Notes and records

Notes on seeds deposited in elephant dung at Tarangire National Park, Tanzania

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Introduction

African elephants (*Loxodonta africana africana* Blumenbach) are generalist browsers and frugivores (Barnes, 1982; Kabigumila, 1993). In a single community, elephants may disperse the seeds of numerous plant species (Burtt & Salisbury, 1929; Koen, 1983; Lieberman, Lieberman & Martin, 1987; Feer, 1995; Yumoto *et al.*, 1995; Dudley, 2000; Cochrane, 2001; Nchanji & Plumptre, 2003). Elephant seed dispersal can range from high quality (Cochrane, 2001; Nchanji & Plumptre, 2003) to low quality or seed predation (Koen, 1983). Few investigations have documented and quantified the species dispersed, or the quality of dispersal by elephants in savanna communities. The aim of this study was to document the seeds present in elephant dung in the savanna-dominated Tarangire National Park, Tanzania. In addition, an elephant-produced seed rain (expressed as the average number of a species' seeds deposited in elephant dung boli per $100\ m^2 = 0.01\ ha^{-1}$) for the microphyll habitat adjacent to the Tarangire River was generated to estimate the density of deposited seeds.

Materials and methods

This study was conducted in the dry season from October to November of 2005, in the northern half of Tarangire National Park (latitude 3°40′–5°35′S and longitude 35°45′–37°E) in north central Tanzania. The total area of Tarangire N. P. is approximately $2600\ km^2$. The average annual rainfall is 620 mm with two periods of rain, the short (November–February) and the long (March–May; Foley, 2002). The Tarangire River is the dominant feature of the park and the main source of water for the entire Masai ecosystem (Van de Vijver, Foley & Olff, 1999). There are two dominant vegetation types. Microphyll wooded savanna makes up the riverine area and the deciduous savanna occupies the ridges and upper slopes (Van de Vijver *et al.*, 1999). The estimated Tarangire elephant population is *c.* 2300 during the dry season when populations concentrate along the river (Foley, 2002).

To assess the seeds of plant species in elephant dung, fresh to nearly fresh boli (barrel shaped segment of a defecation; *c.* 3 l) were collected near (<100 m) or on all major road segments within the study area (Fig. 1). One bolus was randomly selected per sampled dung pile, which was defined as any number of boli in a clump or mound *c.* 1-m distance from any other elephant dung. Dry season diet of elephants in Tarangire N. P. consists of course fibrous materials, such as, bark and other woody tissues, which form distinct dung boli (Gonthier, pers. obs.). A collected bolus was then dissected by hand, and the total numbers of intact, undamaged seeds of each species were identified and counted. All graminoid species were excluded from the survey. Small seeded herbaceous or woody species (<3 mm dia.) were only recorded as absent or present from each bolus. The frequency of boli with the presence of at least one seed of each species and the average number of a species' seeds per bolus were calculated. Fruiting trees in the study area were noted and identified for comparison of seeds found in dung (Van Wyk & Van Wyk, 1997; Dharani, 2002). Seeds of *Adansonia digitata* L., *Balanites aegyptiaca* (L.) Del., *Sclerocarya caffra* Sond. retrieved from boli were germinated to confirm viability after elephant gut passage.

The average number of dung boli per dung pile was estimated by counting the number of boli present in fresh (<1 day old) dung piles. The average number of dung piles $0.01\ ha^{-1}$ was estimated using randomly placed belt-transects (4×25 m) off road segments; the number of dung piles (including old, weathered, aged, and nonintact) was counted within. An elephant seed rain was estimated for each species by multiplying the

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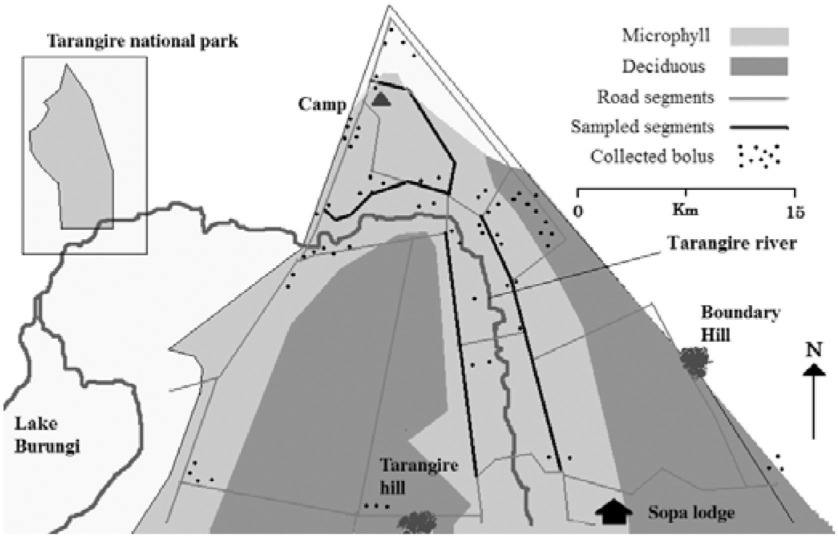

Fig 1 Map of the study area including habitat types, road segments, road segments sampled with belt-transects, and dung boli collection sites. Scale is approximated (modified from Van de Vijver *et al.*, 1999)

Table 1 Elephant seed rain, mean number of seeds per bolus, and frequency of boli containing at least a seed

Species[a]	Habit	Frequency of boli containing a seed	Total no. seeds found	Mean seeds per dung bolus	Elephant seed rain[b]
Acacia tortilis (Forssk.) Hayne (Fabaceae)	Large tree	39.4 ± 9.1	665	10.1 ± 2.9	63 ± 19
Adansonia digitata L. (Bombacaceae)	Large tree	30.3 ± 7.7	76	1.15 ± 0.57	7.2 ± 2.1
Balanites aegyptiaca (L.) Del. (Zygophyllaceae)	Large tree	6.1 ± 3.1	7	0.106 ± 0.058	0.67 ± 0.20
Kigelia africana (Lam.) Benth. (Bignoniaceae)	Large tree	3.0 ± 2.1	2	0.030 ± 0.021	0.190 ± 0.056
Lagenaria sp. Ser. (Cucurbitaceae)	Herbaceous vine	6.1 ± 7.7	22	0.33 ± 0.19	2.09 ± 0.62
Sclerocarya caffra Sond. (Anacardiaceae)	Large tree	9.1 ± 3.9	13	0.20 ± 0.10	1.237 ± 0.36
Solanum incanum L. (Solanaceae)[c]	Herbaceous shrub	40.9 ± 9.4	–	–	–
Tamarindus indica L. (Fabaceae)	Large tree	3.0 ± 2.2	3	0.045 ± 0.034	0.285 ± 0.084
Unknown sp. 1	–	12.1 ± 4.5	25	0.38 ± 0.16	0.157 ± 0.050[d]
Unknown sp. 2	–	10.6 ± 4.2	12	0.182 ± 0.078	1.14 ± 0.34
Unknown sp. 3	–	1.5 ± 1.5	1	0.015 ± 0.015	0.095 ± 0.028

[a]All species were found fruiting in the study area, except *Sclerocarya caffra* (though fruits were found beneath trees) and unknown species. Other species observed fruiting include: *Acacia brevispica* Harms (Fabaceae; Medium tree), *Argemone mexicana* L. (Papaveraceae; Herbaceous shrub), *Borassus aethiopum* Mart. (Arecaceae; Large palm), *Ficus sycomorus* L. (Moraceae; Large tree), *Grewia* sp. L. (Tiliaceae; Small tree), *Terminalia brownii* Fresen. (Combretaceae; Large tree), *Terminalia kilimandscharica* Engl. (Combretaceae; Large tree), *Ziziphus* sp. Mill. (Rhamnaceae; Shrub).

[b]Equal to the product of the average number of dung boli per dung pile, the average number of dung piles 0.01 ha^{-1}, and the average number of seeds per bolus.

[c]Seeds of *Solanum incanum* were too small to count.

[d]Elephant seed rain was calculated from boli only found in microphyll habitat (n = 40).

above two estimations by the average number of a species' seeds per bolus. Road segments used were all located near the Tarangire River in the microphyll habitat; therefore, this estimation only corresponds to that area (Fig. 1).

Results

Sixty-six dung boli were dissected, yielding seeds from 11 different plant species (Table 1). The palm *Borassus aethiopum* Mart. was observed only in deteriorating dung boli, and therefore, not counted in the survey. *Solanum incanum* L., *Acacia tortilis* (Forssk.) Hayne, and *A. digitata* had the highest frequencies of boli (>30% of dung boli; Table 1). Only *A. tortilis* and *A. digitata* were found to average greater than one seed per bolus. Seeds of *S. incanum* were not counted because they were too small, but probably averaged >50 seeds per bolus (Gonthier, pers. obs.; Table 1). Fifteen species were observed fruiting during the study period, of which eight were present in the elephant dung survey (Table 1). Adult trees of all the seed species found in elephant dung were observed in the study area with the exception of the unidentified seeds found. Dry pods of *A. tortilis* and fruits of *B. aegyptiaca* collected from under parent trees were observed to be heavily preyed upon by insects. At least one seed of *A. digitata*, *B. aegyptiaca*, and *S. caffra* was successfully germinated after elephant gut passage.

The average number of boli per dung pile was estimated to be 2.92 ± 0.43 (n = 13). The average number of dung piles 0.01 ha^{-1} of microphyll habitat near the river was estimated to be 2.15 ± 0.40 (n = 20). *Acacia tortilis* had the largest elephant seed rain with 63 ± 19 seeds deposited 0.01 ha^{-1} (Table 1), again *S. incanum* was not counted, but probably had an even larger seed rain. The mean number of seeds per bolus in the microphyll and deciduous habitats were not different for all species, except unknown sp. 1 (two-tailed $t = 2.442$; d.f. = 18.1; $P < 0.05$), therefore all boli collected (n = 66) were used to estimate the elephant seed rain, except in unknown sp. 1 (n = 40).

Discussion

As in other communities (Burtt & Salisbury, 1929; Koen, 1983; Nchanji & Plumptre, 2003), elephants of Tarangire N. P. dispersed seeds of numerous plant species. Estimations of elephant seed rain suggest that a few species can be dispersed in great numbers (*S. incanum*, *A. tortilis*, *A. digitata*). The average number of woody plant seeds per bolus (12.5) was lower than the 45.6 reported in Dudley's (2000) dry season survey of the semi-arid, Hwange National Park, Zimbabwe. The average number of boli per dung pile (2.92 ± 0.43) was also lower than reports of three to six in Rasmussen *et al.* (2005) and five in Dudley (2000). The current study did not attempt to determine the total number of seeds per dung pile or defecation. Seeds can be unevenly distributed between boli that make up a defecation and although boli were sampled at random from dung piles, sample size was small. Nonetheless, the importance of determining the actual quantity of seeds deposited per dung pile may be relatively un-important in comparison to the actual survivorship and recruitment of seeds after gut passage and dispersal.

Very little is known about the fate of seeds after dispersal by elephants of savanna habitats. Dudley (2000) suggested *S. caffra*, *A. digitata*, *Ricinodendron rautanenii* Schinz and *B. aegyptiaca* are the likeliest representatives of savanna habitats dependent on elephant seed dispersal for regeneration. Three of these species' seeds were found in elephant dung in Tarangire N.P. *Adansonia digitata* was present in a high proportion of boli relative to other species and seeds passed and un-passed by elephants achieved germination. *Sclerocarya caffra* was not present in great numbers within the boli survey, yet passed seeds did germinate and it is known that elephants consume their fruits. Lewis (1987) found seeds of *S. caffra* ingested by elephants to have a high frequency of germination, while no un-ingested seeds germinated. Few seeds of *B. aegyptiaca* were found in elephant dung, yet a few seeds passed by elephants were found to germinate. Seeds of *B. aegyptiaca* under parent trees were observed to have high predation from insects (Gonthier, pers. obs.). A rainforest relative, *Balanites wilsoniana* Dawe & Sprague is believed to be dependent on elephants for recruitment because dispersed seeds escape high mortality under parent trees and lack any other effective disperser (Cochrane, 2001). A similar relationship may exist between *B. aegyptiaca* and elephants, if ingested and dispersed seeds have a higher probability of survival and recruitment than un-ingested seeds.

Acacia tortilis was also observed to have high (40–100%) seed predation by insects (Gonthier, pers. obs.). Few pods gathered from below parent trees were found with undamaged seeds, although pods did appear aged (Gonthier, pers. obs.). This observation confirms Miller's (1994) findings of up to 50% of seeds within pods on *A. tortilis* trees infested by bruchids. In the current study, seeds in elephant dung did not show high predation. Only completely intact seeds were counted in the survey although damaged seeds were found. Reduction in mortality of dispersed seeds is important in establishment and regeneration of plant species under high seed predation (Dinerstein & Wemmer, 1988; Fragoso, 1997; Cochrane, 2001). This predatory escape could be important for the regeneration of both *B. aegyptiaca* and *A. tortilis* throughout the savanna ecosystems.

This study is the first to record and quantify the species of seeds present in elephant dung in the savanna habitats of Tarangire N. P. Ecological research on elephant–plant interactions in savanna habitats has focused mostly on the mortality and damage to plants caused by elephant browsing (Norton-Griffiths, 1979; Tchamba, 1995; Gadd, 2002). Such studies have been undertaken in Tarangire N.P. and have concluded that elephant browsing may change the size distribution more than the density of major tree species (Van de Vijver *et al.*, 1999). Elephant seed dispersal may also be an important factor determining the density and distribution of major tree species, if dispersal favours the recruitment of some species over others. Any such differences among species derived from dispersal by elephants remain unknown, however.

This study suggests that elephants play an important role in recruitment of savanna plant species. *Solanum incanum, A. tortilis,* and *A. digitata* were dispersed by elephants in high numbers and *A. tortilis* and *B. aegyptiaca* may benefit from elephant dispersal through escape of seed predation and intraspecific competition. However, the fate of the dispersed seeds remains unknown and may be decided by dung scavengers and secondary dispersers rather than by primary dispersal. To understand fully the role of elephants in recruitment and distribution of plant species, further studies are necessary to understand the fate of those seeds deposited in the elephant dung and those seeds left beneath parent trees. These results represent preliminary findings as the sample size was small and the period of the dry season sampled, short. Furthermore, documentation of the species elephants disperse during other seasons in savanna habitats is needed to determine all species dispersed.

Acknowledgements

This study was conducted as an independent field project under the University of Dar es Salaam and the Associated Colleges of the Midwest. UDSM/ACM directors and students, as well as, park rangers, J. Mountjoy, J. Templeton, C. Saanane, A. Mabulla, J. Kabigumila, A. Barker, A. Jacobson, K. Krause, J. Sueltenfuss, S. Miller, E. Mueller, K. Wright, A. Trevor, E. Miller, A. Gawel, L. Dronyk, A. Rapacz, and Mr Gara are thanked for support in methods, field assistance, and editing. Lara and C. Foley helped in project design. Norbert Cordeiro, K. Murray, and T. Bultman are thanked for editing the manuscript and original project design.

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(*Manuscript accepted 25 September 2007*)

doi: 10.1111/j.1365-2028.2007.00875.x