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The diet of Indian flying-foxes (*Pteropus giganteus*) in urban habitats of Pakistan

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We studied the diet of the Indian flying fox (*Pteropus giganteus*) in Pakistan from March 2008 to February 2009 and found that the bats fed on 20 species belonging to 11 plant families. Of these, four families (Anacardiaceae, Bignonaceae, Malvaceae, and Sapotaceae) were identified from remnants of flower petals in food boluses while the remaining families (Annonaceae, Arecaceae, Ebenaceae, Meliaceae, Moraceae, Myrtaceae, and Sapindaceae) were identified from the seeds in the boluses and from guano samples. Plants in the family Moraceae (50.7%) comprised most of the bat's diet. Fruit of *Ficus retusa* (27.5%) and *F. carica* (23.0%) during winter, *F. glomerata* (30.9%) and *F. religiosa* (28.1%) during spring, *Psidium guajava* (19.6%), *F. bengalensis* (18.7%) and *Diospyros peregrina* (17.8%) during summer, and *D. peregrina* (71.9%) during autumn, were the most frequently identified items. The four seasonal diets varied significantly ($\chi^2 = 435$, *d.f.* = 18, $P < 0.01$). Results confirm that the ecological services rendered by *P. giganteus*, such as pollination and seed dispersal, outweigh its losses, such as damage to the ripe fruit. Hence, the species should not be regarded as a pest; rather efforts should be made to ensure its conservation.

Key words: conservation, *Ficus*, fruit bat, Pakistan, pest, seed dispersal, urban habitat

INTRODUCTION

The Old World fruit bats (Chiroptera: Pteropodidae) are important for the survival of more than 114 plant species of the world (Mickleburgh *et al*., 1992). Their positive roles as pollinators, seed dispersers, and as agents for maintaining plant community diversity has been acknowledged universally (van der Pijl, 1982; Marshall, 1983; Cox *et al*., 1991; Fujita and Tuttle, 1991; Mickleburgh *et al*., 1992; Rainey *et al*., 1995; Eby, 1996; Banack, 1998). Pteropodids are represented by three genera and four species in Pakistan (Roberts, 1997; Mahmood-ul-Hassan *et al*., 2009) and includes the short-nosed fruit bat (*Cynopterus sphinx*), the Indian flying fox (*Pteropus giganteus*), the Egyptian fruit bat (*Rousettus aegyptiacus*) and the fulvous fruit bat (*Rousettus leschenaultii*).

Distributed in Maldive Isles, India (including Andaman Isles), Sri Lanka, Pakistan, Bangladesh, Nepal and Burma, *P. giganteus* is one of the largest bats in the world (Simmons, 2005). It is often labeled as 'vermin' on the assumption that it poaches ripe fruits from orchards and defecates in public places (Chakraverthy *et al*., 2009; Mahmood-ul-Hassan *et al*., 2009). This bat is thought to cause heavy economic losses to arecanut (*Areca catechu*), sapota (*Achrus zapota*), guava (*Psidium guajava*), mango (*Mangifera indica*), and jaman (*Syzigium jambolanum*) (Roberts, 1997; Chakraverthy and Girish, 2003). *Pteropus giganteus* is given no protection by Pakistani law and is hunted for its body fat to be used as potions and as putative cures for rheumatic pains, by local medical practitioners known as 'hakeems' (Roberts, 1997). *Pteropus giganteus* is included in the fourth schedule of the Punjab Wildlife (Protection, Preservation, Conservation and Management) Act 1974 section 2 (v), which lists the species among those that are given no legal protection and can be hunted.

Although extensive literature exists on the food habits of some *Pteropus* species (e.g., Dobat and Peikert-Holle, 1985; Marshall, 1985; Mickleburgh *et al*., 1992; Wiles and Fujita, 1992), few studies offer a detailed investigation of their diet in a single area (Banack, 1998). Information is particularly scanty regarding the diet of *P. g. giganteus* in urban landscapes and no attempt has been made to quantify the ecological role of this species. The present study was designed to determine whether

P. giganteus can indeed be considered a pest to fruit crops and, if so, then to what extent. This study also provides baseline information about the food preferences of this species from Pakistan and its roles in seed dispersal and pollination.

Materials and Methods

Study Area

The study was conducted in Lahore (31°33'N and 74°19'E, about 210 m a.s.l.) at the eastern border of Pakistan, within the Punjab Province, 24 km away from the Pakistan–Indian border. The city covers an area of 1,775 km^2 and is the second most populated city in Pakistan. The average annual precipitation is 500 mm. May, June, and July are the hottest months of the year, with mean maximum temperature reaching 39°C and maximum daily temperatures up to 49°C. The monsoon rains mostly fall in July and August, which are the wettest months. December and January are the coldest months with a mean minimum temperature of 6°C and occasionally passing below freezing (Qureshi *et al*., 2005).

The present study was conducted at Jinnah Garden (35°55'N, 74°33'E; 71.2246 ha) which was established in 1860 by the former Punjab Governor Lord John Laird Lawrence and is one of the oldest known roosts of *P. giganteus* in Pakistan (Roberts, 1997). The garden is divided into 47 plots of varying sizes. At present, the *P. giganteus* roosts in four of 47 plots. These four plots cover 8.5% of the total garden and harbor 12.3% of the total trees (n = 4,119) present in the park.

Food Analysis

The boluses and guano of *P. giganteus* were sampled between March 2008 and February 2009 by spreading polythene sheets on the ground directly below feeding perches and diurnal roost sites (Hodgksin *et al*., 2003). Four polythene sheets, each covering an area of 1 m^2, were placed one night per month in each of four plots in the Jinnah Garden below permanent bat roosts. Each sheet was in place for 10 hours from 20:00 h until 06:00 h Pakistan Standard Time. The recovered food remains were removed the subsequent day for analysis. Two samples each of guano and bolus were collected randomly from each sheet and were air-dried before being placed in polythene bags. These samples were transferred to 20 ml distilled water and shaken well to separate the undigested food items. The petals and seeds thus separated from the boluses and guano were counted and identified by matching them with a reference collection of petals and seeds collected from plants in the Jinnah Garden and within a circumference of 30 km; the distance the flying foxes can commute per night (van der Pijl, 1957).

The majority of the seeds were identified through visual inspection or by using a hand lens and by comparisons with the reference seeds. However, the seeds that could not be identified visually were germinated. The germination experiments involved transferring the unidentified seeds to small plastic pots containing wet cotton under natural conditions of temperature and day length (Hodgkison *et al*., 2003). The seedlings were later transferred to pots containing soil and were allowed to grow for 3–4 weeks until they could be identified.

Statistical Analysis

A χ^2-test was used to compare seasonal importance of different plant families in the diet of *P. giganteus*. Data obtained in December, January, and February were classified as winter; March, April, and May as spring; June, July, and August as summer; and September, October, and November as autumn.

Results

Pteropus giganteus utilized (introduced plants are followed by '*') flowers of *Mangifera indica* and *Pistacia chinensis** (Anacardiaceae), *Kigelia pinnata** (Bignonaceae), *Ceiba pentandra** (Malvaceae), *Madhuca longifolia*, *Manilkara zapota** (Sapotaceae), and *Syzygium jambolanum* (Myrtaceae). It fed most on fruits of *Areca catechu** (Arecaceae), *Diospyros peregrina** and *D. kaki** (Ebenaceae), *Melia azedarach* (Meliaceae), *Ficus bengalensis**, *F. carica*, *F. glomerata*, *F. religiosa**, *F. retusa*, *Morus nigra* (Moraceae), *Psidium guajava** (Myrtaceae), and *Nephelium lappaceum** (Sapindaceae) while both the flowers and fruits of *Polyalthia longifolia** (Annonaceae) were also consumed.

Table 1. Percentage frequency of occurrence (followed by n) of the remnants of petals of different species identified from the regurgitated pellets samples of *P. giganteus* collected from Jinnah Garden, Lahore, Pakistan, in decreasing order of their frequency of occurrence. * — Species that are introduced to the region. Petals were recorded in the ejecata of *P. giganteus* only during the below mentioned monthly samples

Tree species	Mar (6)	Apr (21)	Jul (27)	Sep (15)	Oct (47)	Jan (15)	Total (131)
*Pistacia chinensis**	–	–	100 (27)	–	100 (47)	–	56.5 (74)
*Ceiba pentandra**	–	–	–	–	–	100 (15)	11.5 (15)
Manilkara zapota	–	29.6 (8)	–	–	–	–	6.1 (8)
*Kielia pinnata**	–	–	–	53.3 (8)	–	–	6.1 (8)
*Polyalthia longifolia**	–	–	–	100 (7)	–	–	5.3 (7)
Syzygium jambolanum	–	25.9 (7)	–	–		–	5.3 (7)
Madhuca longifolia	22.2 (6)	–	–	–	–	–	4.6 (6)
Mangifera indica	–	22.2 (6)	–	–	–	–	4.6 (6)

Analysis of Regurgitated Pellets

The regurgitated pellets samples consisted of flower petals (Table 1) and seeds (Table 2). The petals of *P. chinensis* were the most frequently consumed food item in July and October. The other plants identified from the petals in the regurgitated pellets of *P. giganteus*, in order of their decreasing importance, included *C. pentandra* (January), *M. zapota* (April) and *K. pinnata* (September), *P. longifolia* (September) and *S. jambolanum* (April), and *M. longifolia* (March), and *M. indica* (April) (Table 1).

A total of 503 seeds were recovered from the regurgitated pellet samples that belonged to the following plant families, in order of their decreasing frequency, Moraceae (63.4%), Myrtaceae (15.9%), Ebenaceae (13.2%), Sapindaceae (4.4%), and Meliaceae (3.0%). Within family Moraceae, the seeds of *F. retusa* were the most abundant, while those of *M. nigra* were the least frequent in the regurgitated pellet samples. *Psidium guajava* formed the bulk of this species' diet by frequency (Table 2).

Ficus retusa was the only plant species recovered from the samples during winter; *F. glomerata*, *F. religiosa,* and *M. nigra* during spring, while *M. azedarach* and *F. bengalensis* were consumed during summer. The fruits of *P. guajava* were used during winter and summer, *D. kaki* during spring and autumn, and *N. lappaceum* during summer and autumn (Fig. 1A).

Guano Analysis

The seeds of 12 species belonging to seven families were identified from the guano of *P. giganteus* (Table 3). The families Moraceae (37.4%), Ebenaceae (36.1%), and Myrtaceae (14.9%) jointly formed 88.4% of the bats' diet. The seeds of *Diospyros peregrina* were the most frequent of all the plant species identified from the guano of *P. giganteus* (Table 3).

The guano analysis revealed that of the 12 plant species, the fruits of *M. nigra*, *P. longifolia*, *F. glomerata*, and *A. catechu* were consumed only during winter and spring, respectively (Fig. 1B) while the remaining fruits were consumed for at least two other seasons. The bats ate fruits of *F. religiosa* during winter and spring, *F. carica* during winter and autumn, *D. kaki* during winter and summer, *M. azedarach* and *F. retusa* during spring and summer and — *N. lappaceum* and *D. peregrina* during summer and autumn, respectively (Fig. 1B).

TABLE 2. Monthly variations in the percent frequency of occurrence (*n*) of the seeds belonging to different plant species identified from the regurgitated pellets samples collected from Jinnah Garden, Lahore, Pakistan, of *P. giganteus* in decreasing order of their frequency of occurrence; *n* is the number of seeds collected from regurgitated pellets; * — species that are introduced to the region

Tree species	Jan (15)	Feb (79)	Mar (81)	Apr (22)	May (75)	Jun (41)	Jul (30)	Aug (39)	Sep (45)	Oct (0)	Nov (31)	Dec (45)	Total (503)
*Psidium guajava**	–	–	–	–	–	–	50 (15)	51.3 (20)	–	–	–	100 (45)	15.9 (80)
Ficus retusa	–	100 (79)	–	–	–	–	–	–	–	–	–	–	15.7 (79)
F. glomerata	–	–	–	–	100 (75)	–	–	–	–	–	–	–	14.9 (75)
*F. religiosa**	–	–	92.3 (75)	–	–	–	–	–	–	–	–	–	14.9 (75)
*Diospyros peregrina**	–	–	–	100 (22)	–	–	–	–	100 (45)	–	–	–	13.2 (67)
F. carica	100 (15)	–	–	–	–	–	–	–	–	–	90.3 (28)	–	8.5 (43)
*F. bengalensis**	–	–	–	–	–	100 (41)	–	–	–	–	–	–	8.2 (41)
*Nephelium lappaceum**†								48.7 (19)			9.7 (3)		4.4 (22)
Melia azedarach	–	–	–	–	–	–	50 (15)	–	–	–	–	–	3.0 (15)
Morus nigra†			7.9 (6)										1.2 (6)

† — Species identified through germination experiments

The combined analysis of the regurgitated pellets and guano revealed that *P. giganteus* depends heavily on plants in the families Moraceae, Ebenaceae, and Myrtaceae that jointly formed 90.5% of its total diet throughout the year (Table 4). Fruit in the family Moraceae formed the main component during the winter (62.4%) and spring (68.4%). Fruits in the Ebenaceae family became almost equally important during the summer (27.4%), and served as a staple food item during the autumn (71.9%). The seasonal importance of different plant families varied significantly ($\chi^2 = 435$, *d.f.* = 18, $P < 0.01$). The winter diet was similar to the spring diet and the autumn diet to that of the summer.

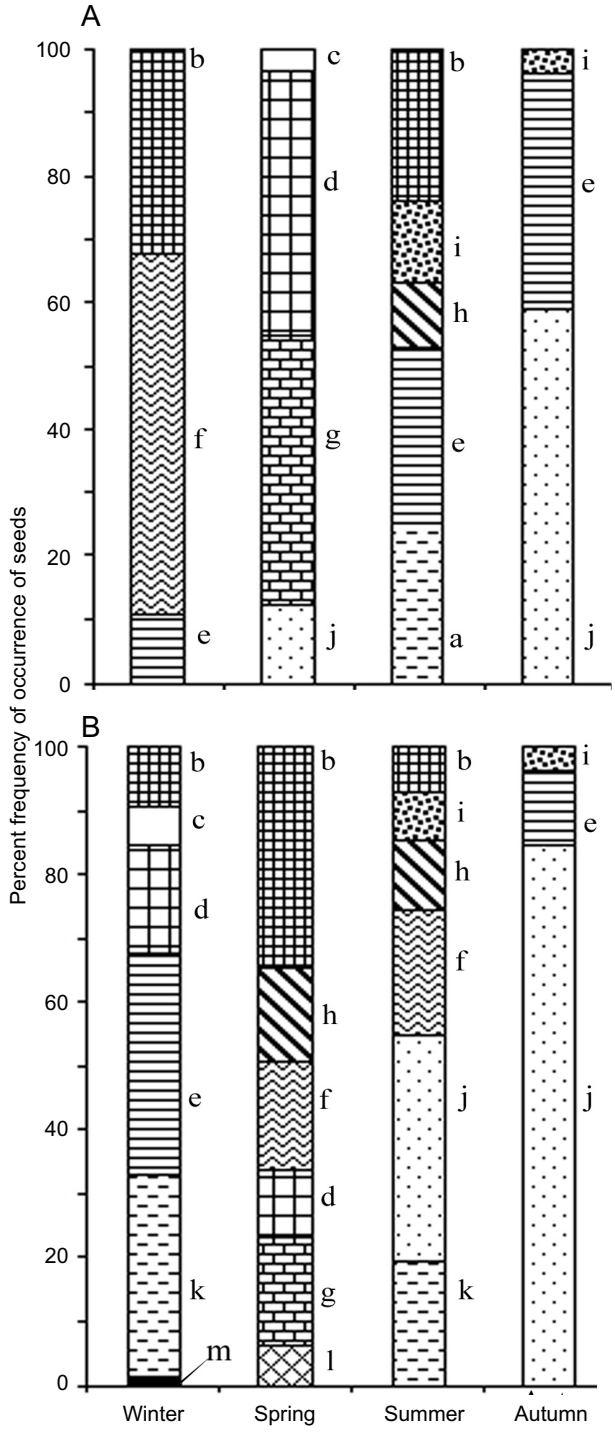

FIG. 1. Seasonal variation in the frequency of occurrence of the seeds collected from Jinnah Garden, Lahore, belonging to different plant species identified from (A) the regurgitated pellets and (B) from the guano of *P. giganteus*. a — *F. bengalensis*, b — *P. guajava*, c — †*M. nigra*, d — *F. religiosa*, e — *F. carica*, f — *F. retusa*, g — *F. glomerata*, h — *M. azedarach*, i — †*N. lappaceum*, j — *D. peregrina*, k — *D. kaki,* l — *A. catechu*, m — *P. longifolia* († identified through germination experiments)

DISCUSSION

Large flying foxes are among the most threatened groups of bats, particularly in southeast Asia (Mildenstein, 2002), where some taxa are considered vermin because they are assumed to poach ripe fruits from orchards (Chakraverthy and Girish, 2003; Mahmood-ul-Hassan and Nameer, 2006; Chakraverthy *et al*., 2009). In comparison to many studies that simply provide lists or tabulations of dietary items used by bats (e.g., Mickleburgh *et al*., 1992; Eby, 1998), only a few studies actually quantify various dietary components of flying foxes (Stier and Mildenstein, 2005) which showed that the fruits of various *Ficus* spp. are a consistent, ubiquitous, and nutritious dietary component of *P. giganteus* and are presumed to be the limiting components in its diet (Stier and Mildenstein, 2005).

Ficus carica and *F. retusa* during winter, *F. glomerata* and *F. religiosa* during spring, *F. bengalensis* during summer, and *F. carica* during autumn are the staple food items of *P. giganteus*. Different *Ficus*, when consumed in combination, have the ability to fulfill the major nutritional requirements of fruit bats (Wendeln *et al*., 2000). These fruits are rich in calcium (Nelson *et al*., 2000), an element that is important for bone development and maintenance, and also vital during parturition and nursing (Barclay, 1994, 1995; Palmer *et al*., 2000). The bats also supplement their food with leaves and flower petals at some part of the year to fulfill their protein requirements (Law, 1992; Kunz and Diaz, 1995; Ruby *et al*., 2000), which is considered to be a limiting nutrient for fruit eating bats as fruits are generally low in nitrogen (Thomas, 1984; Courts, 1998). The *Ficus* and *Diospyros* spp. are the keystone resources for *P. giganteus* as they sustain bats during times of overall resource scarcity (Terborgh, 1986; Lambert and Marshall, 1991).

Although the diet of *P. giganteus* may vary throughout its range, the present study reveals that

this species feeds primarily on members of family Moraceae of which a vast majority belongs to genus *Ficus*. Ebenaceae and Myrtaceae are the other important plant families that contribute a significant part to its diet whereas Annonaceae, Arecaceae, and Meliaceae are notably less important. Flying foxes disperse the seeds of numerous families (e.g., Moraceae, Ebenaceae, Myrtaceae, Sapotaceae, Annonaceae, Anacardiaceae — Fujita and Tuttle, 1991) or perform pollination (e.g., Myrtaceae, Bignoneaceae, Malvaceae). Thus, on the basis of this study, we can conclude that *P. giganteus* is not a pest as previously perceived (Chakraverthy and Girish, 2003; Chakraverthy *et al*., 2009). The population status and trends in the abundance of *P. giganteus* in the last decade indicate that its population is declining and the bat is under a serious threat of becoming endangered associated with the misconception of being a pest species (Mahmood-ul-Hassan *et al*., 2009).

The economic importance of the flying foxes as pollinators of commercial fruit can be illustrated from the fact that during the fiscal year 2007 Pakistan exported 55,000 tons of mangoes (*Mangifera indica*) worth $16.5 million (US) to the United Kingdom, continental Europe, United States, Saudi Arabia, and some other countries (Anonymous, 2007). *Morus* is another economically important multipurpose genus; the leaves of *M. alba* and *M. nigra* are used for rearing silk worms, and a multitude of other purposes.

There are nearly 200 species of pteropodids across the Old World (Simmons, 2005) that feed primarily on a combination of fruit, nectar, and pollen and are persecuted by farmers to protect their fruit production (Fujita and Tuttle, 1991). While the decline of the pteropodids raises serious concerns throughout the world and especially in Paleotropical forests (Strat and Marshall, 1976; Marshall, 1983, 1985; Richards, 1987), there is no current action to legally protect them in Pakistan (Roberts, 1997; Mahmood-ul-Hassan *et al*., 2009). However in India, persistent efforts by bat biologists and non-governmental organizations have resulted in providing legal protection to all 13 species of pteropodid bats (Singaravelan *et al*., 2009).

On the basis of this study we strongly recommend that Jinnah Garden, Lahore should be declared as sanctuary for *P. giganteus* before it declines locally to endangered status and its numbers become insufficient to service forests and cause economic damage to agricultural and medicinal practices that depend on fruits and plants which it disperses and

TABLE 3. Monthly variations in the percent frequency of occurrence (*n*) of the seeds belonging to different plant species identified from the guano samples collected from Jinnah Garden, Lahore, of *P. giganteus* in decreasing order of their frequency of occurrence. *n* is the number of seeds collected from regurgitated pellets; * — species that are introduced to the region

Tree species	Jan (66)	Feb (33)	Mar (39)	Apr (45)	May (58)	Jun (21)	Jul (59)	Aug (29)	Sep (39)	Oct (13)	Nov (25)	Dec (49)	Total (476)
*Diospyros peregrina**	–	–	–	–	–	–	66.1 (39)	–	100 (39)	100 (13)	52.0 (13)	–	21.8 (104)
*Psidium guajava**	–	18.1 (6)	–	45.7 (21)	48.8 (28)	–	–	27.6 (8)	–	–	–	16.3 (8)	14.9 (71)
D. kaki	42.5 (28)	–	–	–	–	–	–	72.4 (21)	–	–	–	38.8 (19)	14.3 (68)
Ficus carica	43.9 (29)	–	–	–	–	–	–	–	–	–	36.0 (9)	44.6 (22)	12.6 (60)
F. retusa	–	–	61.5 (24)	–	–	100 (21)	–	–	–	–	–	–	9.5 (45)
*F. religiosa**	–	75.7 (25)	38.5 (15)	–	–	–	–	–	–	–	–	–	8.4 (40)
Melia azedarach	–	–	–	–	36.2 (21)	–	20.3 (12)	–	–	–	–	–	6.9 (33)
F. glomerata	–	–	–	54.3 (24)	–	–	–	–	–	–	–	–	5.0 (24)
Nephelium lappaceum†*	–	–	–	–	–	–	13.6 (8)	–	–	–	12.0 (3)	–	2.3 (11)
*Areca catechu**	–	–	–	–	15.5 (9)	–	–	–	–	–	–	–	1.9 (9)
Morus nigra†*	13.6 (9)	–	–	–	–	–	–	–	–	–	–	–	1.9 (9)
Polyalthia longifolia†*	–	6.2 (2)	–	–	–	–	–	–	–	–	–	–	0.4 (2)

† — Species identified through germination experiments

TABLE 4. Combined monthly variations in the percentage frequency of occurrence (*n*) of the seeds belonging to different plant families identified from the regurgitated pellets and guano samples collected from Jinnah Garden, Lahore, of *P. giganteus* in decreasing order of their frequency of occurrence

Tree families	Jan (81)	Feb (112)	Mar (120)	Apr (67)	May (133)	Jun (62)	Jul (89)	Aug (68)	Sep (84)	Oct (13)	Nov (56)	Dec (94)	Total (979)
Moraceae	65.4 (53)	92.9 (104)	100 (120)	35.8 (24)	56.4 (75)	100 (62)	–	–	–	–	66.1 (37)	23.4 (22)	50.7 (497)
Ebenaceae	34.6 (28)	–	–	32.8 (22)	–	–	43.8 (39)	30.9 (21)	100 (84)	100 (13)	23.2 (13)	20.2 (19)	24.4 (239)
Myrtaceae	–	5.4 (6)	–	31.3 (21)	21.1 (28)	–	16.9 (15)	40.5 (28)	–	–	–	56.4 (53)	15.4 (151)
Meliaceae	–	–	–	–	15.8 (21)	–	30.3 (27)	–	–	–	–	–	4.9 (48)
Sapindaceae	–	–	–	–	–	–	8.9 (8)	27.9 (19)	–	–	10.7 (6)	–	3.4 (33)
Arecaceae	–	–	–	–	6.8 (9)	–	–	–	–	–	–	–	0.9 (9)
Annonaceae	–	1.8 (2)	–	–	–	–	–	–	–	–	–	–	0.2 (2)

pollinates. We also urge that the species is protected throughout Pakistan.

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