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SEED DISPERSAL OF *SAPINDUS MUKOROSSI* IDENTIFIED BY AN AUTOMATIC CAMERA SYSTEM AT THE KASUGAYAMA FOREST, CENTRAL JAPAN

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奈良県春日山におけるムクロジ (*Sapindus mukorossi*) の自動撮影装置を用いた種子散布者の同定．若杉 (高田) みちよ (株ウエスコ大阪支社)，安田雅敏 (農林水産省森林総合研究所)，神崎護 (京都大学大学院農学研究科)，山倉拓夫 (大阪市立大学大学院理学研究科)

Abstract The seed dispersal of *Sapindus mukorossi* (Sapindaceae) by terrestrial vertebrates was studied by using a spool-and-line method and an automatic camera system in an evergreen oak-laurel forest at the Kasugayama forest, central Japan. The focal species was an introduced tree species bearing fruit with one large nutritious seed surrounded by saponin-rich pulp. The fruit removal rate was low in winter and high in the following spring (May and June). Wood mice, *Apodemus speciosus* Temminck, and *A. argenteus* Temminck, were major seed dispersers for both seeds with and without pulp. Squirrels (*Sciurus lis* Temminck) and deer (*Cervus nippon* Temminck) were other possible seed dispersers for seeds with pulp. The maximum dispersal distance observed was 20.9 m. Two types of seed dispersal modes were recognized: 1) scatter hoarding under litter layer or in surface mineral soil containing one seed , and 2) a seed heap on the forest floor containing 50 to 200 seeds. Teeth marks on seed surfaces suggest that the former was made by rodents, whereas the latter was made by deer. Secondary seed dispersal by mice from the heap was also observed frequently.
Key Words : deer, Kasugayama forest, rodent, *Sapindus mukorossi*, seed disperser

Introduction

Sapindus mukorossi (Sapindaceae) bears relatively large fruit consisting of a soft outer pulp and a hard inner drupe. Since the fruit is heavy (average 3.1 g fresh weight) and has no dispersal organs such as wings, effective fruit or seed dispersal is expected to be achieved by animals. The fruit pulp contains a large proportion of saponin (Kitamura & Murata, 1971), and this may provide a fruit palatability to some dispersal animals. It is also very likely that some animals favor the saponin-rich fruit, though the biological significance of saponin in *S. mukorossi* fruit is so far uncertain.

The fruit of *S. mukorossi* matures around October and November, begins to fall from the mother tree in the following spring, and completely disappears from the crown around the end of spring. During a fruit fall season, not only fruit with pulp, but also drupes without pulp are found simultaneously on the forest floor in our study site at the Kasugayama forest, Nara Prefecture,

central Japan. Such different properties in fruits may affect the attractiveness of the fruit to animals. If so, the seed dispersal process of *S. mukorossi* is more complicated than those of oak species, which bear nuts without pulp and are mainly dispersed by rodents (Shaw, 1968; Kanazawa & Nishikata, 1967; Miguchi & Maruyama, 1984; Miyaki & Kikuzawa, 1988).

In the present study, seed dispersers of *S. mukorossi* were identified by using an automatic camera system. The fates of the seeds dispersed were also traced. The study may results a new insight to the evolution of the seed dispersal mechanism of the species introduced to a new habitat and community from its original ones, because *S. mukorossi* is an introduced tree species in Japan.

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Study Tree and Site

Sapindus mukorossi

Sapindus mukorossi Gaerth of Sapindaceae species is a tall deciduous tree. Although the tree size is determined by site conditions, *S. mukorossi* reaches to 18 m in height and 60 cm in diameter at breast height in the Kinki district, central Japan. Its geographical range covers western Japan, Saishu Island, Taiwan, China, Nepal, and India (Kitamura & Murata, 1971). Its climatological life zone is mainly limited in warm-temperate or subtropical regions, and its occurrence in Japanese natural forest vegetation is rare. This species is believed to be introduced to Japan from another Asian country, probably mainland China, in the past because of its ethnobotanical utility (Hotta, personal communication).

Sapindus mukorossi trees are sometimes used for gardening at public parks, shrines, and temples. The tree was also planted in private gardens for the use of its fruit. Its pulp containing saponin was used as a substitute for soap. Drupes, including seeds, are used for *Juzu* in Buddhist ceremonies and for shuttlecocks of *Oibane* in a traditional Japanese sport. Seeds were sometimes used for food in the past (Hotta et al., 1989).

Sapindus mukorossi produces entomophilous flowers in June. Two of the three carpels in a dioecious flower do not develop, and the other carpel develops to a drupe. The fruit (2.0cm in diameter) becomes yellowish brown and matures in October. The seeds (1cm in diameter) mature in November and consist of a thin brown seed coat and nutritious cotyledon (Y. Okauchi, personal communication) that is covered with black hard and thick endocarp. The fruit falls to the ground around April and May. The existence of dry pulp on seed decreases the seed germinability.

Study site

The population of *S. mukorossi* is exceptionally large in a warm-temperate evergreen oak forest located on the western slope of Mt. Kasuga (497m a.s.l), in Nara City (lat. 34° 41', long. 135° 51'), central Japan, though the species is rare in other Japanese forests. Some patches of this species

occur in an ecological research plot, which was established by Kanzaki and his colleagues at the Kasugayama forest in 1986. The size of the plot is 13 ha, including about 70 tree species. The basal area of the *S. mukorossi* population is 1.05% of the total basal area in canopy trees (dbh≧20 cm) within the plot (Fujii, 1991).

According to the Nara Meteorological Station (104 m alt.) about 2.5 km northwest of the study plot, the mean annual temperature is 14.4℃ with a range of mean monthly temperatures of -0.7℃ (January) to 22.2℃ (August). The warmth index is 120.4℃ months. The coldness index is -2.9℃ months. The mean annual precipitation is 1,355 mm, with mean monthly rainfall ranging from 40.4 mm (December) to 212.3 mm (June). Frost is common in winter, but snow over 10 cm deep is unusual.

The soil of the study forest is brown forest soil (Nakane, 1975) derived from the bedrock of a Ryoke-metamorphic complex deposited in the Cretaceous period (Kokawa, 1954). The accumulation of organic matter on the forest floor is relatively low (about 10 ton/ha). The pH of the surface soil is in a range from 3.8 to 4.6 (Nakane, 1975).

The study area including the research plot is protected as a forest reserve, and is densely covered with original vegetation with oak-laurel dominants. The vegetation type corresponds to an East Asian evergreen oak forest (Kira, 1991) and is classified into the association Symploco-Castanopsietum cuspidate (Koshimizu et al., 1971). In this forest vegetation, the habitats of *S. mukorossi* occur mainly at valley sites.

Methods

Automatic photography

An automatic camera system (Miura et al., 1997, Yasuda et al., 2000) was employed to observe seed dispersers (Fig. 1). The system consists of a camera (eg. XR10M with a 35-70 mm zoom lens, Ricoh, Tokyo, or Myportzoom 320PS, Ricoh, Tokyo) with a synchronized flash (Auto25SR, Sunpack, Tokyo), a far-infrared sensor (Usensor PS-15B, Delcatec, Kobe), and batteries. The camera was on a tripod. The far-infrared sensor, which was connected to the camera with a remote cable, was hung over the baits at a height of 1.5m above the ground. The shutter is clicked when the sensor percepts animal body heat visiting baits. Each piece of the system was covered with a plastic box or bag for waterproofing. Films and batteries were checked every week and changed for new ones when necessary.

Baits

Intact fruit having pulp (hereafter, fruit) and drupes without pulp (hereafter, seeds) were used as baits and set on the forest floor. The fruit and seeds were both used because the fruit dispersers are expected to be different from the seed dispersers. The fruit and seeds as baits were mainly collected from fruiting tree canopies in the study forest in the spring of 1995 and 1996. Some additional fruit and seeds were collected from cultivated trees at the premises of a primary school in Kanmakicho, Nara, Japan, in 1995. Collected fruit and seeds were brought to the laboratory, kept in room temperature, and used as baits.

Observation of dispersers

To identify fruit and seed dispersal animals, three different observations of fruit and seed dispersers were carried out by using the aforementioned automatic photography system.

Observation 1 : seasonal observations of fruit/seed dispersals

A camera system was set at two different sites in the plot during an observation period from

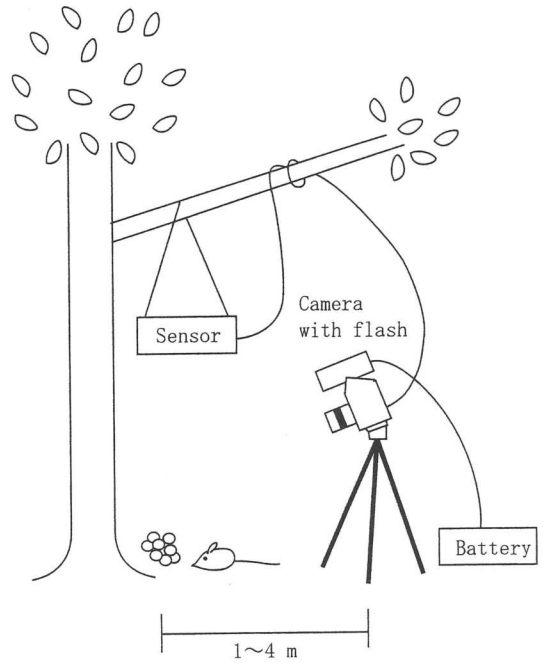


Fig.1. Schematic representation of an automatic camera system for the identification of seed dispersers.

January to July 1996. At each site, the camera was set under a large crown of a mature *S. mukorossi* tree. The distance between the camera and stem base of the tree was about 20 m. The baits consisting of fruit (from 9 to 64) and seeds (from 5 to 29) were put on the forest floor about 2.0 m from the camera. The numbers of fruit and seeds that disappeared were recorded every week during the observation period. New fruit and seeds were added when the baits disappeared.

Observation 2 : seed dispersal distance and seed hoarding

Two automatic photography systems were established under a crown of *S. mukorossi* in the study plot, and the observation was carried out from July to September 1996. Fluorescence ribbons were used for the marking of seeds applied to the spool-and-line method (Yasuda etal, 1991). After being marked with fluorescence ribbons, 130 seeds were set on the forest floor as bait beside the mature *S. mukorossi* tree. The marked seeds or ribbons moved from the initial position were sought and defined the dispersal distance and the locations of caches unconditionally.

Observation 3 : fate of the seed heap

From June to July 1996, an automatic photography system was set up on the forest floor, where about 200 seeds had been heaped by an unknown agent, to identify the heap-making animals and the fate of the seed heap.

Results

Identification of seed dispersers

All photographs from the three observations were compiled together and sorted for the identification of fruit and seed dispersers. The total number of pictures obtained was 473,

including 161 clear pictures of animals. Sometimes it is difficult to distinguish between *Apodemus speciosus* Temminck and *A. argenteus* Temminck, so the two species were tentatively pooled as *Apodemus* spp. in this study. Most pictures were taken at night from 20:00 to at 5:00.

Apodemus spp. accounted for 96.3% of 161 pictures (Table 1 and Fig. 2). *Apodemus* spp. transported fruit and seeds. *Sciurus lis* Temminck accounted for 1.9% of the pictures. *S. lis* was observed to hoard fruit only. One picture of the Sika deer *Cervus nippon* Temminck was taken during the study period, although the seeds in the deer mouth was not discernible in the picture. More fruit were missing from the feeding site than seeds.

Seasonal observation of fruit/seed dispersals

Fruit and seeds were both placed as bait on the forest floor for observation by automatic camera systems (refer to Observation 1). The bait fruit and seeds were removed by dispersal animals. The rate of disappearance of fruit and seeds varied between observatory months. Figure 3 reveals the results from the observation of dispersers in Observation 1. Nothing was removed from January to March, though some pictures of *Apodemus* spp. were taken around baits in this period. The first removal was observed in April and May for fruit and seeds, respectively. This timing of bait removal was consistent with the beginning of the seed fall of *S. mukorossi* in the study forest. The mature fruit of *S. mukorossi* began to fall around mid-April, and there were abundant fruit.

Table 1. Mammal species identified by an automatic camera system and the number of pictures.

Species	Number of pictures	Ratio (%)
Apodemus speciosus Temminck & *A. argenteus* Temminck	155	96.3
Cervus nippon Temminck	1	0.6
Sciurus lis Temminck	3	1.9
Martes melampus Wagner	2	1.2
Total	161	100.0

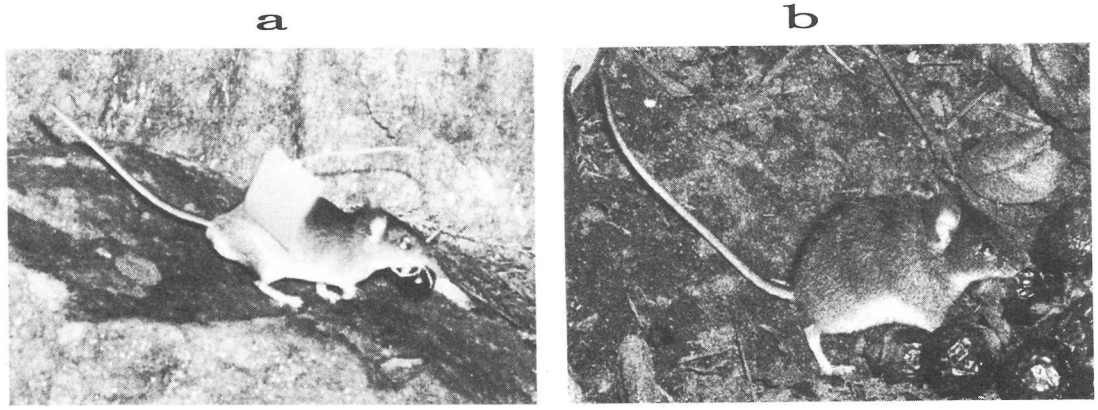


Fig. 2. *Apodemus spesiosus* transporting a *Sapindus mukorossi* seed marked with a fluorescent ribbon (a) and *A. argenteus* visiting baits (b).

Seed dispersal distance and seed hoarding by *Apodemus* spp.

In Observation 2 we observed only *Apodemus* spp. by using the automatic photography and the bait seeds with fluorescence ribbons. Of the total of 130 bait seeds, 116 (89.2%) disappeared from the initial position and were transferred to other places. By tracing the marked ribbons of the removed seeds, we found 101 ribbons, which account for 87.1 % of the removed seeds. Five were attached to seeds and the other 96 were found without seeds. Three of the removed seeds were intact, and the other two had lost their seeds by predation. There were fragments of seed endocarps around the study site.

Of 101 ribbons found away from the feeding site, 78 (77%) were distributed within 5.0 m of the initial bait position, suggesting a relatively short seed dispersal distance (Fig. 4). The maximum dispersal distance from the initial bait position was 20.9 m. Most ribbons were either exposed on the forest floor or individually hidden under stones and fallen tree stems, and two or three were found together at the three places.

Animals concerning a seed heap

In early June 1996, 50-200 seeds had been suddenly heaped by unknown animals on the forest floor within the plot (Fig. 5). No heaped seeds had pulp, though *S. mukorossi* fruit in their natural state on the ground still did. Several seed heaps were found around a mature *S. mukorossi*. To identify the heap-making animals and to observe the changes in number of seeds in a heap, we selected one seed heap and installed an automatic camera system around it on 8 June 1996. The number of seeds in the heap was initially 200, which gradually decreased to 20 on 20 July and to 5 on 27 July. *Apodemus* spp. were the only animals appearing in the pictures. We could not identify the animals that made the seed heaps because none was observed heaping seeds in photographs.

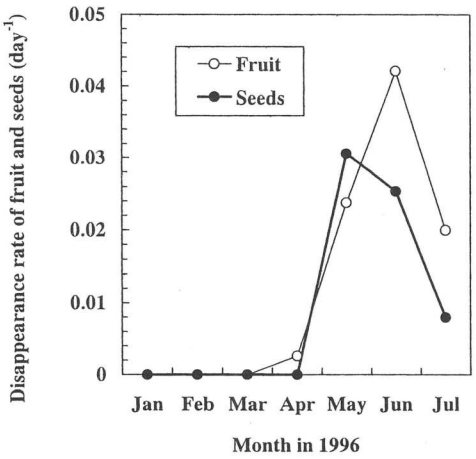


Fig. 3. Monthly changes in disappearance rates of fruit and seeds of *Sapindus mukorossi* used as baits.

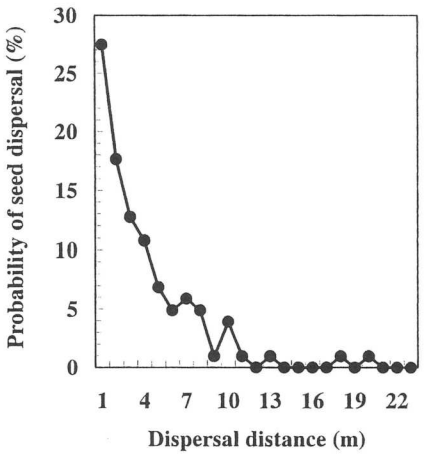


Fig. 4. Dispersal distances of marking ribbons. The probability of seed dispersal is the percentage of bait seeds per total bait seeds used throughout experiments.



Fig. 5. Seed heap consisting of 200 seeds on the forest floor.

Discussion

Rodents as a major seed disperser

Apodemus spp. seem to be the most important disperser of *S. mukorossi*, since the frequency of their pictures was very high. When *Apodemus* spp. were fed *S. mukorossi* fruit in a cage, they removed the pulp and ate the seeds (T. Shimada, personal communication). Therefore *Apodemus* spp. apparently disperse fruit with pulp and seeds without pulp. Furthermore we found three caches on tree branches that had likely been hoarded by *S. lis,* which also seems to be a disperser.

Rodents play an important role in seed dispersals of forest trees that produce large nutritious nuts, such as oaks (Shaw, 1968; Kanazawa & Nishikata, 1976; Miguchi & Maruyama, 1984; Miyaki & Kikuzawa, 1988). Large barochory nuts that fall beneath the crowns of mother trees are dispersed elsewhere apart from the mother trees and are hoarded by rodents either on the forest floor or under fallen stems. They are often buried at an optimal depth for germination. Thus the nuts dispersed by rodents generally have an advantage in their establishment in the following spring (Miguchi, 1993). In the present study, many fruit and seeds of *S. mukorossi* were also dispersed by rodents, which had happened with oak nuts (Table 1). The maximum dispersal distance reached to 20.9 m, which is far enough to avoid the competition for light between a mother tree and a seedling that was newly established. Therefore *S. mukorossi* appears to owe much to rodents in the completion of the life history.

Postponed fruit fall for the scatter seed hoard

The seed hoarding patterns of *Apodemus* spp. are generally classified into two types, the scatter hoard and the nest hoard (Miyaki, 1996). The scatter hoard by a disperser is effective for competition with other seed predators because the disperser can hide many seeds immediately. The nest hoard is effective for keeping a winter food supply because the hoarders need not leave their nests when a drop in their search for and hoarded seeds occurs. In conjunction with the merit of seed dispersal for plants, the scatter hoard is more effective than the nest hoard. In the nest hoard, most seeds are generally buried too deep (Miyaki & Kikuzawa, 1988). Both the reduction of nest hoarded seeds and the increase of scatter hoarded seeds are desirable for plants. Therefore if plants could develop a life strategy available for stimulation of the scatter hoard by rodents, the newly developed strategy would result in much merit to plants in their seedling

regeneration and colonization.

The observed scattering patterns of seeds marked with ribbons suggested that the scatter hoard by rodents is major in the hoarding of *S. mukorossi* seeds. Furthermore, the dispersal of fruits and seeds by animals was not observed in the winter, but it did occur in the spring. The active fruit and seed dispersal in the spring is consistent with the timing of the fruit fall of *S. mukorossi*. In our study forest with evergreen oak and laurel dominants, most canopy trees drop their fruits in the autumn, but seldom in the spring. *S. mukorossi* is one rare species whose fruit falls in the spring. It follows that *S. mukorossi* might increase an opportunity for the scatter hoard by choosing a timing of fruit fall in the spring. A postponed fruit fall is also effective to avoid competition for dispersers between trees in this forest. *Apodemus* spp. need not use stored seeds in their nest in the spring, which is warmer than the preceding winter. Thus the scatter hoard of *S. mukorossi* seed appears to have much merit for both *Apodemus* spp. and *S. mukorossi* and seems to be obliged by the postponed fruit fall in the spring.

Questions resulted from seed heaps

No animals have been reported to make exposed heaps like those observed in the present study. Mice, squirrels, and jays were recorded as hiding seeds (Miguchi, 1993). We could not confirm the animals that made seed heaps because no animals were observed heaping seeds as described above. However, we could confirm teeth marks of the Sika deer (*C. nippon*) on the surfaces of all seeds (drupes) in the heaps(Fig.6). We fed the fruit of *S. mukorossi* to them and observed that they ate only the pulp and discarded the intact seeds at Nara Park near the study plot. In conjunction with this, deer is seed disperser of *S. mukorossi* in our study forest. Deer are protected around the study area, and their population is very large. The estimated number of deer there was 1,293 in 1994 (Society of Deer Conservation, Nara, 1994). Here we tentatively propose the following two hypothetical explanations for the construction of seed heaps. The first explanation assume deer as the heap making animals. Deer might discard seeds at particular sites after eating the pulp, and resulting in seed heaps. The second explanation assumes that at least two animals made seed heaps. The seeds discarded elsewhere by deer were collected and heaped by other animals, excluding deer and rodents, *Apodemus* spp., because rodents are specialists of the scatter hoard in the *S. mukorossi* seed dispersal as already described above. These hypothetical explanations lead to further ecologically important questions of what animals make seed heaps



Fig. 6. Teeth marks of deer on the heaped seeds (drupes).

and how important the heaps are for the seed dispersal of *S. mukorossi*. We lack enough data to answer the questions, which remain to be confirmed by field research in the future.

Roll of wild rodents in forest maintenance at the Kasugayama forest

The main dispersers of *S. mukorossi* were *Apodemus* spp., which are native in Japan (Shiotani, 1996). However, we could not confirm the role of rodent as a disperser of *S. mukorssi* in other countries, such as China. Instead of the introduced species, *S. mukorossi* can get dispersers in the Kasugayama forest. This result shows that other introduced species can get seed dispersers at the introduced area, if they have an opportunity. Without rodents as seed dispersers, trees with zoochory seeds can not expand their local territories in our study forest. Hence rodents are indispensable in the maintenance of species composition in the forest, suggesting the important roll of wild rodents for the conservation of the Kasugayama forest.

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要　約

本研究の対象種であるムクロジ（*Sapindus mukorossi*）は帰化種であるとされている。その大型で栄養価の高い種子は非常に硬い内果皮によって保護されており，さらにその外側はサポニンを多く含む果肉に覆われている。奈良県春日山原始林内におけるムクロジの種子散布者を自動撮影装置とリボンによる種子のマーキングによって同定することを試みた。種子散布者同定実験ではムクロジの果実および核（種子および内果皮）を成木の下に置いて，訪れた散布者の撮影を行った。撮影装置はカメラと赤外線センサー，電池からなり，哺乳類が餌を訪れるとセンサーが温度の変化を感知してシャッターが下りる仕組みになっている。餌として設置した果実および核の数の増減，貯食先の追跡も行った。その結果，果実，核の両方ともその消失率は冬季に低く，春季に高くなっており，主要な散布者はアカネズミ（*Apodemus spesiosus* Temminck）とヒメネズミ（*A. argenteus* Temminck）であることが明らかになった。ニホンリス（*Sciurus lis* Temminck）とニホンジカ（*Cervus nippon* Temminck）は果実のみを散布した。最大散布距離は 20.9 m であった。ここではリボンの位置を無条件に散布距離としている。果実および種子の散布様式として，1）落葉の下，または浅い土中に 1 個づつ埋められる分散貯蔵，2）50～200 個の核が林床に積み上げられる「集積」が認められた。核についていた歯形から，前者はげっ歯類によること，後者はニホンジカが関与することが推測された。核の集積に関しては，集積後のネズミによる二次散布が確認された。