Journal of Tropical Ecology (2007) **23**:373–376. Copyright © 2007 Cambridge University Press
doi:10.1017/S0266467407004026 Printed in the United Kingdom

SHORT COMMUNICATION

Frugivory and seed dispersal by Asian elephants, *Elephas maximus*, in a moist evergreen forest of Thailand

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(*Accepted 27 December 2006*)

Key Words: *Choerospondias axillaris*, *Diospyros glandulosa*, faecal analysis, *Garcinia cowa*, germination trial, *Irvingia malayana*, Khao Yai National Park, *Platymitra macrocarpa*, *Sandoricum koetjape*, *Spondias pinnata*

The Asian elephant *Elephas maximus* is the only living species of the genus *Elephas* (Elephantidae) that evolved in Africa *c.* 5–6 million y ago and migrated into Eurasia (Sukumar 2003). The Asian elephant is one of the few remaining extant megafauna (Owen-Smith 1988) and has disappeared from *c.* 95% of its historical range (Sukumar 2006). Asian elephants eat fruit when it is available, defecating intact seeds, of which some later germinate in the dung (Lekagul & McNeely 1977, Ridley 1930). However, to date there has been no detailed study of frugivory and seed dispersal by Asian elephants (Corlett 1998). The only common feature of the fruit reported to be eaten by Asian elephants is their relatively large size, but there is no evidence that they are exclusive dispersers of any plant species (Corlett 1998), in contrast to the more frugivorous African forest elephants, *Loxodonta africana cyclotis* (Babweteera *et al.* 2007, Chapman *et al.* 1992, Cochrane 2003, Feer 1995).

In this paper, we evaluate the prevalence of woody-plant seeds and fruits in the diet of elephants in the moist evergreen forest of Khao Yai National Park (KY, 14°05′–15′N, 101°05′–50′E), Thailand. The current population of *E. maximus* in KY is estimated to be *c.* 150 individuals (Lynam *et al.* 2006, Srikosamatara & Hansel 1996), representing one of the largest populations in Thailand (Storer 1981). Preliminary results of investigations into the fruit species eaten by elephants show fruit–frugivore interactions at the community level (Kitamura *et al.* 2002). In this paper, we have concentrated on the quantitative aspect of frugivory and seed dispersal by elephants.

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Elephant dung was sampled from July 1998 to August 1999 and July 2000 to February 2002, to determine the presence or absence of seed or fruit matter, and the net seed and/or fruit contents. In total, we conducted 57 surveys throughout the study and found elephant dung in 37 of them. The seed content of elephant dung was determined through analyses of data collected from road transect samples and opportunistic *ad libitum* site samples. The paved road (17 km length) from the Forestry Training Centre to Heaw Narok waterfall was used for the road transect samples and was visited once or twice a month throughout the study period. Dung piles were sampled by hand shredding and dissection to determine the seed content of the dung, usually *in situ*. Standard data measures that were recorded included: the number of dung boli per defecation, dung condition (intact, fragmented, recent/old), and net seed and/or fruit content. When field identification of seeds was uncertain, specimens were collected and compared to reference seed collections from the same study site (Kitamura *et al.* 2002). Voucher specimens of intact seeds recovered from elephant dung were deposited in our laboratory at KY. Plant nomenclature follows Gardner *et al.* (2000).

Germination trials were carried out to assess seed viability and to determine if there was a difference between the germination success of (1) defecated seeds collected from the elephant dung and (2) seeds taken by hand from ripe fruit, collected under fruiting trees. Each treatment of 100 seeds was placed in nursery bags with fresh elephant dung under partial shading at our research laboratory in KY. Seeds of *Sandoricum koetjape* were used for this purpose, since it was the most abundant seed species found in the elephant dung (Table 1).

Table 1. Frequency and abundances of plant seed recorded in the dung of Asian elephants (*Elephas maximus*) in Khao Yai National Park, Thailand. Data for the size of fruit/seed extracted from Kitamura *et al.* (2002) and those of fruiting season are from S. Kitamura (unpubl. data). Plant nomenclature follows Gardner *et al.* (2000). The frequency measure refers to seed incidence in dung piles over the period when the species was in fruit. The median number of seeds per defecation did not include the many defecations where no seeds were found. Note that the major fruiting season of *Platymitra macrocarpa* occurred January–March but small numbers of ripe fruit were also available in other months.

Family	Species	No. of dung piles with seeds	Frequency (%)	Median no. of seeds per defecation	Fruit size (mm)	Seed size (mm)	Fruiting season
Anacardiaceae	*Choerospondias axillaris*	7	1.9	1.0	25.7 × 23.3	18.5 × 15.1	July–November
Anacardiaceae	*Spondias pinnata*	4	3.5	5.5	38.7 × 32.6	33.4 × 23.8	January–February
Annonaceae	*Platymitra macrocarpa*	8	4.5	3.0	80.6 × 63.6	28.2 × 16.7	January–March
Ebenaceae	*Diospyros glandulosa*	2	1.7	1.0	27.2 × 25.9	14.8 × 8.4	August–September
Guttiferae	*Garcinia cowa*	12	5.0	2.0	53.5 × 49.4	28.4 × 15.4	July–September
Irivingiaceae	*Irvingia malayana*	1	0.8	2.0	36.6 × 32.8	30.2 × 22.9	August–September
Meliaceae	*Sandoricum koetjape*	114	57.6	8.5	58.3 × 49.6	25.5 × 15.1	May–July
All samples (n = 701 dung piles)		148					

The frequency of seed and/or fruit matter found in each survey (n = 37) varied highly, from 0 to 56.3%. We did not find any seeds in 24 of 37 of the surveys. In total, seed and/or fruit matter was identified in 21.1% of dung piles (n = 701). The average number of dung boli per defecation was 4.8 (SD ± 2.1), within an observed range of 1–10 boli. The abundance of plant species recorded from total seed count samples are presented in Table 1. Seeds of seven species were recorded from elephant dung. One defecation contained only a single seed species. Seeds present in greatest abundance were those of *S. koetjape* (2365 seeds in 114 piles), followed by *Garcinia cowa* (40 seeds in 12 piles) and *Platymitra macrocarpa* (48 seeds in 8 piles). Of 2365 seeds of *S. koetjape*, 21.1% germinated and 21.2% established as seedlings in the dung. One *Choerospondias axillaris* seedling was also found in the dung. The seeds of *S. koetjape* were often found in elephant dung during their fruiting season (57.6% of defecations contained the seeds), but other fruit species were rare (less than 5%). We did not find any evidence of seed foraging of elephant dung by vertebrates, but several species of dung beetle were commonly found.

The colour of the ripe fruits eaten by elephants was yellow, except for *P. macrocarpa*, which has brown fruit. All fruit species had a sweet aroma as perceived by the first author. Seed species recovered from elephant dung ranged in size from 25.7–80.6 mm in fruit length and from 14.8–33.4 mm in seed length; the largest fruit were those of *P. macrocarpa* and the largest seeds were those of *Spondias pinnata*. All fruit species had hard seeds i.e. the seed coats were difficult to penetrate without a knife. The fruiting season of species eaten by elephants usually continues for 2–3 mo, except for *C. axillaris*, which lasts 5 mo.

We found no statistically significant difference between the germination success of the elephant-defecated seeds (60%) and the control seeds (65%) over 2 wk (Fisher's exact test: P = 0.28). However, we were unable to continue the germination experiment because of disturbance by a Malayan porcupine (*Hystrix brachyura*), which predated the remaining seeds in the nursery bags.

The faecal analysis revealed that Asian elephants consumed only a small number of seed species in KY (Table 1), despite the availability of a diverse range of fruit during the study period (Kitamura *et al.* 2002). It is possible that our study underestimated the number of seed species consumed by elephants since we examined elephant dung *in situ*. Fallen fig consumption by elephants around large strangler figs has been recorded for at least two fig species (*Ficus altissima* and *F.* cf. *subcordata*) in KY (Poonswad *et al.* 1998). Even when we added these species to our results, the number of species eaten by elephants in KY was still at the lower end of the range of species richness reported from African forest elephants. For example, the number of seed species found in dung piles of African forest elephants, *L. africana cyclotis*, was 11 in Bia, Ghana (Lieberman *et al.* 1987), 14 in Kahuzi-Biega, Zaire (Yumoto *et al.* 1995), 22 in Santchou, Cameroon (Tchamba & Seme 1993), 27 in Hwange, Zimbabwe (Dudley 2000), 35 in Ghana (Short 1981), 37 in Tai, Ivory Coast (Alexandre 1978), 50 in Banyang-Mbo, Cameroon (Nchanji & Plumptre 2003), 66 in Bossematie, Ivory Coast (Theuerkauf *et al.* 2000), 72 in Makokou, Gabon (White *et al.* 1993), and 235 in Shimba Hills, Kenya (Engel 2000). Similar to our result, only 14 fruit species (including *Choerospondias axillaris*, *Spondias pinnata*, *Irvingia malayana*, *Sandoricum koetjape* and *Ficus* spp.) were recorded as the diet of Asian elephants in Phu Luang Wildlife Sanctuary in northern Thailand (Chanard *et al.* 1998). Elephant fruits are defined as 'large, tough and indehiscent' fruits with a 'fibrous pulp, dull colours, and resistant seeds' (Gautier-Hion *et al.* 1985, Howe 1986). However, such characteristics were not recognized for the fruits eaten by Asian elephants in this study (Table 1) as well as those fruits reported in northern Thailand (Chanard *et al.* 1998).

The frequency of seed species recorded in droppings of African forest elephants was frequently over 80% (Dudley 2000, Engel 2000, Short 1981, White *et al.* 1993), in contrast to our result (21%). The number of fruit species consumed by elephants is also substantially smaller than those of other major frugivore groups in KY (Kitamura *et al.* 2002). In KY, elephants consume various kinds of grasses, bananas, bamboo shoots and tree bark (Srikosamatara & Hansel 1996). The relative fruit abundance fluctuates highly both seasonally and annually in KY (S. Suzuki, unpubl. data). Although fruits may be ingested as a byproduct when feeding on foliage (Engel 2000), the fruits elephants ate in this study seem to be similar in their occurrence in large patches on the ground (Kitamura *et al.* 2002). This may be the reason why elephants in our study area did not use more kinds of fruit as a food resource.

Passage through the gut of Asian elephants was not harmful to seeds of *Sandoricum koetjape*, but large numbers of seeds deposited in elephant dung may attract seed-predating animals. A Malayan porcupine disturbed our germination trial and predated most of the *S. koetjape* seeds in the elephant dung. This is not direct evidence of seed predation from elephant dung by mammals in KY, but it is likely that these seed-predating mammals consume seeds from elephant droppings in the field. In Africa, seeds taken from elephant dung by vertebrates constitute a significant food resource, and foraging in dung seems to be a widespread phenomenon (Magliocca *et al.* 2003). In central Borneo, gibbon-generated seed shadows were profoundly altered by post-dispersal events, especially by vertebrates (McConkey 2005a). We found no evidence of the secondary dispersal by dung beetles in this study, but the role of dung beetles as secondary dispersers has recently been reported in this region (McConkey 2005b). As our data were mostly collected from road transect samples, we likely underestimated the activity of these secondary dispersers as well as seed-predating animals that altered the fate of elephant-dispersed seeds.

African forest elephants are a major terrestrial disperser, and some plant species may be primarily dependent on them for dispersal (Babweteera *et al.* 2007, Cochrane 2003, Gautier-Hion *et al.* 1985). In KY, all fruit species consumed by elephants highly overlap with those of other mammalian frugivores such as primates (Kitamura *et al.* 2002). Large-bodied frugivores, with large home ranges and longer gut retention times are likely candidates for long-distance dispersal (Cosyns *et al.* 2005, Fragoso *et al.* 2003, Vellend *et al.* 2003, Westcott *et al.* 2005). The known home range size of Asian elephants varies from site to site but generally exceeds 100 km^2 (Sukumar 2003) and it is much larger than that of white-handed gibbons, *Hylobates lar*, 30–40 ha for a family (Bartlett 2003) and pig-tailed macaques, *Macaca nemestrina*, *c.* 200 ha for a troop (T. Maruhashi, unpubl. data) in KY. The known retention time of African forest elephants is frequently over 10 h (Dudley 1999), and elephants move faster from place to place. Thus, one possible benefit of elephant seed dispersal for consumed plant species may be long-distance dispersal, allowing colonization of new habitats in KY. Additionally, elephants might create suitable places for the germination of seeds and the successful growth of seedlings by disturbing the dense covering of vegetation (Yumoto *et al.* 1995). Seed dispersal by elephants will also provide protection from desiccation directly by the bolus and provide indirectly further safe sites due to endozoochory/dung-dependent dispersal mode by dung beetles or other dung visitors (Engel 2000). Asian elephants can make a tremendous impact on their habitats through their feeding activities (Sukumar 2003) and there are no known elephant-dependent plants in KY, however the different seed shadows generated by elephants may increase the chance that a seed is dispersed to a favourable site which has an unpredictable location (Wheelwright & Orians 1982).

ACKNOWLEDGEMENTS

We are grateful to the National Research Council of Thailand and National Park Division of the Royal Forest Department of Thailand, for granting us permission to conduct the activity in KY. We extend our hearty thanks to the staff at KY. We thank B. Saengthong, S. Chuailua, S. Nakkuntod, S. Sanguanchat, N. Jirawatk and all staff of the Thailand Hornbill Project for supporting our field work. Thanks to T. Maruhashi, N. Noma and S. Suzuki for providing useful suggestions and discussions. T. B. Engel made useful comments to a previous version of the paper. This research is partly supported by a Research Fund of the Japan Society for the Promotion of Science (#1357006) and JSPS Research Fellowships for Young Scientists for S. Kitamura.

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