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Frugivory and seed dispersal by the Asian Elephant *Elephas maximus* in the tropical forests of Nilgiri Biosphere Reserve, southern India

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Abstract: Seed dispersal plays a potential role in plant species demographic processes. Elephants are important seed-dispersing agents. We studied frugivory and seed dispersal by Asian Elephants in the tropical deciduous and thorn forests of the Nilgiri Biosphere Reserve, southern India. We determined fruit consumption based on the presence of seeds and fruit remnants in elephant dung piles. In total, we identified seeds of eight plant species belonging to seven families in 16% out of 455 dung piles examined between 1991 and 2004. Coinciding with a peak fruiting season in the study area, seeds and other fruit parts appeared in the dung piles significantly more frequently during the dry season than in the wet seasons (southwest and northeast monsoons). Owing to differences in fruit species abundance in different habitats, there was more evidence of fruit consumption in the dry thorn than in the dry and moist deciduous forests. This corresponds with insufficient grass availability in thorn forests during the dry season and an increase in browse consumption as a supplementary diet. Seeds of *Tamarindus indica* and *Acacia intsia* were found in elephant dung more frequently than other species. Seed and fruit remnants were found in almost an equal number of dung piles of both bulls and herds.

Keywords: Asian Elephant, fruit consumption, seed dispersal, southern India.

Seed dispersal plays a potential role in plant species demographic processes such as predation, germination, growth and reproduction (Nathan & Muller-Landau 2000). Elephants are important seed-dispersing agents (Alexander 1978; Lieberman et al. 1987; Chapman et al. 1992). Being a wide-ranging animal that consumes large quantities of fruits and defecating intact seeds, the elephant not only disperses the seeds but also carries them farther away from the parent trees where they would otherwise suffer higher mortality from density-dependent factors (Barnes 1996) and high predation (Janzen 1970; Connell 1971). Seeds passing through the gut of mammalian frugivores may have a greater probability of seed germination (Willson 1993) while elephant dung also promotes the establishment of seedlings by providing a suitable nutritive medium (Ridley 1930; Coughenour & Delting 1986; Dinerstein & Wemmer 1988; Campos-

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Arceiz et al. 2008) and protection from desiccation (Kitamura et al. 2007). Thus, elephants are regarded as the largest frugivore and the "mega-gardener" of the forest (Campos-Arceiz & Blake 2011). Fruits form a part of elephants' diet in both Africa (Merz 1981; Short 1981; Lieberman et al. 1987; White et al. 1993; Tchamba & Seme 1993; Feer 1995) and Asia (Oliver 1978; Sukumar 1989; McKay 1990; Sivaganesan & Johnsingh 1995; Kitamura et al. 2007; Campos-Arceiz et al. 2008; Campos-Arceiz 2009; Roy 2009). A large number of studies focus on the feeding behaviour of Asian Elephants in India (Sukumar 1989; Sivaganesan & Johnsingh 1995; Baskaran 1998; Roy 2009; Baskaran et al. 2010) but none of them have specifically focused on frugivory and seed dispersal. This paper reports the frugivory and seed dispersal by Asian Elephants in the Nilgiri Biosphere Reserve, southern India.

Study Area

The study was carried out in the Nilgiri Biosphere Reserve, southern India (10^{0}5'–12^{0}15'N & 76^{0}0'–77^{0}15'E), extending over 5,520km^2, between 1992–1994 and 2000–2004. Within the Biosphere Reserve, the study focused on the elephants' frugivory and seed dispersal in the Mudumalai Wildlife Sanctuary (at present a Tiger Reserve), Nilgiri North, Sathiyamangalam and Coimbatore forest divisions in Tamil Nadu, Bandipur Tiger Reserve in Karnataka and Wayanad Wildlife Sanctuary in Kerala. This area has an estimated population of 4,500–5,800 elephants (Synchronized Elephant Census 2005). It receives a rainfall of 600–2000 mm from both the southwest (May–August) and northeast (September–December) monsoons. The vegetation mainly consists of tropical dry, moist deciduous and dry thorn forests (Champion & Seth 1968).

Tropical dry deciduous forest is the dominant type in the study area, distributed in the central part of Bandipur Tiger Reserve and Mudumalai Wildlife Sanctuary. The tree species composition is mainly *Anogeissus latifolia*, *Tectona grandis* and *Terminalia* sp. The tree canopy is mostly semi-open and the understorey is dominated by grass species *Themeda cymbaria*, *Cymbopogon flexuosus* and *Themeda triandra*. Fruit trees found edible to elephants include *Bauhinia racemosa* and *Grewia tiliifolia,* and shrub species *Grewia hirsuta*.

Tropical moist deciduous forest occurs only in the northern part of the reserve (covering the western part of the Mudumalai Wildlife Sanctuary, most of Wayanad Wildlife Sanctuary and the northwestern part of Bandipur Tiger Reserve). The dominant tree species are *Tectona grandis, Lagerstroemia lanceolata, Grewia tiliifolia, Kydia calycina, Pterocarpus marsupium* and *Syzygium cumini*. The tree canopy is mostly closed. The ground cover is mainly composed of *Helicteres isora, Desmodium* spp. and *Curcuma* sp. Weed species such as *Lantana camara* and *Chromolaena odoratum* are common. The dominant grass species are *Cyrtococcum patens*, *C. oxiphyllum*, *Themeda cymbaria*, *Apluda mutica* and *Imperata cylindrica*. Bamboo *Bambusa arundinacea* is very common along the perennial water sources and is a characteristic feature of this forest type. Woody plant fruit species eaten by elephants here include *Artocarpus heterophyllus*, *Bauhinia recemosa*, *Mangifera indica* and *Grewia tiliifolia* but are found in low densities except the last species which is found in moderate density.

Tropical thorn forest is confined to the eastern side of Mudumalai Wildlife Sanctuary, Bandipur Tiger Reserve, the western parts of Sathiyamangalam and the southern parts of Coimbatore Forest Division. The dominant tree species include *Ziziphus mauritiana*, *Acacia* spp., *Anogeissus latifolia*, *Albizzia amara* and *Erythroxylum monogynum*. *Acacia intsia* (an important elephant browse) and *Lantana* sp. are the common woody shrubs that are abundant along the dry streams and perennial water sources. The tree canopy is mostly open. The understorey consists of *Acacia intsia, Opuntia* sp. and *Gymnosporea emarginatus*. These shrubs are distributed in isolated patches separated from one another by intervening strips of grass cover. *Heteropogon contartus, Bothriochloa* sp., *Digitaria* sp. and *Aristida adscencionis* are the dominant grass species. Grass availability is poor because of low rainfall, and poor soil nutrients coupled with severe cattle grazing in many areas. Unlike the deciduous habitats, dry thorn habitats support a wide variety of fruit species edible to elephants, which includes *Acacia intsia* and *Grewia hirsuta* which belong to the shrub category, and *Bauhinia racemosa, Mangifera indica, Tamarindus indica, Ziziphus mauritiana which* belong to the tree category.

Methods

Free ranging elephants were followed and fresh dung piles were collected on observed defecation. The dung samples were collected during the course of systematic observations on the feeding and ranging behavior of radio-collared elephants between (1991 and 1995) and population demography monitoring based on opportunistic sightings of non-collared elephants between (1991 and 2004) in the Nilgiri Biosphere Reserve, southern India. Date, habitat type, assessment of age of defecating individual into adult, sub-adult and juvenile and if the defecation was that of a herd or a bull were also recorded. The dung piles were broken up into small pieces and thoroughly examined for woody plant

fruit remains such as seeds, pericarp and pulp. The fruit remains were further segregated and identified up to species level by comparing them with fresh specimens of fruits/seed from the field. It is likely that our study underestimated the number of fruits species consumed by elephants since we examined elephant dung in situ and this estimate should be treated as the minimum number of fruits consumed. Occurrence of fruit remains (presence) in the dung piles was expressed as % occurrence arrived by dividing the total number of dung piles containing a given species of fruit remnants by the total number of dung piles sampled with respect to habitat, age category and social status of elephants. The observed difference was tested for statistical significance using chi-square analysis. Biases arising due to the wide-ranging nature of elephants across habitats can be considered overcome by rigorous monitoring of ranging and habitat-use using radio-telemetry. For the same reason, care was also taken to avoid sampling dung piles at the periphery of any habitat.

Observations and Results

Of the 455 elephant dung piles examined, woody plant fruit remains that were mainly seeds from eight species namely—*Acacia intsia, Artocarpus heterophyllus*, *Bauhinia racemosa*, *Grewia hirsuta*, *Grewia tiliifolia*, *Mangifera indica*, *Tamarindus indica* and *Ziziphus mauritiana*, belonging to seven families occurred in 72 dung piles (15.8%). Seeds of *A. intsia, T. indica* and *M. indica* appeared more frequently (Table 1). Fruit matter/seed was recorded significantly in more number of dung piles examined during the dry season (25.7%) than in the first wet (17.1%) and second wet (10.1%) seasons (Table 1) (c^2 = 8.187, *df* = 2, P = 0.01). *T. indica*, *A. intsia* and *B. recemosa* seeds had the highest occurrence during the dry season, while in first wet season it was seeds of *M. indica* and *G. tiliifolia* and in the second wet season it was seeds of *G. hirsuta* and *Z. mauritiana*.

Fruit remains and seeds appeared almost in an equal number of dung piles of bulls (18.3%) and herds (14.9%) (χ^2 = 0.751, *df* = 1, P = 0.386).

Among the three habitats, the elephant dung piles examined in dry deciduous forests were rarely found with seeds or other fruit remnants (6.5%) compared to moist (17.1%) and dry thorn forests (25.7%) (Table 2). *G.tiliifolia* was the only seed recorded in dry deciduous forests, while in moist deciduous forests, two species—*M. indica* and *Artocapus heterophyllus*—were found with the former being more frequent. More diverse seeds (six species) had appeared in the elephant dung in dry thorn forest. Seeds of *A. intsia* (9.3%), a common shrub, and *T. indica* (9.3%), a relatively rare tree species, in the study area occurred often in the dung piles. A considerable number of dung piles also had seeds of *G. hirsuta* (3.5%) and *B. racemosa* (3.1%), while the most common fruit species, *Z. mauritiana* was noticeable only in 0.89% of dung piles revealing that this species was not the preferred choice. The consumption of fruit species in different habitats by and large related to their availability in each habitat (Table 2). However, some of the fruit species though commonly

Table 1. Percent frequency occurrence of various species of fruits with respect to the total number of elephant dung piles sampled in different seasons in Nilgiri Biosphere Reserve, southern India

Family / Fruit species	Season			Annual (n = 455)
	Dry (n = 109)	Wet I (n = 129)	Wet II (n = 217)	
Leguminose *Acacia intsia*	10.09	-	4.61	4.62
Moraceae *Artocarpus heterophyllus*	-	3.10	-	0.88
Caesalpiniaceae *Bauhinia racemosa*	5.50	-	0.46	1.54
Tiliaceae *Grewia hirsuta*	1.83	-	2.76	1.76
Grewia tiliifolia	-	6.20	-	1.76
Anacardiaceae *Mangifera indica*	1.83	9.30	-	3.08
Fabaceae *Tamarindus indica*	11.93	-	3.69	4.62
Rhamnaceae *Ziziphus mauritiana*	-	-	0.92	0.44
Overall	25.7	17.1	10.1	15.8

Table 2. Percent frequency occurrence of various species of fruits appeared with respect to the total number of elephant dung piles sampled in different habitats and the index of availability of those fruit species in different habitats of Nilgiri Biosphere Reserve, southern India.

Fruit species	% frequency occurrence in different habitat			Index of availability in different habitat *		
	Dry deciduous (n = 123)	Moist deciduous (n = 106)	Dry thorn (n = 226)	Dry deciduous	Moist deciduous	Dry thorn
Acacia intsia	-	-	9.29	x	x	+++
Artocarpus heterophyllus	-	3.77	-	x	+	x
Bauhinia racemosa	-	-	3.10	++	+	++
Grewia hirsuta	-	-	3.54	+	x	++
Grewia tiliifolia	6.50	-	-	+	++	x
Mangifera indica	-	11.32	0.88	x	+	x
Tamarindus indica	-	-	9.29	x	x	+
Ziziphus mauritiana	-	-	0.88	x	x	+++
Overall	6.5	13.2	22.1			

Index of availability: x indicates absent; +, ++, and +++ indicate available respectively at low, moderate and high density. * derived from Baskaran (1998).

found in some habitats did not appear in the dung piles. For example *B. racemosa,* a species found in moderate numbers in dry deciduous habitats, had not been recorded in the dung piles from the same habitat and similarly, the *G. tiliifolia* in moist deciduous habitats.

Discussion

Comparison of diet in other elephant ranges: Seeds and fruit remains were found in >90% of the elephant dung piles in Bia National Park, Ghana (Short 1981; Lieberman et al. 1987), 80% in the rain forests of Gabon (White et al. 1993; Feer 1995) and 65% in Santchou Reserve, Cameroon (Tchamba & Seme 1993). Our study however shows that seeds and fruit remains occurred in only 15.8% of the dung piles, which is very low compared to the studies reported above. Such differences in fruit consumption could be attributed to the variation in the habitat quality and availability of other food resources between the areas. The direct observation on the feeding behaviour of elephants in Sri Lanka (McKay 1990) indicated that elephants occasionally ate fruits. Olivier (1978) and Roy (2009) also reported that fruits appear to form a minor constituent of elephant's diet respectively in the rain forests of Malaysia and northeastern India, respectively. Therefore, it is apparent that elephants do not rely much on fruits not only in the present study area but also in other parts of India and Asia unlike the elephants in Africa.

The number of woody plant fruit species recorded in the present study (eight species) was less than those recorded by Short 1981 (35 species); Lieberman et al. 1987 (11 species); White et al. 1993 (72 species); Tchamba & Seme 1993 (22 species); Feer 1995 (55 species) in Africa and Olivier 1978 (nine genera) in Asia. The dependence of elephants on more varieties of fruit species in Africa than in Asia (except Malaya) could be related to habitat conditions. Most of the African and Malayan habitats where the seed dispersal studies were conducted are rain forests unlike the tropical dry habitats found in most of the elephant ranges in India and Sri Lanka (South Asia). The tropical dry forests of South Asia, the deciduous and dry thorn habitats that harbour the major proportion of elephant population, are grass dominated habitats. Since the elephants are highly adapted to feeding on grass (Olivier 1978), they consume grass as the principal diet and thus the contribution of fruits to the annual diet of elephants is very low in the tropical dry forests of South Asia (McKay 1990; Baskaran 1998; Baskaran et al. 2010). However, the ability to survive in varying habitats such as rain forests and deserts is helped by their ability to shift to browse resources including fruits in the absence or insufficient supply of grass as seen in West Africa (Short 1981; Feer 1995; White et al. 1993) and South-east Asia (Olivier 1978; Kitamura et al. 2007).

Fruit consumption observations in study area: The greater occurrence of seeds and fruit fragments during the dry season than the wet season in the present study is consistent with White et al. (1993) and Roy (2009). The highest use of fruits during the dry season coincided with the peak fruiting season of major fruit species such as *T. indica*, *A. intsia* and *B. racemosa*. Fruit consumption by elephants observed in the dry thorn forest during the dry season in Mudumalai Wildlife Sanctuary (Sivaganesan & Johnsingh 1995) is consistent with present findings. Ripe fruits of *M. indica* and *A. heterophyllus* were available during the first wet season and thus these species were eaten more often during the first wet season.

To summarize, elephants consume a lesser number of fruit species in the tropical dry forests of Nilgiri Biosphere Reserve than in the rainforest habitats of Asia and Africa. The elephants' ability to retain the seeds in the gut for a longer time (Campos-Arceiz 2009) along with longer daily displacement (Baskaran 1998), plays a potential role in tropical plant species demographic processes through dispersing the seeds over long distances from parent trees. Although this study has produced base line information on frugivory and seed dispersal by Asian Elephants, a more detailed study on the elephants' role in aspects including the rate of fruit removal and fruit foraging efficiency, seed dispersal distance, germination success, seedling growth and establishment rates in the Indian region would increase our understanding and address the lacuna in the available information on the role Asian Elephants play in maintaining the tree species diversity in Asian forests.

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