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Research Article

Diversity of Fig species and their ecological services in Pakke Wildlife Sanctuary, Arunachal Pradesh, India

Dipika Parbo[1], Awadhesh Kumar[*2], Ashalata Devi[3], Janmejay Sethy[4], Yengkhom Roamer Zest[5], Rakesh Basnett[6]

[1,2,5]Wildlife Resource and Conservation Laboratory, Department of Forestry, NERIST, Nirjuli, Arunachal Pradesh, India, 791109

[3]Department of Environmental Science, Tezpur University, Tezpur, Sonitpur, Assam, India

[4]Amity Institute of Forestry and Wildlife, Amity University, Noida, Uttar Pradesh, India

[6]Forest and Environment Department, Government of Sikkim, East Sikkim, India 737101

*Email: tpileatus@gmail.com

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Abstract

Ficus *spp*. belongs to the Moraceae family and is primarily found in tropical lowland rainforests. They exhibit various growth types including hemi-epiphytes, climbers, shrubs, and trees. The Ficus genus plays a vital role as a keystone species as it significantly impacts its microhabitat and serves as the primary food supply for frugivores throughout the year. Arunachal Pradesh, a state in Northeast India, located in the Eastern Himalayas, comprises a diverse range of forests, including deciduous, evergreen, pine, temperate, alpine, and grassland enriched with a variety of flora and fauna. The current study was conducted in Pakke Wildlife Sanctuary, Arunachal Pradesh, to determine the Ficus diversity and associated frugivores. The survey was done using 20m X 20m quadrats (41 nos.), which were randomly placed within the sanctuary. Ficus-dependent frugivore diversity was examined in their fruiting season using either focal or scan animal sampling techniques by direct sighting. A total of 21 Ficus species comprising 482 individuals were recorded, with the highest distribution in the Tipi Range and the lowest in the Pakke Kessang Range. Four habits of Ficus species, large trees, small trees, shrubs and climbers, were documented. There are five sub-genera of Ficus that have been recorded. *Ficus semicordata* is the most abundant species, while *F. religiosa* is the least abundant. The frequency percentage of *F. benghalensis* (46.34%) is the highest, and *F. religiosa* (2.44%) is the least, while the density of *F. auriculata* (146.34 ha-1) is the highest, and *F. religiosa* (2.44 ha-1) has the lowest. The highest level of similarity among Ficus species is observed between the Tipi and Seijosa Range. The figs of Pakke Wildlife Sanctuary are associated with 54 frugivore species out of them 43 avian and 11 mammalian species.

Keywords: Abundance**,** Distribution, *Ficus*, Frugivore, Keystone, Morphology

Introduction

Figs (*Ficus spp*,) belonging to the Family Moraceae exhibit a diverse type of habits and growth forms such as hemi-epiphytes, enormous woody climbers as well as trees and shrubs with fruit positions including cauliflory, on the surface of the soil and among leaves (Harrison & Shanahan, 2005; Shanahan et al., 2001). Fig trees have been characterized as the "most distractive of widespread genera of tropical plants". According to Bagla and Menon (2000), figs are massive trees, that grow to a very great height, and girth with spreading crowns and evergreen barged of tropical lowland rainforest. There are about 755 species of *Ficus* spp. worldwide as reported by van Noort and Rasplus (2004-2012). Out of these, 115 taxa (consisting of 89 species and 26 infra-specific taxa) have been recorded to occur in India (Chaudhary et al., 2012). *Ficus* spp. is distributed in the tropics and other warm regions of the world, especially in Indo-Malaysia to Australia, Africa and America comprising six subgenera, *viz*. *Urostigma, Pharmacosycea, Sycomorus, Sycidium, Synoecia* and *Ficus* (Berg & Corner, 2005). The distribution of this species in India is primarily concentrated in the North-Eastern States, Peninsular region and Andaman & Nicobar Islands (Chaudhary et al., 2012).

Figs are considered a keystone species for wildlife conservation in tropical forests due to their ability to provide a consistent supply of fruits, flowers, and leaves throughout the year. This is especially important during periods of food scarcity in the habitat. Figs are highly valued by frugivorous animals for their abundant and reliable food resources. Several studies have highlighted the significance of figs in supporting wildlife populations (Barua & Tamuly, 2011; Budiman et al., 2017; Milton, 1991; Ragusa-Netto, 2002; Shanahan et al., 2001). Fig plants thus meet all the necessary criteria to be considered a keystone species: 1) exhibit low redundancy, (2) consumed by a large range of the frugivores, (3) exhibit inter-annual reliability and (4) abundant (Peres, 2000). In addition, the spreading branches of figs with dense foliage also provide shelter to many canopy-dwelling vertebrates or on land surfaces and help to retain moisture under the canopy (Vanitharani et al., 2009).

Being a part of the Eastern Himalayas (one of the 36 Biodiversity Hotspots) and the hills of Northeast India, Arunachal Pradesh is the most bio-diverse and largest state among Northeastern states, ranking second largest forest cover state with 66,688 sq. km after Madhya Pradesh (77,482 sq. km) and 4thin terms of percentage of forest cover (79.63%) in India (Indian State of Forest Report, 2019; Mittermeier et al., 2011). The state has 16 protected areas, which include 2 National Parks, 13 Wildlife Sanctuary and 1 Orchid Sanctuary. These protected areas encompass a total area of 9,488.48 sq. km of state forests. Pakke Wildlife Sanctuary (PWLS) is well-managed and

highly regarded protected area which is surrounded by contiguous forests and undulating terrain and hills on most sides with higher hills in the northern part of the sanctuary. Pakke Wildlife Sanctuary consists of different habitat types, including lowland semi-evergreen, evergreen forest and Eastern Himalayan broadleaf forests. The main vegetation type is classified as Assam Valley tropical semi-evergreen vegetation (Champion & Seth, 1968). A total of 234 plant species (angiosperms) have been recorded with the highest number of species from the family *Euphorbiaceae* and *Lauraceae* in PWLS (Dasgupta et al., 2015; Datta & Goyal, 1997; Padmawathe et al., 2004). However, the diversity of figs in the PWLS area has not been thoroughly studied about the assemblage of frugivores. Thus, the main objective of this study was to investigate the diversity of figs in the Pakke Wildlife Sanctuary.

Martial and methods

Study Area

The present study was conducted in Pakke Wildlife Sanctuary, situated within the geographical coordinates of longitude 92º 36' - 93º 09' E and latitude 26º 54' - 27º 16' N (Fig. 1). The sanctuary covers an area of 861.95 km^2, which accounts for 20% of the East Kameng district in Western Arunachal Pradesh (Dasgupta et al., 2015; Datta et al., 2008). The sanctuary is bordered by Bhareli River (also known as Kameng River) in the north and west, Pakke River to the east, and the Nameri National Park and Nauduar Reserve Forest of Assam to the south. PWLS is surrounded by Reserve Forest and other Protected Forests, indicating that it is not an isolated area of forest. The headquarter of the sanctuary is Seijosa, which is 60 km away from Tezpur, a town in Assam, on National Highway - 52 (Dasgupta et al., 2015; Kumar et al., 2019). The altitudinal variations starting from 200 to 2040 m above mean sea level. In addition, the area is drained by several small rivers and perennial streams of the Bhareli and Pakke Rivers, both of which are tributaries of the Brahmaputra and the main perennial streams are the Nameri, Khari and Upper Dikorai (Datta & Goyal, 1997; Kumar & Solanki, 2008).PWLS exhibits a high level of floral and faunal diversity and serves as a habitat for numerous threatened wild animals (Datta et al., 1998; Datta & Rawat 2008; Kumar &Solanki 2009; Singh, 1991, 1994).

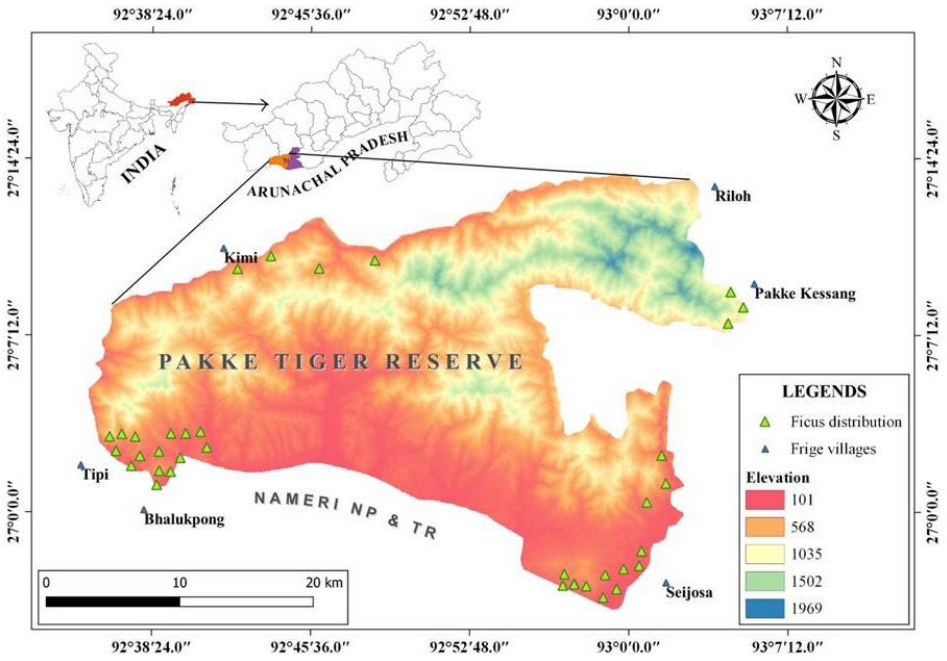


Figure 1. Study area showing sampling points of *Ficus* species in the entire Pakke Wildlife Sanctuary

The diversity and population density of fig plants were studied using the quadrats method (Pound & Clements, 1900). Randomly placed quadrats measuring 20m X 20m quadrats were used to sample the area dominated by fig plants in the sanctuary (Schemnitz, 1980). A total of 41 quadrats were laid randomly in the three ranges namely, Pakke Kessang Range, Seijosa Range and Tipi Range having five, 17, and 19 quadrats, respectively. Within each quadrat, the data on the total number of individuals of *Ficus* species, their height, GBH (Girth at Breast Height) and canopy cover were recorded. Photographs of all recorded *Ficus* species were taken, and their identification was done by referring to the 'Flora of Assam' (Kanjilal & Bor, 2005) and consulting the regional herbarium at BSI, Itanagar. The identification of *Ficus* species was done with the assistance of experts from NERIST. During the field survey, the phenophase of each adult fig tree was studied to document the fruiting season and the type of fig. The relationship between Ficus species and frugivore species was also explored during the field survey.

The data collected was analyzed for community parameters, such as frequency, density, and abundance as per Curtis and McIntosh (1950). Importance Value Indices (IVI) were calculated for each species by summing up the relative frequency, relative density and relative abundance (Philips, 1959). Based on the number of individuals of a given species, *Ficus* species is categorized as very rare (single individual), rare (2-10), common (11-25), dominant (26-50) and predominant (>50) as per Kadavul and Parthasarathy (1999). The Jaccard similarity index (Jaccard, 1901) and species diversity index (Shannon & Weiner, 1963) were also calculated. The concentration of dominance was measured following Simpson's index method (Simpson, 1949).

Results

Ficus sp. distribution

The Pakke Wildlife Sanctuary records a total of 21 species of *Ficus* trees. These trees are distributed among different ranges within the sanctuary. The highest number of *Ficus* trees, with a total of 284 individuals belonging to 19 species, is found in the Tipi Range. The Seijosa Range has 135 individuals belonging to 13 species, while the Pakke Kessang Range has the lowest number of *Ficus* trees, with only 63 individuals belonging to 3 species (Fig. 1, Fig. 2). Two *Ficus* species (*Ficus hirta* and *F. semicordata*) are recorded from all the three ranges. In the Tipi and Pakke Kessang ranges, only one species (*F. auriculata*) is found. However, in the Seijosa and Tipi ranges, nine species are shared (*F. benghalensis, F. benjamina, F. curtipes, F. elastica, F. hispida, F. geniculata, F. drupacea, F. microcarpa, and F. squamosa*). Seven species (*F. altissima, F. cyrtophylla, F. glaberrima, F. hederacea, F. heterophleura, F. racemosa*and *F. variegata*) are present only at Tipi Range, whereas two species (*F. religiosa* and *F. rumphii*) are found only at Seijosa range. There are no species that are exclusively found in the Pakke Kessang range. Additionally, there are no species that are shared commonly across the Seijosa and Pakke Kessang range (Fig. 2). Based on the total number of individuals of each species, *Ficus* species is categorized as Predominant (*F. auriculata, F. benghalensis, F. hirta, F. squamosa*), Dominant (*F. curtipes, F. elastica, F. semicordata*), Common (*F. benjamina, F. cyrtophylla, F. drupacea, F. geniculata, F. hispida*), Rare (*F. altissima, F. glaberrima, F. hederacea, F. heteropluera, F. microcarpa, F. racemosa, F. rumphii, F. variegata*) and Very rare (*F. religiosa*) as shown in Fig. 3.

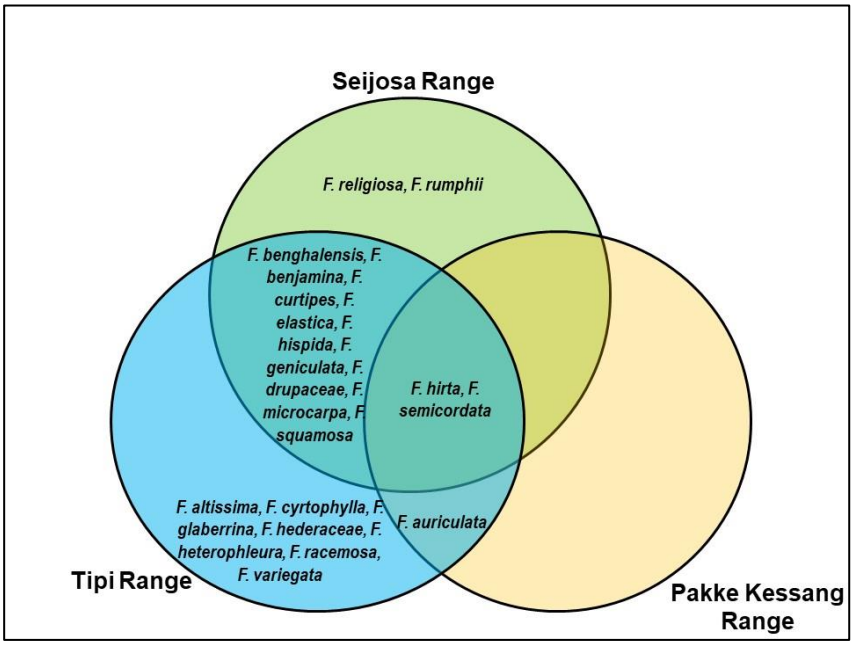


Figure 2. Distribution of *Ficus* species in all three ranges of Pakke Wildlife Sanctuary

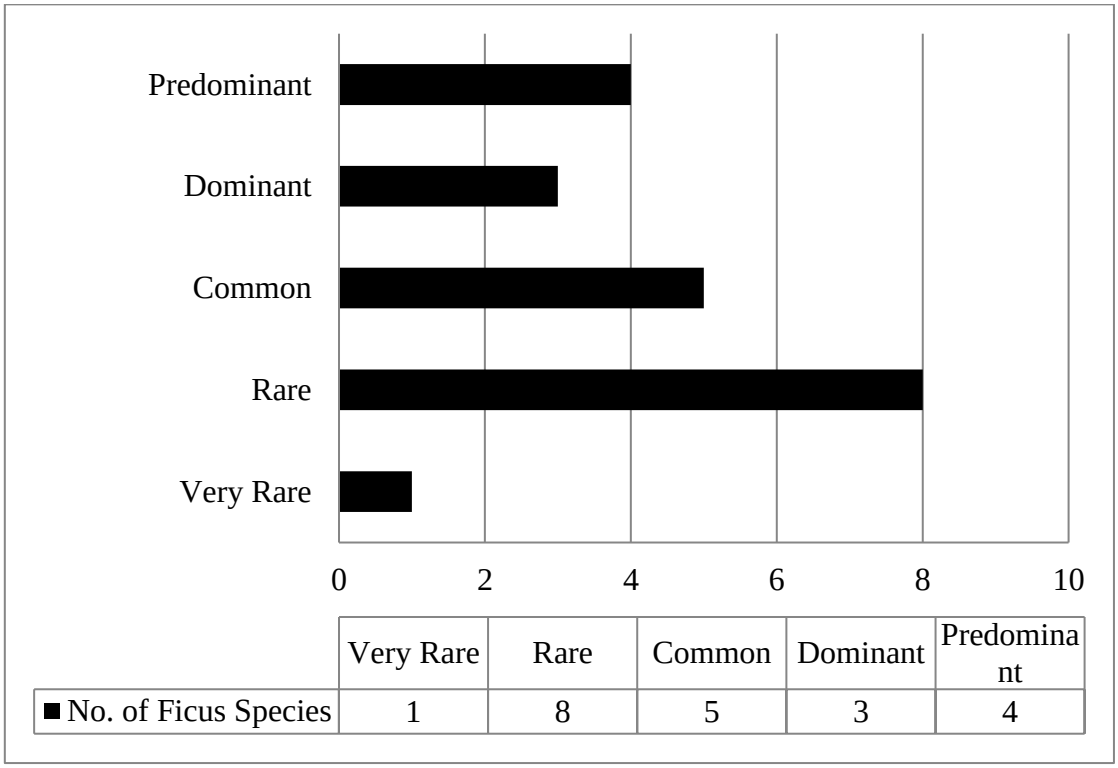


Figure 3. Status of *Ficus* distribution in Pakke Wildlife Sanctuary

Morphology of *Ficus* species

The *Ficus* species found in the Pakke Wildlife Sanctuary can be classified into five sub-genera such as *Ficus*, *Sycidium*, *Sycomorus*, *Synoecia* and *Urostigma*. Among 21 species, one species each from *Ficus* and *Synoecia* sub-genus, two species from *Sycidium* sub-genus, six species from *Sycomorus* and 11 species from *Urostigma*. The highest canopy coverage observed is 82% for the *F. curtipes*. Additionally, three species (*F. religiosa, F. hispida,and F. squamosa*) are found in open canopy. Among 19 *Ficus* species, GBH of *F. elastica*is was found to be highest (1120 cm) and *F. cyrtophylla* was lowest (42 cm). It is worth noting that *F. squamosa* is a shrub while *F. hederacea* is a climber. Considering the height, *F. elastica* is found to be the tallest (30 m) while *F. squamosal was* recorded shortest growing up to 2 meters (Table 1).

Fig positions of four species (*F. auriculata, F. racemosa, F. semicordata, F. variegata*) are cauliflory, while the other 17 species have axillary fig positions. Maximum number of *Ficus* species have a globose fig shape. All figs are soft when they are ripe, with the exception of *F. curtipes*, which are hard. The colour of the fig varies from red to black, and from yellow to green. The length of the Fig of *F. drupacea* is the highest, measuring 4.6 cm, while *F. cyrtophylla* and *F.*

hederacea have the lowest length (0.8 cm); *F. auriculata* has the largest diameter (5 cm), *F. cyrtophylla* has smallest diameter, measuring 0.6 cm (Table 1).

Leaf arrangements of 18 *Ficus* species are simple, and alternate; two species (*F. hisida, F. squamosa*) are simple and opposite; while *F. hirta* is either simple or compound, alternate. *F. squamosa* is spirally arranged too. Seven species have ovate-elliptic leaf shape, five species have ovate leaf shape and the remaining species leaf shape ranges from cordate to obovate, oblong to elliptic, lanceolate to oblanceolate. The leaf shape of *F. hirta* is either cordate or palmately 3-5 lobed. *F. hirta* has leaves with the largest length (35 cm) and *F. benjamina* has leaves with the smallest length (8 cm) (Table 1).

The recorded *Ficus* species exhibits four types of habits: trees, small trees, shrubs and climbers. The majority of the species in this group are trees (14 species), five species are small trees, one species is shrubs, and one species is climber. Based on growth forms, *Ficus* species are divided into two types: hemiepiphytic and non-hemiepiphytic. Twelve speciesincluding *F. altissima, F. benghalensis, F. benjamina, F. curtipes, F. drupacea, F. elastica, F. glaberrima, F. geniculata, F.heteropleura, F.macrocarpa, F. religiosa and F.rumphii*, are hemiepiphyticandare classified as trees; whereas nine species- *F. auriculata, F. cyrtophylla, F. hederacea, F. hirta, F. hispida, F. racemose, F. semicordata, F. squamosa, F. variegata* are non-hemiepiphytic, among which two are trees (*F. racemosa, F. variegata*), five are small trees (*F. auriculata, F. cyrtophylla, F. hirta, F. hispida, F. semicordata*), one is shrub (*F. squamosa*) and one is a climber (*F. hederacea*) (Fig. 5, Fig. 6).

Table 1. Morphological characteristics of *Ficus* species recorded in Pakke Wildlife Sanctuary, Arunachal Pradesh.

Sl. No.	Sub-genus	Species	Canopy	GBH (cm)	Height (m)	Fig characteristics					Fruiting period	Leaf characteristics		
						Position	Shape	Texture (ripe)	Colour	Size (L, D; in cm)		Arrangement	Shape	Length (cm)
1.	*Ficus*	*Ficus hirta* Vahl	45%	65	7	Axillary	Globose	Soft	Brownish red	3, 3	Nov-Feb	Simple or compound, alternate	Cordate or palmately 3-5 lobed	34
2.	*Sycidium*	*Ficus cyrtophylla* (Miq.) Miq.	10%	42	21	Axillary	Ovoid	Soft	Yellowish green	0.8, 0.6	Sept-Nov	Simple, alternate	Obovate-lanceolate, asymmetry	26
3.		*Ficus heteropleura* Blume	60%	230	12	Axillary	Pear-shaped	Soft	Bright red	0.9, 1	Jan-March	Simple, alternate	Ovate- elliptic	12
4.	*Sycomorus*	*Ficus auriculata* Lour	60 %	50	8	Cauliflory	Pear-shaped	Soft	Dark red	4, 5	Jan-April	Simple, alternate	Broadly ovate	31
5.		*Ficus hispida* L.f.	Open	50	3.5	Axillary	Globose	Soft	Pale yellowish green	1.9, 1.8	Dec-June	Simple opposite	Ovate-elliptic	25
6.		*Ficus racemose* L.	50%	420	17	Cauliflory	Pear-shaped	Soft	Deep red	2, 4.1	Oct-Dec	Simple, alternate	Ovate	21
7.		*Ficus semicordata* Buch.-Ham. ex Sm.	50%	60	5	Cauliflory	Globose	Soft	Dark red	1.4, 1.5	July-Oct	Simple, alternate	Oblong, lanceolate or elliptic, asymmetry	27
8.		*Ficus squamosa* Roxb.	Open	Shrub	2	Axillary	Globose	Soft	Yellowish green	3.4, 3.6	April-July	Simple, opposite, spirally arranged	Oblanceolate	14

9.		*Ficus variegata Blume*	50%	340	18.5	Cauliflory	Pear-shaped	Soft	Deep red	2.3, 3.7	Oct-Feb	Simple, alternate	Broadly ovate	22
10.	*Synoecia*	*Ficus hederacea* Roxb.	44%	Climber	Climber	Axillary	Round	Soft	Bright red	0.8, 0.9	Oct-Feb	Simple, alternate	Ovate	11
11.	*Urostigma*	*Ficus altissima* Blume	54%	750	20	Axillary	Ellipsoid	Soft	Reddish yellow	2.3, 2	Jan-June	Simple, alternate	Ovate- elliptic	15
12.		*Ficus benghalensis* L.	75%	470	25	Axillary	Globose-ellipsoid	Soft	Reddish yellow	3.4, 4.4	May-Aug	Simple, alternate	Ovate	15
13.		*Ficus benjamina* L.	52%	240	23	Axillary	Globose	Soft	Dark red	2.1, 2.5	Dec-Feb	Simple, alternate	Ovate-lanceolate	8
14.		*Ficus curtipes* Corner	82%	340	24	Axillary	Globose to depressed globose	Hard	Dark red	1.3, 1.6	Through out the year	Simple, alternate	Obovate	18
15.		*Ficus drupacea* Thunb.	60%	1040	26	Axillary	Ellipsoid	Soft	Reddish yellow	4.6, 2.9	Through out the year	Simple, alternate	Ovate-elliptic	25
16.		*Ficus elastic* Roxb. ex Hornem.	77%	1120	30	Axillary	Ovoid-ellipsoid	Soft	Yellowish green	1.3, 0.7	Through out the year	Simple, alternate	Oblong-elliptic	18
17.		*Ficus geniculata* Kurz	70%	920	24	Axillary	Depressed globose	Soft	Red	1, 1.2	Through out the year	Simple, alternate	Obovate-oblong	11
18.		*Ficus glaberrima* Blume	15%	390	17	Axillary	Globose	Soft	Yellow	0.9, 0.9	Dec-Feb	Simple, alternate	Narrowly ovate- elliptic	12
19.		*Ficus microcarpa* L.F.	80%	370	16	Axillary	Depressed globose	Soft	Greenish yellow	1, 1	Dec-April	Simple, alternate	Ovate- elliptic	10
20.		*Ficus religiosa* L.	Open	340	24	Axillary	Globose to depressed globose	Soft	Red	1.1, 0.8	Feb-June	Simple, alternate	Broadly ovate-cordiform	14
21.		*Ficus rumphii* Blume	65%	510	21	Axillary	Globose	Soft	Black	1.4, 0.8	Jan-March	Simple, alternate	Ovate- elliptic	12
Note: GBH - Girth at Breast height; L- Length; D- diameter														

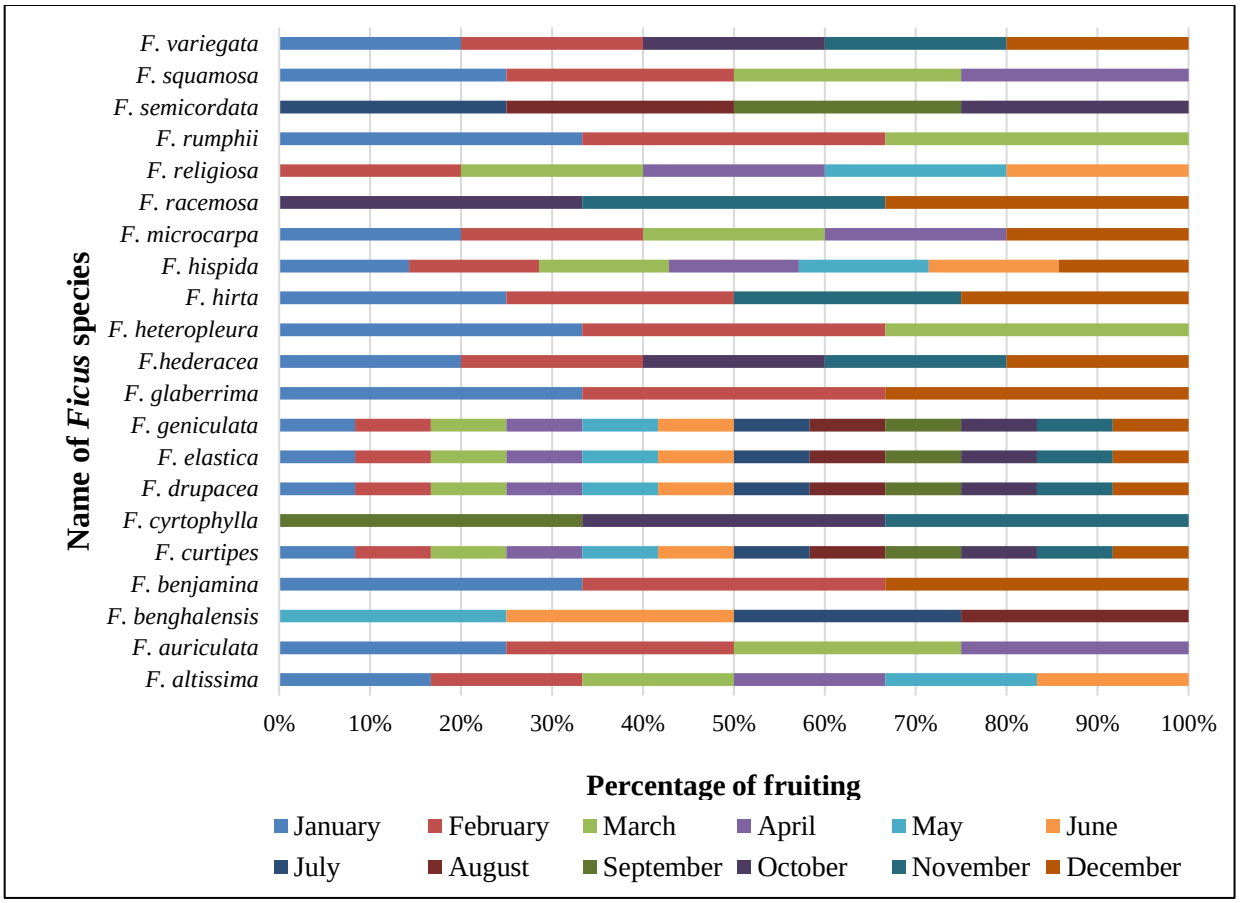


Figure 4. Fruiting season of the Fig trees at Pakke Wildlife Sanctuary

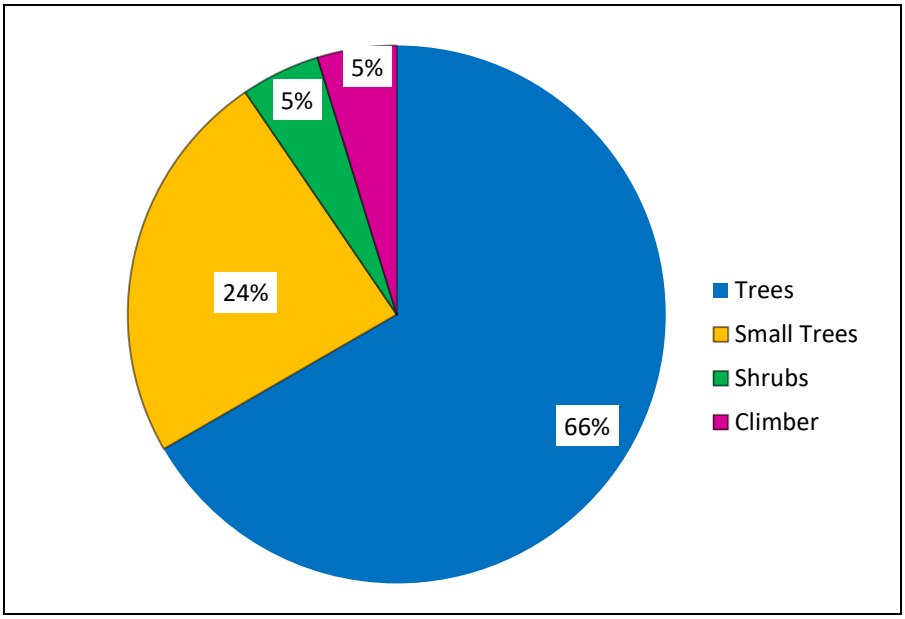


Figure 5. Habits of recorded *Ficus* species in Pakke Wildlife Sanctuary

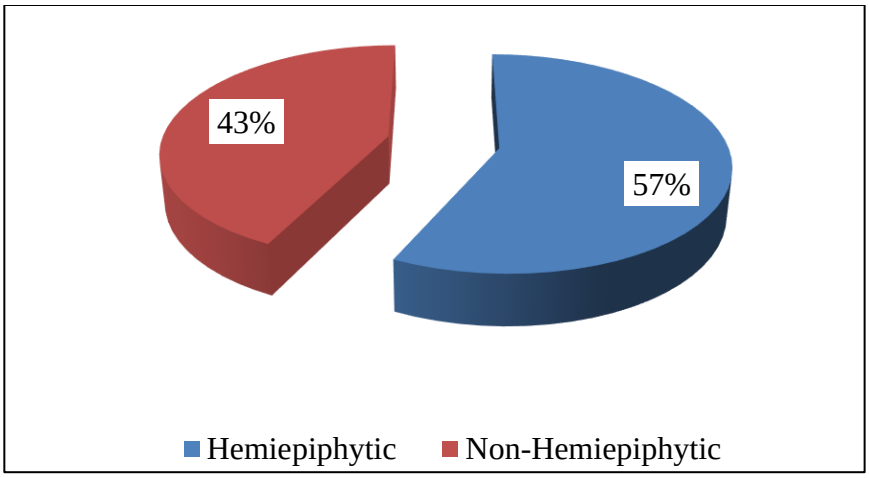


Figure 6. Growth forms of recorded *Ficus* species

Community structure of *Ficus* species

The frequency of the recorded Ficus species ranges from 2.44 to 46.34%, density ranges from 0.02 to 1.46 ha^{-1} and abundance ranges from 1.00 to 29.5. Among 21 *Ficus* species, *Ficus squamosa* (29.5) is the most abundant and *F. religiosa* (1) is least abundant. The frequency of *F. benghalensis* (46.34%) is highest and *F. religiosa* (2.44%) is least, while the density of *F. auriculata* is highest (146.34ha^{-1}) and *F. religiosa* least (2.44 ha^{-1}) (Table 2). The relative frequency ranges from 0.73 to 13.87, relative density ranges from 0.21 to 12.45, relative abundance ranges from 1.12 to 33.01, and IVI ranges from 2.06 to 46.71. From the calculated values of IVI, *F. squamosa* is found to be highly dominated and *F. religiosa* least dominated (Table 2).

Table 2. Quantitative community parameters of the *Ficus* species recorded in Pakke Wildlife Sanctuary

S. No.	Species	Frequency (F %)	Density (ha^{-1})	Abundance (A)	RF	RD	RA	IVI
1.	*Ficus auriculata*	21.95	146.34	6.67	6.57	12.45	7.46	26.48
2.	*Ficus benghalensis*	46.34	124.39	2.68	13.87	10.58	3	27.45
3.	*Ficus benjamina*	14.63	39.02	2.67	4.38	3.32	2.98	10.68
4.	*Ficus altissima*	04.88	24.39	5.00	1.46	2.07	5.59	9.13
5.	*Ficus curtipes*	26.83	65.85	2.45	8.03	5.6	2.75	16.38

6.	*Ficus cyrtophylla*	12.20	46.34	3.80	3.65	3.94	4.25	11.84
7.	*Ficus drupacea*	19.51	58.54	3.00	5.84	4.98	3.36	14.18
8.	*Ficus elastica*	36.59	90.24	2.47	10.95	7.68	2.76	21.39
9.	*Ficus geniculata*	19.51	29.27	1.50	5.84	2.49	1.68	10.01
10.	*Ficus glaberrima*	07.32	14.63	2.00	2.19	1.24	2.24	5.67
11.	*Ficus hederacea*	04.88	07.32	1.50	1.46	0.62	1.68	3.76
12.	*Ficus heteropluera*	09.76	14.63	1.50	2.92	1.24	1.68	5.84
13.	*Ficus hirta*	14.63	136.59	9.33	4.38	11.62	10.44	26.44
14.	*Ficus hispida*	19.51	39.02	2.00	5.84	3.32	2.24	11.40
15.	*Ficus macrocarpa*	14.63	24.39	1.67	4.38	2.07	1.86	8.32
16.	*Ficus racemosa*	04.88	12.2	2.50	1.46	1.04	2.80	5.29
17.	*Ficus religiosa*	02.44	2.44	1.00	0.73	0.21	1.12	2.06
18.	*Ficus rumphii*	14.63	19.51	1.33	4.38	1.66	1.49	7.53
19.	*Ficus semicordata*	24.39	117.07	4.80	7.30	9.96	5.37	22.63
20.	*Ficus squamosa*	04.88	143.9	29.5	1.46	12.24	33.01	46.71
21.	*Ficus variegata*	09.76	19.51	2.00	2.92	1.66	2.24	6.82

Ficus Diversity

Shannon Weiner Diversity Index of *Ficus* species in Pakke Wildlife Sanctuary is 2.69 (Fig. 7). According to Shannon Weiner Diversity Index (H), Tipi range is the most diverse with 19 *Ficus* species exhibiting H value 3.3), followed by Seijosa Range with 13 *Ficus* species (H=2.24) and Pakke Kessang least diverse with 03 *Ficus* species (H=0.71) (Fig.7). Similarly, from Simpson index it is recorded that *Ficus* species diversity is the highest in Tipi Range (1-ʎ =0.92) and lowest dominance value with ʎ =0.09, whereas Pakke Kessang Range have lowest *Ficus* diversity (1-ʎ =0.49) and highest dominance (ʎ =0.51) among the three ranges of PWS. Thus, there is about 92% chance that two randomly selected individuals from the Tipi Range would be from different species and 9% chance that the two randomly selected individuals would be from the same species (Fig.8).

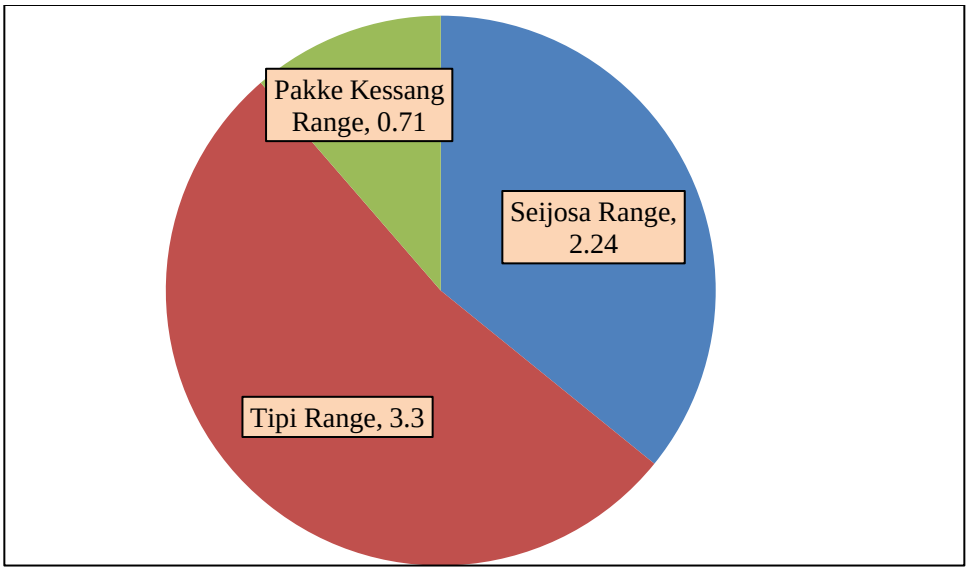
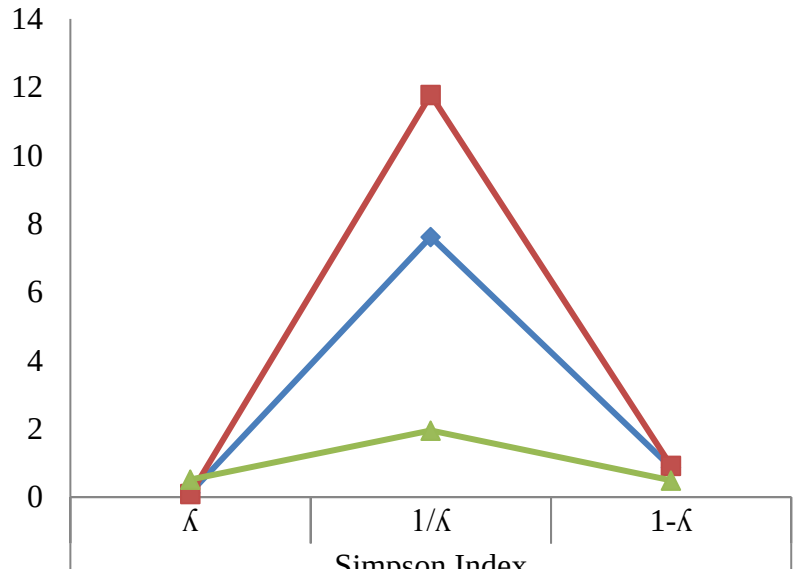


Figure 7. Shannon-Weiner diversity index of *Ficus* species recorded in three range of Pakke Wildlife Sanctuary



	Ʌ	1/Ʌ	1-Ʌ
Seijosa Range	0.13	7.62	0.87
Tipi Range	0.09	11.78	0.92
Pakke Kessang Range	0.51	1.95	0.49

Figure 8. Simpson diversity index of *Ficus* species recorded in three range of Pakke Wildlife Sanctuary

After comparing the three ranges of Pakke Wildlife Sanctuary (Seijosa Range, Tipi Range, and Pakke Kessang Range) using the Jaccard Similarity Index and Jaccard Distance Index, it was found that the highest similarity in *Ficus* species is between Tipi Range and Seijosa Range (0.524). The next highest similarity is between Tipi Range and Pakke Kessang Range (0.158), and the lowest similarity is between Pakke Kessang Range and Seijosa Range (0.118), as shown in Table 3(a). In the contrary, the highest dissimilarity is observed between the Pakke Kessang Range and the Seijosa Range (0.882), followed by the similarity between the Tipi Range and the Pakke Kessang Range (0.842), and the lowest similarity appears between the Tipi Range and the Seijosa Range (0.476) according to Table 3(b).

Table 3(a): Jaccard Similarity Index for similarity of *Ficus* species among the three ranges of Pakke Wildlife Sanctuary- Seijosa Range, Tipi Range and Pakke Kessang Range

	Seijosa Range	**Tipi Range**	**Pakke Kessang Range**
Seijosa Range	1	0.524	0.118
Tipi Range	0.524	1	0.158
Pakke Kessang Range	0.118	0.158	1

Table 3(b): Jaccard Distance for the dissimilarity of *Ficus* species among the three ranges of Pakke Wildlife Sanctuary- Seijosa Range, Tipi Range and Pakke Kessang Range

	Seijosa Range	**Tipi Range**	**PakkeKessang Range**
Seijosa Range	1	0.476	0.882
Tipi Range	0.476	1	0.842
Pakke Kessang Range	0.882	0.842	1

Figs as keystone species

As a keystone species, 16 out of 21 *Ficus* species of Pakke Wildlife Sanctuary are found consumed by a large number of frugivores, including birds and mammals. *F. benghalensis* is found supporting the highest species number of frugivore i.e. 32 species, followed by *F. geniculata* and *F. drupacea* supporting 31 and 30 frugivore species respectively, and only four Frugivore species depend on *F. hirta*, which is least. Five *Ficus* species, *F. auriculata,*

F. cyrtophylla, F. hederacea, F. racemose and *F. squamosa* are found not supporting any frugivore (Fig. 9). A total of 54 frugivore species with 1131 individuals are documented being supported by *Ficus* species of Pakke Wildlife Sanctuary; of which 43 species (942 individuals) are avian species and 11 species (189 individuals) are mammalian species. 43 avian species comprised within 27 genera and 15 families. While 11 mammalian species belong to 10 genera and six families. Among avian species, *Pycnonotus flaviventris* is found to be visiting the highest number of *Ficus* species (11 species). On the other hand, *Anthracoceros albirostris*, *Treron curvirostra*, *Sturnia malabarica*, *Oriolus traillii*, Chloropsis *hardwickii* and *Yuhina flavicollis* each are supported by only one *Ficus* species. Whereas among mammals, *Muntiacus muntjak* is associated with 13 *Ficus* species, while *Pteropus giganteus* visits only *Ficus drupacea* (Table. 4).

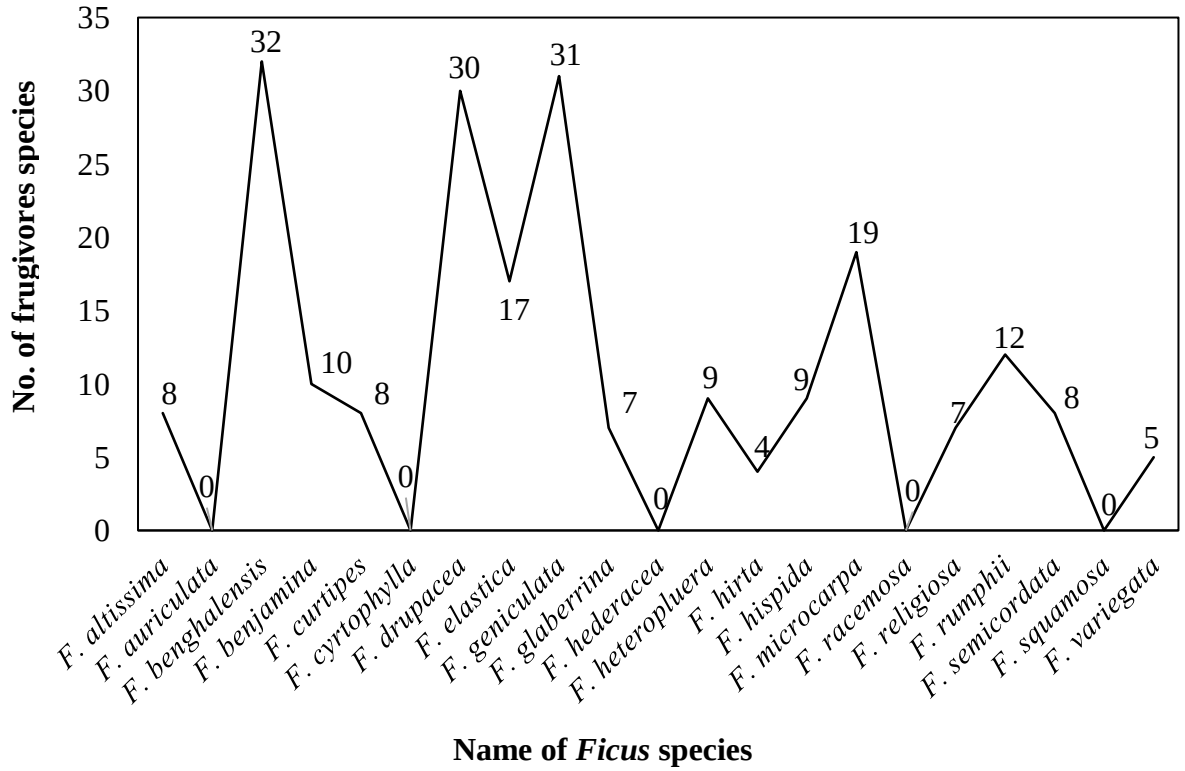


Figure 9. Number of frugivores feed on *Ficus* species

Table 4: Association of *Ficus* species with the recorded individuals of frugivore species

FRUGIVORE SPECIES				ASSOCIATED *FICUS* SPECIES	
Family	**Scientific name**	**Common name**	**No. of individuals**	**No. of species**	**Scientific name**
BIRDS					
Bucerotidae	*Anthracoceros albirostris*	Oriental Pied Hornbill	5	1	*F. drupacea*
	Buceros bicornis	Great Hornbill	17	5	*F. benghalensis, F. benjamina, F. curtipes, F. drupacea, F. geniculata*
	Rhyticeros undulates	Wreathed Hornbill	8	3	*F. drupacea, F. geniculata, F. macrocarpa*
Chloropseidae	*Chloropsis aurifrons*	Golden Fronted Leafbird	15	2	*F. geniculata, F. macrocarpa*
	Chloropsis hardwickii	Orange Bellied Leafbird	6	1	*F. geniculate*
Columbidae	*Chalcophaps indica*	Emerald Dove	36	3	*F. benghalensis, F. drupacea, F. elastica*
	Ducula aenea	Green Imperial Pigeon	14	3	*F. benghalensis, F. drupacea, F. rumphii*
	Ducula badia	Mountain Imperial Pigeon	11	2	*F. benghalensis, F. drupacea*
	Treron apicauda	Pin tailed Green Pigeon	28	4	*F. benghalensis, F. drupacea, F. geniculata, F. rumphii*
	Treron curvirostra	Thick billed Green Pigeon	5	1	*F. benghalensis*
	Treron phoenicoptera	Yellow Footed Green Pigeon	27	4	*F. benghalensis, F. elastica, F. geniculata, F. rumphii*
	Treron sphenurus	Wedgetailed Green Pigeon	15	4	*F. benghalensis, F. drupacea, F. geniculata, F. rumphii*
Cuculidae	*CuculusMicropterus*	Indian Cuckoo	12	4	*F. benghalensis, F. benjamina, F. drupacea, F. geniculata*
Dicruridae	*Dicrurus aeneus*	Bronze Drongo	8	2	*F. hispida, F. religiosa*
	Dicrurus hottentottus	Hair Crested Drongo	14	4	*F. benghalensis, F. curtipes, F. geniculata, F. macrocarpa*
	Dicrurus leucophaeus	Ashy Drongo	15	3	*F. glaberrima, F. microcarpa, F. religiosa*
	Dicrurus paradiseus	Greater Racket Tailed Drongo	9	3	*F. benghalensis, F. drupacea, F. geniculata*
	Dicrurus remifer	Lesser Racket Tailed Drongo	10	3	*F. benghalensis, F. drupacea, F. geniculata*
Irenidae	*Irena puella*	Asian Ferry Blue Bird	32	3	*F. benghalensis, F. drupacea, F. macrocarpa*
Muscicapidae	*Myophonus caeruleus*	Blue Whistling Thrush	13	2	*F. elastica, F. macrocarpa*

Oriolidae	*Oriolus traillii*	Maroon Oriole	14	1	*F. geniculate*
	Oriolus xanthornus	Black Hooded Oriole	17	2	*F. geniculata, F. macrocarpa*
Phasianidae	*Gallus gallus*	Red Jungle Fowl	18	9	*F. benghalensis, F. altissima, F. drupacea, F. elastica, F. geniculata, F. glaberrima, F. hirta, F. hispida, F. semicordata*
	Lophura leucomelanos	Kalij Pheasant	8	3	*F. altissima, F. drupacea, F. semicordata*
	Polyplectron bicalcaratum	Grey Peacock Pheasant	4	2	*F. altissima, F. semicordata*
Pycnonotidae	*Alophoixus flaveolus*	White Throated Bulbul	10	3	*F. drupacea, F. elastica, F. rumphii*
	Hemixos flavala	Ashy Bulbul	26	3	*F. elastica, F. geniculata, F. heteropleura*
	Hypsipetes leucocephalus	Black Bulbul	40	5	*F. benghalensis, F. drupacea, F. elastica, F. geniculata, F. heteropleura*
	Ixos mcclellandii	Mountain Bulbul	14	2	*F. drupacea, F. elastica*
	Pycnonotus cafer	Red Vented Bulbul	70	7	*F. benghalensis, F. elastica, F. geniculata, F. hispida, F. microcarpa, F. religiosa, F. rumphii*
	Pycnonotus flaviventris	Black Crested Bulbul	97	11	*F. benghalensis, F. benjamina, F. curtipes, F. drupacea, F. elastica, F. geniculata, F. glaberrima, F. heteropluera, F. hispida, F. microcarpa, F. rumphii*
	Pycnonotus jocosus	Red whiskered bulbul	16	2	*F. benghalensis, F. microcarpa,*
Ramphastidae	*Psilopogon asiaticus*	Blue Throated barbet	78	9	*F. benghalensis, F. benjamina, F. curtipes, F. drupacea, F. elastica, F. geniculata, F. glaberrima, F. microcarpa, F. rumphii*
	Psilopogon cyanotis	Blue Eared Barbet	38	6	*F. benghalensis, F. curtipes, F. geniculata, F. glaberrima, F. heteropluera, F. hispida*
	Psilopogon lineatus	Lineated Barbet	38	5	*F. benghalensis, F. drupacea, F. elastica, F. geniculata, F. microcarpa*
	Psilopogon virens	Great Barbet	18	3	*F. benjamina, F. curtipes, F. elastica*
Sturnidae	*Acridotheres fuscus*	Jungle Myna	28	3	*F. benghalensis, F. benjamina, F. elastica*
	Acridotheres grandis	Great Myna	17	2	*F. benghalensis, F. microcarpa*
	Gracula religiosa	Common Hill Myna	54	8	*F. benghalensis, F. benjamina, F. curtipes, F. drupacea, F. geniculata, F. heteropluera, F. microcarpa, F. rumphii*
	Sturnia malabarica	Chestnut Tailed Starling	9	1	*F. macrocarpa*

Trogonidae	*Harpactes erythrocephalus*	Red Headed Trogon	12	3	*F. benghalensis, F. elastica, F. geniculata*
Turdidae	*Cochoa viridis*	Green Cochoa	11	2	*F. benjamina, F. variegata*
Zosteropidae	*Yuhina flavicollis*	Whiskered Yuhina	5	1	*F. geniculate*
MAMMALS					
Cercopithecidae	*Macaca assamensis*	Assamese Macaque	49	4	*F. drupacea, F. geniculata, F. heteropleura, F. hirta*
	Macaca mulata	Rhesus Macaque	43	6	*F. curtipes, F. drupacea, F. geniculata, F. hirta, F. hispida, F. religiosa*
Cervidae	*Muntiacusmuntjac*	Barking Deer	17	13	*F. benghalensis, F. benjamina, F. altissima, F. drupacea, F. geniculata, F. glaberrima, F. heteropleura, F. hispida, F. microcarpa, F. religiosa, F. semicordata, F. variegata, F. rumphii*
	Rusa unicolor	Sambar	9	6	*F. benghalensis, F. drupacea, F. geniculata, F. microcarpa, F. semicordata, F. variegata*
Pteropodidae	*Pteropus giganteus leucocephalus*	Indian Flying Fox	2	1	*F. drupacea*
Sciuridae	*Callosciurus pygerythrus*	Hoary Bellied Squirrel	26	11	*F. benjamina, F. altissima, F. elastica, F. geniculata, F. glaberrima, F. heteropleura, F. hirta, F. hispida, F. religiosa, F. variegata, F. rumphii*
	Ratufa bicolor	Himalayan Giant Squirrel	11	7	*F. benghalensis, F. altissima, F. drupacea, F. geniculata, F. microcarpa, F. religiosa, F. rumphii*
Suidae	*Sus scrofa*	Wild Boar	5	3	*F. benghalensis, F. semicordata, F. variegata*
Viverridae	*Arctitis binturong*	Binturong	8	3	*F. benghalensis, F. drupacea, F. geniculata*
	Paguma larvata	Himalayan Palm Civet	10	5	*F. benghalensis, F. altissima, F. drupacea, F. geniculata, F. semicordata*
	Parodoxurus hemaphroditus	Common Palm Civet	9	4	*F. benghalensis, F. altissima, F. drupacea, F. semicordata*

Discussion

The Eastern Himalayas of India have always been rich in biodiversity with its high highly diverse flora and fauna, unique germplasm, and endemic species. Pakke Wildlife Sanctuary of Arunachal Pradesh is enriched with high biodiversity with a higher level of taxonomic diversity. A study conducted in Arunachal Pradesh documented the presence of over 40 species of *Ficus* (Giri et al., 2008). Arunachal Pradesh has a recorded number of over 70 species of plants from the Moraceae family, which are classified into six genera: *Artocarpus, Broussonetia, Ficus, Maclura, Morus,* and Streblus. Among these, *Ficus* has the highest number of species, with a total of 51 (Buragohain, 2014; Singh & Hage, 2017) documented four *Ficus* species (*F. auriculata, F. hispida, F. semicordata, F. subulata*) from eight districts of Arunachal Pradesh including Lower Subansiri, Lower Dibang valley, Upper Subansiri, KraDadi, Papumpare, West Siang, Tawang and Tirap. Bhuyan and Pangu (2020) recorded 11 *Ficus* species from East Kameng district of Arunachal Pradesh – *F. auriculata, F. benghalensis, F. benjamina, F. dumosa, F. elastica, F. elmeri, F. fistulosa, F. hirta, F. hispida, F. racemosa and F. rumphii.* According to Kumar (2006), four *Ficus* species serve as food plants for Capped Langur (*Trachypithecus pileatus)* in Pakhui Wildlife Sanctuary. A total of 165 species were enumerated from Pakke Wildlife Sanctuary with 1,899 trees, of which 128 species are identified with 51 families and 37 species are unidentified. Dutta & Rawat (2008) have recorded 128 plants in Pakke comprising 12 species of Moraceae family. Out of the recorded species from Moraceae family, 10 species were *Ficus*. Out of these 10 *Ficus* species, three species namely *F. altissima, F. cyrtophylla,* and *F. elastica* are recorded in the present study with varying numbers of individuals. Devi, et al. (2012) noted one species, *Ficus racemosa,* from Pakke Tiger Reserve, whereas Tag et al. (2012) documented almost 215 species of higher plants belonging to 165 genera and 70 families. Out of 215 species, there were five species of *Ficus*, all of which are recorded in the present study. Balkrishna et al. (2022) mentioned six *Ficus* species in the Seijosa circle to be used for various indigenous purposes. Gogoi et al. (2023) also documented five *Ficus* species, viz. *F. altissima*, *F. drupacea*, *F. geniculata*, *F. nervosa* and *F. variegata* from Pakke Wildlife Sanctuary. In the present study, a total of 21 *Ficus* species are documented from Pakke Wildlife Sanctuary with 482 individuals. The recorded species in the present study are found to be higher in number than (Kumar, 2006; Dutta & Rawat, 2008; Devi et al., 2012; Tag et al., 2012; Balkrishna et al., 2022; Gogoi et al., 2023) (Table 5).

Table 5. *Ficus* species reported to be found in Pakke Wildlife Sanctuary by various studies.

Sl. Nos.	*Ficus* species	References
1.	*Ficus altissima*	Dutta and Rawat 2008; Balkrishna *et al.* 2022; Gogoi *et al.* 2023; Present Study
2.	*Ficus auriculata*	Present Study
3.	*Ficus benghalensis*	Kumar 2006; Tag *et al*. 2012; Present Study
4.	*Ficus benjamina*	Balkrishna *et al.* 2022; Present Study
5.	*Ficus curtipes*	Present Study
6.	*Ficus cyrtophylla*	Dutta and Rawat 2008; Present Study
7.	*Ficus drupacea*	Gogoi *et al.* 2023; Present Study
8.	*Ficus elastica*	Dutta and Rawat 2008; Tag *et al*. 2012; Balkrishna *et al.* 2022; Present Study
9.	*Ficus geniculata*	Gogoi *et al.* 2023; Present Study
10.	*Ficus glaberrima*	Present Study
11.	*Ficus glomerata*	Kumar 2006
12.	*Ficus hederacea*	Present Study
13.	*Ficus heteropluera*	Present Study
14.	*Ficus hirta*	Present Study
15.	*Ficus hispida*	Tag *et al*. 2012; Balkrishna *et al.* 2022; Present Study
16.	*Ficus hookeri*	Dutta and Rawat 2008
17.	*Ficus lamponga*	Kumar 2006; Dutta and Rawat 2008
18.	*Ficus macclellandi*	Dutta and Rawat 2008
19.	*Ficus macrocarpa*	Present Study
20.	*Ficus mysorensis*	Dutta and Rawat 2008
21.	*Ficus nervosa*	Dutta and Rawat 2008; Gogoi *et al.* 2023
22.	*Ficus pomifera*	Dutta and Rawat 2008
23.	*Ficus racemosa*	Devi *et al.* 2012; Present Study
24.	*Ficus religiosa*	Kumar 2006; Balkrishna *et al.* 2022; Present Study
25.	*Ficus rumphii*	Present Study
26.	*Ficus semicordata*	Balkrishna *et al.* 2022; Present Study
27.	*Ficus scandens*	Dutta and Rawat 2008
28.	*Ficus squamosa*	Present Study
29.	*Ficus variegata*	Gogoi et al 2023; Present Study

Ficus species are often observed in human dominated areas. Similarly, *F. religiosa* and *F. hispida* are observed to found in human dominated areas surrounding the Sanctuary. Several *Ficus* species are considered in associations with religious factors such as *F. benghalensis, F. religiosa, F. virens* (Barua & Tamuly, 2011). Shu (2003) mentioned the plants of *Ficus* species vary greatly in habits from trees to shrubs, climbers to stranglers, or sometimes woody epiphytes. According to Harrison and Shanahan (2005), the *Ficus* comprises of enormous woody climbers, trees and shrubs along with strangling plants. Most of the *Ficus* plants from the present study are trees (14 species), the small trees (five species) and very few are shrubs (one species) and climbers (one species). Twelve species are hemiepiphytic, which are all trees. Among nine non-hemiepiphytic species, two are trees, five are small trees, one is shrub, and one is climber (Fig. 5, Fig. 6). Kattan and Valenzuela (2013) observed five *Ficus* species (*F. mutisii, F. andicola, F. hartwegii, F. killipi* and *F. aff. cuatrecasana*) at Otun Quimbaya Flora and Fauna.

Sanctuary of the Andes of Colombia produces ripe figs throughout the year whose availability varied to an extent, from the least fig production of one individual per species in August and September to the highest of 10 individuals per species in March. Maximum of the fruiting species in tropical areas tend to bear fruits either at the peak rainy season or just before its onset (David et al., 2012; Lieberman, 1982; Murali & Sukumar, 1994; Sundarapandian et al., 2005). Whereas the figs (*Ficus*) do not fruit seasonally and are available. On studying the fruiting phenology of four fig species *Ficus benghalensis, F. amplissima, F. microcarpa* and *F. racemosa* in Sriharikota of Andhra Pradesh, India, the lowest in December and January and the highest number of individuals with ripe figs were in April, November and May (David et al., 2012). In Pakke Wildlife Sanctuary, the fruiting period of most of the *Ficus* species, like *F.curtipes, F. drupacea, F. elastica, F. geniculata,* is not confined to one particular season of a year. Instead, different individuals of a particular *Ficus* species bear fruits at different times of the year, providing food for wild animals throughout the year. Few *Ficus* species like *F. auriculata, F. squamosa* are found fruiting in one particular season of the year. For example, *F. auriculata* is found fruiting from October to January and *F. squamosa* from May to August (Fig. 4, Table 1).

Figs (*Ficus* sp.) are always considered as 'Keystone species' of tropical forests, because they have the capacity to produce abundant and constant figs and other food resources (flowers and leaves) throughout the year unlike any other plant groups (Milton, 1991; Peres, 2000; Ragusa-Netto, 2002; Shanahan et al., 2001). In Pakke Wildlife Sanctuary the documented *Ficus* species feeds the 43 bird species and 11 mammal species throughout the whole year. Shanahan et al., (2001) specified over 1200 species of birds and mammals: over 10% of world's bird species and 6% of mammals prominently feed on figs. Kattan & Valenzuela (2013) observed 36 avian and three mammalian frugivores feeding on three species of figs (*F. andicola, killipaa* and *F. mutisii*) in Otun Quimbaya

Flora and Fauna Sanctuary, Columbia. Barua & Tamuly (2011) recorded 67 species of avian frugivores depending on five *Ficus* species, *F. religiosa, F. virens, F. rutusa, F. benghalensis* and *F. racemosa* around Kaziranga National Park and Panbari Reserve Forest, Golaghat, Assam. Vanitharani et al. (2009) discussed the dependency of 30 bird species, 12 species of bats and 17 species of mammals on 18 *Ficus* species, as feeders as well as habitat users. Daru et al. (2015) also witnessed 12 *Ficus* species associated with 48 bird species at Amurum Forest Reserve. Ragusa-Netto (2002) observed 12 birds' species depending on *F. calyptroceras,* while Budiman et al. (2017) observed three hornbill species *(Anthrococeros albirostris, Anthroceros malayanus, Buceros rhinoceros) on F. crassiramea.* In Pakke Wildlife Sanctuary, Gogoi et al. (2023) documented 54 vertebrate species (43 birds and 11 mammals) surviving on *Ficus drupacea, Ficus geniculata, Ficus altissima* and *Ficus variegata*. Only 16 *Ficus* species out of 21 are found to be associated with 54 frugivore species 43 avian species and 11 mammalian species. *F. benghalensis* is found to be the most preferred food source being visited by 32 frugivore species and *F. hirta* is least visited by four frugivore species. Pothasin et al. (2014) mentioned *F. squamosa*, along with 33 other *Ficus* species, as a riparian species. *F. squamosa* of Pakke Wildlife Sanctuary, Gogoi et al. (2023) documented 54 vertebrate species (43 birds and 11 mammals) surviving on *Ficus drupacea, Ficus geniculata, Ficus altissima* and *Ficus variegata*. Of the recorded *Ficus* species in the present study area. Only 16 species are documented to be fruiting from April to July, which lies in the monsoon period. Thus, the species happens to be either washed away or covered by the flood water leaving no chance for any frugivore to feed on.

Conclusion

In Pakke Wildlife Sanctuary, *Ficus* species plays a very important role as a food source for the 54 species of both mammalian and avian frugivores. The three ranges of the sanctuary have different distributions, and abundance of *Ficus* species, with the Tipi range having the highest diversity and Pakke Kesang Range least. Except *F. curtipes*, every document species has soft ripe figs. Few species have no canopy cover while the maximum has a canopy of 10%– 82%. The fruiting of figs does not depend on the season of the year; only four species bear figs throughout the year, and all different individuals of the same species may bear figs in different periods of the year. Thus, by attracting a diverse range of frugivores for sustenance, refuge, and various other behaviours year-round, the species serves a keystone species of Pakke Wildlife Sanctuary. Consequently, these frugivores may aid in the dispersal of fig seeds, contributing to conservation efforts within the sanctuary. Therefore, the highly associated *Ficus* species should be given priority in plantation programme in the recovery of degraded wildlife habitats for the conservation of frugivore species.

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Declaration of Interest

The authors declare no conflict of interest. The authors are solely responsible for the content and writing of the paper.

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