Frugivorous bird diversity and their post-feeding behaviour in fruiting *Syzygium cumini* (Myrtaceae) in fragmented forests of central Western Ghats, India

Frugivorous animals play an important role in the spatial arrangement and distribution pattern of plants in the tropics[1–4]. Seed dispersal mutualism is vulnerable in fragmented habitats of the tropics[5]. *Syzygium cumini* L. (Skeels) (Myrtaceae) is an economically and ecologically important native tree of tropical moist deciduous and evergreen forests of the Western Ghats, a biodiversity hotspot[6]. It is also cultivated in many countries as an avenue tree and as a source of fruit for human consumption[7]. Different parts of the plant are used in folk medicine in India and elsewhere[8,9]. Fruits of *S. cumini*, commonly called the Indian blue berry, are an important food for a range of wild animals[7,10,11].

On the basis of foecal matter analysis, sloth bear[12] and common Indian mongoose[13] have been reported to be seed dispersers of *S. cumini* in drylands. Birds have been reported to be frugivores of *S. cumini* in other parts of the tropics[7,10]. However, their dispersal efficiency has not been studied in either of the above-mentioned studies. We studied the role of birds in seed dispersal of *S. cumini* in a fragmented evergreen forest of the Western Ghats. We asked the following questions: (i) What is the diversity of frugivorous birds visiting fruiting trees of *S. cumini*? (ii) What is the post-dispersal behaviour of the interacting frugivorous birds and how is this likely to influence the dispersal mechanism of *S. cumini*?

We conducted the study during the fruiting season of 2007 and 2008 in community-managed Soppinabetta forests[13,14] of Sringeri, Chikmagalur district, Karnataka, India. These are fragmented evergreen forests (generally surrounded by agricultural lands). They contain more than 200 species of angiosperms[15]; seven species of *Syzygium* are important sub-canopy trees of these forests (pers. obs.). Among them, *S. cumini* flowers early in the year between late January and mid February and fruits during April–May. *Syzygium laetum* is the last *Syzygium* species to flower in the year; it flowers during late November to mid-December. The intensity of flowering in all *Syzygium* species varies between trees across years; major flowering occurs every alternate year.

Observations of frugivorous birds of *S. cumini* were made on ten fruiting trees, one in each forest fragment around Sringeri (12°55′–13°54′N and 75°01′–75°22′E; 725 m amsl) during the peak fruit-ripening period. Initial days of observation were used for defining the visitation patterns of different bird species and habituating the birds. Subsequently, systematic observations were made each day from dawn to 09 : 00 h and from 12 : 00 noon to dusk on all the selected fruiting trees for 3 days. A total of 10 hours was spent per tree per day. Visitation bouts of birds to the focal tree (number of visits) and abundance (number in a visitation flock) of birds in each of their visitation bouts were recorded. We also recorded the time spent for feeding and the number of fruits consumed by an individual bird in each visitation bout. If the birds visited in a flock, we followed a single bird using a pair of binoculars to record the feeding activity all through its visitation bout. We used a digital stop watch to record the time used to consume a fruit. Close monitoring using a pair of binoculars helped us to get a clear picture about the number of fruits consumed by a given bird. These data were used to calculate the likely fruit consumption by an individual bird of a given species in an hour. From our observations, feeding behaviour of birds was categorized into swallowing entire fruit, spitting out seeds and piecemeal (pecking the flesh from the seeds that remain on the tree). Post-feeding behaviour was also recorded for each visitor species. The first post-feeding flight distance from the fruiting *S. cumini* and the time spent in post-flight location were recorded for birds that swallowed the fruits. For breeding birds such as Red-Whiskered Bulbul, we measured the distance between the nesting location and the fruiting tree.

Fruiting in *S. cumini* coincides with that of *Dimocarpus longan*, *Olea diocea*, *Holigarna arnotteana*, *Aporusa lindleyana*, *Garcinia morella* and *Elaeocarpus tuberculatus* – trees whose seeds are potentially bird-dispersed (pers. obs.). *S. cumini* trees produced large crops (average number of fruits/inflorescence = 124.53 ± 43.13, range = 36–242, $N = 90$) of fruits during our study. Fruits of co-fruiting species differed in size, colour and pulpiness from those of *S. cumini*, which may influence the feeding behaviour of frugivorous birds[16]. *S. cumini* produces pulpy, small fruits (2.22 cm × 1.7 cm wide; $N = 30$ fruits) that are rich in water (85%), total water-soluble carbohydrates (53%) and sugar (18.9%), but poor in lipids (1%)[10]. We followed Grimmett *et al.*[17] for common and scientific names of birds.

Eleven species of birds interacted with the fruiting trees of *S. cumini* in the Soppinabetta forests of Sringeri. Of these, nine species were frugivorous and two were insectivorous. The frugivorous birds are: Red-Whiskered Bulbul (*Pycnonotus jocosus*), Blossom-Headed Parakeet (*Psittacula roseate*), White-Cheeked Barbet (*Megalaima viridis*), Oriental White-Eye (*Zosterops palpebrosus*), Crimson-Backed Sunbird (*Nectarinia minima*), Yellow-Browed Bulbul (*Iole indica*), Purple-Rumped Sunbird (*Nectarinia zeylonica*), Common Myna (*Acridotheres tristis*) and Coppersmith Barbet (*Megalaima haemacephala*). Among them, the first five species were commonly encountered on all selected fruiting trees. The other four species were occasional visitors. Golden-Fronted Leafbird (*Chloropsis aurifrons*) and Blue-Winged Leafbird (*C. cochinchinensis*) were insectivorous birds frequently seen in the foliage of *S. cumini*.

The overall mean (± SD) number of birds in a visitation bout of a species is given in Figure 1 *a*. The number of birds in a visitation bout of a species did not show significant variation between morning and afternoon hours.

Red-Whiskered Bulbul and White-Cheeked Barbet swallowed the fruits; Blossom-Headed Parakeet breaks a whole inflorescence of fruits or a part of it, roll the fruits in its mouth to consume the pulp and then spit out the seed under the fruiting tree; Oriental White-Eye and Small Sunbird pecked the pulp from seeds and left the seed attached to the tree. An individual Red-Whiskered

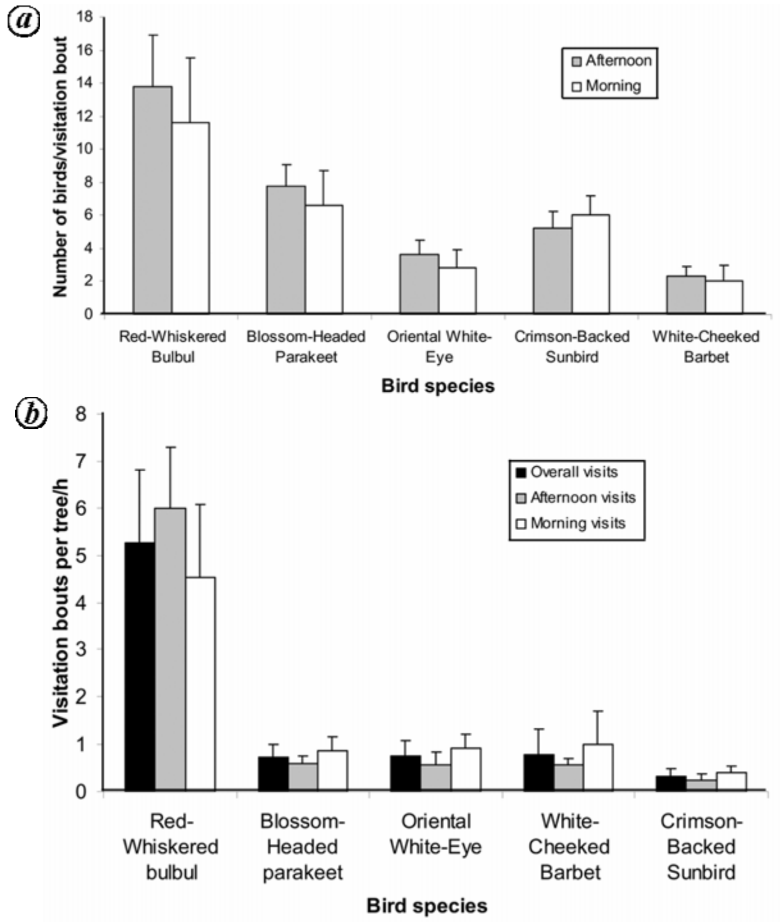

Figure 1. Mean (± SD) number of birds in a visitation bout (***a***) and the mean (± SD) number of visitation bouts per tree per hour (***b***) by individuals of different bird species to *Syzygium cumini* fruiting trees.

Bulbul spent relatively less time in each visitation bout that lasted an average of 3.31 ± 1.76 min (N = 178 birds; Table 1). This was significantly lower than that of the other four bird species (one-way ANOVA-test, $F_{4,236} = 601.81$, $P = 0.0000$; N = 40 each). A Duncan's post-hoc pairwise comparison ($\alpha = 0.05$) revealed that the time spent by an individual bird of a given species varied from that of another species ($P < 0.03$). Red-Whiskered Bulbul made an average of 5.26 ± 1.54 (N = 178) visits per hour that ranged between 2.67 and 8.16 among trees, which was significantly higher than that made by the other four bird species (one-way ANOVA test, $F_{4,45} = 74.99$, $P = 0.0000$; N = 40 each; Figure 1 *b*). A Duncan's post-hoc test ($\alpha = 0.05$) revealed that only the number of visitation bouts of Red-Whiskered Bulbul varied from those of other four bird species ($P < 0.005$; Table 1). Visitation bouts of all five bird species were consistent in the morning and afternoon hours (Figure 1 *b*). Our estimation showed that, an individual Red-Whiskered Bulbul is likely to consume, if that bird had devoted its whole time in an hour for frugivory, an average of 124.39 ± 50.09 fruits/h (Table 1) that was significantly higher than the estimated fruit consumption of a Blossom-Headed Parakeet (56.15 ± 7.16), an Oriental White-Eye (61.19 ± 25.23) and a White-Cheeked Barbet (65.96 ± 18.83; one-way ANOVA test, $F_{4,45} = 74.99$, $P = 0.0000$).

Red-Whiskered Bulbul flew to its nest site immediately after each visitation bout to fruiting trees of *S. cumini*. The average distance to the nest site of a Red-Whiskered Bulbul was 99.17 ± 15.82 m (range = 75–130 m; N = 30). A White-Cheeked Barbet made its first post-feeding flight to a nearby tree and the distance ranged between 5 and 20 m (9.57 ± 3.06; N = 35) from the fruiting *S. cumini* tree. A White-Checked Barbet spent an average of 13.39 min (± 6.18; N = 35) before either returning to a fruiting tree of *S. cumini* or flying away from the site.

The pulpy and reddish-black fruit characteristics of *S. cumini* suggest that birds are primary seed dispersal agents of the species on the tree canopy[11,16,18]. Red-Whiskered Bulbul and White-Cheeked Barbet are important frugivores and seed dispersal agents of *S. cumini* in human-influenced, fragmented evergreen forests of the Western Ghats. Red-Whiskered Bulbul-facilitated seed dispersal can be considered as an example of directed seed dispersal[3]. Habitats of most of the *Syzygium* species are riparian or swampy (pers. obs.) and the seeds are desiccation-sensitive[19]. Fruit-ripening period of *S. cumini* coincides with the breeding period of the resident Red-Whiskered Bulbul that has a habit of constructing nests in permanent locations year after year[20]. In seven of our study sites, the nesting sites of Red-Whiskered Bulbul were seen in shrubby plants adjacent to agricultural lands and rivulets, and in three places in the thickets of forest edges. White-Cheeked Barbet made its post-feeding flight to a tree inside the closed-canopy forest, where it spent a considerable time without any activity. Saplings of different ages were located under the nesting sites of Red-Whiskered Bulbuls in all study sites, but this aspect has to be studied in detail. Hence, we can consider that the seeds of *S. cumini* are directed to a favourable site for germination and population dispersion by Red-Whiskered Bulbul. Frequent visitation bouts to and fro between the nest and fruiting trees, the number of fruits consumed/visitation bout and the time spent on the fruiting tree, confirmed the Red-Whiskered Bulbul as an important dispersal agent of *S. cumini*, which visited the tree in a large flock. Apart from consuming some fruits on the fruiting tree, it carried one fruit to the nest for feeding the nestlings. Red-Whiskered Bulbul did not defecate the seeds while on the fruiting trees, but each of its visitation bouts to the tree lasted for a shorter period. Thus, post-feeding behaviour of a frugivorous bird influences the seed-dispersal mechanism in *S. cumini*[3,21,22]. Our results indicate that dispersal mutualism may not be a major concern in *S. cumini*[5], as the frugivorous bird community of *S. cumini* included the small and medium-sized common birds in the study area. Though small and large vertebrates and frugivorous bats have been identified

Table 1. Characteristics of frugivory by most common bird species in *Syzygium cumini*

Common frugivorous bird species	Number of visitation bouts by birds/h	Time spent/ visitation bout (min)	Estimated likely number of fruits consumed by an individual bird/h
Red-Whiskered Bulbul	5.27 ± 1.54	3.31 ± 1.73	124.39 ± 50.09
White-Cheeked Barbet	0.78 ± 0.53	9.75 ± 3.62	65.96 ± 18.83
Oriental White-Eye	0.75 ± 0.32	8.33 ± 3.17	61.19 ± 25.23
Crimson-Backed Sunbird	0.31 ± 0.16	5.26 ± 2.01	105.34 ± 22.03
Blossom-Headed Parakeet	0.73 ± 0.26	26.7 ± 2.29	56.15 ± 7.16

as frugivores of *S. cumini* elsewhere[7,10–12], we did not locate them in the fruiting trees in the study sites, although we carried out some nocturnal observations (17:00–22:00 h) in the fruiting trees. Recent studies[7,23] in a village and urban ecosystem also did not observe frugivorous bats in the fruiting *S. cumini*, though they were common in the study area.

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Coral architecture as a choice for palaeontological studies in India

Coral reefs are the most productive ecosystems supporting a wide variety of marine biodiversity. Scleractinian corals are often recognized as potential environmental indicators because of their rapid and significant response to changes in physico-chemical factors such as sea-surface temperature (SST) and alkalinity. As corals have a slow growth rate, growing only a few centimetres per year, they have been exposed to various environmental changes which are probably imprinted in their structural forms. Analysis of elemental ratios such $^{18}O/^{16}O$, $^{13}C/^{12}C$, Sr/Ca, Ba/Ca, Cd/Ca, Mn/Ca, Pb/Ca and X-ray studies of corals provide us valuable information on historical records of SST, salinity, nutrients upwelling, El Niño–Southern Oscillation (ENSO) and even terrestrial run-offs[1–3]. Further, the long-term history of living reef organisms provides an opportunity to understand the evolutionary and ecological processes over extended time-frames not available to modern ecology over years or decades[4].

Spreading approximately over an area of about 5,790 sq. km, the corals of India are confined to the Gulf of Kutch, Gulf of Mannar (GoM), Laccadives and