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Short communication

Seed dispersal by Japanese macaques (*Macaca fuscata*) in western Tokyo, central Japan: a preliminary report

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Japanese macaques, *Macaca fuscata*, play an important role in dispersing seeds of plants in both warm and cool temperate forests in the Japanese archipelago (e.g., Yumoto et al. 1998; Otani 2003; Tsuji et al. 2011a). The frugivorous diet of the macaques, which was recorded by direct observation of their foraging behavior (e.g., Maruhashi 1980; Tsuji et al. 2006) or indirect fecal analyses (e.g., Hayashi 1992; Koganezawa 1996) implies that they act as seed dispersers everywhere in Japan. In order to evaluate a species' role as a seed disperser, it is essential to examine which plant species and/or how many seeds they actually disperse (Otani 2003). However, in central Japan (Kanto and Tokai Districts), which is one of the core habitats of Japanese macaques (Muroyama and Yamada 2010), there are few study sites where enough information about seed dispersal characteristics of macaques: list of plant species whose seeds are dispersed, rate of seed appearance, life form composition, seed size, number of seeds dispersed at once, number of plant species per feces, and intact rate. Thus, in this study I preliminary report results of the analysis of fecal samples of macaques collected along an intercity forest path in western Tokyo, central Japan. I then compare the results with those of previous studies conducted in other sites in order to address the uniqueness of characteristics of seeds detected from feces of the macaques in western Tokyo.

Materials and methods

Fecal sampling was conducted along the Bonbori Forest Path (36°N, 139°E, 400–500 m a.s.l.) between Hachioji City and Akiruno City in Tokyo. The vegetation at the study site is dominated by deciduous–coniferous mixed natural forest, as well as planted coniferous forest species such as *Cryptomeria japonica* and *Chamaecyparis obtusa* (Nakamura et al. 2001; Tsuji et al. 2011b).

I collected all amount of feces of the macaques by walking or cycling (less than 10 km·hr^{-1}) surveys along the forest path on clear days (number of collected feces: 1–12). I conducted these surveys at least once a month between July 2007 and July 2008 (23 surveys in total, and I found at least one feces at 10 out of 23 surveys). I discriminated the feces of the macaques from those of sympatric canids (red fox *Vulpes vulpes* and raccoon dog *Nyctereutes procyonoides*) and of mustelids (Japanese marten *Martes melampus* and Japanese weasel *Mustela itatsi*), on the basis of their shape, content, and size. Feces were washed through a 0.5-mm-mesh sieve and any seeds remaining in the sieve were identified and counted. Seed identification was based on Nakayama et al. (2000). According to Tsuji et al. (2011a), I classified the identified species into four life forms: tall trees (≥5 m in height), shrubs (<5 m), vines, and herbaceous plants.

I measured the longest axis (a_1), second longest axis (a_2), and third longest axis (a_3) of 10 randomly selected seeds for each plant species to the nearest 0.05 mm using a vernier caliper (Tsuji et al. 2011b). For *Berchemia racemosa*, I only measured five seeds for each dimension due to a dearth of seeds in my samples. From averaged values, I calculated the mean cubic diameter (MCD) of seeds (Tsuji et al. 2011a).

All data analyses were carried out using the statistical software R. 2.9.1 (R Development Core Team 2009). For all analyses, significance levels (α) were set at 0.05.

Results and discussion

A total of 52 fecal samples were collected during the study period. Considering the small sample size, I divided the whole year into three seasons, not four seasons: spring and summer (March to August), fall (September to November), and winter (December to February). Seed dispersal characteristics discussed below are based on this classification.

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Table 1. Seasonal changes in mean ± *SD* number of seeds obtained from fecal samples of the Japanese macaques at Bonbori Forest Path, central Japan from 2007 to 2008

Species	Life form	MCD (mm)[b] (mean ± *SD*)	Number of seeds/feces (mean ± *SD*)					
			Spring and Summer (Mar–Aug)		Fall (Sep–Nov)		Winter (Dec–Feb)	
			n = 10		*n* = 31		*n* = 11	
Actinidia arguta	vine	2.64 ± 0.24	535.3 ± 879.6	(3)	504.4 ± 374.3	(23)	11.0 ± 14.1	(2)
Ilex macropoda	high tree	4.64 ± 0.28	317.0 ± 284.6	(3)	—		—	
Akebia sp.	vine	5.59 ± 0.23	256.0 ± 11.3	(3)	1.0	(1)	—	
Poaceae species A*	herbaceous	3.17 ± 0.27	12.0 ± 10.5	(3)	—		—	
Actinidia polygama	vine	1.61 ± 0.19	10.0	(1)	—		—	
Poaceae species B*	herbaceous	2.75 ± 0.35	7.5 ± 9.2	(2)	—		—	
Polygonaceae sp.*	herbaceous	2.49 ± 0.27	7.0	(1)	13.3 ± 12.7	(2)	3.0 ± 1.4	(2)
Berchemia racemosa	vine	2.96 ± 0.32	5.0	(1)	—		—	
Rubus sp.	shrub	1.60 ± 0.07	1.0	(1)	—		—	
Ilex pedunculosa	shrub	4.22 ± 0.08	—		27.0 ± 36.8	(2)	—	
Diospyros kaki[a]	high tree	9.24 ± 0.36	—		18.3 ± 23.4	(3)	—	
Eurya japonica	shrub	1.94 ± 0.22	—		13.0	(1)	—	
Aphananthe aspera	high tree	3.47 ± 0.62	—		12.0	(1)	—	
Celtis sinensis	high tree	6.14 ± 0.50	—		8.5 ± 9.2	(2)	—	
Citrus junos[a]	high tree	11.83 ± 1.60	—		7.0 ± 7.3	(4)	5.5 ± 0.7	(2)
Stachyurus praecox	high tree	1.64 ± 0.11	—		2.0 ± 1.4	(4)	2.5 ± 0.7	(2)
Sorbus sp.	high tree	4.40 ± 0.15	—		2.0	(1)	—	
Amphicarpaea sp.*	herbaceous	3.77 ± 0.36	—		1.7 ± 1.2	(3)	8.7 ± 11.6	(3)
Viburnum dilatatum	shrub	5.05 ± 0.29	—		1.0	(1)	—	
Vitis sp.	vine	3.98 ± 0.24	—		1.0	(1)	—	
unidentified			—		1.0	(1)	1.0	(1)
Total number of seeds			314.3 ± 484.4	(10)	438.0 ± 388.9	(27)	10.1 ± 11.3	(7)
# Species detected/feces			1.7 ± 1.3	(10)	1.9 ± 0.7	(27)	1.7 ± 1.0	(7)

Species are arranged in decreasing order of the mean seed number. *n* means number of collected fecal samples. MCD: mean cubic diameter. Figures in parenthesis mean number of fecal samples containing seeds of given species.
[a]Cultivated species.
[b]From Tsuji et al. (2011b) except for *Berchemia racemosa*.
*Not fleshy-fruited species.

In total, 84.6 % (44/52) of feces contained seeds consisting of 20 plant species: 7 high tree species, 4 shrub species, 5 vine species, and 4 herbaceous plants (Tables 1 and 2). Percentage of freshy-fruit species in my study site (80.0%) was similar to other study sites except for Kinkazan Island (Table 2). Rate of seed appearance in spring and summer, fall, and winter were 100.0% (10/10), 87.1% (27/31), and 63.6% (7/11), respectively, and did not change seasonally (chi-square test, $\chi^2 = 0.50$, $df = 2$, $P = 0.778$). This result was different from that in Kinkazan Island in which the rate of dispersal event was greater in summer and fall and lower in winter (Tsuji et al. 2011a).

Numbers of plant species detected in spring and summer, fall, and winter were 9, 14, and 5, respectively. Among them, seeds of *Actinidia arguta* (Actinidiaceae) appeared frequently in all seasons. In spring and summer, seeds of *Ilex macropoda* (Aquifoliaceae), *Akebia* sp. (Lardizabalaceae), and two herbaceous plant species (Poaceae) appeared several times. In fall and winter, seeds of non- *A. arguta* species appeared less frequently. In fall, seeds of cultivated *Diospyros kaki* (Ebenaceae) and *Citrus junos* (Rutaceae) sometimes appeared (Table 1). Seeds of *Vitis* sp., those were found from feces of the macaques in the cool temperate region (Hayashi 1992; Otani 2003), were rarely found in this study site.

The mean number of seeds in a single fecal sample was 341.8 ± 405.6 (±*SD*, $n = 44$). Number of seeds in single fecal samples in spring and summer, fall, and winter were 314.3 ± 484.4, 438.0 ± 388.9, and 10.1 ± 11.3, respectively (Table 1), and significantly changed seasonally (Kruskal-Wallis test, $\chi^2 = 14.95$, $df = 2$, $P < 0.001$).

Table 2. Regional variation in characteristics of seeds detected from feces of Japanese macaques

Study site	Yakushima	Bonbori	Kashima	Kinkazan	Shimokita
Climate zone	W	W	C	C	C
Sampling period	1995–2004	2007–2008	2000–2001	2000–2009	2000–2001
# Fecal samples	132	52	107	1294	75
# Feces contained seeds (%)	131 (99.2)	44 (84.6)	99 (92.5)	747 (57.7)	59 (78.7)
# Identified plant species	33	20	18	35	12
Life-form composition (%)					
High trees	13 (38.2)	7 (35.0)	3 (16.7)	11 (30.6)	1 (8.3)
Shrubs	11 (32.4)	4 (20.0)	7 (38.9)	5 (13.9)	3 (25.0)
Vines	9 (26.5)	5 (25.0)	6 (33.3)	5 (13.9)	7 (58.3)
Hemi-parasites	0 (0.0)	0 (0.0)	0 (0.0)	1 (2.8)	0 (0.0)
Herbaceous plants	0 (0.0)	4 (20.0)	2 (11.1)	13 (36.1)	1 (8.3)
# Freshy-fruit species (%)	31 (91.2)	16 (80.0)	16 (88.9)	20 (55.6)	11 (91.7)
MCD (Mean ± *SD*) (mm)	2.5 ± 1.7 (n = 12)	4.2 ± 2.6 (n = 20)	2.3 ± 1.1 (n = 15)	3.0 ± 2.0 (n = 35)	2.7 ± 1.2 (n = 11)
Range	1.1–6.4	1.6–11.8	1.2–4.1	0.8–10.8	1.2–4.1
# Species/feces (Mean ± *SD*)	2.8 ± 1.4 (n = 131)	1.8 ± 0.9 (n = 44)	2.4 ± 1.5 (n = 99)	2.0 ± 0.9 (n = 747)	1.9 ± 0.8 (n = 59)
References	Otani (2005)	This study	Otani (2003)	Tsuji et al. (2011a)	Otani (2003)

C: cool temperate zone, W: warm temperate zone, MCD: mean cubic diameter of seeds.

Further, Scheffe's *Post-hoc* tests showed that mean seed number in fall was significantly greater than that in winter ($P < 0.05$). Obtained seasonal pattern in seed number within the feces was clearly attributed to the greater number of *Actinidia arguta* seeds in fall, and such clear seasonal changes in seeds in a single fecal sample have been also found in other study sites in cool temperate region: Shimokita Peninsula (Otani 2003), Kashima (Otani 2003), Hakusan mountains (Hayashi 1992), and Kinkazan Island (Tsuji et al. 2011a). On the other hand, on Yakushima Island belonging to the warm temperate region, much number of seeds of *Ficus* spp. were dispersed for longer period (7–8 month per year), and degree of seasonal change is known to be low (Yumoto et al. 1998). From the viewpoint of this, seasonality in seed dispersal in western Tokyo seemed similar to macaques inhabiting the cool temperate zones, in spite of their warm temperate habitat.

The mean (±*SD*) number of plant species whose seeds were detected in a single fecal sample was 1.8 ± 0.9, which was lower than corresponding values in other study sites: Yakushima Island (2.8 ± 1.4, Otani and Shibata 2000), Shimokita Peninsula (1.9 ± 0.8, Otani 2003), Kashima (2.4 ± 1.5, Otani 2003), and Kinkazan Island (2.0 ± 0.9, Tsuji et al. 2011a) (Table 2). I cannot clearly explain the reason of the small value in my study site, but there is a possibility that effects of previous forestation and/or existence of the paved path lowered the diversity of available plant species at Bonbori, which then affected the result. On the other hand, number of seed species in single fecal samples in spring and summer, fall, and winter were 1.7 ± 1.3 (n = 10), 1.9 ± 0.7 (n = 27), and 1.7 ± 1.0 (n = 7), respectively, and did not change seasonally (Kruskal-Wallis test, $\chi^2 = 1.62$, $df = 2$, $P = 0.444$). Again, this result was different from that in Kinkazan Island in which the seed species in single fecal samples was greater in summer and fall and lower in winter (Tsuji et al. 2011a).

Seed size (as MCD) ranged from 1.6 mm to 11.8 mm with a mean (±*SD*) of 4.2 ± 2.6 mm (Tables 1 and 2). Seeds of two cultivated species, *Diospyros kaki* and *Citrus junos* were both approximately 10 mm in diameter. The annual mean MCD in this study was greater than those in other study sites: Yakushima Island (2.5 ± 1.7, Otani and Shibata 2000), Shimokita Peninsula (2.7 ± 1.2, Otani 2003), Kashima (2.3 ± 1.1, Otani 2003), and Kinkazan Island (3.0 ± 2.0, Tsuji et al. 2011a) (Table 2), even when I omitted two large-seeded cultivated species from the analysis (3.4 ± 1.4). Further, maximum MCD in this study was also greater than those in other study sites (Table 2). These implied that the macaques in western Tokyo potentially disperse a wider range of seeds than the macaques in other habitats. However, further discussion without data regarding composition of available fruits is difficult. On the other hand, in future analysis, we should also consider the effects of other factors that we did not consider in this study, such as fruit pulp properties (e.g., texture and chemistry), and shape of seeds, on defecated seed size.

Evidence of seed destruction was obtained only for *Celtis sinensis*: several cracked seeds of this relatively large-seeded species were found in fecal samples. This finding indicates that macaques in my study site act not only as seed dispersers, but also sometimes as seed destroyers of some (perhaps large-seeded) plant species. Tsuji et al. (2011a) showed that intact rate of seeds was negatively correlated with the seeds' MCD. In future, with more fecal samples, we should test whether such relationship to be applicable in my study site.

In western Tokyo (and perhaps, in central Japan), similar to other study sites, Japanese macaques dispersed seeds of high tree, shrub, vine, and herbaceous species in every season, though there were several main plant species, like *Actinidia arguta*. Several dispersal characteristics shown by the macaques at Bonbori, such as rate of seed appearance and life form composition, were intermediate between those in cool and warm temperate region (Table 2). This seemed a reflection of environmental inclination, like vegetation.

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