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Influence of tree thinning on abundance and survival probability of small rodents in a natural deciduous forest

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Abstract: This study was conducted to investigate the influence of tree thinning on habitat variables and small rodents in a natural deciduous forest in South Korea. We focused on the populations of the small forest-dwelling rodents, striped field mouse *Apodemus agrarius* and Korean field mouse *A. peninsulae*. Populations were monitored for 2 years in a natural deciduous forest subject to tree thinning. The coverage of ground vegetation and number and volume of downed trees were significantly increased after thinning. However, the coverage of overstory and understory vegetation and number of standing trees were decreased in postthinning session. The abundance and survival probability of captured *A. agrarius* and the total small rodents were significantly influenced by tree thinning. We hypothesize that the major factors determining the greater abundance and survival of small rodents after thinning may be the increased coverage of ground vegetation and number of downed trees, and the decreased number of standing trees. This study suggests that tree thinning could be a tool to both encourage tree productivity and create suitable habitats for small rodents.

Key words: *Apodemus agrarius*, *Apodemus peninsulae*, downed tree, ground vegetation, habitat variable

1. Introduction

Forests cover more than 6.3×10^6 ha in South Korea, but most of this area has been disturbed by human activities (Ministry of Land, Infrastructure, and Transport, 2017). In particular, urbanization, road construction, forest management, and forest fires have been major disturbance factors in the last several decades (Lee et al., 2017; Son et al., 2017). These disturbances can lead to habitat loss, fragmentation, and degradation and, as a result, decreased biodiversity (Rhim and Lee, 2007; Fischer and Schröder, 2014).

As the environmental, social, and cultural functions of forests increase in importance, forest managers have focused on sustainable forest management (Spiecker, 2003). Ecologically oriented approaches have been used for the conservation and protection of biodiversity (Gasperini et al., 2016). We need a more detailed understanding of the mechanistic processes of forest management practices.

Some forest management practices are widely used in many countries (Krojerová-Prokešová et al., 2016). One in particular, tree thinning, can modify habitat characteristics such as vegetation structure and composition and availability of food and shelter, and thus can have both direct and indirect influences on wildlife (Bowman et al., 2001). Moreover, wildlife might react to thinning trees by selecting different habitats, or by increasing their population in the current habitat. The mechanisms behind how habitat changes caused by thinning affects wildlife are, however, not well known.

Certain practices of forest management, such as selective cutting and shelter-wood cutting, seem to be more suitable for sustainable forest management and biodiversity conservation than others (Klenner and Sullivan, 2009). However, these management practices are not used widely because of the high costs involved. Moreover, practical and reliable methods for assessing sustainable forest management practices remain elusive (Krojerová-Prokešová et al., 2016).

Small rodents play important roles in forest ecosystems as prey of carnivores; consumers of fungi, invertebrates, and plants; and seed dispersers (Orrock and Connolly, 2016). They also influence the structure and diversity of plant communities (Decocq et al., 2005; Krojerová-Prokešová et al., 2016). In this study, we focused on striped field mouse *Apodemus agrarius* and Korean field mouse *A. peninsulae*. These mammals are forest-dwellers and the most common small rodent species in South Korea (Lee et al., 2008). The studied species prefer more open forest by forest management (Kang et al., 2013b). In addition, they immediately respond to habitat changes because they have

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short generation times (Lee et al., 2008; Carrilho et al., 2017). Therefore, small rodents may be suitable for studies on how a community is influenced by habitat changes.

Because of their ecological importance, understanding the ecological factors affecting small rodents is essential to sustainable forest management and conservation of biodiversity. We used two parameters, abundance and survival probability, to determine the effects of tree thinning on these mammals. We tested two hypotheses: (1) habitat variables are changed by tree thinning and (2) tree thinning influences the abundance and survival probability of small rodents.

2. Materials and methods

This study was performed from May to November in 2014 and 2015 in a natural deciduous forest on Mt. Maehwa, Hongcheon, South Korea (37°39′48″N to 37°39′53″N, 127°52′23″E to 127°52′34″E). The altitude ranged from 220 to 340 m above sea level. The annual mean temperature was 12.0 °C (ranging from 37.1 to –19.9 °C). The annual precipitation was 722.8 mm. Sawtooth oak *Quercus acutissima*, cork oak *Q. variabilis*, and Mongolian oak *Q. mongolica* were the dominant tree species (Kang et al., 2013b). We selected two study sites (100 × 100 m). In each study site, a grid (15 × 15 m array of 49 trapping stations) was established for the habitat variable survey and small rodent trapping. Tree thinning was performed in February 2015. We divided the study period into two periods: prethinning (May to November 2014) and postthinning (May to November 2015).

We set a circle (5.64 m radius) around 49 trapping stations in both sites. Habitat variables were surveyed within each circle in July of both 2014 (prethinning) and 2015 (postthinning). The coverage of each vertical layer of vegetation, tree diameter at breast height (DBH), the number of standing trees, and the number and volume of downed trees were measured. The vertical layers were classified as overstory (20–30 m), sub-overstory (8–20 m), mid-story (2–8 m), understory (1–2 m), and ground (<1 m). Vegetation coverage (hereafter vegetation) was classified as 0 (0% coverage), 1 (1%–33%), 2 (34%–66%), and 3 (67%–100%) (Rhim et al., 2012).

We trapped small rodents using the capture–recapture method during three consecutive nights each month from May to November in 2014 and 2015. A Sherman live trap was placed at all 49 trapping stations in each study site. The traps were baited with peanuts and checked the next morning (Kang et al., 2013a). During the trapping periods, we recorded the trapped rodent species, trap location, individual identity, sex, body mass, age class, and release condition. Toe-clipping was used for individual identification of all captured small rodents. Immediately after recording this information, we released the animals at the captured trap station (Lee et al., 2008). The experimental protocols describing the treatment and care of animals were reviewed according to the guidelines of the local ethics committee (Institutional Animal Care and Use Committee, Chung-Ang University; approval number: CAU 2014-005).

The Mann–Whitney U test was employed with IBM SPSS Statistics 23.0 (IBM Corp., Armonk, NY, USA), to analyze the differences in vegetation (overstory, sub-overstory, mid-story, understory, and ground), number of standing trees, number and volume of downed trees, and abundance of small rodents between pre- and postthinning periods. Small rodent population size and survival probability were estimated with the Jolly–Seber stochastic model and POPAN analysis using MARK 8.0 (Seber, 1982; Lee et al., 2012; Lee, 2017). The means of parameter estimates were computed across all models occupied by a given variable, along with the 95% confidence interval (Burnham and Anderson, 2002; Kang et al., 2013b).

For every mode, MARK processed the Akaike information criterion (AIC) corrected for a small sample size. Throughout the analysis, an information-theoretic philosophy of model selection was employed with a focus on multimodel inference (Burnham and Anderson, 2002; Kang et al., 2013a) that included habitat variables. AIC model weights (ω) were determined for each of the variables that were present in at least one selected model resulting from the generalized linear model using the program R 3.3.3. Values were considered statistically significant at $P < 0.05$.

3. Results

Ground vegetation, number of downed trees, and volume of downed trees were significantly different between pre- and postthinning periods. These variables were all dramatically increased in the postthinning period. However, overstory vegetation, understory vegetation, and number of standing trees were significantly decreased in the postthinning period. There were no differences in sub-overstory or mid-story vegetation between pre- and postthinning periods (Table 1).

Two small rodent species, the striped field mouse *Apodemus agrarius* and Korean field mouse *A. peninsulae*, were captured during the study period. These were the only two species captured in our study. There were no differences in species composition between pre- and postthinning periods. The number of *A. agrarius* captured monthly (Mann–Whitney U test, $Z = -2.89$, $P = 0.004$) and total number of small rodents captured monthly ($Z = -2.34$, $P = 0.02$) were significantly higher in postthinning than prethinning. However, the number of *A. peninsulae* captured monthly did not differ ($Z = -0.87$, $P = 0.45$) between periods (Figure 1).

Table 1. Values (mean ± SE) of habitat variables and results of Mann–Whitney U test between prethinning and postthinning periods in a natural deciduous forest, Mt. Maehwa, Hongcheon, South Korea.

Variables	Periods		Z	P
	Prethinning	Postthinning		
Coverage of overstory vegetation (20–30 m)	0.28 ± 0.05	0.17 ± 0.05	–2.02	0.043
Coverage of sub-overstory vegetation (8–20 m)	1.27 ± 0.09	1.04 ± 0.08	–1.52	0.129
Coverage of mid-story vegetation (2–8 m)	1.79 ± 0.10	1.55 ± 0.08	–1.73	0.084
Coverage of understory vegetation (1–2 m)	1.27 ± 0.04	1.00 ± 0.02	–5.04	<0.001
Coverage of ground vegetation (0–1 m)	1.59 ± 0.07	1.86 ± 0.07	–2.62	0.009
No. of standing trees/ha	845.89 ± 47.62	650.77 ± 38.43	–3.35	<0.001
No. of downed trees/ha	97.05 ± 19.24	1422.08 ± 80.00	–11.67	<0.001
Volume of downed trees/ha (m^3)	5.88 ± 1.61	30.45 ± 2.62	–9.84	<0.001

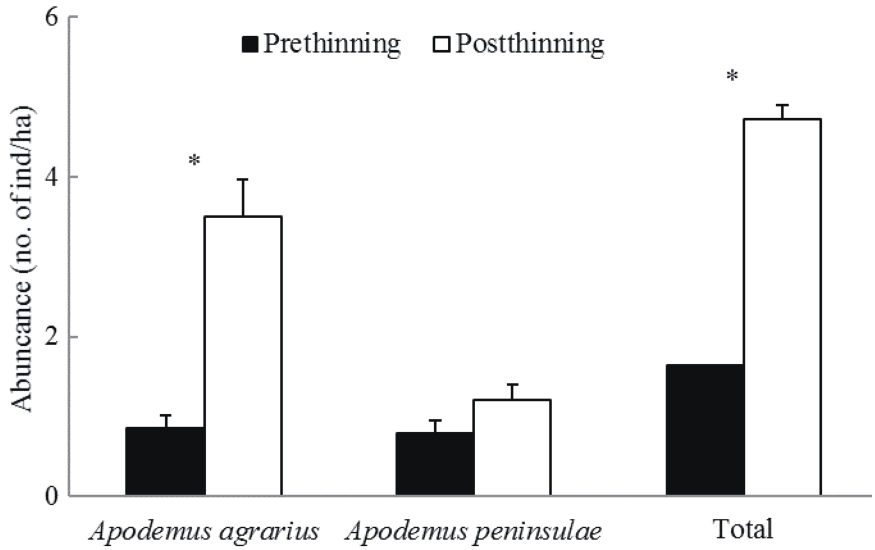

Figure 1. Mean numbers of small rodents captured per month (individuals/ha; mean ± SE) in the prethinning and postthinning periods in a natural deciduous forest, Mt. Maehwa, Hongcheon, South Korea. Asterisk indicates a significant difference (P < 0.05) according to a Mann–Whitney U test.

The estimated abundances of *A. agrarius* (Z = –3.14, P < 0.001) and total small rodents (Z = –2.49, P = 0.01) were significantly higher after thinning than before thinning. The estimated abundance of *A. peninsulae* was not significantly different (Z = –0.71, P = 0.53) between the pre- and postthinning periods (Figure 2).

The survival probability of *A. agrarius* (Z = –3.84, P < 0.001) and total small rodents (Z = –2.21, P = 0.02) were significantly different between prethinning and postthinning periods. The survival probability of *A. agrarius* was dramatically increased from 42% to 85% by the thinning. Moreover, survival probability of total small rodents was an absolute 17% higher in the postthinning period than in the prethinning period. However, there was no difference in survival probability of *A. peninsulae* between the study periods (Z = –0.57, P = 0.58) (Figure 3).

The best models of abundance of small rodent species had Akaike weight (ω) of 0.26–0.44. The top-ranked model for *A. agrarius* was –0.567 + 0.417 × ground vegetation (Z = 2.41, P = 0.01) – 0.729 × understory vegetation (Z = –1.50, P = 0.01) – 0.001 × number of standing trees (Z = –3.03, P = 0.01) + 0.001 × number of downed trees (Z = 2.16, P = 0.03) – 0.017 × volume of downed trees (Z = –1.82, P = 0.05). The second-ranked model contained ground vegetation, numbers of standing trees and downed trees, and volume of downed trees (Table 2).

The top-ranked model for *A. peninsulae* was –2.74 + 0.432 × ground vegetation (Z = 1.73, P = 0.08). The second-ranked model for *A. peninsulae* contained the ground vegetation and overstory vegetation. The top-ranked model for total small rodents was –0.469 + 0.482 × ground vegetation (Z = 3.46, P < 0.001) – 0.577

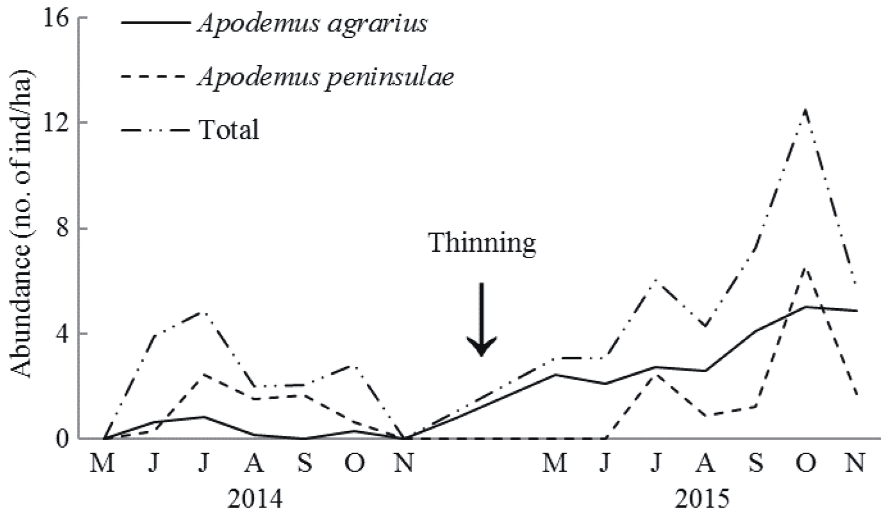

Figure 2. Estimated mean (n = 2) abundance of small rodents in the prethinning (2014) and postthinning (2015) periods in a natural deciduous forest, Mt. Maehwa, Hongcheon, South Korea.

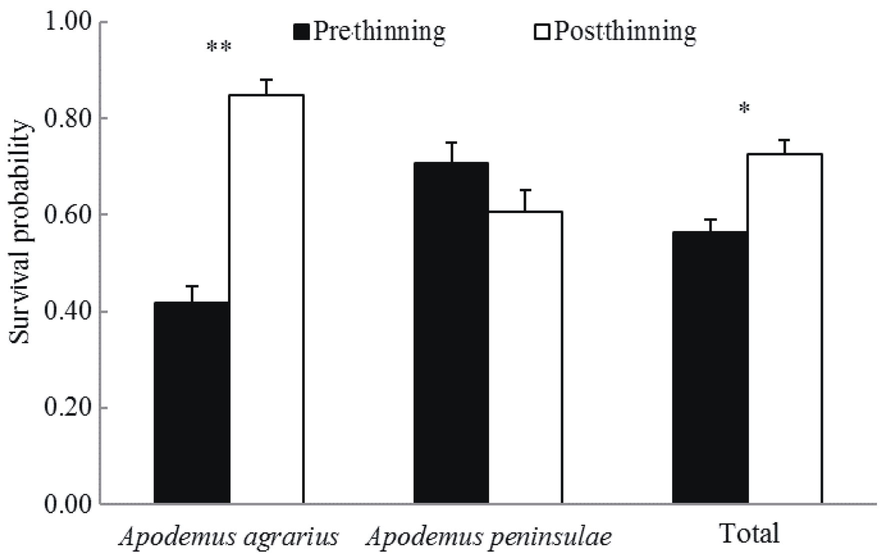

Figure 3. Survival probability (mean ± SE) of small rodents in the prethinning and postthinning periods in a natural deciduous forest, Mt. Maehwa, Hongcheon, South Korea. *: P < 0.05, **: P < 0.001 according to a Mann–Whitney U test.

× understory vegetation ($Z = -1.58$, $P = 0.12$) − 0.001 × number of standing trees ($Z = -3.19$, $P < 0.001$). Ground vegetation and number of standing trees dominated as two predictor variables in the second-ranked model for abundance of total small rodents (Table 2). The coverage of ground vegetation and number of downed trees were higher positively correlated and number of standing trees was highly negatively correlated with the density of small rodents (Table 3).

4. Discussion

The effects of forest management on small rodent abundance appear to be species- and area-specific (Fuller et al., 2004). However, there have been few studies on how forest management practices affect their survival probability (e.g., Escobar et al., 2015; Gasperini et al., 2016). Demographic factors including survival probability are good subjects for more detailed studies on the influences of habitat changes on small rodents (Ranta et

Table 2. Top-ranked models based on the correlated Akaike information criterion (AIC*c*), explaining the abundance of each small rodent species based on model selection resulting from a generalized linear model.

Species	Top-ranked models	AIC*c*	ΔAIC*c*	ω
Apodemus agrarius	[intercept + ground vegetation + understory vegetation + no. of standing trees + no. of downed trees + volume of downed trees]	266.98	0.00	0.40
	[intercept + ground vegetation + no. of standing trees + no. of downed trees + volume of downed trees]	267.42	0.44	0.33
	[intercept + ground vegetation + understory vegetation + no. of standing trees]	267.80	0.81	0.27
Apodemus peninsulae	[intercept + ground vegetation]	173.83	0.00	0.43
	[intercept + ground vegetation + overstory vegetation]	174.51	0.67	0.30
Total	[intercept + ground vegetation + understory vegetation + no. of standing trees]	351.63	0.00	0.44
	[intercept + ground vegetation + no. of standing trees]	352.36	0.73	0.30
	[intercept + ground vegetation + understory vegetation + mid-story vegetation + no. of standing trees]	352.69	1.06	0.26

Table 3. Variables including the best models explaining the variability in relative abundance of each model's categories

Species	Variables	Coefficient	SE	Z	P	95% CI	
						Lower	Upper
Apodemus agrarius	Intercept	−0.5677	0.6792	−0.84	0.403	−1.8989	0.7635
	Ground vegetation	0.4176	0.1731	2.41	0.016	0.0783	0.7569
	Understory vegetation	−0.7299	0.4843	−1.51	0.132	−1.6791	0.2193
	No. of standing trees	−0.0011	0.0003	−3.04	0.002	−0.0017	−0.0005
	No. of downed trees	0.0005	0.0002	2.16	0.031	0.0001	0.0009
	Volume of downed trees	−0.0179	0.0098	−1.82	0.069	−0.0371	0.0013
Apodemus peninsulae	Intercept	−2.7420	0.5256	−5.21	<0.001	−3.7722	−1.7118
	Ground vegetation	0.4320	0.2497	1.73	0.084	−0.0574	0.9214
Total	Intercept	−0.4698	0.5160	−0.91	0.363	−1.4812	0.5416
	Ground vegetation	0.4820	0.1394	3.46	<0.001	0.2088	0.7552
	Understory vegetation	−0.5772	0.3663	−1.58	0.115	−1.2951	0.1407
	No. of standing trees	−0.0009	0.0003	−3.19	0.001	−0.0015	−0.0003

al., 2006). There is considerable concern about the impacts of forest practices such as logging and thinning on forest biodiversity. Effects of tree thinning can be multiscaled and complex, ranging from individual trees to entire landscapes (Perry et al., 2008; Lindenmayer et al., 2010).

In this study area, the number of standing trees was dramatically decreased after tree thinning. This process resulted in decrease in the coverage of overstory vegetation, which led to an increased amount of light reaching the ground (Richards and Coley, 2007; Rhim et al., 2015). Since light is a crucial factor for vegetation growth, the ground vegetation was densely developed in the postthinning period (Costa and Magnusson, 2003; Krebs, 2008). The number and volume of downed trees were increased in the postthinning period due to residues that occurred from thinned trees. The habitat variables directly and/or indirectly changed by tree thinning had critical influences on habitat quality (Mortelliti et al., 2010; Gasperini et al., 2016).

We found that tree thinning strongly affected the *Apodemus agrarius* population. The abundance of *A. agrarius* in the postthinning period was more than three times the abundance in the prethinning session. Moreover, the survival probability in the postthinning period was more than twice that before thinning. In addition, ground vegetation and the number of downed trees positively influenced this population during the study period. Food and shelter, as essential requirements of habitat, are important factors in habitat selection (Ecke et al., 2002). The ground cover and the downed trees provide food (e.g., fruit, fungi, and invertebrates) and shelter resources to small rodents (Ausden, 2007; Bush et al., 2012; Earl et al., 2016). The large amount of ground vegetation and the high number of downed trees during the postthinning period provided more food and shelter resources for this species, allowing for an icrease in population.

In this study, the monthly numbers of captured *A. peninsulae* were lower than those of *A. agrarius*. Moreover, we found that abundance and survival probability of *A. peninsulae* did not differ between periods. However, ground vegetation was a major variable for its abundance. Interspecific competition occurs because of similarities in habitat requirements, such as food and cover, between sympatric species (Lee et al., 2012). In this area, interspecific competition may occur between *A. agrarius* and *A. peninsulae.* Because of this interspecific competition, the nondominant species *A. peninsulae* is limited in its use of the available food and shelter (Amori et al., 2015).

By the tree thinning, structural diversity of habitat was increased by the increase of ground vegetation and downed trees. The increase of structural diversity could influence small rodents in terms of higher food abundance and allowance of avoidance of predators (Buesching et al., 2008; Lee et al., 2008). We quantified the immediate postthinning responses of small rodents in natural deciduous forest. Determining the medium- and long-term responses of the small rodents and habitats is also needed for planning forest management.

In conclusion, the abundance and survival probability of small rodents were significantly influenced by tree thinning. Ground vegetation, standing trees, and downed trees were major factors in the best model of abundance of small rodents. Thus, we hypothesize that the major factors determining the increased abundance and survival of small rodents in the postthinning period may be the higher coverage of ground vegetation and number of downed trees, and the lower number of standing trees. This study suggests that tree thinning could be a tool that can encourage an increase in tree productivity and also create suitable habitat for small rodents.

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