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Quantitative analysis of acorn transportation by rodents using magnetic locator

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Abstract

Transported distance and mortality of acorns scattered by rodents were investigated with magnets inserted into acorns (40 of *Quercus serrata* and 20 of *Quercus acutissima*) and a magnetic locator in a natural forest stand. All the treated acorns were transported, and 60% of them were discovered again with a magnetic locator from autumn to the next spring. Most transported acorns suffered predation within one month after the start of the experiment. Several acorns were rehoarded at least two or three times. Average transported distance of scattered acorns was 22.1 ± 8.9 m (max = 38.5 m) and the survival rate was 3.0%. The magnet method is one of the most effective methods for tracking acorns through the winter.

Introduction

The caching behavior of small mammals and its role in tree regeneration have been studied intensively in recent years (Price & Jenkins 1986; Vander Wall 1990). In temperate forests, a large part of *Quercus* and *Fagus* acorns are removed or eaten by rodents (Shaw 1968; Kanazawa & Nishikata 1976; Miguchi & Maruyama 1984; Kikuzawa 1988). Rodents store acorns away from the seed source to eat them later; uneaten acorns may succeed in establishing if the hoarding site is suitable for growth (Olmsted 1937; Jensen & Nielsen 1986). Therefore, rodents have been considered to play an important role in seed dispersal.

Quantitative clarifications on transported distance together with the mortality of acorns are necessary to evaluate the role of rodents. Several methods to do this have been developed; including the radio-tagged method (Abbott & Quink 1970; Jensen 1985; Jensen & Nielsen 1986), metal-tagged method (Sork 1984), and spool-and-line method (Yasuda et al. 1991). Every method has both advantages and disadvantages, and more efficient methods to detect acorns hoarded by small mammals should be developed. Information on transported distance and mortality of rodent-dispersed acorns is still limited, especially regarding their dynamics between seed fall and germination.

In this study, searches for acorns scattered by rodents were conducted during the season after seed fall until the beginning of germination with magnet-inserted acorns and a magnetic locator. This study has two objectives: 1) to discuss the effectiveness of this method, and 2) to clarify the transported distance and mortality of acorns scattered by rodents in a natural forest stand.

Study site and methods

This study was conducted in the Ogawa Forest Reserve in the northern part of Ibaraki Prefecture, Japan. *Quercus serrata* and *Fagus crenata* dominate this deciduous old-growth forest. This stand is about 600 m above sea level and there is not enough snow fall (up to 30–50 cm deep) to cover the ground throughout the winter. In the fall of 1992 when the experiment was started, very few seeds were produced either by *Quercus* or *Fagus* species, or by other tree species whose seeds could be eaten by rodents (Iida et al., unpubl.).

Two rodent species, *Apodemus speciosus* and *Apodemus argenteus*, were found at the site but the activity of rodents during this study was very low, as evidenced by the number captured with live-traps (176 live-traps baited with peanuts were regularly spaced in a 100 × 150 m area; semimonthly investigations were conducted for 7 consecutive nights from January to early November in 1992, and 2 consecutive nights after that.) which was one-tenth that of summer or autumn 1992 (Shioya & Koizumi, pers. commun.).

The acorns used in the study were collected in Tsukuba City, Ibaraki Prefecture in mid-November 1992. Acorns of *Quercus serrata* ($n=40$) and *Quercus acutissima* ($n=20$) were drilled with an electric hand drill and a small ferrite magnet (11 × 6 × 3 mm, surface magnetic flux density of 900 Gs) was inserted inside each of them. The holes in the acorns were filled with grafting wax to protect them from drying. Both acorns and magnets were marked with a serial number to make individual identification possible. They were set in the forest just after finishing the magnet insertion in mid-November. Leaf and seed fall in the forest had already finished by that time. In the case of *Q. mongolica*, even though acorns are suffered predation, if their embryo are sound, they will germinate (Ooba et al. 1988). Magnets insertion into acorns in this method does not hurt their embryo, therefore, this method has not influence on their germinative capacity.

The average weights of fresh acorns of *Q. serrata* and *Q. acutissima* were 2.76 ± 0.34 g (s.d., $n=40$) and 5.89 ± 1.08 g ($n=20$), respectively. The average weight of a magnet was 1.00 ± 0.01 g ($n=20$). After inserting the magnets into the acorns, average acorn weights were 3.42 ± 0.33 g (*Q. serrata*) and 6.60 ± 1.01 g (*Q. acutissima*), representing on additional 0.66 g (+23.9%) and 0.71 g (+12.1%) over their initial weights, respectively.

Ten magnet-inserted and 10 intact acorns were placed on the forest floor at 6 sites all under tree canopies of *Q. serrata*. The sites were covered with steel baskets having 4 square holes (3 × 3 cm) which could be accessed by rodents but not by birds or other mammals larger than wood mice.

After acorn removal by rodents (2 weeks after setting), a magnetic locator (GA-52B, Schonstedt Instrument Company, Virginia, USA) was used 9 times to locate them (3 times in each November and December, 1 time in February, and 2 times in April) until April 1993. The sites where acorns were relocated were described as nest or burrow of rodents, under litter layer, or beside fallen logs. The detectable depth of treated acorns was investigated on bare ground by burying magnet-inserted acorns at different depths. Acorns buried up to 12 cm deep could be detected easily, but detectability decreased for ones more deeply buried.

Results

Detection rate

All magnet-inserted and intact acorns were removed by rodents within 2 weeks after the start of the experiment. At each site, all treated and intact acorns were carried away by rodents during the investigation interval, suggesting no preference of rodents due to the magnet treatment.

Out of 60 treated acorns, 36 (60%) were found at least once again. Among these, 33 acorns were tracked either until they were eaten or the experiment ended (April, 1993). Detection rates of *Q. serrata* and *Q. acutissima* were 62.5 and 40.0% respectively, and these were not significantly different ($p>0.05$, χ^2 test).

Survival rate of acorns

A large proportion of acorns transported by rodents suffered predation until mid-December (about one month after starting the experiment), and moreover, all of predated acorns left only magnets. The proportion of surviving acorns among those which were tracked was 14.7% (16.0% for *Q. serrata*, 11.1% for *Q. acutissima*) in mid-December. In April 1993, the ratio was only 3.0% (4.0% for *Q. serrata*, 0.0% for *Q. acutissima*). Survival rates of detected acorns between the 2 species were not significantly different ($p>0.05$, Fisher-Yates test).

Transported site

Several acorns were transported at least two or three times during the study. Eighteen acorns from 3 different seed sources (1 ~ 22 m distant from each other) had been transported into the same nest 25 cm under the ground, and all of them had already been eaten when they were detected. Ten acorns were hoarded at entrances of burrows but 9 of them were eaten there. Six of these acorns were found at the same burrow entrance but they were brought from 2 different seed sources (42 m distant from each other), while the other 4 acorns were hoarded alone at a different entrance. One of these solitary acorns survived until April 1993.

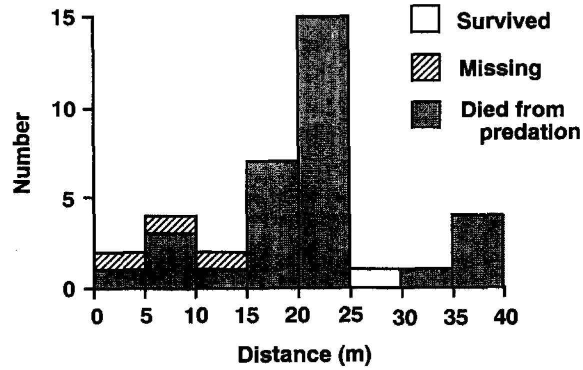

Figure 1. Distance distribution of magnet-inserted acorns ($n = 36$: 27 of *Q. serrata* and 9 of *Q. acutissima*). The transported distances from seed source to the place where acorns were either consumed or found intact in April 1993 are shown.

Five acorns were hoarded under a litter layer out of nests or burrows, but all were eaten.

Transported distance

The average transport distance of acorns from the seed source to the place where they were either eaten or found intact at the end of the experiment was 22.1 ± 8.9 m (s.d) (max = 38.5 m) for both species combined (Figure 1); 21.2 ± 10.0 m (max = 38.5 m) for *Q. serrata*; and 24.7 ± 2.6 m (max = 30.8 m) for *Q. acutissima*. These average transport distances were not significantly different ($p<0.01$).

Discussion

Effectiveness of this method

The detectability of scattered acorns by the present method was high compared with other methods which have been reported. Detection rates in past reports were 1.4% (Abbott & Quink 1970), 9.7% (Jensen 1985) and 65% (Jensen & Nielsen 1986) for the radio-tagged method, 28.5 ~46.1% for the metal-tagged method (Sork 1984), and 26% for the line-and-spool method (Yasuda et al. 1991). However, the durations of experiment in most of these studies (2 days ~ 1 month) were shorter than this study (except Sork 1984, about three quarters year), the detection rate in this study (60%) was comparable to the highest case (Jensen & Nielsen 1986).

Every method has both advantages and disadvantages. Treatment of radioactive materials requires special and careful techniques, and outdoor use is highly restricted in Japan. The line-and-spool method makes it easy to find scattered acorns and the transport routes are visible. However, detectable transport distance depends on the length of line and if lines are cut they get lost. Thus, the method is not suitable for long-term (ex. whole winter) pursuit. The metal-tagged method is similar to the magnet method; however, the detectability of acorns with the magnet method is higher than the metal tagged method, because the magnet is easily detected.

Merits of the magnet-tagged method are: 1) since the magnet remains in place after the acorn is eaten, the mortality of scattered acorns can be estimated, 2) relatively long-term monitoring is possible, 3) the routes of transported acorns can be roughly mapped with frequent census. Wood mice and squirrels hoard acorns from different sources, and frequently rehoard them (Jensen 1985; Jensen & Nielsen 1986; Hayashida 1988, this study). Therefore we should continue investigation until the acorns germinate to evaluate the role of rodents in seed dispersal.

The problems of this method are: 1) it is not suitable for extensive census because it requires much effort to look for scattered acorns over a wide area, 2) it is impossible to detect acorns that are hoarded deep underground and 3) inserting magnets into numerous acorns requires considerable time. However, these problems 1) and 2) are common to other methods as well as this method. About 40% of the acorns removed by rodents were never detected during the census. These undetected acorns probably were either transported too far or hoarded too deep to be detectable. In spite of these problems, however, the present method is one of the most effective methods that can be applied anywhere without skilled techniques.

Contribution of rodents to the dispersal of acorns

Transported distances of acorns scattered by rodents in this study were comparable to the results of Jensen and Nielsen (1986), and these transported distances were within the home-range of rodents (Miyaki & Kikuzawa 1988; Oka 1992). These results suggest that the distance of seed dispersal by rodents is smaller than that by birds (Darley-Hill & Johnson 1981; Johnson & Adkisson 1985). However, this is inconclusive, since 40% of the acorns were never relocated by the present method, indicating that some of the lost acorns might have been transported to very distant sites.

The distribution of hoarding depths is important for tree regeneration. When acorns of *Q. mongolica* var. *grosseserrata* (about 3 g in seed weight) are buried in the soil at a depth of 10 cm, the emergence rate of their epicotyls above the soil surface is lower than that of more shallowly buried acorns (Saito 1981). Since the maximum depth of detected acorns in a nest was 25 cm in this study, it is too deep for an acorn to emerge even if it escaped predation. However, I could not obtain enough samples to estimate the depth distribution of surviving acorns because of their high mortality.

There might be some possibility of 'directed dispersal' (Howe & Smallwood 1982) of acorns. Four acorns were hoarded at the entrances of burrows near a fallen branch or tree. Obstacles, such as fallen branches or trees which may provide refuges for rodents from their predators (Rood & Test 1968), are abundant in canopy gaps. If this is generally the case, such sites are suitable for regeneration because the light level on the forest floor is high in a canopy gap. The existence and contribution of such directional dispersal by rodents could be studied more quantitatively using the present method.

In this study, the survival rate of scattered acorns was low, suggesting the dispersal of *Quercus* acorns by rodents is of little importance in this case. Jensen (1982) reported that in the mast years the ratios of predation by rodents to seed production were significantly lower compared with those of low mast production years because of predator satiation. In 1992, the number of fallen seeds in this stand was the lowest since 1987 (Iida, unpubl.), suggesting a high intensity of predation by rodents for acorns. The importance of the year-to-year variation of seed production, rodent population and caching behavior should be studied to understand further the role of rodents in tree regeneration.

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