FRUGIVORY BY BIRDS AND MAMMALS IN SRIHARIKOTA ISLAND, SOUTHERN INDIA

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Fleshy-fruits and their consumers were documented in a coastal tropical dry evergreen forest in southern India from April 2005 to May 2008. Twenty-one species of birds and nine species of mammals were recorded feeding on 56 fleshy-fruit species. The major avian frugivores were Red-whiskered Bulbul *Pycnonotus jocosus* and White-browed Bulbul *Pycnonotus luteolus*. Bonnet Macaque *Macaca radiata*, Golden Jackal *Canis aureus*, Small Indian Civet *Viverricula indica*, Short-nosed Fruit Bat *Cynopterus sphinx* and Indian Flying Fox *Pteropus giganteus* were the major mammalian frugivores.

The frugivore assemblage in Sriharikota is typical of degraded secondary vegetation. Use of fleshy-fruits by birds was limited by seed protection in the form of husk and tough fruit/seed coat and to some extent by fruit colour, whereas mammals used a variety of fleshy-fruits. Green ripe fruits, avoided by birds and most mammals, were chiefly or exclusively eaten by fruit bats.

Figs (*Ficus* species) are an important fleshy-fruit resource for frugivores. The Coppersmith Barbet *Megalaima haemacephala* shows a high degree of dependency on figs. Fruit bats utilized figs almost in all months of the study period. The conservation of fig trees, and other bird and bat attracting flora is vital for the survival of frugivores, which are important components in forest ecosystems, due to their crucial role in seed dispersal and regeneration.

Key words: Frugivory, *Ficus*, Figs, Fruit bats, keystone species, Sriharikota

INTRODUCTION

Many tropical plants produce fleshy fruits which are consumed by a variety of frugivorous birds and mammals to fulfill their nutritional requirements (Snow 1981; Balasubramanian and Bole 1993; Remsen *et al*. 1993; Balasubramanian 1996; Corlett 1998b; Clark *et al*. 2001; Ganesh and Davidar 2001; Bollen *et al*. 2004). Other than seed-eating frugivores, frugivores in general aid in seed dispersal, and also help seeds escape the deleterious effects of seed and seedling predators (Janzen 1970). They also help in the germination success of seeds as the hard seed coat get softened (thereby, breaking the dormancy), as they pass through the gut. Thus, many frugivorous birds and mammals play a crucial role in the regeneration of forest plants. In fact, the spectacular evolutionary success of tropical flowering plants over the past several million years can be attributed to their reliance on animals for pollination and seed dispersal rather than wind (Fleming *et al.* 1987).

Globally, not considering the temperate regions; sites in the neotropics have the richest assemblage of frugivorous birds, while sites in Southeast Asia have the lowest avian frugivore diversity (Fleming *et al*. 1987). In the Indo-Malayan region, birds of at least 41 families include fruit in their diet; 17 of which are highly frugivorous (Corlett 1998b). In southern India, 66 species of birds from 16 families have been documented for frugivory with Columbidae, Pycnonotidae and Muscicapidae representing the most number of species (Balasubramanian and Maheswaran 2003). Among mammals, primates and fruit bats are the chief frugivores in tropical regions (Fleming *et al*. 1987; Corlett 1998b).

Community level studies on frugivory and seed dispersal has brought into focus the importance of fruit characters such as size, colour and nutritional value in fruit selection by birds and mammals (Gautier-Hion *et al.* 1985; Wheelwright 1985; Bollen *et al*. 2004; Kitamura *et al*. 2005), and enabled scientists to identify important fruiting trees or keystone resources (Terborgh 1986; Bleher *et al*. 2003). In India, most of the studies on frugivory have focused on a single animal or plant species (Borges 1993; Kannan and James 1999; Sreekumar and Balakrishnan 2002; Datta and Rawat 2003; Balasubramanian *et al*. 2004; Prasad *et al*. 2004; Mishra and Gupta 2005) with very few community level studies (Balasubramanian and Bole 1993; Balasubramanian 1996; Ganesh and Davidar 2001).

In degraded landscapes, knowledge of the relative attractiveness of native plants to frugivorous birds is useful in planning reafforestation because fruiting trees will attract

birds which carry seeds of other species in their guts, thus increasing the diversity of the forest (Corlett 1992). With this background and understanding, a community level study on fruit-frugivore interactions was undertaken in a Tropical Dry Evergreen Forest (TDEF) in Sriharikota Island from April 2005 to May 2008.

The paper chiefly deals with the fleshy-fruit resources of birds and mammals, their physical traits, and the utilization pattern by birds and mammals. It shortlists the major fleshy-fruit species, whose conservation is vital for the survival of frugivores, and the overall health of the forest ecosystem on the Island.

STUDY AREA

The study was undertaken in Sriharikota (13° 45' N; 80° 20' E) lying in the southern Indian states of Andhra Pradesh and Tamil Nadu with an area *c*. 180 sq. km (Fig. 1). It is bounded on the east by the Bay of Bengal and on the west by Pulicat lake. Sriharikota has been connected by road to Sullurpet (18 km) on the mainland since 1970.

Though the Island is affected by both the monsoons, the principal rainfall is mainly from the North-east monsoon. The annual rainfall averages around 1,200 mm. The average humidity varies from 55% in summer to 75% during monsoon. Temperature ranges from 20°C in winter to 40°C during summer. Low-lying areas of Sriharikota get inundated during the North-east monsoon, creating streams and pools. Besides the monsoonal inundation, the wetlands of Sriharikota comprise of lakes (both fresh and brackish), streams (both fresh and brackish), creeks, and natural and man-made freshwater ponds. Cane brakes line most of the waterways. The water table is *c*. 2 to 5 m.

The forest in the Island has been classified as Tropical Dry Evergreen Forest (TDEF) (Champion and Seth 1968). The forest has a long history of disturbance. Forest exploitation goes back to the British era when patches of forest were selectively felled for timber. Subsequently, people from the mainland settled along the margins of the Island, which were earlier inhabited by tribal Yanadis. The settlers cleared areas for cultivation, especially along the western borders of the Island (central and southern parts) with alluvial soil facing Pulicat lake. Some important fruit-bearing and shade trees such as Mango *Mangifera indica*, Neem *Azadirachta indica*, Indian Ash Tree *Lannea coromandelica*, Tamarind *Tamarindus indicus* and Palmyra *Borassus flabellifer* were introduced in village areas. During the early 1970s, the Indian Space Research Organisation (ISRO) took over the Island and set its spaceport. As a result of this long and varied human exploitation, what remains today are patches of secondary

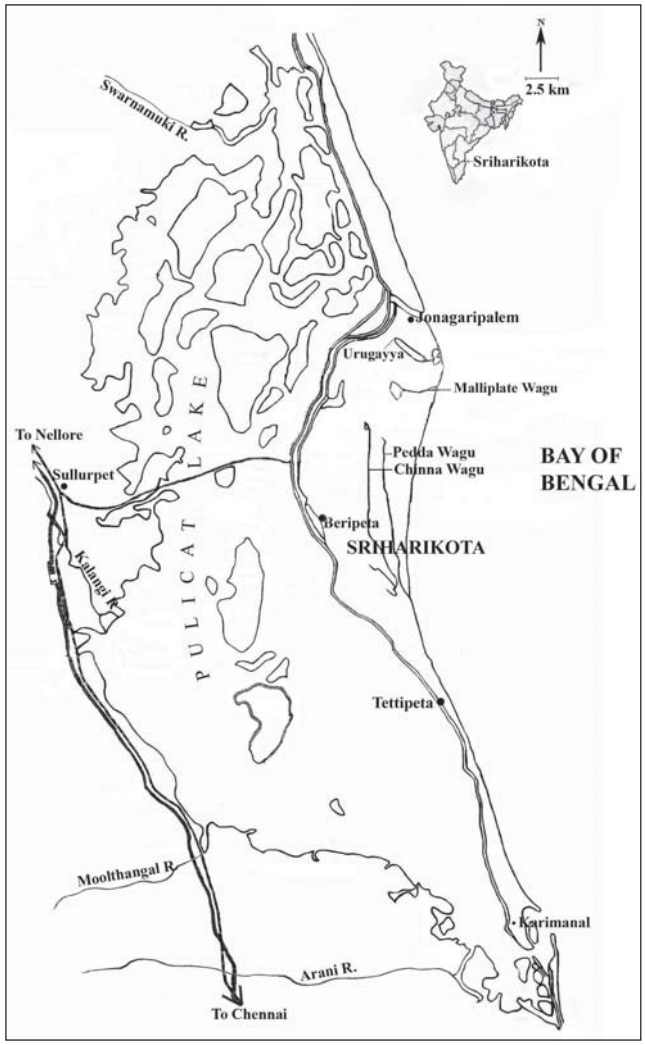

Fig. 1: Sriharikota Island and its adjoining areas

forest in various stages of regeneration with isolated old, tall trees that were not felled, especially *Tamarindus indicus*, *Syzygium cumini* and *Sapindus emarginatus*.

There are broadly five major vegetation types/habitats in the Island:

Tropical Dry Evergreen Forests (TDEF): Found in the central part of the Island, stretching from south of Urugayya lake till around Picheru Gunta, except in sandy tracts or areas under plantations. The tree species include *Syzygium cumini*, *Pterospermum canescens*, *Manilkara hexandra*, *Garcinia spicata*, *Strychnos nux-vomica*, *Pongamia pinnata*, *Tamarindus indicus* and *Cordia dichotoma*. The shrub layer includes *Memecylon umbellatum*, *Glycosmis pentaphylla*, *Eugenia bracteata*, *Grewia rhamnifolia* and *Breynia vitis-idaea*. Climbers such as *Abrus precatorius*, *Asparagus racemosus*, *Cissus vitiginea*, *Jasminum* spp. *Carissa spinarum*, *Olax scandens*, *Coccinia grandis* and *Ziziphus oenoplia* make the forest dense and impenetrable.

Herbs are mainly restricted to the open patches in the forests. Along streams and shallow basins, which are inundated during the monsoon, *Terminalia arjuna*, *Barringtonia acutangula* and *Pongamia pinnata* are dominant, *T. arjuna* occurring in pure stands in some patches. Canebrakes line most of the waterways.

Open Scrub: Open scrub forest is largely present in the sandy tracts, which mostly occur in the northern, eastern and southern fringes of the Island. The ground is sandy and much exposed with a predominance of shrubs like *Gmelina asiatica*, *Diospyros ferrea*, *Securinega leucopyrus*, *Catunaregum spinosa*, *Canthium parviflorum*, *Maytenus emarginatus*, *Dodonea viscosa*, *Capparis* spp., *Carissa spinarum*, *Pavetta indica* and *Atalantia monophylla*. Scattered trees of *Syzygium cumini*, *Sapindus emarginatus*, *Lannea coromandelica*, *Ficus* spp., *Azadirachta indica*, *Albizia amara*, *Walsura trifolia*, *Pamburus missionis* and *Ochna obtusata* occur.

Abandoned Village Forest: The stretch of land situated on a low basin between Kothachenu to Tettipeta, and to a lesser extent around Penubakkam to the former Chengalapalem was cultivated in the past. Ponds were maintained to irrigate the paddy fields in the basin and the other crops at its borders. Now abandoned, these areas have their own characteristic vegetation comprising the regenerating forest of largely *Ficus* spp., *Albizia amara* and *A. lebbeck* amidst coconut, palmyra, neem and tamarind trees. The irrigation ponds have been colonized by canebrakes and *Barringtonia acutangula*.

Eucalyptus Plantation: Eucalyptus plantations are mainly seen from about Urugayya lake to the south of Picheru Gunta. Shrubby elements such as *Memecylon umbellatum*, *Securinega leucopyrus*, and *Catunaregam spinosa* form the undergrowth. An understorey of *Strychnos nux-vomica*, *Garcinia spicata* and *Ochna obtusata* has also come up in some of the more open plantations.

Casuarina Plantation: Casuarina plantations are seen in a narrow belt almost all over the sea coast, starting from east of Chandrasikuppam to Karimanal. Unlike eucalyptus, the casuarina plantations form dense, pure stands with some mixture of native species. Shrubs and trees like *Securinega leucopyrus*, *Azadirachta indica* and *Pavetta indica* form the understorey. *Olax scandens* is a common climber, while *Dendrophthoe falcata* (=*Loranthus longiflorus*) is a common stem parasite on casuarina (Suryanarayana *et al*. 1998).

The flora and fauna of the Island has been well-documented through a number of studies with 445 species of plants of 117 families, 27 species of mammals, 223 species of birds, 12 species of amphibians, 34 species of reptiles, 44 species of fish and 51 species of butterflies recorded (Suryanarayana *et al*. 1989, 1998; Samant and Rao 1996; Rao 1998; Manakadan and Sivakumar 2004a, b; Sivakumar and Manakadan 2004, Sivakumar *et al*. 2004). The mammals in the island include the Bonnet Macaque *Macaca radiata*, Slender Loris *Loris lyddekerianus*, Golden Jackal *Canis aureus*, Rusty-spotted Cat *Prionailurus rubiginosus*, Small Indian Civet *Viverricula indica*, Indian Flying Fox *Pteropus giganteus* and Short-nosed Fruit Bat *Cynopterus sphinx*.

For more details of the island and description of habitats, see Venugopal Rao (1977), Reddy (1981), Reddy (1983), Suryanarayana *et al*. (1998), Rao 1998, and Manakadan and Sivakumar (2004a, b).

METHODS

Fruit-use by Birds

Data on avian visitors to fruiting plants and fruit handling technique was obtained through tree watches (extended observations on fruiting trees) and opportunistic observations (Bollen *et al*. 2004). In tree watches, fruiting plants were observed between 06:00-09:00 hrs from a hide set up 15-20 m away. During this period, for every five minutes, records were kept on the bird and mammal species, and numbers visiting the fruiting tree and their fruit handling techniques. Twenty-one fleshy-fruit species were observed, totalling 242 tree watch hours (TWH). The observation period for each fleshy-fruit species varied depending on crop size, availability of fruiting plants and season. Additional frugivory records were obtained opportunistically during bird census, phenology trips and other field visits comprising 305 frugivory records. We could not quantify the number of fruits removed by frugivores during tree watches due to dense foliage and high visitation rates of birds, which made it difficult to track individual birds. So, only the number of visits was quantified.

Fruit-use by Mammals: Data on fruits utilized by mammals was obtained by collecting and examining faeces from direct feeding observations on fruiting trees (tree watches and opportunistic records) and fruit debris evidence. Faeces of Golden Jackal, Small Indian Civet and Bonnet Macaque were collected fortnightly while walking along 10 phenology trails totalling *c*.10 km. Faeces were also collected by travelling along a 5 km road on a motorbike once a fortnight. We mainly relied on the knowledge of our tribal field assistant, who had good knowledge of the wildlife of the Island, on the identity of the faeces and on animal footprints around the faeces. Faeces that could not be recognized were classified as "unidentified". The seed species and their numbers were recorded separately for each faeces.

Information on fruits utilized by the two fruit bat species in the Island, Short-nosed Fruit Bat and Indian Flying Fox, was collected from examination of fruit debris, i.e., spat-out pulp after extraction of juices (Long and Racey 2007). We could not clearly distinguish between fruit debris of Short-nosed Fruit Bat and the Indian Flying Fox, so a general term 'fruit bats' is used referring to both the species.

For fruits that were intensively used by fruit bats (*Atalantia monophylla, Garcinia spicata, Pamburus missionis* and *Opilia amentacea*), the quantity of fruits eaten was estimated by clearing the ground below the fruiting tree and monitoring these fruit plots (cleared patches) during the entire fruiting period. The fruit debris in the fruit plots was categorized into bat-chewed pellets, partially eaten fruits, seeds, ripe fruits and unripe fruits. In *Atalantia monophylla*, the number of fruits eaten by fruit bats was estimated by dividing the total number of seeds by the average number of seeds (5) per fruit. In the one-seeded *Opilia amentacea*, a seed was equivalent to one fruit. In *Garcinia spicata* and *Pamburus missionis*, a bat-chewed pellet was considered as one fruit. For these two species, the number of seeds was not taken into consideration as these fruits were also eaten by the Bonnet Macaque and Asian Koel *Eudynamys scolopaceus* (only *Pamburus missionis*), with a lot of seeds dropped in the process. This sampling does not take into account fruits carried away from the fruiting tree by fruit bats and those eaten by rodents on the ground. However, it does provide a rough idea of fruit-use by fruit bats and the competition with other frugivores.

Fig-use by Bats: A total of 119 fig trees of 4 species were tagged to estimate fig utilization by fruit bats. The trees were visited fortnightly from September 2006 to May 2008, and the presence/absence of bat-eaten fruits below the fruiting trees was recorded.

Statistical Analysis: To assess for differences in fruit traits used by mammals and birds, G-test was used. To compute G-values for fruit colour, violet was clubbed with black, and orange with yellow. Similarly fruit types other than drupe, berry and achene were clubbed together as one fruit type, and in the case of life forms, small trees and large trees were clubbed together as trees.

RESULTS

Frugivore Assemblage: A total of 21 species of birds and 9 species of mammals were recorded to include fleshy-fruits in their diet. Among birds, 11 species were sighted rarely in the study area or fed on fruits only occasionally and these are not discussed further. The remaining 10 species fall under 7 genera and 7 families. Family Pycnonotidae was represented by 3 species, Corvidae by 2 species and the rest of the families by a single species (Table 1). The major avian frugivores were the Red-whiskered Bulbul *Pycnonotus jocosus* and White-browed Bulbul *P. luteolus*.

Table 1: Avian and mammalian frugivores of Sriharikota

Common Name	Scientific Name	Family	Diet Category	No. of plant species utilised
Birds				
Orange-breasted Green-Pigeon	*Treron bicinctus*	Columbidae	Chiefly frugivorous	7
Rose-ringed Parakeet	*Psittacula krameri*	Psittacidae	Chiefly frugivorous	10
Asian Koel	*Eudynamys scolopaceus*	Cuculidae	Omnivore	23
Coppersmith Barbet	*Megalaima haemacephala*	Capitonidae	Chiefly frugivorous	7
Red-vented Bulbul	*Pycnonotus cafer*	Pycnonotidae	Chiefly frugivorous	16
Red-whiskered Bulbul	*Pycnonotus jocosus*	Pycnonotidae	Chiefly frugivorous	31
White-browed Bulbul	*Pycnonotus luteolus*	Pycnonotidae	Chiefly frugivorous	29
Common Myna	*Acridotheres tristis*	Sturnidae	Omnivore	12
House Crow	*Corvus splendens*	Corvidae	Omnivore	5
Indian Jungle Crow	*Corvus (macrorhynchos) culminatus*	Corvidae	Omnivore	12
Mammals				
Bonnet Macaque	*Macaca radiata*	Cercopithecidae	Chiefly frugivorous	34
Golden Jackal	*Canis aureus*	Canidae	Carnivore	23
Small Indian Civet	*Viverricula indica*	Viverridae	Carnivore	16
Three-striped Palm Squirrel	*Funambulus palmarum*	Sciuridae	Herbivore	17
Fruit bats (Short-nosed Fruit Bat, Indian Flying Fox)	*Cynopterus sphinx*, *Pteropus giganteus*	Pteropodidae	Chiefly frugivorous	19

The mammals with significant fleshy-fruit intake in their diet were Bonnet Macaque, Golden Jackal, Small Indian Civet, Indian Flying Fox, Short-nosed Fruit Bat and Three-striped Palm Squirrel *Funambulus palmarum* (Table 1). The other species for which frugivory records were obtained occasionally were the Common Mongoose *Herpestes edwardsii*, Spotted Deer *Axis Axis* and Wild Boar *Sus scrofa*.

Fruit-Use: A total of 56 fleshy-fruit species of 33 families were eaten by frugivores. Birds accounted for 38 of these species and mammals 46 species. Ten fruit species were exclusively consumed by birds and 18 exclusively by mammals. The family Moraceae was represented by the highest number of species (5), followed by Rubiaceae (4). Twelve species were climbers, 13 were shrubs, 14 were small trees and 17 were large trees (Appendix 1).

Fruit-use by birds: The Red-whiskered Bulbul and the White-browed Bulbul consumed 34 of the 38 fleshy-fruits eaten by birds and are the major avian frugivores of Sriharikota. The Red-vented Bulbul *P. cafer* was recorded to feed on 16 species and the Asian Koel on 23 species. The Coppersmith Barbet *Megalaima haemacephala* has a narrow diet range, using only 7 of the 38 species, of which 4 were figs; the others were *Lannea coromandelica*, *Syzygium cumini* and *Ziziphus oenoplia*.

Fruit-use by mammals: The Bonnet Macaque was recorded to feed on 34 of the 46 fleshy-fruits eaten by mammals (Table 1). Seventeen species were recorded in 95 droppings (with all figs clubbed as one species), the rest were based only on feeding observations. The bulk of seeds recorded in the droppings were of *Ficus* spp. and *Cordia dichotoma* (Appendix 2). More than 50% of droppings contained plant remains other than seeds, such as leaves, skin of fruits, flowers and twigs. Opportunistic feeding records and faeces analysis indicate that figs are a major food resource for the Bonnet Macaque.

Faeces analysis (n= 473) and direct feeding observation showed that the Golden Jackal feeds on 23 native species and 4 introduced species (*Anacardium occidentale*, *Calamus rotang*, *Morinda tinctoria* and *Guazuma ulmifolia*). The bulk of the fruit diet (judging by the abundance of seeds and frequency of occurrence) was contributed by *Syzygium cumini*, *Phoenix farinifera*, *Memecylon umbellatum*, *Cordia dichotoma* and *Grewia rhamnifolia* (Appendix 2). The number of seeds per scat was relatively high in Golden Jackal (Fig. 2). The Small Indian Civet scats (n=134) contained seeds of 16 species, mostly comprising of species recorded in the Golden Jackal scats.

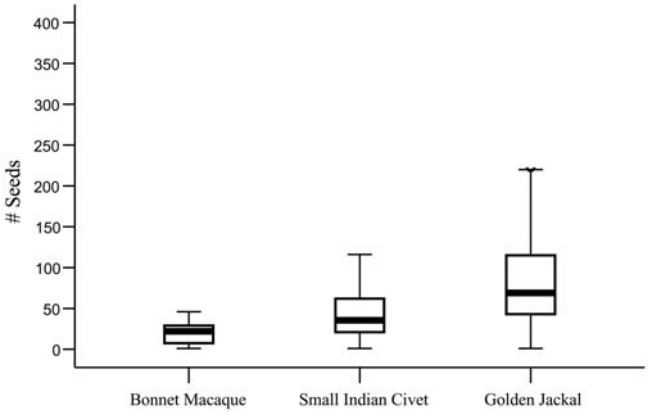

Fig. 2: Box plot showing number of seeds in the mammal droppings

Fruit bats were recorded to feed on 21 species of fleshy-fruits, which included two introduced species (*Polyalthia longifolia* and *Spondias pinnata*). The important fruit resources for fruit bats in Sriharikota are *Atalantia monophylla*, *Garcinia spicata*, *Opilia amentacea*, *Pamburus missionis* and *Syzygium cumini*. Among these, *A. monophylla* and *O. amentacea* were almost exclusively eaten by fruit bats (Table 2). Four of the 5 green fruits used by mammals were consumed chiefly/exclusively by fruit bats. Except for *Garcinia spicata*, none of the fruits had an odour perceivable to humans. Fruit bats were also recorded to feed on the leaves of *Sapindus emarginatus* and *Ficus benghalensis*.

In addition to these five major mammalian frugivores, four more species were recorded to feed on fleshy-fruits. The Three-striped Palm Squirrel used 17 species of fleshy-fruits. Seeds of *Catunaregam spinosa* were recorded in the droppings

Table 2: Quantity of fruits eaten by fruit bats as recorded in fruit plots below fruiting trees

Species	No. of plants monitored	Frequency of monitoring	No. of bat eaten fruits	Partially eaten fruits	Full fruits	
					Ripe	Unripe
Atalantia monophylla	10	Once in 3-5 days	3,664	-	1,810	47
Garcinia spicata	9	Once in 3-5 days	114	211	250	80
Opilia amentacea	7	Daily in the mornings	13,593	226	4,323	1,266
Pamburus missionis	10	Once in 3-5 days	374	700	6,590	112

Note: Refer Methodology and Discussion for details.

of Spotted Deer *Axis axis*; *Syzygium cumini* in Wild Boar dung; and *Phoenix farinifera*, *Grewia rhamnifolia* and *Syzygium cumini* in Common Mongoose scats.

Fruit Traits: Overall, red was the dominant fruit colour, followed by yellow and black (Fig. 3). A high proportion of fruits (71%) (Fig. 4) and seeds (96%) were ≤15 mm in diameter. The largest fruit recorded was *Strychnos nux-vomica* (44 mm) and the smallest was the seedless fruits of *Salvadora persica* (2.4 mm) (Appendix 1). Regarding fruit types, 46% were drupes, 35% were berries, 9% were achenes, 4% were capsules, and the rest comprised of pods, schizocarp and aril (Appendix 1). A comparative assessment of fruits consumed by birds and mammals is given in Table 3. There was no statistically significant difference between birds and mammals with respect to fruit colour (G=4.6, df-5, p>0.05), fruit type (G=0.5, df-3, p>0.05), fruit size (G=4.3, df-2, p>0.05) and life form (G=1.1, df-3, p>0.05).

Bird-Fruits: Red, yellow and black were the major colours displayed by fleshy-fruits eaten by birds (Table 4). Green, brown and violet were displayed only by one species each. Regarding fruit size, 58% of fruits (n=38) ≤ 10 mm in diameter and 84% ≤ 15 mm. Seed diameter ranged from 1.4 mm in *Catunaregam malabarica* to 10.9 mm in *Canthium parviflorum* (excluding very small seeds). Slightly more than 50% of fruits were single-seeded. Large-sized fruits, such as *Capparis brevispina*, *Coccinia grandis*, *Lepisanthes tetraphylla* and *Ficus benghalensis* were multi-seeded (more than 2 seeds/fruit). Two fruit species, *Alangium salvifolium* (stone) and *Casaeria esculenta* (aril) had protection for seeds.

Mammal-Fruits: Among fruits used by mammals, red was the dominant fruit colour displayed by 37% of the species, followed by yellow (20%), and black (15%). Brown was displayed by 3 species (2 more than birds) and green by

Table 3: A comparative analysis of fleshy-fruits eaten by birds and mammals

Fruit Traits	Birds	Mammals
No. of fruit species used	38	46
Major fruit colours	Red, Yellow, Black	Red, Yellow, Black
No. of species with green coloured fruits	1 (*Ficus amplissma*)	5
Dominant fruit type	Drupe, berry	Drupe, berry
Largest fruit eaten	*Ficus racemosa* (27.8 mm)	*Strychnos nux-vomica* (44 mm)
Largest fruit ingested whole	*Syzygium cumini* (14.7 mm)	*Phoenix sylvestris* (28 mm)
Smallest fruit eaten	*Salvadora persica* Seedless (2.4 mm)	*Ehretia pubescence* (4.6 mm)
% of fruits ≤ 10 mm diameter	58% (n=38)	39% (n=46)
% of fruits with seed protection	5% (n=38)	24% (n=46)

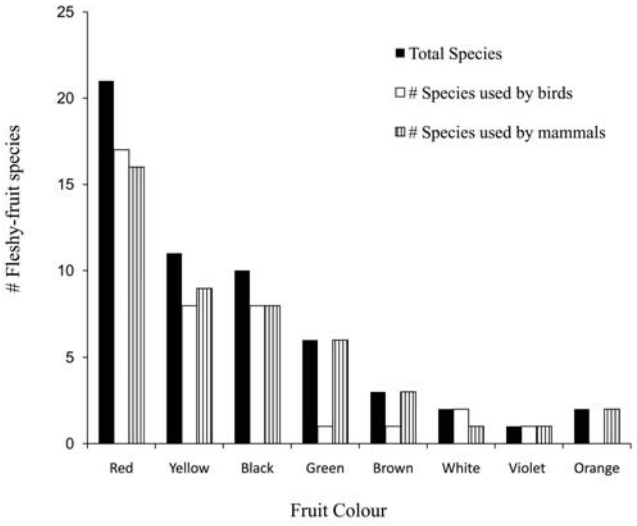

Fig. 3: Fruit colour spectra of bird (n=380) and mammal (n=46) fleshy-fruits

5 species (4 more than birds) (Table 4). Nearly 39% of fruits ≤ 10 mm in diameter and 63% ≤ 15 mm (n = 46). Mean fruit size ranged from 4.6 mm to 44 mm. Mean seed size ranged from 1.4 mm (*Catunaregam malabarica*) to 29.5 mm (*Calophyllum inophylum*). When fruits exclusively eaten by mammals were considered (n=14, excluding *Borassus flabellifer* and some fruits showing bird-fruit characters), the mean fruit size ranged from 10.2 mm (*Cassine glauca*) to 44 mm (*Strychnos nux-vomica*). 54% of fruits were single-seeded. Eleven species (25%) had protection for seeds (nine more than birds).

Bird visitation rates to fruiting trees: Tree watches on fruiting trees indicate that some fleshy-fruits attract more number of birds than others (Table 5). The top five species with the highest number of visits were *Ficus amplissima* (91 visits/hr), seedless fruits of *Salvadora persica* (47 visits/hr),

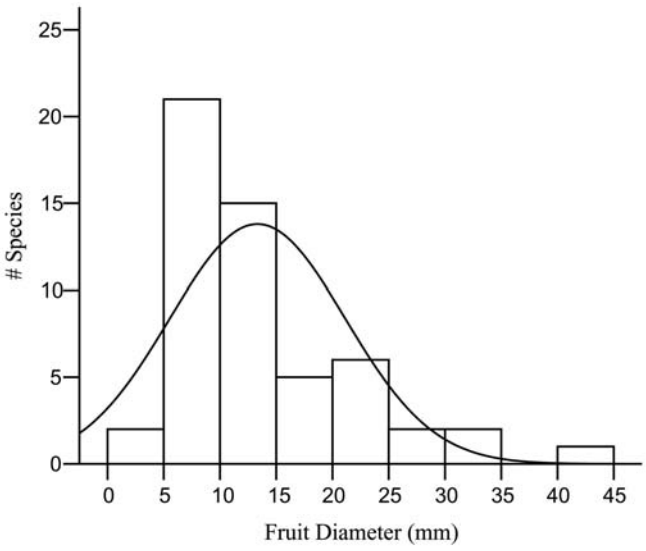

Fig. 4: Frequency distribution of mean diameter of fruits (n=54)

Table 4: Physical traits of fruits consumed by birds and mammals

Taxon	Fruit Colour							
	Black	Red	Yellow	Green	Brown	White	Violet	Orange
Birds	7	18	8	1	1	2	1	0
Mammals	7	17	9	6	3	1	1	2
	Fruit Type							
	Berry	Drupe	Achene	Capsule	Pod	Schizocarp	Aril	
Birds	13	16	5	2	0	0	1	
Mammals	17	22	4	1	1	1	0	
	Fruit Size							
	Large	Medium	Small					
Birds	7	25	6					
Mammals	17	26	3					
	Habit							
	Large Tree	Small Tree	Shrub	Climber				
Birds	10	11	9	8				
Mammals	16	11	8	11				

Note: The 'Fruit Type' under birds does not add to 38 as one species was unidentified

Lannea coromandelica (30 visits/hr), *Walsura trifolia* (28 visits/hr), *Ficus microcarpa* and *Cordia dichotoma* (18 visits/hr). The Red-whiskered Bulbul was the most frequently observed bird species in almost all fruiting trees, except in *Hugonia mystax, Lannea coromandelica* and *Securinega leucopyrus* (Common Myna was the frequent visitor for these species) and in *Eugenia bracteata* (Asian Koel was the common visitor for this species) (Figs 5a,b).

Fruit-handling Behaviour

Birds: The majority of fruits (71%, n=38) were swallowed whole by all the bird species. Large fruits like *Pamburus missionis* and *Ficus racemosa* were eaten in bits. In *Azadirachta indica*, *Lannea coromandelica*, *Olax scandens, Salacia chinensis* and *Walsura trifolia*, the fruit coat was removed and the seed was swallowed. In *Lepisanthes tetraphylla* (20.1 mm with 3 seeds), the fruit was opened by pecking and the juicy pulp consumed along with the seed. The Rose-ringed Parakeet is a seed-eater or seed-predator or seed dropper (drops the seed below the parent tree, thus not aiding dispersal). While feeding on *A. indica*, it crushed the seeds and ate it in pieces. Its handling of small seeds of *Securinega leucopyrus* and *Coccinia grandis* is unclear. While feeding on fruits of *Alangium salvifolium*, it dropped large amount of seeds under the fruiting tree.

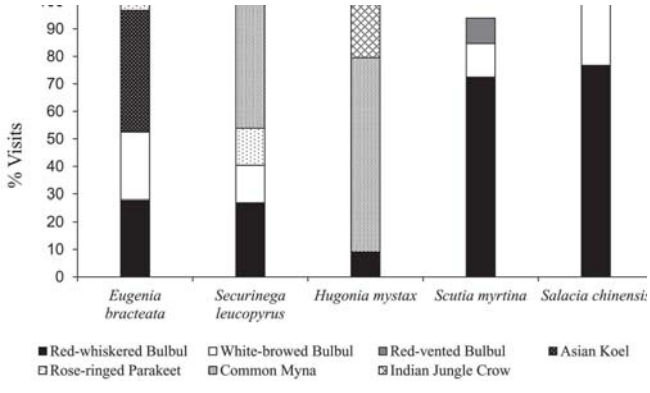

Fig. 5a: Frequency of visits by avian frugivores to some species of fleshy-fruit shrubs and climbers

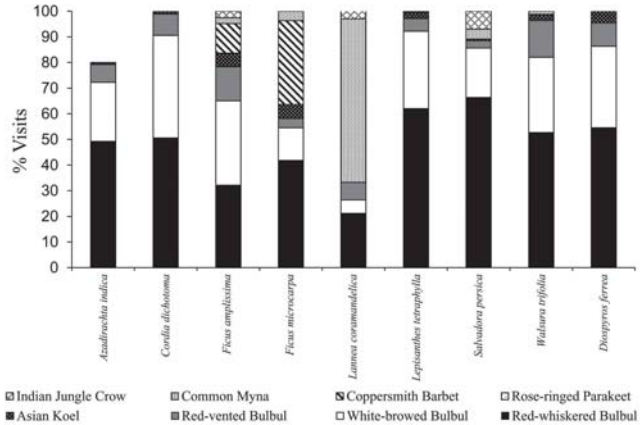

Fig. 5b: Frequency of visits by avian frugivores to some species of fleshy-fruit trees

Mammals: The presence of both fruit-coat and seeds in Golden Jackal and Small Indian Civet scats suggests that they eat the fruits whole. The Bonnet Macaque handled the fruit in three ways: swallowing the seeds whole (aiding in dispersal), crushing and eating the seeds (seed predation) and dropping the seeds either under or away from the parent tree. The Three-striped Palm Squirrel is both a seed dropper and predator. Seeds of *Cordia dichotoma* (tree watch hours = 30) and *Ziziphus oenoplia* (opportunistic observation, n=3) were dropped; *S. cumini* and *Z. mauritiana* (fruit debris data) were predated. From the only direct record of feeding habits in the Short-nosed Fruit Bat (while feeding on *Atalantia monophylla* fruits), it was observed that they ingested only the fruit juice after chewing the pulp and the seeds were dropped.

Fig-Use

Birds: All the avian frugivores were recorded feeding on figs (*Ficus*). Out of the 305 opportunistic frugivory records, 128 were on figs. *F. amplissima* recorded the highest number of avian frugivores (398 visits in 4½ hours) during the tree watches. The highest number of opportunistic records were also made on *Ficus amplissima* (48), followed by *Ficus benghalensis* (44) and *Ficus microcarpa* (31). Frugivory records on *Ficus racemosa* and *Ficus religiosa* were less, as the former is primarily used by mammals and the latter is very rare in the island.

The Coppersmith Barbet was chiefly a fig-eater, 90% of its frugivory records (n = 30) were on three *Ficus* spp. Among the 21 species subjected to tree watches, the Coppersmith Barbet was recorded only on *F. amplissima* and *F. microcarpa*. The Orange-breasted Green-Pigeon *Treron bicinctus* also chiefly feeds on figs. Six out of the 10 frugivory records for this species were on fig fruits (Table 6), including the sighting of 31 birds feeding on a *F. amplissima* tree. Totally, 132 bulbuls were recorded feeding on figs on 58 occasions. Out of the 58 feeding records, the Red-whiskered Bulbul was sighted on 37 occasions.

Mammals: Among mammals, fruit bats used figs frequently. Figs produced ripe fruits almost throughout the study period and fruit debris evidence indicate that fruit bats utilized figs in 19 of the 21 months of study (Fig. 6). The highest number of trees utilized in any given month was 17 (14%, n= 119 trees) in February 2008. The Bonnet Macaque and Three-striped Palm Squirrel also fed significantly on figs (Table 6). The highest number of opportunistic records for both these species was on fig trees, and fig seeds were recorded in 14% of Macaque faeces.

Table 5: Number of visits made by birds to various fleshy-fruit species

Fleshy-fruit Species	Tree Watch Hours	Total Visits /hr								Grand Total
		RWB	WBB	RVB	AK	RRP	CB	CM	IJC	
Ficus amplissima	4.35	29.4	30.1	12.2	4.8	-	10.6	2.1	2.3	91.5
Salvadora persica (seedless)	17	31.6	10.4	0.7	0.4	-	-	2.0	2.4	47.5
Lannea coromandelica	30	6.3	1.6	1.3	-	-	-	18.9	1.6	29.6
Walsura trifolia	6	14.7	8.2	4.0	0.7	-	-	0.3	-	27.8
Salvadora persica (seeded)	16	13.4	2.6	1.3	-	-	-	0.6	2.4	20.3
Cordia dichotoma	30	9.3	7.4	1.5	0.2	-	-	-	-	18.4
Ficus microcarpa	3	7.7	2.3	0.7	1.0	-	6.0	0.7	-	18.3
Hugonia mystax	6	0.7	-	-	-	-	-	5.2	1.5	17.3
Scutia myrtina	6	11.8	2.0	1.5	-	-	-	-	-	15.3
Eugenia bracteata	6	2.8	2.5	-	4.5	0.3	-	-	-	10.2
Lepisanthes tetraphylla	30	5.8	2.8	0.5	0.2	-	-	-	-	9.4
Diospyros ferrea	5.3	4.2	2.3	1.3	0.4	0.2	-	-	-	8.3
Azadirachta indica	16	4.0	1.9	0.6	0.1	-	-	0.5	1.1	8.1
Alangium salvifolium	3	-	-	-	-	1.7	-	-	-	1.7
Securinega leucopyrus	16	3.9	0.9	0.4	-	-	-	1.5	-	6.7
Salacia chinensis	16	2.1	0.6	-	-	-	-	-	-	2.7
Ehretia pubescence	8	-	0.8	-	0.9	-	-	-	-	1.6
Syzygium cumini	4	1.0	0.3	-	-	-	-	-	-	1.3
Ochna obtusata	9	0.7	0.1	-	0.1	-	-	-	-	0.9
Memecylon umbellatum	3	0.3	-	-	-	-	-	-	-	0.3
Olax scandens	3.5	-	-	-	-	-	-	-	-	0.0
Pachygone ovata	4	-	-	-	-	-	-	-	-	0.0

RWB - Red-whiskered Bulbul, WBB - White-browed Bulbul, RVB - Red-vented Bulbul, RRP - Rose-ringed Parakeet, AK - Asian Koel, CB - Coppersmith Barbet, CM - Common Myna, IJC - Indian Jungle Crow.

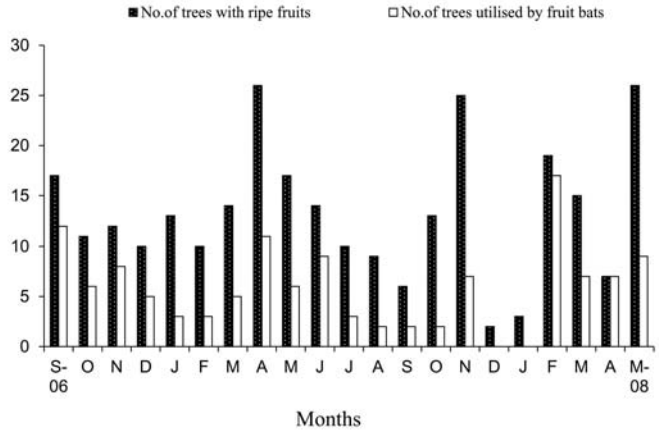

Fig. 6: Utilisation pattern of fig trees (n=119) by fruit bats from September 2006-May 2008

DISCUSSION

Avian Frugivore Assemblage

The avian frugivore assemblage in Sriharikota is typical of open degraded secondary forest associated with human presence. The major avian frugivores were the Red-whiskered and White-browed Bulbuls. Bulbuls are the most important frugivores in anthropogenic open habitats in the Oriental Region (Corlett 1998a, b); e.g., Red-whiskered and Light-vented *Pycnonotus sinensis* bulbuls in a Hong Kong shrub land (Corlett 1998a), and Red-whiskered and Red-vented Bulbuls in many Pacific Ocean islands and in North America where they have colonized (Carleton and Owre 1975; Freifeld 1999). Next to bulbuls, the major avian frugivore in Sriharikota was the Asian Koel. While most cuckoos are carnivorous, the Asian Koel includes large quantities of fruit in its diet (Ali 2002). The Asian Koel occurs from the Indian subcontinent and Southeast Asia through Indonesia to New Guinea and northern Australia (Rasmussen and Anderton 2005). The Rose-ringed Parakeet is another common frugivore encountered in Sriharikota. It is a widespread resident in India and is also found in Africa, Arabia and in the east up to Myanmar. Besides a frugivore, it is a seed predator and causes immense damage to agricultural crops (Rasmussen and Anderton 2005).

Table 6: Opportunistic records of frugivores feeding on fig and non-fig species

Frugivores	Figs	Non-figs
Red-whiskered Bulbul	37	61
White-browed Bulbul	15	32
Red-vented Bulbul	6	10
Asian Koel	13	20
Rose-ringed Parakeet	1	15
Coppersmith Barbet	27	3
Orange-breasted Green-Pigeon	6	4
Common Myna	11	17
Indian Jungle Crow	11	16
Bonnet Macaque	19	16
Three-striped Palm Squirrel	25	17

In open country and human dominated landscapes, members of the family Corvidae and Sturnidae are important frugivores. In such areas, they are often amongst the largest birds, and thus, even these less frugivorous species may be significant as dispersers of fruits and seeds that are too large for smaller frugivores (Corlett 1998b). In Sriharikota, these are represented by the Indian Jungle Crow, House Crow and Common Myna. They are major frugivores and important seed dispersing agents in abandoned village forest and may aid in rapid regeneration of native vegetation.

There are two specialist fig-eaters in Sriharikota, the Coppersmith Barbet and Orange-breasted Green Pigeon. Barbets are among the most highly frugivorous birds in the Indo-Malayan region and several species feed largely on figs for which they are the major dispersal agents (Corlett 1998b). In Sriharikota, the Coppersmith Barbet is rare in TDEF, but is occasionally seen in abandoned village forest where fig trees are abundant (David *et al*. 2008). Members of the genus *Treron* (green-pigeons) are known to be voracious fig feeders and pigeons in general form one of the principle groups of fig-eating birds in Southeast Asian forests (Lambert 1989a). The Orange-breasted Green-Pigeon is a sporadic visitor to the Island from the nearby hills of the Eastern Ghats.

When compared with the avian frugivores of Point Calimere Wildlife Sanctuary (Balasubramanian 1996), a TDEF site 450 km south of Sriharikota, some differences and similarities in the avian frugivore assemblages emerge. There are three species of bulbuls in Sriharikota, *contra* two in Point Calimere. The Red-whiskered bulbul is absent in Point Calimere. The Coppersmith Barbet was also not recorded in Point Calimere (probably due to paucity of figs), but was recorded in Vedaranyam, 11 km to its north, and in adjoining small town and villages, which have fig trees along roads and in temples (Ranjit Manakadan pers. obs). The Rosy Starling *Sturnus roseus* is a regular winter visitor to Point Calimere, but was recorded only occasionally in the southern parts of Sriharikota, where sampling was not done due to difficult logistics. On one occasion, it was observed feeding on *Phoenix farinifera* fruits in April (Manakadan and Sivakumar 2004a), probably on the return from their wintering grounds further south. The Grey-headed Starling *Sturnia malabarica*, a minor frugivore in Point Calimere, has not been recorded in Sriharikota. The Brahminy Starling S*turnus pagodarum* and Orange-breasted Green-Pigeon are seasonal migrants to Point Calimere and Sriharikota.

Mammalian Frugivore Assemblage

The mammalian frugivore assemblage in Sriharikota is very similar to Point Calimere. It comprises of 2 species that are both arboreal and terrestrial (Bonnet Macaque and Three-striped Palm Squirrel), 2 terrestrial species (Golden Jackal and Small Indian Civet) and 2 volant species (Short-nosed Fruit Bat and Indian Flying Fox). The Bonnet Macaque can live in tiny forest patches, use young secondary forest, cross open ground and eat a wide variety of foods (Corlett 1998b). The Golden Jackal is an opportunistic feeder which eats significant amounts of fallen fruit, as reported from studies in Bangladesh, India and Pakistan (Corlett 1998b). The Small Indian Civet is tolerant of human intrusion as long as they are not hunted and appear to thrive in degraded landscapes (Corlett 1998b). The two species of fruit bats recorded in Sriharikota, the Short-nosed fruit bat and Indian Flying Fox, are common and widespread in India (Bates and Harrison 1997) and are the most studied species with regard to frugivory in India and in other regions (Balasubramanian and Bole 1993; Bhat 1994; Elangovan *et al*. 1999; Singaravelan and Marimuthu 2006; Tang *et al*. 2008).

Fruit Traits

Most of the studies across the world associate bird-fruits with black and red colour, small fruit size and without any protection for seeds, while mammals feed on a variety of fruits irrespective of colour, size and texture (Janson 1983; Gautier Hion *et al*. 1985; Corlett 1996; Balasubramanian and Maheswaran 2003; Bollen *et al*. 2004). The traits of bird and mammal fruits of sriharikota are discussed below.

Bird-Fruits

As for fruit colour most of the bird-fruits in Sriharikota display red, black and yellow colour. Does this mean birds avoid other fruit colours? *Walsura trifolia*, a brown fruit was also consumed by birds. *Ficus amplissima*, a green coloured fruit, was fed on by all bird species and opportunistic records on green colour were more than black. Birds are also known to feed on unripe fruits, which are mostly green (Bhat and Kumar 2001). This suggests birds do also eat green and brown fruits, usually associated with mammal-fruits. However, it must be noted that fruits that were small, without protection, but displaying green colour (*Cassine glauca* and *Opilia amentacea*) were still not eaten by birds. The reasons are not yet clear. Green may signal unpalatability or enhance crypsis (Snow 1971). However, Knight and Siegfried (1983) postulated that greenness could be a consequence of genetic pleiotropy with no significant cryptic or advertising function, suggesting that the association of red and black colour fruits with avian frugivores may simply be a reflection of the higher occurrence of fleshy-fruit species with these colours, rather than preference. It would be interesting to test if green and other non bird-fruit colours are avoided in a natural environment if these colours are predominant.

Secondly, bird-fruits are small. This is true in Sriharikota as 58% of fruits (n=38) $\leq$ 10 mm in diameter and 84% $\leq$ 15 mm. However, large sized fruits were also sometimes used by small birds such as bulbuls. Out of the 38 fleshy-fruit species, 6 were larger than the gape width of bulbuls, they were all eaten, but in bits. Birds will be able to exploit large-sized fruits if they are soft.

The bird-fruits in Sriharikota also do not have thick husk or a hard fruit/seed. Only 1 fruit (*Alangium salvifolium*) had a hard seed coat. The pulp of this fruit was consumed by the Rose-ringed Parakeet and the seeds were mostly dropped. Seed protection in the form of a thick husk, or a tough fruit/seed coat is the main factor preventing birds from feeding on some fleshy-fruits. For example, fruits of *Atalantia monophylla* (tough fruit coat), *Mimusops elengi* and *Phoenix sylvestris* (thick husk) were not used by birds in Sriharikota.

Mammal-Fruits

Mammals, unlike birds, have hands and teeth to hold and crush fruits, and hence, feed on a variety of fruits irrespective of colour, size or seed protection. Hence, the number of fleshy-fruit species used by mammals is more than birds. The single fruit trait that could be solely associated with mammals is seed protection (thick husk or tough fruit/seed coat). Out of the 18 species used exclusively by mammals, 11 had seed protection in the form of husk or a tough fruit coat.

Four species of mammal-fruits in Sriharikota are green (*Atalantia monophylla*, *Cassine glauca*, *Opilia amentacea* and *Calophyllum inophyllum*). These were exclusively used by fruit bats and formed 21% (n=19) of the total fruit species used by fruit bats. In a study in Malaysia and Singapore, about 50% of bat-fruits were found to be green in colour, matching the surrounding foliage (Hodgekison and Balding 2003; Boon and Corlett 1989). The majority of fig fruits used by neotropical Phyllostomid bats were also green (Kalko *et al.* 1996). A high proportion of green fruits in the diet of fruit bats could be because green ripe fruits go undetected by birds, as birds associate such fruits with unripeness and/or since green fruits are difficult to spot against the green foliage, and thus, this unharvested fruit resource becomes available to fruit bats. However, birds, as discussed earlier, have colour vision and are also known to feed on some species of green fruits. Flying foxes have no colour vision and therefore olfaction could play a key role in location of ripe fruits (Kalko *et al.* 1996). Except for *Garcinia spicata*, none of the other fruits

produced a strong odour (detectable by humans). Hodgekison and Balding (2003) also reported that none of the fruits used by fruit bats produced a strong odour. Conversely, most of the figs used by neotropical Phyllostomid bats produced odour and they used odour as the primary cue to detect figs (Kalko *et al*. 1996).

Fruit-Use

Fruit use by birds: The Red-whiskered Bulbul and White-browed Bulbul consumed more species of fleshy-fruits than other birds. These two species are the most abundant and widespread of birds in Sriharikota (David *et al*. 2008), and hence, they were able to exploit fruit resources available in all the habitats. Open area preferring species like Red-vented Bulbul, Indian Jungle Crow and Common Myna did not exploit fruit resources available in the dense forest such as *Canthium dicoccum*, *Ehretia pubescens* and *Cordia dichotoma*, and thus fed on less number of fleshy-fruit species. The number of fleshy-fruit species eaten by the Asian Koel was less than the bulbuls, though they have a larger gape size. This is probably because they are encountered only occasionally in the Island, mainly during winter (David *et al*. 2008), and it is a secretive species with inconspicuous feeding habits (Corlett and Ping 1995). The Asian Koel because of its large gape size (17.5 mm: source, Balasubramanian 1996) is able to swallow large fruits such as *S. cumini*. In Hong Kong, three large fruits (*Arenga engleri*, *Livistona chinensis* and *Syzygium cumini*) were recorded to be swallowed whole only by the Asian Koel (Corlett and Ping 1995).

Fruit use by mammals: The Bonnet Macaque ate more fleshy-fruit species (34) than the other major mammalian frugivores. Fruits are documented to form a major portion of the diet of the Bonnet Macaque (Ali 1986; Krishnamani 1994; Kuruvilla 1980). Macaques in general, eat anything edible, ripe or unripe, also seeds and leaves, soft or hard skinned fruits, and contribute both to dispersal and predation (Pijl 1982). In Sriharikota, the low number of seeds in droppings, and record of fruit skins without seeds indicate that they either drop seeds or eat them more than swallowing and defecating them intact. Moreover, the high percentage of occurrence of leaves in Macaque droppings points to general deficiency of fleshy-fruit availability.

The Golden Jackal and Small Indian Civet are recorded to include fruits in their diet throughout their range (Corlett 1998b; Jhala and Moehlman 2004). Studies on jackal and civet diet indicate that they prefer insects, rodents, lizards and birds, and fruits form part of their diet whenever they become seasonally available (Rabinowitz 1991; Chuang and Lee 1997; Jhala and Moehlman 2004). Similarly, in Sriharikota, in addition to fruits, remains of rodents, birds and insects were recorded in the scats of Golden Jackal and Small Indian Civet. The Jackal used nearly 50% of fleshy-fruit species for which there is a record of frugivory. Along with the Civet, it was an important disperser of *Syzygium cumini* and *Memecylon umellatum*. They are also the major dispersers for *Calamus rotang*, an introduced species that has attained invasive proportions in Sriharikota. The frequency of occurrence of seeds in scats of these species reflected the abundance of the fleshy-fruit plants, their seasonality and fruiting intensity (David *et al*. 2008).

Fruit bats were recorded to feed on 19 fleshy-fruit species. The fleshy-fruits used by fruit bats could be an underestimate as we relied only on fruit debris and not systematic tree watches. In Point Calimere, Balasubramanian and Bole (1993) recorded fruit bats to feed on 35 fleshy-fruit species, including shrubs and climbers that also occur in Sriharikota. Fruits that are green when ripe are chiefly or exclusively eaten by fruit bats. Among the 4 species intensively used by fruit bats, *Atalantia monophylla* and *Opilia amentacea* appear to be chiefly or exclusively used by fruit bats. The low number of partially eaten fruits of *Opilia amentacea*, the absence of partially eaten fruits of *Atalantia monophylla* and the high number of bat-eaten fruits of these two species indicate that other frugivores did not feed on these two fruit resources. These fruit species are green when ripe and they remain attached strongly to the plant. In contrast, the two other major bat-fruits, *Garcinia spicata*, and *Pamburus missionis* are used by the Bonnet Macaque and Asian Koel. These fruits are delicate and fall off easily, and hence, more partially eaten and fallen ripe fruits were recorded in plots below these two tree species.

Overall, the number of fleshy-fruit species consumed by avian and mammalian frugivores could be higher than recorded. Records of frugivory for some fruits could not be obtained because of rarity (e.g. *Toddalia asiatica*) or due to very poor fruiting (e.g., *Flacourtia indica* and *Carissa spinarum*).

Importance of Figs for Frugivores

In some tropical and subtropical forests, figs (*Ficus*) are acknowledged to be keystone resources for frugivores (Terborgh 1986; Lambert and Marshall 1991; Bleher *et al*. 2003). The features that make figs keystone resources are their ability to support large number of avian and mammalian frugivores, large crop size and fruiting throughout the year (asynchronous fruiting pattern), thus sustaining frugivores through periods of fruit scarcity (Lambert and Marshall 1991).

In Sriharikota, three species of figs, *Ficus amplissima*, *F. benghalensis* and *F. microcarpa*, are common in abandoned village forest (*F. racemosa* and *F. religiosa* are rare). Some

fig trees are also found within TDEF. Together, figs fruited almost throughout the year and all the avian frugivores were recorded feeding on fig fruits. However, the importance of figs to frugivores varies. The Coppersmith Barbet feeds intensively on fig fruits (27/30 records were on figs). They track fruiting fig trees throughout the Island and were recorded wherever fig trees were in fruit, even among dense forest patches. In Kuala Lompat (Malaysia), a radio-tagged Yellow-crowned Barbet *Megalaima henricii*, a fig specialist, regularly flew over 700 m from its roost site to feed on fruiting *F. binnendijkii* (Lambert 1989b). In general, barbets are amongst the most frequently observed fig-eaters in Asia and they show a certain degree of dietary specialization towards figs (Shahnahan *et al*. 2001). In Sriharikota, the Coppersmith Barbet was recorded to feed only on three other fleshy-fruit species, but only rarely. Intensive use of fig fruits and a narrow range of non-fig diet confirm figs as keystone resource for the species. Figs are also an important resource for the visiting Orange-breasted Green Pigeon as they are known to be largely voracious fig-eaters (Lambert 1989a).

Tree watches and opportunistic records indicate that bulbuls also consume considerable amounts of fig fruits. Some important fleshy-fruit resources for the bulbuls (*Salvadora persica*, *Lepisanthes tetraphylla* and *Cordia dichotoma*) show unpredictable fruiting patterns and are not reliable (David *et al*. 2008). Hence, figs with their year round fruiting pattern could be a critical fruit resource for bulbuls. Pycnonotidae members are one of the frequently observed bird groups on fruiting fig trees in Asia and Africa (Lambert 1989b; Shahnahan *et al*. 2001). Bulbuls have been recorded to feed on 63 *Ficus* species, and in terms of fig seed dispersal, are probably the most important of the smaller frugivores (Shahnahan *et al*. 2001). Among the three species of bulbuls, the highly mobile Red-whiskered Bulbul is at a distinct advantage. They can fly extensively in search of fruiting fig trees, which are mostly confined to the abandoned village forest. On the contrary, the White-browed Bulbul with its shy nature, sulking behaviour and poor flight will not be able to track fig trees like the Red-whiskered Bulbul and has to rely on the few fig trees within TDEF (its preferred habitat). The Red-vented Bulbul is abundant in open scrub and abandoned village forest (David *et al*. 2008), and so has easy access to fig trees.

Among mammals, figs were found to be important for the Bonnet Macaque and fruit bats. Field observations and faecal dropping analysis revealed that fig fruits are a major component in the diet of the Bonnet Macaque as reported in other studies (Ali 1986; Krishnamani 1994). More than 50% of feeding records on Bonnet Macaque were on fig fruits, and figs appeared in many Macaque droppings compared to other fruits. However, Bonnet Macaques are very catholic in their diet and include a variety of fruit and non-fruit resources (Kuruvilla 1980; Ali 1986; Krishnamani 1994), hence figs may not be a keystone resource for them. Additionally, fig-eating species with territorial lifestyles (as the Bonnet Macaque) may vary in their dependence on figs (Borges 1993).

As fruit bats are obligate frugivores, the availability of figs would be especially important for them. Pteropodidae members are the major consumers of figs in the tropics (Shahnahan *et al*. 2001). In the neotropics, figs constitute the dominant portion in the diet of Phyllostomid bats (Kalko *et al*. 1996). In Sriharikota, figs are very important in the diet of fruit bats as they consumed fig fruits in 19 of the 21 months of study. Secondly, non-fig fruits preferred by fruit bats are mainly available only from June-October and two: *Opilia amentacea* and *Pamburus missionis* are not common in the island (David *et al.* 2008). Other important fleshy fruit resources show unpredictable fruiting patterns. Therefore, the year round availability of fig fruits is crucial to ensure a continuous food supply for fruit bats, and hence, figs can be regarded as a keystone resource for fruit bats in Sriharikota. Figs as a key fruit resource have also been reported for *Pteropus* sp. from the Philippines and Australia (Eby 1998; Stier and Mildenstein 2005) and for Lesser Dog-faced Fruit Bat *Cynopterus brachyotis* from Malaysia (Tan *et al.* 1998).

Thus, figs appear to be an important food resource for both avian and mammalian frugivores, and may be a keystone resource for some species. The loss or decline of fig trees could lead to decline in population of some species of frugivorous birds. Primary fig-eaters, like Coppersmith Barbet may become (locally) extinct and the Orange-breasted Green-Pigeon could stop visiting the Island. This prediction finds support in the findings in a subtropical South African forest where the destruction of *Ficus sycomorus* trees in Umfolozi Nature Reserve after a cyclone in 1984 led to local elimination of some frugivores (Bleher *et al.* 2003). Based on this, they hypothesized that removal of another *Ficus* species, *F. thonningii* in the Oribi Gorge Nature Reserve could drastically influence the frugivore community and hence figs must be considered as a keystone resource.

RECOMMENDATIONS

The findings of this study revealed that the abandoned village forest is an important habitat for avian and mammalian frugivores primarily due to the abundance of

fig trees. Hence, even though the abandoned village forest is not a Tropical Dry Evergreen Forest, we suggest that these areas should be given low priority for land acquisition plans for the expansion of the spaceport. Where acquisition is unavoidable, possibilities of avoiding cutting of *Ficus* trees should be explored.

Salvadora persica trees, which are very attractive to avian frugivores, should also be protected. This species occurs only in saline water basins close to Pulicat lake around the former villages of Penubakkam and Beripeta. Within the TDEF, we recommend protection for *Lepisanthes tetraphylla*, *Ehretia pubescens* and *Canthium dicoccum*. These trees occur in low densities. The juicy fruits of *Lepisanthes tetraphylla* are important for birds and bats in summer, while *Ehretia pubescens* and *Canthium dicoccum* are important fruit resources during the north-east monsoon and winter. Other plants of importance for frugivores are *Azadirachta indica*, *Cordia dichotoma* and *Lannea coromandelica* for birds, and *Atalantia monophylla*, *Garcinia spicata* and *Opilia amentacea* for fruit bats.

In addition to these important fleshy-fruit species, visually attractive species such *Breynia vitis-idaea*, *Casaeria esculenta*, *Cansjeera rheedei*, *Pavetta indica* and *Phoenix farinifera* can be grown in gardens and residential facilities of the SDSC-SHAR in Sriharikota and Sullurpet. *Salvadora persica* and *Lannea coromandelica* can be planted along road margins from Attakanithippa to Sriharikota, Pernadu and Veenadu. This recommendation is based on observations of existing trees along the road which are doing well compared to other species that wither due to the impact of salt and strong winds. *Lannea coromandelica* can also be grown and planted along the road from Sullurpet to the SDSC-SHAR residential area (Pulicat Nagar).

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Appendix 1: Fleshy-fruit species and their fruit-traits

Species	Fruit Colour	Fruit type	Mean Frui Size (mm)	Mean Seed Size (mm)	No. of seeds	Seed Protection	Consumer
Large Trees							
Alangium salvifolium	Red	Berry	16.0	10.0	1	Yes	BM
Azadirachta indica	Yellow	Drupe	10.7	5.5	1	No	BM
Borassus flabellifer	Black	Drupe	-	-	-	Yes	M
Calophyllum inophyllum	Green	Drupe	31.3	29.5	1	Yes	M
Cassine glauca	Green	Drupe	10.2	5.7	1	No	M
Ficus amplissima	Green	Achene	13.6	-	multi	No	BM
Ficus benghalensis	Red	Achene	18.3	-	multi	No	BM
Ficus microcarpa	Yellow	Achene	7.3	-	multi	No	BM
Ficus racemosa	Red	Achene	27.8	-	multi	No	BM
Ficus religiosa	Red	Achene	7.7	-	multi	No	B
Lannea coromandelica	Red	Drupe	6.6	5.3	1	No	BM
Manilkara hexandra	Yellow	Berry	8.6	5.0	multi	No	BM
Mimusops elengi	Yellow	Berry	15.8	10.1	1	Yes	M
Phoenix sylvestris	Orange	Drupe	28.0	17.0	1	Yes	M
Strychnos nux-vomica	Orange	Berry	44.0	7.3	multi	Yes	M
Syzygium cumini	Black	Berry	14.7	7.3	1	No	BM
Tamarindus indicus	Brown	Pod	-	-	multi	Yes	M
Small Trees							
Atalantia monophylla	Green	Berry	22.3	3.8	multi	Yes	M
Canthium dicoccum	Black	Drupe	8.4	7.5	1	No	BM
Cordia dichotoma	Yellow	Drupe	8.9	4.8	1	No	BM
Diospyros ferrea	Red	Berry	11	8.2	multi	No	BM
Ehretia pubescens	Red	Drupe	4.6	2.6	multi	No	BM
Garcinia spicata	Yellow	Berry	30.0	11.3	multi	No	M
Lepisanthes tetraphylla	Yellow	Drupe	20.1	7.3	multi	No	BM
Ochna obtusata	Black	Drupe	8.3	5.5	1	No	B
Pamburus missionis	Yellow	Berry	21.8	10.7	multi	No	BM
Premna latifolia	Black	Drupe	5.9	2.3	1	No	B
Salvadora persica	Red	Drupe	8.0, 2.4	3.5	1	No	BM
Walsura trifolia	Brown	Berry	12.1	9.3	1	No	BM
Ziziphus mauritiana	Red	Drupe	20.2	9.5	1	No	M
Unidentified Species	White	-	4.6	-	1	No	B
Allophylus serratus	Red	Schizocarp	9.1	6.0	1	No	M
Breynia vitis-idaea	Red	Capsule	6.5	2.1	multi	No	B
Casaeria esculenta	Red	Aril	8.6	3.2	multi	Yes	B
Canthium parviflorum	Yellow	Drupe	11.8	10.9	1	No	B

Appendix 1: Fleshy-fruit species and fruit-traits in Sriharikota (*contd*.)

Species	Fruit Colour	Fruit type	Mean Fruit Size (mm)	Mean Seed Size (mm)	No. of seeds	Seed Protection	Consumer
Shrubs							
Capparis brevispina	Red	Berry	15.0	-	multi	No	B
Catunaregam malabarica	Black	Berry	8.2	1.4	multi	No	BM
Catunaregam spinosa	Green	Berry	20.0	-	multi	Yes	M
Eugenia bracteata	Red	Berry	10.0	7.6	1	No	B
Glycosmis pentaphylla	Red	Drupe	9.1	6.1	1	No	M
Grewia rhamnifolia	Brown	Drupe	11.4	4.7	multi	Yes	M
Memecylon umbellatum	Black	Berry	7.8	5.0	1	No	BM
Phoenix farinifera	Black	Drupe	7.4	6.8	1	No	BM
Securinega leucopyrus	White	Capsule	5.1	2	multi	No	BM
Climbers							
Calamus rotang	Yellow	Drupe	15.6	9.8	1	Yes	M
Cansjera rheedei	Red	Drupe	11.9	9.6	1	No	BM
Cissus vitiginea	Black	Berry	8	5.0	multi	No	M
Coccinea grandis	Red	Berry	21	2.7	multi	No	BM
Hugonia mystax	Red	Drupe	8.5	7.6	1	No	BM
Olax scandens	Yellow	Drupe	12.0	7.1	1	No	B
Opilia amentacea	Green	Drupe	14.4	11.4	1	No	M
Pachygone ovata	Red	Drupe	11.2	6.5	1	No	M
Salacia chinensis	Red	Berry	13.6	8.8	1 or 2	No	BM
Scutia myrtina	Violet	Drupe	10.0	6.6	multi	No	BM
Solanum trilobatum	Red	Berry	9.4	3.2	multi	No	BM
Ziziphus oenoplia	Black	Drupe	7.6	4.8	1	No	BM

Note: Fruits containing more than two seeds are categorised as 'multi-seeded'. For *Salvadora persica,* the 2nd value under mean fruit size is the diameter of seedless fruits. M: Mammals, B: Birds, BM: Birds and Mammals

Appendix 2: Frequency of occurrence of seeds in droppings of Golden Jackal, Small Indian Civet and Bonnet Macaque (June 2006-May 2008)

Species	Frequency of Occurrence (%)			Mean no. of seeds/scat and range		
	Jackal (n=473)	Civet (n=134)	Macaque (n=95)	Jackal	Civet	Macaque
Azadirachta indica	-	-	4	-	-	27 (14-44)
Allophylus serratus	-	-	1	-	-	-
Cordia dichotoma	15	10	15	91(12-214)	32 (6-86)	24 (2-34)
Catunaregam malabarica	1	-	-	-	-	-
Calamus rotang	3	1	4	28 (1-135)	-	39 (27-46)
Catunaregam spinosa	-	-	1			
Diospyros ferrea	5	4	4	82 (1-280)	20 (2-76)	18 (3-34)
Ficus spp.	0.2	-	14	-	-	-
Glycosmis pentaphylla	1	2	-	21 (1-93)	3 (1-6)	-
Grewia rhamnifolia	9	4	1	109 (1-372)	21(2-64)	-
Hugonia mystax	4	1	-	141 (1-316)	-	-
Lannea coromandelica	-	-	3	-	-	6 (5-8)
Lepisanthes tetraphylla	0.2	1	-	-	-	-
Mimusops elengi	0.4	-	-	20 (12-28)	-	-
Manilkara hexandra	3	3	-	30 (1-84)	13 (1-31)	-

Appendix 2: Frequency of occurrence of seeds in droppings of Golden Jackal, Small Indian Civet and Bonnet Macaque (June 2006-May 2008) (*contd*.)

Species	Frequency of Occurrence (%)			Mean no. of seeds/scat and range		
	Jackal (n=473)	Civet (n=134)	Macaque (n=95)	Jackal	Civet	Macaque
Memecylon umbellatum	14	19	4	87 (3-246)	61 (1-173)	52 (7-99)
Phoenix farinifera	18	18	1	105 (9-311)	47 (2-146)	-
Pamburus missionis	0.2	-	-	-	-	-
Pachygone ovata	-	-	3	-	-	2 (2-3)
Phoenix sylvestris	0.2	-	-	-	-	-
Scutia myrtina	0.4	1	-	2 (1-3)	119 (116-121)	-
Syzygium cumini	33	25	3	43 (1-89)	28 (1-121)	15 (2-40)
Securinega leucopyrus	1	7	-	-	-	-
Solanum trilobatum	0.2	-	-	-	-	-
Tamarindus indicus	1	1	3	9 (4-12)	-	7 (1-13)
Walsura trifolia	-	-	4	-	-	21 (17-25)
Ziziphus mauritiana	2	-	-	13 (1-37)	-	-
Ziziphus oenoplia	1	1	2	166 (64-354)	24 (19-30)	4 (1-8)

Note: *Lepisanthes tetraphylla*, *Mimusops elengi*, *Pamburus missionis* and *Ziziphus mauritiana* seeds were recorded in the scats of Bonnet Macaque prior to June 2006.

■ ■ ■