	18	120	8	N	1	5	11	
31	Papanasam	N 8.714131° E 77.363122°	*Polyalthia longifolia*	22	101	5.5	N	2	7	16	HA/AF/RWB/NP
32	Parameshwarapuram	N 8.243873° E 77.699131°	*Borassus flabellifer*	10	134	7	N	1	6	10	VA/AF/NP
33	Parayadi	N 8.742213° E 77.693636°	*Borassus flabellifer*	13	98	7	N	2	2	7	AF/VA/NP
34	Perumpattu	N 8.861796° E 77.329669°	*Polyalthia longifolia*	20	126	5	N	2	2	18	NP/AF/VA

S.No	Location	Gps Coordinates	Roost Characteristics				Colony Size				Topography
			Name of the Tree Species	Roost Height in (Ft)	Girth at Breast Height (GBH) (Cm)	Crown Width in (Ft)	Origin	Solitary	Harem	Total Number of Individuals	
35	Pettai	N 8.719689° E 77.650429°	*Borassus flabellifer*	14	140	5	N	4	6	14	HC/HRA/NP/AF
36	Puliyarai - I	N 9.006664° E 77.185208°	*Polyalthia longifolia*	25	138	5	N	4	4	19	HA/HC/HRA
37	Puliyarai - II	N 9.007812° E 77.167946°	*Borassus flabellifer*	16	122	6	N	4	9	11	
38	Ravanasamudram	N 8.799439° E 77.374966°	*Polyalthia longifolia*	19	66	4	N	2	5	10	VA/AF/NP
39	Sankarankovil - I	N 8.795699° E 77.663418°	*Polyalthia longifolia*	25	79	5.5	N	1	3	7	HC/AF/HRA
40	Sankarankovil - II	N 9.170705° E 77.534933°	*Borassus flabellifer*	12	141	7	N	3	6	15	
41	Sendamaram	N 9.067529° E 77.435169°	*Borassus flabellifer*	22	114	8	N	1	3	8	HRA/HC
42	Shenkottai	N 8.973838° E 77.258432°	*Borassus flabellifer*	17	126	7	N	1	9	23	NP/AF/HRA
43	Singampatti	N 8.645213° E 77.423548°	*Borassus flabellifer*	11	153	5	N	2	2	7	HA/VA/AF/NP
44	Sivagiri	N 9.343841° E 77.430577°	*Borassus flabellifer*	13	122	5	N	3	8	22	HC/HRA/NP/AF
45	Surandai	N 8.976879° E 77.422162°	*Borassus flabellifer*	20	112	5	N	1	3	7	HRA/HC
46	Suthamalli	N 8.690533° E 77.633414°	*Borassus flabellifer*	12	140	6	N	4	3	11	AF/NP/HRA
47	Tenkasi	N 8.969976° E 77.302104°	*Pritchardia pacifica*	17	71	6	E	2	4	8	RWB/AF/HC/HRA
48	Therku Kallidaikurichi	N 8.664027° E 77.487059°	*Borassus flabellifer*	25	127	7	N	2	5	12	AF/VA/NP
49	Thirumalapuram	N 9.069148° E 77.600087°	*Borassus flabellifer*	28	155	5	N	1	3	7	AF/NP/VA
50	Thiruppudaimarudur	N 8.726434° E 77.496775°	*Borassus flabellifer*	14	161	6	N	3	6	23	AF/RWB/VA/AF
51	Thottavilai - I	N 8.252047° E 77.801621°	*Borassus flabellifer*	10	148	6	N	1	4	19	AF/VA/NP
52	Thottavilai - II	N 8.252067° E	*Borassus flabellifer*	27	120	6	N	1	3	9	

S.No	Location	Gps Coordinates	Roost Characteristics				Colony Size				Topography
			Name of the Tree Species	Roost Height in (Ft)	Girth at Breast Height (GBH) (Cm)	Crown Width in (Ft)	Origin	Solitary	Harem	Total Number of Individuals	
		77.801643°									
53	Tirunelveli	N 8.879197° E 77.773168°	*Borassus flabellifer*	15	117	5	N	2	3	7	HC/NP/HRA
54	Uthumalai	N 8.986261° E 77.530305°	*Borassus flabellifer*	10	153	8	N	1	9	23	AF/VA/NP
55	Vadakuvalliyur	N 8.387959° E 77.609503°	*Polyalthia longifolia*	17	140	4.5	N	4	15	16	HC/HRA
56	Veerakeralampudur	N 8.929858° E 77.449794°	*Borassus flabellifer*	11	156	6	N	3	4	22	R/HC/NP/AF
57	Veeranam	N 8.937853° E 77.491748°	*Borassus flabellifer*	18	122	7	N	2	6	20	NP/AF/VA
58	Palavoor	N 8.293055° E 77.78500°	*Borassus flabellifer*	15	130	4	N	1	5	18	VA/NP/AF
59	Thisayanvilai	N 8.532755° E 78.005277°	*Borassus flabellifer*	24	111	6	N	1	4	14	HC/HRA
60	Ilakaivilai	N 8.557497° E 78.125833°	*Pritchardia pacifica*	20	59	3.5	E	2	8	12	VA/AF/NP
61	Uvari	N 8.317500° E 78.150350°	*Borassus flabellifer*	14	127	5	N	3	4	23	CA/HC/HRA
62	Kudankulam - I	N 8.603333° E 77.983055°	*Borassus flabellifer*	25	133	7	N	1	3	15	CA/HRA
63	Kudankulam - II	N 8.691381° E 77.825080°	*Polyalthia longifolia*	13	48	5.5	N	3	4	20	
64	Kadambankulam	N 8.538055° E 77.959722°	*Borassus flabellifer*	15	140	5	N	1	6	22	AF/VA/NP
65	Acchambadu	N 8.7672497° E 77.847292°	*Borassus flabellifer*	21	123	5	N	2	3	7	NP/AF/VA

Topography: NP - Near by Pond, RWB - Running Water Bodies, HRA - Human Residential Area, VA - Village Area, HC - Heart of the City, AF - Agriculture Field, HA - Hills Area, CA - Coastal Area
Origin: N - Native, E - Exotic

Table 3. Roost Information and popolation size of Fulvous fruit bat, *Rousettus leschenaulti*

S.No	Location	Gps Coordinates	Roost Information				Topography
			Roost Site	Bat Population	Roost Height/Depth (Ft)	Area of Spread sq.ft	
1	Ambasamudram	N 8.755414° E.77.636261°	Temple	21	10	64	RWB/HRA/HC/AF/R/NP
2	Athalanallur	N 8.811388° E 77.650833°	Temple	12	8	56	VA/AF/NP
3	Brahmadesam	N 8.976127° E 77.634593°	Temple	55	15	120	NP/VA/AF
4	Cheranmahadevi	N 8.700833° E 77.721388°	Temple	730	12	420	AF/HC/NP
5	Kallidaikurichi	N 8.778611° E 77.532541°	Stone Building	350	15	340	HC/AF/RWB/R
6	Radhapuram	N 8.250564° E 77.670702°	Water Well	100	8	150	VA/AF/NP
7	Sankarankovil	N 9.234694° E 77.540277°	Temple	80	23	50	HC/AF/HRA
8	V. K. Pudur	N 8.953333° E 77.697571°	Temple	500	15	260	R/HC/NP/AF
9	Veeravanallur - I	N 8.954166° E 77.673887°	Temple	17	15	40	HC/HRA/AF/NP
10	Veeravanallur - II	N 8.824163° E 77.363652°	Temple	27	12	121	
11	Mannarkovil	N 8.730551° E 77.420082°	Temple	83	15	60	AF/NP/VA
12	Maruthakulam	N 8.602384° E 77.716064°	Water Well	400	12	320	VA/AF/NP
13	Vasudevanallur	N 9.236185° E 77.408492°	Abandoned House	210	18	80	HRA/HC/AF
14	Thottavilai	N 8.252339° E 77.802137°	Stone Building	43	20	65	NP/VA/AF
15	Keezhapavur	N 8.907477° E 77.396833°	Stone Building	70	17	110	RWB/NP/AF/VA

Topography: NP - Near by Pond, RWB - Running Water Bodies, HRA - Human Residential Area, VA - Village Area, HC - Heart of the City, AF - Agriculture Field

Table 4. Details of roost characteristics of three pteropodid bats

S.No	Roost Characteristics	*P. medius*	*C. sphinx*	*R. leschenaulti*
1	Total number of roosts	29	65	15
2	Total number of individuals sighted	10743	884	2698
3	Range	26-640	4-23	12-730
4	Roost Height Average (Ft)	8.59	5.81	3.58
5	Range of Girth at Breast Height Tree (Range)	152-451	48-167	*
6	Area of Spread (sq.ft)	*	*	40-420
7	Crown width ft & cm (Range)	44-75	2-8	*
8	Solitary Range	*	1-5	*
9	Harem Range	*	2-15	*

** Not applicable*

Table 5. Diversity indices of three symbiotic pteropodid bats

S.No	Name of the bat Species	Biodiversity measure values		
		Margalef index (Species Richness)	Berger Parker index (Species Dominance)	Evenness e^ H/S (Evenness)
1	*P. medius*	3.013	0.091	0.865
2	*C. sphinx*	9.433	0.026	0.925
2	*R. leschenaulti*	1.772	0.270	0.558

3.2 Distribution of Fulvous fruit bat, *Rosettus leschanulti*

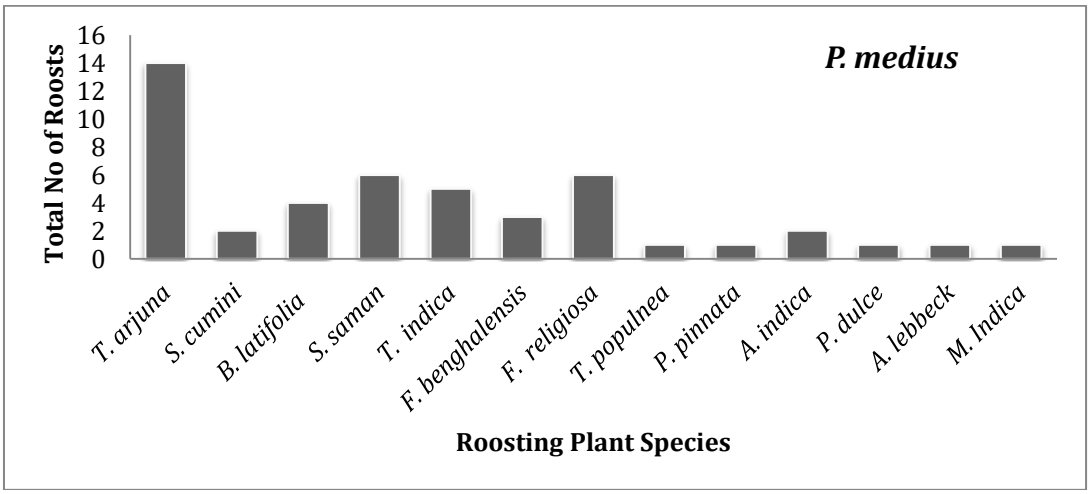
Not like other two pteropodid bats, *Rosettus leschanulti* dwell in dark places of temples (56.52%), wells (18.53%), stone buildings (17.16%) and abandoned houses (7.78%). The selected roosting height ranges from 8 - 28 ft and the colony size ranges from 12 - 730 (Table 3, Table 4 and Fig. 1). The area of spread was observed concerning *R. leschenaulti* is 420 sq.ft in temple. One temple roost of *R. leschenaulti* (n=260) is shared by *H. speoris* (n=525).

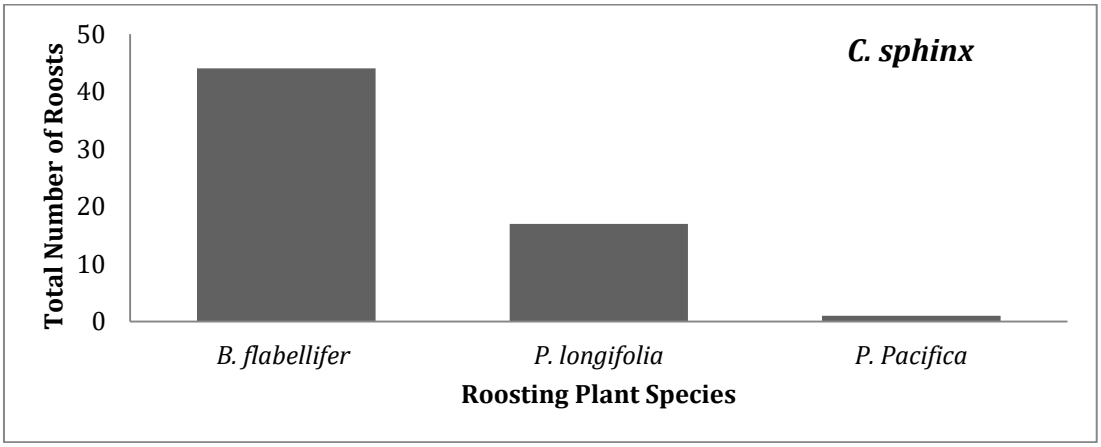
3.3 Biodiversity Indices

The greatest degree of species richness is found in *C. sphinx* (9.433) followed by *P. medius* (3.013) and *R. leschenaulti* (1.772). The species dominance value of *R. leschenaulti* (0.270) *P. medius* (0.091) and *C. sphinx* is 0.026. The species evenness of *P. medius* (0.925) followed by *C. sphinx* (0.865) and *R. leschenaulti* (0.558) was observed in Tirunelveli (Table 5).

3.4 Environmental Parameters

Megachiropteran bats showed a varied pattern of environment selection for their foraging activity. *P. medius*' roost preference is among the agriculture fields (51.72%). Buildings offer roosting site for 17.24% of bats, nearby water bodies for 27.58% bats and only 3.44% bats prefer mines. Roost preference of *C. sphinx* is on agriculture fields 64.61%, residential areas 30.76%, coastal areas 3.07% and hill areas 1.53%. The roost preference of *R. leschenaulti* on agriculture fields 60%, residential areas 13.33%, and water bodies 26.66%. On studying the habitat preferences of three megachiropteran bat species, it is evident that, they choose to roost in agricultural areas and nearby irrigated lands, canal banks, rivers and nearby ponds. It is evident that these three species of symbiotic bat species exhibit roost preference, and roost resources partitioning in the study area (Fig. 1).





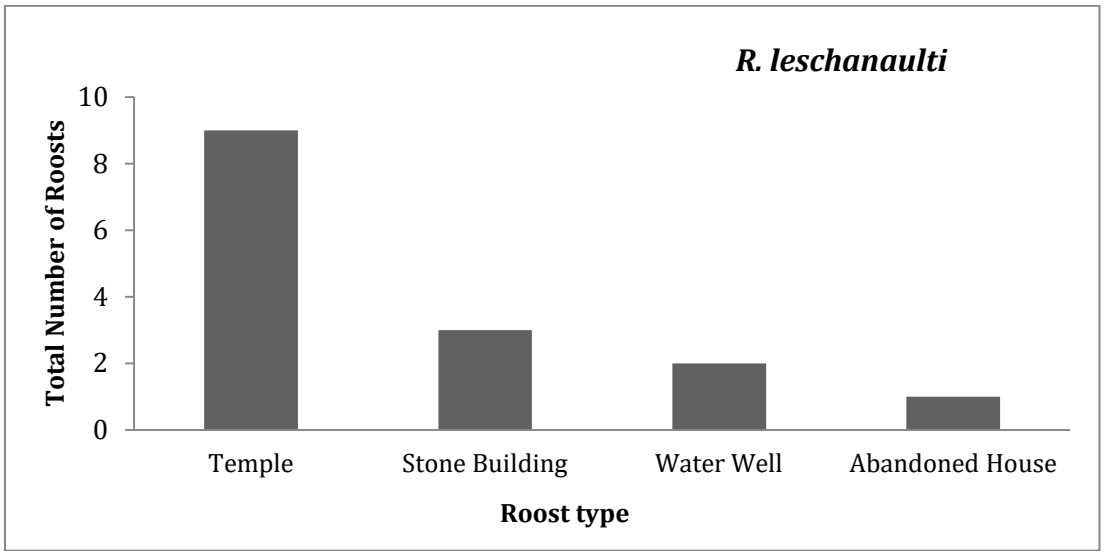


Fig. 1. Shows the roost type and roosting plant species preferred by the bats of the study area

4. DISCUSSION

The Pteropodidae bats, grouped under the suborder megachiroptera (*Pteropus medius*, *Cynopterus sphinx* and *Rousettus leschenaulti*) were found in the southern districts of Tamil Nadu, Tirunelveli and Tenkasi.

The Indian flying fox, *Pteropus medius* is widespread on mainland of India. They are also widely distributed in the tropics and sub-tropics of Asia, Australia, Indonesia, islands off East Africa, but not in mainland Africa, and a number of remote oceanic islands in both the Indian and Pacific Oceans [41]. The previous survey revealed that these were 22 roosts with the population of 15, 720 [15] But in the same area the number of roost has been increased with lower number of total population (around 10,743) which may be due to habitat distraction and bats' diverse roost selection.

The Indian short-nosed fruit bat, *C. sphinx* is a common plant-visiting bat that occurs throughout the Indo-Malayan region, and roosts solitarily or in small groups in the foliage [22]. *C. sphinx* was found to be present at a higher rate in Tirunelveli district and this is mainly due to the presence of sumptuous foraging and roost resources. The availability of the ideal roost and food resources favor the distributional status of bats [12]. *C. sphinx* prefers to roost at higher rate in urban areas with human settlements. It may be mainly due to the presence of food and roost resources, as people may grow curtain creepers, mast trees and palms which provide roosts and grow fruit bearing trees like Guava, Zapota and Mango, etc., which provide food sources [23]. Six fruit species *R. leschenaulti, P. giganteus, C. brachyotis, C. sphinx, L. salimalii* and *E. spelaea* were distributed in KMTR (Kalakad Mundanthurai Tiger Reserve) forests starting from the foothill to the highest mountain peaks [42]. *R. leschnaulti* and *C. sphinx* are of great importance for maintenance and reestablishment of plant diversity in tropical ecosystem of Tirunelveli district by pollen and seeds [43,44].

R. leschenaulti camps in temples, stone buildings, and abandoned houses and in wells with a gregarious roosting behavior and colonies consisting of 12 to 730 individuals. Temples provide ideal roosting sites for *R. leschenaulti* with low temperature, high humidity, dim lighted chambers and undisturbed places and as most of the chambers in the temple roost are larger in size. It enables and facilitates them to fly from one chamber to another; temple roost provides all such conditions when compared to the other types of enclosed roost. Temperature and humidity and other physiological and biological parameters are observed to play a vital role in the roosting habits of bats in cave and other man-made structures [45,12,46,47]. Various food selections, processing strategies, the economical and ecological importance of bat - dependent plants have provided a glimpse on the fruit bats' bio-agent role in the ecosystem which can be of use to revise the status of fruit bats under Schedule V, Indian Wildlife Protection Act 1972 [44]. Over and above the economic value of their pollination and seed dispersal services, plant-

visiting bats provide important ecological services by facilitating the reproductive success of their food plants, including seed set and the recruitment of new seedlings and saplings. Many of these plants are among the most important species in terms of biomass in their habitats [10].

The three megachiropteran (*C. sphinx*, *R. leschenaulti* and *P. medius*) bat species, as pollinating the flowers, were found to be providing important ecosystem services [13]. Bats are considered as sacred animals and worshipped by the local people residing in and around the villages. They believe that the bats are serving as guards protecting the tree and the deity would punish if anybody hurt the bats. Thus, the bat colony is protected inside this scared grove for several decades [48].

P. medius has chosen 8 native trees (*T. arjuna*, *S. cumini*, *F. benghalensis*, *A. indica, F. religiosa, P. pinnata*, *B. latifolia*, and *M. Indica*) and 4 exotic (*T. populnea*, *T. indica*, *P. dulce*, *A. lebbeck* and *S. saman*) as most favourable roost. Among all the tree roosts, the tallest is *T. arjuna* (115 ft) which may give them a secure microclimate. Three plant species (*B. flabellifer*, *P. logifolia* and *P. pacifica*) offer 65 roosts to *C. sphinx. B. flabellifer* an native tree with a height of 28 ft harbor more number of *C. sphinx* (n=23). Unlike *P. medius* and *C. sphinx*, *R. leschenaulti* with a small population size (730) roost in temples enjoying a dark, cool microclimate but distributed by the visit of devotees. Tirunelveli district shows abundance of 3 fruit bats *P. medius* (22 in Tirunelveli 11 in Tenkasi) *C. sphinx* (40 in Tirunelveli and 25 in Tenkasi) and *R. leschenaulti* (11 in Tirunelveli and 4 in Tenkasi). As perennial river Tamirabarani, pond, lake give rooms for the tree roost and Agriculture fields (*Mangifera indica, Psidium guajava, Pouteria sapota, Carica papaya* and *Terminalia catappa*) that offer a good foraging resource.

Margalef's index is a straightforward measure of species diversity that places an emphasis on species richness. By dividing the species count by the natural log of the total number of organisms sampled, it tries to account for the fact that more species are gathered with larger number of organisms being sampled. It also expresses the dependence between the quantity of organisms sampled and the species diversity that persists between them [49]. In the current analysis of the species richness of bats in the different bat species measured they are proportionally high (9.433) in *C. sphinx.*

The Berger-Parker index quantifies the relative importance of the most abundant type. This metric is heavily influenced by sample size and richness, and it does not utilise all of the information available from the sample [50]. In the current research, the species abundance of pteropodid bats in various trees/ billets has been calculated and is high in *R. leshenaulti* (0.270).

Evenness indices are typical functions of some diversity measure and the number of individuals in a species sample or collection, denoted by the Evenness index [51] Evenness is a measure of the relative abundance of pixels in the selected area, with a value ranging from >0 to 1. An evenness is found high in *C. sphinx* (0.925) followed by *P. medius* (0.865) and *R. leshenaulti* (0.558).

In Tamirabarani river basin of south India, bat species richness and abundance are related to the availability of dark rooms, and the temple [18]. The topography of the districts also reveal such a factor that it is on the perennial Tamirabarani River and surrounded by agricultural lands, orchards and numerous wild varieties of bat feeding fruits were also observed to prevail in this district resources [17]. In the present study, it is also evident that bats prefer roosting on mostly agriculture fields (60.55%), human residential areas (24.77%), water bodies (11.00%), coastal areas (1.83%), mining areas (0.91%) and hill areas (0.91%) as their roosting sites provide suitable micro-habitats, semi-darkness with less anthropogenic disturbance that are located in the vicinity of agricultural landscape. Bats roosting in anthropogenic structures such as temples and old/unused buildings, bring them into conflict with human and make conservation of bats a challenge.

5. CONCLUSION

In the present study, among the three symbiotic pteropodid bat species, *P. medius* prefers to roost in 13 different tree species, while *C. sphinx* roosts only in 3 other tree species in the study area. Both choose the different plant species for roosting purpose, thus exhibit resource partitioning which may reduce competition in roosting resources. However, *R. leschenaulti*, a semi-echolocating bat species roosts inside temples, unused buildings, and water wells. Hence, it is concluded that these three species of bats show resource partitioning in roosting sites as reported in sympatric insectivorous bats which show variation in patterns of habitat use and other parameters [52,53].

ETHICAL APPROVAL

As per international standard or university standard written ethical approval has been collected and preserved by the author(s).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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