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Application of radiotelemetry to the survey of acorn dispersal by *Apodemus* mice

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We examined the applicability of radiotelemetry to studies of acorn dispersal by *Apodemus* mice and compared its efficiency with the of this spool-and-line method. Installation of a transmitter (2.2 g) onto acorns did not interfere with the transporting and feeding behavior of the mice. We were able to detect all transmitter-installed acorns and follow the daily changes in the sites in which they were hoarded, while we missed 59% of the spool-tied acorns due to mice breaking the threads. Mice carried transmitter-installed acorns farther than spool-tied ones. The radiotelemetry method is superior to the spool-and-line method and useful for the study of hoarding behavior in rodents.

Key words: acorn dispersal; *Apodemus* mice; radiotelemetry; spool-and-line method.

INTRODUCTION

Two species of field mice, *Apodemus speciosus* Temminck and *Apodemus argenteus* Temminck, widely distributed in forests in Japan, eat and hoard seeds and acorns (Doi & Iwamoto 1982; Miyaki & Kikuzawa 1988). Such granivorous mammals are considered to play an important role in the dispersal of seeds and establishment of seedlings (Vander Wall 1990).

The hoarding behavior of granivorous mammals has often been studied by direct observation (Hayashida 1988, 1989; Daly *et al.* 1992) and by using radioisotopes (Abbott & Quink 1970; Quink *et al.* 1970; Jensen 1985; Vander Wall 1992). However, because *Apodemus* mice are nocturnal and inhabit forests with dense ground vegetation, it is very difficult to observe their hoarding behavior directly in the field. In Japan, radioisotopes cannot be applied to field experiments due to many limitations.

Miyaki and Kikuzawa (1988) surveyed the spatial distribution of *Quercus mongolica* Fisch. var. *grosseserrata* Rehd. *et* Wils. acorns which had been carried from a bait box by *A. speciosus* in an area where there was no other acorn resource in a natural deciduous oak stand. In their experiments, the survey of acorn dispersal should have been limited to a small area. Yasuda *et al.* (1991) placed *Q. mongolica* acorns attached by threads of a spool, on the ground in a *Pinus densiflora* Sieb. et Zucc. stand and traced the route of acorn transport by field mice. However, since the trace is limited to the length of the thread on the spool, this spool-and-line (SAL) method may be insufficient to detect long-distance dispersal of acorns.

Recently, very small transmitters have been developed and radiotelemetry has become applicable to the study of the social structure of small rodents (Wolton 1985). Tamura (1994) tried to trace the dispersal of transmitter-installed walnuts by squirrels, *Sciurus lis* Temminck, and got good results. We applied this method to the investigation of the dispersal of acorns by field mice. Because field mice are much smaller than squirrels, installation of a transmitter should have greater effects on the hoarding behavior of field mice. In this study, we examined the effects of installation of a transmitter on the feeding, gathering and transporting of acorns by mice. We also tried to trace the dispersal of transmitter-installed acorns by *Apodemus* mice and

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compared the efficiency of the radiotelemetry (R) methods with that of the SAL method.

STUDY SITE AND METHODS

Study site

This study was conducted in a mature stand of *Chamaecyparis obtusa* Endl. mixed with *Q. serrata* Thunb., *Q. glauca* Thunb., *Cinnamomum camphora* (Linn.) Sieb., and *Aleurites cordata* R.Br. at Tama Forest Science Garden, Hachioji, Tokyo. The stand was about 0.6 ha in area and located on a slope of 12–15° with southern exposure. Based on the understory and ground vegetation, the stand could be divided into two areas, the eastern half and western half. We established a station at the center of each area (station A in the eastern area and B in the western area) where we set acorns for the experiments. These stations were about 30 m apart. There were some *Pasania edulis* Makino trees near the stand and they produced many acorns in 1991 and 1992.

In a live-trapping census, we caught two species of field mice, *A. speciosus* (35–50 g) and *A. argenteus* (10–18 g), in one year and shrew-moles, *Urotrichus talpoides* Temminck, on a few occasions. The density of *A. speciosus* was three times higher than that of *A. argenteus* (Soné, unpubl. data). Squirrels, *S. lis*, occasionally visited the stand to collect nest materials.

Materials

The acorns used in this experiment had to be large enough to be installed with a transmitter. Among the acorns which we could collect in and near the stand, acorns of *Q. serrata* (*Qs*) and *P. edulis* (*Pe*) met this condition. The cotyledons of *Qs* acorns deteriorate soon after the acorns fall to the ground. Therefore, we used *Pe* acorns (mean weight 2.1 g) in this study.

Spools were made as described by Yasuda *et al.* (1991). Polyester thread of 15 m was wound onto a spool and each spool was coated with paraffin. A spool was tied to an acorn by a piece of wire 0.2 mm in diameter (Fig. 1). The weight of the spool-tied acorns (S-acorn) ranged from 2.6 to 3.0 g.

The transmitter used in this study was a ZTS-7 type (Nakane Kobo, Kamakura, Japan; 2.5 cm × 0.8 cm × 0.5 cm, 2.2 g). The frequency bands of the transmitters were 53 MHz and the longevity of the battery was about 50 days. A transmitter was attached to an acorn with polyethylene filler (Fig. 1) The weight of transmitter-installed acorns (T-acorn) ranged from 6.0 to 6.5 g.

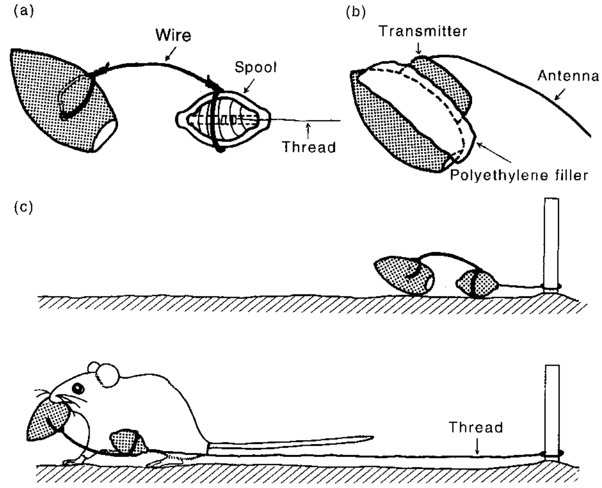

Fig. 1. A spool-tied acorn (a) and a transmitter-installed acorn (b) and the schema of the spool-and-line method (c).

Methods

The effects of transmitter installation on mice feeding behavior

In June 1992, we gave five T-acorns to two caged *A. speciosus* mice in the laboratory in order to examine whether the installation of a transmitter interfered with the feeding activity of mice.

Field observation of mice handling behavior of transmitter-installed acorns and numbered acorns

The mice handling behavior of T-acorns and acorns which were numbered with ink (N-acorns) were observed in the stand using a video camera (Toshiba IK536, Tokyo, Japan) from 22 to 23 April 1993 and from 24 May to 11 June 1993. Four T-acorns were placed with five N-acorns at station B in the evening of 22 April, and 10 T-acorns were set at station A in the evening of 24 May. The stations were illuminated by red light. The visits to the stations and the behavior of mice at the stations were recorded from 17:00 to 7:00 every night.

Comparison between the SAL and the R method

Three to five S- and T-acorns, respectively, were placed together with N-acorns at the two stations in the evening. In order to remove the possible effects of the abundance of acorns on the feeding and transportation of acorns by the mice, the total number of the three types of acorns placed at a time was fixed at 10. The next morning, the location was determined for each treated acorn and recorded on a map.

In the SAL method, the route of the S-acorns was traced easily by following the thread drawn out from the spool (Fig. 1). When we observed broken threads or cracked nutshells within 0.5 m of the stations, these events were considered to have occurred at the release stations. In the R method, the position of each T-acorn was detected using a receiver (YAESU FT-690 mkII). The position of each acorn was relocated again every morning until it was eaten by a mouse. N-acorns were occasionally discovered in caches or on the ground during the survey and their positions were also recorded.

Acorns were placed at station A on six occasions (27 July, 10, 24 and 31 August and 1 and 7 September) and at station B on five occasions (27 July, 10, 24 and 31 August and 7 September). A total of 54 S-acorns and 37 T-acorns were placed with 19 N-acorns at both stations.

RESULTS

Feeding of T-acorns by mice

Both in field and laboratory experiments, mice made a hole on the opposite side of the nutshell to the location of the transmitter and ate the cotyledons of all acorns within a few days.

Field observations of handling of T- and N-acorns by mice

During the night of 22 April, all acorns set were carried by one individual of *A. speciosus*. This mouse was easily able to carry a T-acorn in its mouth, and it seemed to carry away T-acorns before N-acorns (Table 1). Only one individual of *A. argenteus* visited the station during the period from 1 June to 5 June. T-acorns were so heavy and large for this smaller mouse that it often failed to carry them away (Table 1).

Table 1 Visits to the stations and responses of two species of *Apodemus* mice to T- and N-acorns

Date	Time of visit	Mouse species	Responses to acorns
22 April 1993	19:00:20	*A. speciosus*	Carried a T-acorn
	19:08:45	*A. speciosus*	Carried a N-acorn
	19:11:45	*A. speciosus*	Carried a T-acorn
	19:17:18	*A. speciosus*	Carried a T-acorn
	19:23:24	*A. speciosus*	Carried a N-acorn
	19:28:02	*A. speciosus*	Carried a N-acorn
	19:31:58	*A. speciosus*	Carried a N-acorn
	21:46:43	*A. spesiosus*	Carried a T-acorn
	22:24:00	*A. speciosus*	Carried a N-acorn
	23:35:33	*A. speciosus*	Visited only (no acorn remained)
1 June 1993	00:34:57	*A. argenteus*	Carried a T-acorn
	00:38:09	*A. argenteus*	Failed to carry a T-acorn
	00:40:14	*A. argenteus*	Only visited
	03:13:45	*A. argenteus*	Failed to carry a T-acorn
2 June 1993	01:01:27	*A. argenteus*	Failed to carry a T-acorn
4 June 1993	03:41:39	*A. argenteus*	Visited only
5 June 1993	02:49:19	*A. argenteus*	Visited only

Comparison of the the SAL and the R methods

Because mice showed a similar tendency in the handling and transportation of acorns at stationsA and B, the data at both stations were pooled in the comparison of the efficiency of the two methods.

In the SAL method, 32 out of 54 S-acorns (59%) were missed during the first night because the threads were broken at the release stations (n = 13) or after they had been carried for an average ($\pm$ SD) 2.5 $\pm$ 1.9 m (range: 0.8–9.0 m; n = 19). The cotyledons of 10 acorns were eaten at the release stations, and the cracked nutshells of 12 acorns were discovered 2.9 $\pm$ 1.5 m (range: 0.5–5.2 m; n = 12) from the release stations (Fig. 2).

In the R method, mice carried all T-acorns away during the first night and we were able to locate them the next morning. Mice ate cotyledons of 7 out of 37 T-acorns. Nutshells of these acorns were located 7.1 $\pm$ 3.9 m (range: 3.5–13.5 m; n = 7) from the release stations (Fig. 2). These nutshells were located significantly farther away from the release stations than cracked nutshells of S-acorns (Mann-Whitney U-test: U = 10, $P < 0.05$).

Thirty T-acorns were hoarded singly. These hoarded acorns were located 11.5 $\pm$ 5.0 m (range: 2.7–23.5 m; n = 30) from the release stations (Fig. 2). These distances were significantly larger than those of the S-acorns whose threads were broken (U = 14, $P < 0.001$). Mice recovered cached acorns within a few days, carried them for 0.8–45 m in one night, and hoarded them again, sometimes with other acorns, or ate them within 14.6 $\pm$ 7.7 m (range: 3.5–36.5 m; n = 37) of the release stations.

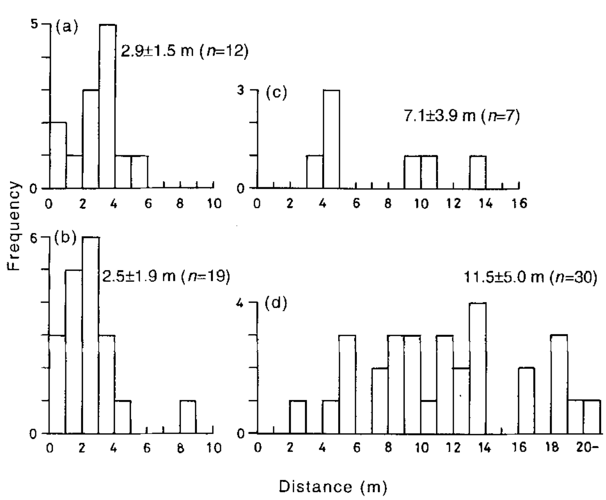

Fig. 2. Frequency distributions of the distances of traced carriages of spool-tied acorns eaten (a) and with broken threads (b), and those of the first dispersal of transmitter-installed acorns eaten (c) and hoarded (d).

We recovered cached T-acorns on a total of 42 occasions. In 27 cases, acorns were discovered in the soil; they were buried more than 20 cm deep in two cases and 0–5 cm deep in 25 cases. In other instances, acorns were discovered under a fallen tree (n = 4) and in the nest burrows (n = 11).

Dispersal of N-acorns

In some cases, N-acorns were eaten or hoarded with T-acorns. The nutshells of eaten N-acorns were located 12.0 $\pm$ 8.7 m (range: 2.2–22.2 m; n = 4) from the release stations. These distances did not differ significantly from those for eaten T-acorns (F = 0.409, $P >> 0.05$).

DISCUSSION

In the study stand, the *A. speciosus* mouse easily carried T-acorns in its mouth, but T-acorns were too large for *A. argenteus* to carry. Interspecific interactions between the two *Apodemus* mice were one-way from *A. speciosus* to *A. argenteus* (Sekijima & Soné 1994) and *A. argenteus* is much more arboreal than *A. speciosus* (Doi & Iwamoto 1982). During the study period, the density of *A. speciosus* was much higher than *A. argenteus*. These results suggest that most acorns set at the release stations in the stand were likely to be carried by *A. speciosus* in this study.

Installation of a transmitter on the nutshell of an acorn changes the weight and shape of the acorn. These changes did not interfere with the feeding and gathering of acorns by *A. speciosus*. Furthermore, some N-acorns were hoarded with T-acorns, and field mice ate them at the same distance from the source as T-acorns. These results show that installation of a transmitter also did not have significant effects on the transportation of acorns by *A. speciosus*.

The present results showed that radiotelemetry is applicable to the study on acorn dispersal by *Apodemus* mice and should be superior to the SAL method in at least three respects. First, the recovery rate of released acorns is higher in the R method than the SAL method. In the SAL method, mice broke threads or destroyed spools, resulting in acorns being frequently missed. In this study, only 22% of S-acorns could be found after transportation during the first night. Yasuda *et al.* (1991) recovered about 26% of 54 *Q. mongolica* acorns with a spool the next morning. Using the R method, however, all acorns were recovered the next morning even if they were buried more than 20 cm deep in the soil.

Second, daily changes in the hoarding sites of acorns could be detected by the R method. Spools and threads were often caught by twigs or rocks on the ground, which interfered with smooth transportation of acorns. In these cases, threads were broken by mice or by accident during transportation, and consequently S-acorns were often missed. Thus, it should be difficult to trace the second or latter dispersal of S-acorns; Yasuda *et al.* (1991) were not able to measure this.

Third, the R method was able to trace the transportation of acorns much longer than the SAL method. In this study, mice carried T-acorns for about 15 m, on average, to feeding sites from the release points. Although 15 m of thread was wound onto each spool, about 43% of acorns were eaten or their threads were broken at the release points and we could trace the transportation for only an average of 2.9 m from the release stations. The distances that we traced S-acorns in this study did not differ significantly from those reported by Yasuda *et al.* (1991) (3.02 ± 2.51 m). Jensen (1985) detected the distributions of a total of 2000 European beech seeds labeled with either Cs^{134} or Na^{24} in a 95-year-old beech stand. He reported that *Apodemus flavicollis* carried the seeds for an average of 4.13 ± 2.28 m and that only a few seeds were dispersed for more than 10 m. Yasuda *et al.* (1991) compared their results with those obtained by Jensen (1985) and stated that the initial dispersal of acorns by field mice could be traced accurately by the SAL method. However, Miyaki and Kikuzawa (1988) inferred that *A. speciosus* would transport *Q. mongolica* acorns for 30–40 m judging from the mean size of their home ranges. The maximum distance of one-night transportation of T-acorns was 45 m in this study. The long distance dispersal of acorns can be detected by the R method but not by the SAL method and the SAL method may underestimate the dispersal distances of acorns by mice.

In conclusion, radiotelemetry is a powerful tool for the study of acorn dispersal by field mice. However, T-acorns used in this study were too heavy and large for smaller *A. argenteus* mice to carry. Smaller transmitters are necessary for the study of the dispersal of smaller acorns and seeds, and that of hoarding behavior of smaller granivorous rodents.

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