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鼠类对山杏(*Prunus armeniaca*)种子扩散及存活作用研究

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摘要:虽然有关鼠类搬运森林种子的证据已很清楚,但这些被移走种子的存活情况却知之甚少。提出了一个新的标记和跟踪种子的方法——标签法,即将种子拴一带有编码的细长金属片,研究了北京东灵山地区山杏(*Prunus armeniaca*)种子的扩散距离和存活率。于 1998 年 6 月 19～20 日,7 月 3 日和 10 月 23 日共在 24 个样点释放 1440 粒山杏种子。几乎所有释放的种子在 10d 内被鼠类取走。夏天释放的种子比秋天释放的种子消失的速度快。大多数种子的扩散距离在 20m 以内,小于鼠类的活动距离。鼠类吃掉种子的速度很快,但当种子变得稀少时,种子存活率有所提高。山杏种子 6、7 月份的每日存活率小于其它月份的每日存活率。

关键词:山杏 *Prunus armeniaca*;鼠类;种子命运;森林更新;种子扩散;种子存活;协同进化;互惠

Effect of rodents on seed dispersal and survival of wild apricot (*Prunus armeniaca*)

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Abstract: It is well recognized that rodents remove most seeds of forests. But few are known about the seed survival of the removed seeds. In this study, by using a new method of labeling seeds with small pieces of coded tin-tags, the seed removal and survival of the wild apricot (*Prunus armeniaca*) were studied in a mountainous area (40°00′N, 115°30′E) of Beijing, China. A total of 1440 tin-tagged seeds were released on June 19～20, July 3, and October 23, 1998. Almost all the tin-tagged seeds disappeared within 10 days due to the removal by rodents. The seeds released in summer disappeared more quickly than in autumn. In the same season of summer, seeds in large clumps (40 seeds/plot) disappeared more quickly than the seeds released in small clumps (20 seeds/plot). Most of the tagged seeds or their fragments were dispersed less than 20 m from the original releasing plots. Seeds were destroyed rapidly by rodents, but seed survival was obviously improved when seeds became rare. The daily seed survival rate during June to July was lower than that during the other periods of the year.

Key words: wild apricot (*Prunus armeniaca*); rodent; seed fate; forest regeneration; seed dispersal; seed survival; co-evolution; mutualism

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1 INTRODUCTION

Prior studies indicate the regeneration of forests is affected greatly by rodents. Seeds fallen or placed

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on the ground surface disappear very quickly due to the removal by rodents[1~5]. Most of seeds removed by rodents are consumed and only very few can become seedlings[5~7]. Predation by rodents is sometimes believed to be the reason for the failure of some seeding regeneration in small fragments or low-density oak forests[6,8]. However, when abundant seed production leads to seed predator satiation, rodents consume a small proportion of seeds[9~12]. On the other hand, rodents are also recognized as an important agent for the regeneration of some forests because they disperse and bury seeds[13].

Although it is relatively easy to quantify seed removal[14], and it is even possible to observe which species remove seeds[14,15], it is difficult to know what proportion of the removed seeds survived out of rodent consumption[6]. Recently, in order to quantify seed fate some useful techniques have been employed, such as labeling seeds with radioactive[13,16,17], fluorescent pigments[18], metals[6] and threads[19,20]. These methods performed well in obtaining more detailed information on the survival, dispersal, food cache and microenvironments of the tagged seeds. In this study, we used a new method of labeling seeds with small pieces of tin-tags. The tin-tagged seeds are coded and then distinguished easily from each other. Therefore, the seeds released at different times and at different plots would not be confused.

The wild apricot shrubs or low forests are widely distributed in the mountainous areas at latitudes of 700～1200 m in the suburb of Beijing, China[21]. They are usually found in the deforested or degenerated areas of sunny slopes. The seed of apricot weighs about 1.5 g. The seed cover is very hard and only rodents are able to open it. The seeds of apricot become ripe in summer, usually in mid-June. New seedlings will be established by early May in the following year. The apricot seeds are of economic significance, locally used as materials of a Chinese medicine and of a kind of soft drink. Wild apricot can survive in very harsh conditions with poor soil quality, and thus is widely recommended to plant in degenerated regions for the reduction of soil erosion and increasing the income of local residents[21]. There were only few preliminary observations on the impact of rodent on seed removal and seedling recruitment of the wild apricot[22,23]. The purpose of this study is to study the seed removal, seed dispersal and seed survival rate of the wild apricot by using the new tin-tagged method.

2 METHODS

2.1 Study site

The study site is located at the Liyuanling Village (40°00′ N, 115°30′ E), Qijiazhuang County, Mentougou District of Beijing, China. The elevation of the village is 1100 m. Villagers were evacuated out 12 years ago under the policy of restoring the degenerated areas and poverty-alleviation of mountainous residents. The experiment area is very degenerated due to extensive cutting and goat grazing for almost a century. Liaodong oak (*Quercus liaotungensis*), wild walnut (*Juglans mandshurica*), wild apricot (*Prunus armeniaca*), *Vitex negundo* and *P. davidiana* shrubs are commonly found. Under shrublands, *Elymus excelsus*, *Poa* spp, *Elsholtzia stauntoni* are common grasses. *Laxix principis-rupprechtii* and *Pinus tabulaeformis* are planted trees by local forestation farm in small areas.

2.2 Rodent species removing seeds of apricot

On October 3～4, 1998, wooden snap traps baited with fresh and ripe seeds of apricot were used for identifying rodent species of removing seeds of apricot. Three transects were selected nearby the experiment area. Twenty-five traps were set along each of the three sites with an interval of 10 m apart for two successive days. The traps were checked every day and the captured rodents were recorded.

2.3 Seed-release test

Intact and ripe seeds (without pulp) of wild apricot were collected on June 10～15, 1998 for the seed-release test. Tiny holes were drilled at the bottom sides of seeds without destroying the inside kernels, and tied with small and light tags about 4 cm long and 1 cm wide by using thin metal-strings of 3 cm long. The tag is made of a small strip of tin and coded by using a sharpen metal-pen or hard printing blocks with numbers. The whole tag weighs about 0.2g. The tin-tagged seeds are easy to find after being dispersed by rodents. If buried in soil by rodents, the tin-tags are left on the surface.

A 240 m transect across 4 slopes of three small hills was located for seed release. Along this transect, 24 plots (Plot A～F, Plot 1～18) were located with 10 m apart. On June 19, 1998, 20 seeds were placed on the ground surface within 1 m^2 nearby each of Plot 1～18, and 40 seeds were placed in Plot A～F similarly on June 20, 1998. On July 3, 1998, 20 seeds were placed in each of Plot 1～18 again. On October 23, 1998, 20 seeds were placed in each of Plot A～F again and of Plot 1～18 for third time. A total of 1440 seeds were released. The released seeds of all plots were counted later to check seed removal by rodents.

After seed placement, both sides of the transect of 50 m wide were extensively checked by scanning every quadrate of 2×2 square meters with roughly equal efforts to find the tagged seeds or their fragments. The checking dates were on June 21～22, June 26～27, July 4～5, July 11～12, October 24～25, October 31 and November 1 of 1998, and May 15～16, June 20～21, July 4～5 of 1999 respectively.

Four categories of seed-states were defined for the tin-tagged seeds or their fragments: (1) Intact and buried (IB). The tagged seed is intact and buried in soil with tin-tag out of the soil. (2) Intact and on the surface (IS). The seed is intact and left on the surface. (3) Eaten up (E). There is a gnawing hole opened by a rodent on the tagged seed. The inside kernel of the tagged seed was taken away. Only the seed cover is left on the surface with the tin-tag attached on. (4) Cut off (C). The seed is cut off from the tin-tag. Only the tin-tag is left on the surface. The seed is gone and its fate is unclear.
The distances of the tagged seeds or their fragments to their original releasing plots were measured.

2.4 Estimation of seed survival rate (*SSR*) and seed disappearance rate (*SDR*) on the surface

The seed survival rate (*SSR*) is the proportion of seeds not destroyed by rodents during a period. Here we assumed that the probability of IB+IS being found is equal throughout the surveying period, then the seed survival rate (*SSR*) during time t to $t+T$ is defined as the proportion of IB+IS at time $t+T$ to that at time t: $SSR=N(t+T)/N(t)$, where $N(t)$ and $N(t+T)$ are the numbers of IB+IS being found at time t and $t+T$ respectively. The daily seed survival rate (*DSSR*) is converted from *SSR*: $DSSR=e^{\ln SSR/T}$. The seed disappearance rate (*SDR*) on the surface is the proportion of seeds removed from the seed plots during a period. *SDR* or daily *SDR*(*DSDR*) are calculated similarly as *SSR* or *DSSR* are calculated.

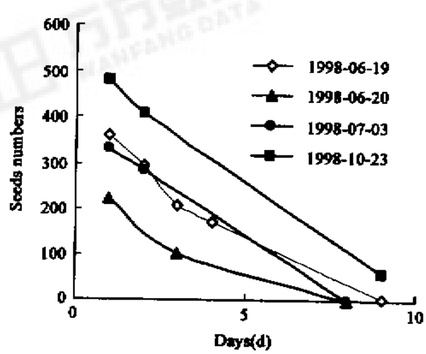

Fig. 1　Seed removal by rodents after the tagged seeds were placed on the surface on June 19 & 20, July 3 and October 23, 1998. The clump size was 20 seeds/plot on June 19 ($n=18$), 40 seeds/plot on June 20 ($n=6$), 20 seeds/plot on July 3 ($n=18$), and 20 seeds/plot on October 23 ($n=24$)

3　RESULTS

3.1　Rodent species of removing seeds

200 snare traps baited with apricot seeds were used to indentify rodent species of removing these seeds in October 3～4, 1997. A total of 28 rodents was captured. Three species, field mouse (*Apodemus speciosus*), white-bellied rat (*Rattus confucianus*), striped field mouse (*Apodemus agrarius*), were identi-

fied as remover of apricot seeds, and occupying 57.1%, 25.0%, and 17.9% of the total catches respectively. Comparing to the average trap success (5.4%) during 1993～1995 in the study region (Ma *et al* 1999), the population density (14%) in the study year of 1998 was medium-high.

3.2 Seed removal by rodents

The seed removal by rodents after seed releases on June 19～20, July 3 and October 23 of 1998 was shown in Fig. 1. The mean daily seed disappearance rate (*DSDR*) on the surface for seeds released on June 19 is 0.3097±0.1941 ($n = 4$, n is the sample numbers based on 5 observations), 0.46, ($n = 2$) for seeds released on June 20, the *DSDR* is 0.3733 ($n = 2$) for seeds released on July 3, 0.1966 ($n = 2$) for seeds released on October 23. Therefore, the expected seed disappearance rates within 10 days were 0.9754 ($n = 360$) for seeds released on June 19, 0.9978 ($n = 220$) for seeds released on June 20, 0.9907 ($n = 330$) released on July 3, and 0.8880 ($n = 480$) for seeds released on October 23. Thus seeds released in summer disappeared more rapidly than in autumn ($p < 0.01$). In the same season of summer, seeds in large clumps (i.e. 40 seeds/plot on June 20) disappeared slightly more quickly than seeds placed in small clumps (20 seeds/plot on June 19) ($p > 0.05$). All seeds released in June and July disappeared in less than 10 days, but some seeds released in October still existed after 10 days.

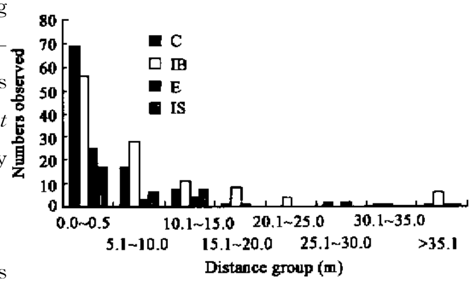

Fig. 2 The frequency of the dispersal distance of the tagged seeds or their fragments (IB, IS, C and E) by rodents

3.3 Dispersal distance

Fig. 2 showed that dispersal of the tagged seeds or their fragments by rodents were not very far. Among the seeds or fragments recovered, 59.9% was found within 5 m, and 93.2% of them was found within 20 m away from the releasing sites. The mean dispersal distance of tagged seeds or their fragments were given in Table 1. The dispersal distances of seed fragments C and seeds IS were significantly shorter than that of seeds or fragments of IB and E ($p < 0.01$). This indicated that rodents tended to cut the seed from the tags at the releasing plots.

3.4 Seed survival rate

The survival dynamic of IB+IS after three seed releases on June, July and October were shown in Table 2 and Fig 3. This figure showed that seeds were destroyed rapidly after seeds were released. However, survival increased when intact seeds became rare. Only 5.9% (2/34) of the first released seeds on June became to seedlings next May, 22.2% (2/9) of the second released seeds on July became to seedlings next May, and 8.3% (5/60) of the third released seeds on October became to seedlings next May (Table 2). The seed survival rate (*SSR*) and the daily *SSR* (*DSSR*) of IB+IS were shown in Table 3. It is noticeable that the DSSR during the short period from June to July

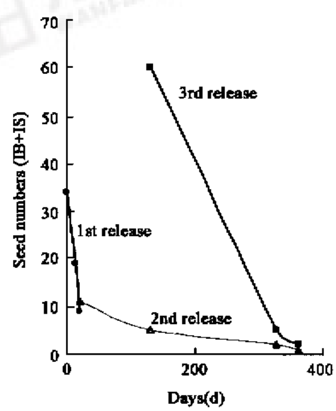

Fig. 3 Survival of the tagged seeds (IB+IS) after 1st (on June 19～20), 2nd (on July 3) and 3rd (on October 23) releases in 1998

was obviously lower than that in the other periods of the year. This conforms to the above observation that seeds released on surface in summer disappeared more rapidly than seeds released in autumn. Fig. 3 also showed that seed survival improved when seeds (IB+IS) became rare.

Table 1　The dispersal distance (m) of the tagged seeds or their fragments (IB, IS, E and C) by rodents

Seed state	Mean	Std Dev.	Min	Max	N
IB	10.97	17.38	0.30	110	114
IS	6.9	8.37	0.00	45	31
E	12.53	39.50	0.20	250	39
C	5.62	15.92	0.00	150	97

4　DISCUSSION

4.1　Rodent species of removing seeds

In this study, only three rodent species were identified as major agents for seed disappearance of apricot on the surface. The rat-like hamster was observed to eat seeds of apricot in laboratory. There are several other rodent species, house mouse (*Mus musculus*), Norway rat (*Rattus norvegicus*), brown-backed vole (*Clethrionomys rufocanus*), gray squirrels (*Sciurotamias davidianus*) and chipmunks (*Eutamias sibiricus*), not captured in this region[22]. The major reason would be because of the small probability of being captured due to their small abundance, and also because of the relatively small trapping effort. The gray squirrels and chipmunks were often observed to eat seeds of apricot.

Table 2　Numbers of the tagged-seeds with different seed states (IB, IS, C, E) when checked on different dates.

Seed release	Seed state	Dates						
		1998				1999		
		06-21～22	07-04～05	07-11～12	10-31～11-1	05-15～16	06-20～21	07-04～05
1st	IB	18	18	7		1		
	IS	16	1	2		1		
	C	3	42	21	8	10		
	E	0	3	5	4	7	3	3
2nd	IB			9	5	1		
	IS			2		1		
	C			1	1			
	E			1	7	7	1	
3rd	IB				52	4	2	
	IS				8	1		
	C				4	1		
	E				1	5		

The 1st seed release was on 1998-06-19～20. The 2nd seed release was on 1998-07-03. The 3rd seed release was on 1998-10-23.

4.2　Seeds disappearance

In this study, high-density seeds suffered higher predation by rodents. This corresponded to many prior observations[5,24]. Nearly all seeds released disappeared within only 10 days. This observation also conforms to many previous findings that seeds fallen on surface were removed by rodents rapidly[1～5]. The reason why seeds released in summer suffered higher predation than in autumn might be because food resources were relatively limited in summer comparing to that in autumn. In autumn, abundant seed production of other trees (e.g. oak) might have leaded to a state widely known as seed predator satiation[9～12], which might have reduced the predation pressure on the released seeds of apricot. Not like some studies on oak[6]①, there were very few seeds of apricot consumed at plots where they are released. This might be due to that seed cover of apricot was very hard although the apricot seed is more nutritional than the acorn of oak. It would certainly take longer time for rodents to open seeds of apricot and then pose high risk of predation.

① ZHANG Zhi-Bin, Unpublished

4.3 Seed dispersal

The home range of field mouse (*A. speciosus*) was estimated to be 341～1620m^2 square meters with maximum moving distance of 35 m by using radio telemetry method[4]. Xia and Long (1978) reported that the home ranges of male and female striped mouse (*A. agrarius*) were 1034 ± 70.1 and 769.1 ± 56.9m^2, and the moving distances for male and female were 53.4 ± 2.4 m and 45.4 ± 2.6 m respectively when population density was 28.9 mice/hm^2[25]. Yang and Zhu (1989)[26] reported that the home ranges of male and female striped mouse were 2271 ± 204 and 1841 ± 183m^2, and the moving distances for male and female were 88.4 ± 4.9 m and 82.1 ± 5.1 m respectively when population density was lower (10.1 mice/hm^2) than that reported by Xia and Long (1978)[25]. The home range and moving distance of white-bellied rat should be larger than that of mice because its body mass is much bigger than that of these mouse species. The dispersal distances of the tagged seeds were obviously shorter than the normal dispersal distance of the dominant rodent species. This implied that rodents did not take foods to their original nests. This also conforms to the observation that rodent preserved seeds in very short distance[17].

4.4 Survival of the tagged seeds

Although almost of the tagged seeds was destroyed by rodents, there was still few seeds escaped the rodent predation. Many forests may regenerate depending upon these few survived seeds. In an oak dominated reserve, 0.9% (n = 428) metal-tagged acorns of Red oak (*Q. rubra*) survived from Fall of 1981 with relatively large seed crops to summer of 1982 with abundant acorn production[6]. While in an experiment by Jensen and Nielsen (1986)[13], 2.4% (12/485) radioactive tagged seeds of *Q. robur* and *Q. petrea* became seedlings. Of the 211 acorns buried, only 0.9% (2/211) seedlings survived the first year, and none survived the second year[5]. The observed seedling recruitment rates of seeds of apricot in our study are higher than that of oak acorns reported by the above authors, and also much higher than that (<1%) of acorns of Liaodong oak in the same study area①. Here, we suggested that the hard cover of apricot seeds might have contributed the high survival of the tagged seeds of apricot. Field observation also supported this suggestion. A-year-old young seedlings of apricot were commonly observed, while it is very hard to see the seedlings of Liaodong oak in the study area. The natural seeding regeneration of wild apricot looks very good, while oak seems to have some difficulty in seeding regeneration, probably due to too much acorn predation by rodents.

Table 3 The seed survival rates (*SSR*) and daily SSR (*DSSR*) of the tagged seeds

Period	1998			1998-10-31～1999-05-15	1999	
	06-21～07-04	07-04～11	07－11～10-31		05-15～06-20	06-20～07-04
Days(d)	13	7	110	195	35	14
SSR(1st)	19/34	9/19	0/9	2/0	0/2	0/0
SSR(2nd)			5/11	2/5	0/2	0/0
SSR(3rd)				5/60	2/5	0/2
Average *SSR*	0.5588 (n=34)	0.4743 (n=19)	0.2500 (n=20)	0.1385 (n=65)	0.2222 (n=9)	— (n=2)
Average *DSSR*	0.9562	0.8989	0.9875	0.9899	0.9579	—

The 1st seed release was on 1998-06-19～20. The 2nd seed release was on 1998-07-03. The 3rd seed release was on 1998-10-23

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