



# Short-term effects of tree thinning on microhabitat variables and rodents in Japanese larch *Larix kaempferi* forest

Seung-Hun Son, Jae-Kang Lee, Hyun-Su Hwang, Tae-Kyung Eom & Shin-Jae Rhim

To cite this article: Seung-Hun Son, Jae-Kang Lee, Hyun-Su Hwang, Tae-Kyung Eom & Shin-Jae Rhim (2021) Short-term effects of tree thinning on microhabitat variables and rodents in Japanese larch *Larix kaempferi* forest, *Forest Science and Technology*, 17:1, 39-45, DOI: [10.1080/21580103.2021.1880976](https://doi.org/10.1080/21580103.2021.1880976)

To link to this article: <https://doi.org/10.1080/21580103.2021.1880976>



© 2021 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.



Published online: 05 Feb 2021.



Submit your article to this journal [↗](#)



Article views: 144






View related articles [↗](#)



View Crossmark data [↗](#)

## Short-term effects of tree thinning on microhabitat variables and rodents in Japanese larch *Larix kaempferi* forest

Seung-Hun Son, Jae-Kang Lee , Hyun-Su Hwang , Tae-Kyung Eom  and Shin-Jae Rhim 

School of Bioresource and Bioscience, Chung-Ang University, Ansong, South Korea

### ABSTRACT

We examined the short-term effects of tree thinning on microhabitat factors and the abundances of striped field mice *Apodemus agrarius*, Korean field mice *Apodemus peninsulae*, and Korean red-backed voles *Myodes regulus* within a Japanese larch *Larix kaempferi* forest in South Korea. Three different stands were thinned to 0%, 25%, or 50%. Ground vegetation was higher in the second year of tree thinning than in the first year. In the first year of thinning, ground vegetation was significantly higher in the control than in the 50% thinned stand, whereas the opposite trend was observed in the second year. Mid-story vegetation was higher in the control than in the 50% thinned stand. In the first year of thinning, the sub-overstory vegetation was higher in the control than in the 50% thinned stand. Basal area was the highest in the control stand. Abundances of the three rodent species were higher in the second year of tree thinning than in the first year. The abundance of *A. peninsulae* was higher in the control than in the 50% thinned stand. Overall, the three rodent species preferred microhabitats with dense ground vegetation. Our results showed that the short-term effects of tree thinning altered microhabitat factors and disturbed microhabitat conditions in the first year; furthermore, the 50% thinned stand did not provide suitable habitats for *A. peninsulae*. In this study, moderate (25%) tree thinning resulted in a convenient balance between biodiversity conservation and human demands for forest wood.

### ARTICLE HISTORY

Received 18 December 2020  
Accepted 20 January 2021

### KEYWORDS

Ground vegetation;  
microhabitat factor;  
managed monocultures;  
small rodents;  
thinned stand

### Introduction

An ever increasing demand for forest wood creates additional pressure on natural forests (Carrilho et al. 2017). An anthropogenic pressure influences biodiversity because of its effects on forest ecosystems, such as habitat loss and degradation (Newbold et al. 2014). Consequently, many forest-dwelling species are now endangered (Rouvinen and Kuuluvainen 2005; Rassi et al. 2010). Therefore, conservation of biodiversity should be considered when managing ecological functions of forest ecosystems. Natural forests are rapidly declining worldwide; thus, additional efforts should be designed and implemented for preserving biodiversity in commercial monoculture plantations (Cummings and Reid 2008; Thompson et al. 2009; Kitagawa et al. 2018). Moreover, forestry practices are widely followed in commercial plantations to ensure sustainable forest management; however, it is still necessary to identify suitable forestry practices for best maintenance of ecological functions and biodiversity conservation in the managed forests.

Forestry practices change the vegetation structure and biodiversity of forest ecosystems (Durak 2012). Tree thinning is common in managed plantations, although it has controversial effects on habitat conditions and wildlife. Ground vegetation development

surges vigorously after tree thinning because of an increased amount of sunlight reaching the bare ground (Ito et al. 2006). This effect improves habitat heterogeneity in managed plantations, as vegetation structure is more diverse (Kuehne et al. 2015). However, physical disturbance of the ground can occur during the tree thinning process and negatively affect ground vegetation development in the first year of tree thinning (Ares et al. 2009). Moreover, small rodents can be crushed by machinery, vehicles, and logs during the tree thinning process, thereby increasing the mortality of small rodents (Escobar et al. 2015).

The effects of thinning on forest wildlife have been investigated in managed forests (Converse et al. 2006; Kalies et al. 2010; Son et al. 2017). However, identifying the manner in which changes in forest attributes affect entire habitats can be a difficult task (Escobar et al. 2015) due to heterogeneous environmental factors in the habitat, variability among experimental designs (Kalies et al. 2010), and the specific responses of different wildlife species (Homyack et al. 2005).

Japanese larch *Larix kaempferi* (Lamb.) Carrière (1856), is a common tree species planted in South Korea. Altogether, Japanese larch trees have been planted on 620,358 ha (i.e. 36.2% of the total area under silviculture) in South Korea (Korea Forest Service 2018). Forestry practices, such as clearcutting

and thinning, have been implemented in plantations since the 1960s; however, the manner in which these forestry practices within *L. kaempferi* forests alter heterogeneity and biodiversity is poorly understood (Korea Forest Service 2012).

We tested the effects of tree thinning on microhabitat factors and small rodent abundance. Rodents are an important part of forest ecosystems because of their essential functional roles (Krojerová-Prokešová et al. 2016) as prey for larger mammals, birds, reptiles, and amphibians (Dawson and Bortolotti 2000) and as predators of invertebrate species (Carey and Harrington 2001); furthermore, they contribute importantly to the dispersal of fungal spores and tree seeds (Bermejo et al. 1998; Kirkland and Kirkland 1990).

The primary objective of this study was to describe the short-term trends shown by microhabitat factors and rodents following a thinning in a *L. kaempferi* forest. We focused on the following three main questions: (1) whether tree thinning affects microhabitat conditions over time; (2) whether small rodent populations show species-specific responses to tree thinning over time; and (3) whether small rodents prefer ground vegetation. We hypothesized that: (1) ground vegetation is decreased in the first year of tree thinning but is resilient in the second year; (2) small rodent populations have species-specific responses to tree thinning and increase in the second year of thinning; and (3) small rodents prefer ground vegetation.

## Materials and methods

### Study site

The study was conducted from May to October in 2014 and 2015 in an *L. kaempferi* forest (37°27'–37°28' N, 127°33'–127°34' E) on Mt. Gariwang, Pyeongchang, South Korea. Mt. Gariwang covers an area of approximately 40 km<sup>2</sup>. The annual mean temperature was 11.1 °C (range of –15.4 to 35.4 °C) and annual precipitation 809 mm. The study area lies at an elevation ranging between 1000 and 1400 m above sea level. The dominant tree species in the area is *L. kaempferi*, which was planted in 1982 (National Institute of Forest Science 2013).

### Experimental design and data collection

Standing trees were thinned in November 2013. Three different stands were thinned to different percentages using random tree selection: control stand with no thinning and stands thinned to 25% or 50% (i.e. control, 25% thinned, and 50% thinned, respectively). We randomly sampled two study plots per stand (2 study plots/stand × 3 stands;  $n=6$ ) based on operational scale, proximity, location, and elevation (Sullivan et al. 2000; Converse et al. 2006; Lee et al. 2008). The study plots were separated by a minimum distance of 100 m to enhance statistical independence and to consider rodent movement distance (Lee and Rhim 2016). Each study plot was 0.81 ha (90 × 90 m) in size.

Rodents were captured using Sherman live traps (H. B. Sherman Traps, Inc., FL, USA) placed in 7 × 7 grids with 15-m spacing in a total of 49 traps in each study plot. Rodents were live-trapped over three consecutive nights each month from May to October in 2014 and 2015. Traps were baited with peanuts and checked each morning. We recorded the species, sex, weight, and reproductive condition of each trapped rodent. Toe-clippings were used for individual identification, and individuals were immediately released in the same area where they were captured (Rhim et al. 2013).

We recorded microhabitat factors in 0.01 ha circles (5.64 m in radius) around each trapping station (49 stations per study plot). We recorded the number and volume of felled trees on the ground (parts of thinned trees or fallen trees), the number of stand trees, and the diameter at breast height of each standing tree. We classified vegetation vertical layers into ground (0–1 m), understory (1–2 m), mid-story (2–8 m), sub-overstory (8–20 m), and overstory (>20 m). Foliage cover in each vegetation layer was measured and classified as: 0 (percentage cover = 0%), 1 (1–33%), 2 (34–66%), and 3 (67–100%) (Son et al. 2017). Experimental protocols for the treatment and care of rodents adhered to the guidelines of the local ethics committee (Institutional Animal Care and Use Committee, Chung-Ang University; approval number: 2014-005). This study did not involve protected or endangered species.

### Statistical analysis

The number of captured rodents and the microhabitat factors were tested for normality using a Shapiro-Wilk test before statistical analyses. Next, the multicollinearity of independent variables was tested using the Spearman rank-sum test. When a pair was highly correlated ( $r \geq 0.7$ ), we removed the independent variable with the lowest correlation with response variables or less ecological meaning (Carrilho et al. 2017; Lee et al. 2018). Accordingly, we removed the number of standing and felled trees in the stand from further statistical analysis.

We conducted three statistical analyses using the generalized linear mixed model (GLMM; Zuur et al. 2009) to confirm the effect of tree thinning on microhabitat variables and small rodent populations over time. The first GLMM procedure was performed to evaluate the effect of tree thinning on microhabitat conditions using the site as a random factor (microhabitat factor ~ stands\*year + [1|site]) (R packages: lme4; Bates et al. 2015). The second GLMM procedure was conducted to explain the responses of small rodents to tree thinning over time using the site as random factor (no. of captured individuals ~ stands\*year + [1|site]). Lastly, the third GLMM procedure was carried out to find key factors for habitat selection by small rodents (no. of captured individuals ~ ground vegetation + understory vegetation + mid-story vegetation + sub-overstory vegetation + overstory vegetation + basal area + volume of felled trees + [1|site]). Models were selected using the Akaike information criterion with corrections for small samples (AICc;

**Table 1.** Results of generalized linear mixed models explaining variation in microhabitat factors using stands and year.

Microhabitat factor	Model	AICc	$\Delta$ AICc	$\omega_i$
GV	[Intercept + Stands + Year + Stands*Year]	1673.50	0.00	1.00
UV	[Intercept]	1288.57	0.00	0.73
	[Intercept + Year]	1290.51	1.95	0.27
MV	[Intercept + Stands]	1603.80	0.00	1.00
SOV	[Intercept + Stands + Year]	1609.84	0.00	0.36
	[Intercept + Stands + Year + Stands*Year]	1609.90	0.06	0.35
	[Intercept + Stands]	1610.28	0.45	0.29
OV	[Intercept + Year]	1027.00	0.00	0.61
	[Intercept]	1027.91	0.91	0.39
BAS	[Intercept + Stands]	5533.96	0.00	0.57
	[Intercept + Stands + Year]	5534.53	0.57	0.43
VFT	[Intercept + Stands + Year + Stands*Year]	11,950.30	0.00	1.00

GV: ground vegetation; UV: understory vegetation; MV: mid-story vegetation; SOV: sub-overstory vegetation; OV: overstory vegetation; BAS: basal area; VFT: volume of felled trees.

Models were selected using Akaike Information Criterion with corrections for small sample size (AICc) ( $\Delta$ AICc < 2).

Burnham and Anderson 2002; Kang et al. 2013) that included microhabitat variables. Akaike weights ( $\omega$ ) described the probability of each model. We selected models with  $\Delta$ AICc < 2 and performed model averaging procedures (R packages: MuMin; Bartoń 2016). Values were considered statistically significant at  $p < 0.05$ . All statistical analyses were conducted using R (R Core Team 2017).

## Results

### Effects of tree thinning on microhabitat conditions

In the first GLMM procedure, the interaction between stand and year was included in the ground and sub-overstory vegetation and the volume of felled trees models (Table 1). The understory and overstory vegetation models had the null model as first and second model, respectively; thus, we excluded these two microhabitat factors from model averaging procedures. Ground vegetation increased more in 2015 than in 2014 ( $\beta = 0.3351$ ,  $Z = 3.63$ ,  $p < 0.001$ ; Table 2). While ground vegetation in 2014 was higher in the control than in the 50% thinned stand ( $\beta = -0.5949$ ,  $Z = -3.55$ ,  $p < 0.001$ ), that in 2015 was lower in the control than in the 50% thinned stand ( $\beta = 0.6481$ ,  $Z = 4.47$ ,  $p < 0.001$ ). The mid-story vegetation was significantly higher in the control than in the 50% thinned stand ( $\beta = -0.4953$ ,  $Z = -5.73$ ,  $p < 0.001$ ), and in 2014, sub-overstory vegetation was significantly lower in the 50% thinned stand ( $\beta = -0.4389$ ,  $Z = 0.55$ ,  $p < 0.001$ ) than in the control stand. The basal area was the highest in the control, followed by the 25% ( $\beta = -0.6699$ ,  $Z = 7.18$ ,  $p < 0.001$ ) and the 50% thinned stands ( $\beta = -0.7848$ ,  $Z = 8.38$ ,  $p < 0.001$ ). The volume of felled trees decreased more in 2015 than in 2014 ( $\beta = -0.2421$ ,  $Z = -7.21$ ,  $p < 0.001$ ). In 2015, this volume was the highest in the 25% thinned stand ( $\beta = 0.3133$ ,  $Z = 6.83$ ,  $p < 0.001$ ), followed by the 50% thinned ( $\beta = 0.0977$ ,  $Z = 2.16$ ,  $p < 0.001$ ) and the control stand.

### Effects of tree thinning on small rodents

Three rodent species were captured during the study period; striped field mice *Apodemus agrarius* (146

captures of 113 individuals), Korean field mice *Apodemus peninsulae* (311 captures of 214 individuals), and Korean red-backed voles *Myodes regulus* (579 captures of 441 individuals). *M. regulus* was the most abundant species in the study area. In the second GLMM procedure, models for *A. agrarius* and *M. regulus* included the stand\*year interaction (Table 3). The abundance of the three rodent species increased more in 2015 than in 2014 (*A. agrarius*:  $\beta = 0.7345$ ,  $Z = 2.69$ ,  $p = 0.007$ ; *A. peninsulae*:  $\beta = 0.3442$ ,  $Z = 3.00$ ,  $p = 0.003$ ; *M. regulus*:  $\beta = 0.5237$ ,  $Z = 4.89$ ,  $p < 0.001$ ; Table 4). *A. agrarius* and *M. regulus* did not respond to tree thinning, whereas *A. peninsulae* preferred the control over the 50% thinned stand ( $\beta = -1.1189$ ,  $Z = -3.71$ ,  $p < 0.001$ ).

### Relationship between microhabitat conditions and small rodents

In the third GLMM procedure, twenty different models were built and selected ( $\Delta$ AICc < 2): nine models for *A. agrarius*, seven models for *A. peninsulae*, and four models for *M. regulus* (Table 5). The models for *A. agrarius* and *A. peninsulae* included seven variables: the ground, understory, mid-story, sub-overstory, and overstory vegetation, the basal area, and the volume of felled trees. The four *M. regulus* models consisted of four variables: the ground, understory, mid-story, and sub-overstory vegetation. The models for the three rodent species tended to use sites with abundant ground vegetation (*A. agrarius*:  $\beta = 0.5942$ ,  $Z = 4.95$ ,  $p < 0.001$ ; *A. peninsulae*:  $\beta = 0.1935$ ,  $Z = 2.88$ ,  $p = 0.004$ ; *M. regulus*:  $\beta = 0.2166$ ,  $Z = 4.66$ ,  $p < 0.001$ ; Table 6). *A. agrarius* preferred sparse mid-story ( $\beta = -0.2300$ ,  $Z = 2.43$ ,  $p = 0.015$ ) and sub-overstory vegetation ( $\beta = -0.1966$ ,  $Z = 2.10$ ,  $p = 0.036$ ).

## Discussion

Tree thinning in a *L. kaempferi* forest caused significant differences in microhabitat factors between the control and thinned stands, especially, the 50% thinned stand. Tree thinning changes vegetation structure and species composition (Thomas et al. 2012). As the habitat stabilized over time after the disturbance caused by thinning, ground vegetation increased more in 2015

**Table 2.** Descriptive statistics from the selected models of stands and year explaining variation in microhabitat factors.

Microhabitat factor	Variable	$\beta$	S.E.	Z	p	95% C.I.	
						Lower	Higher
GV	Intercept	0.7085	0.110	6.47	<0.001	0.4654	0.9452
	2015	0.3351	0.092	3.63	<0.001	0.1548	0.5171
	25% thinned	-0.0296	0.155	-0.19	0.849	-0.3693	0.3106
	50% thinned	-0.5949	0.168	-3.55	<0.001	-0.9512	-0.2361
	25% thinned:2015	0.0687	0.131	0.53	0.599	-0.1875	0.3251
MV	50% thinned:2015	0.6481	0.145	4.47	<0.001	0.3655	0.9342
	Intercept	0.6723	0.054	12.48	<0.001	0.5667	0.7778
	25% thinned	-0.0814	0.078	-1.05	0.294	-0.2335	0.0706
SOV	50% thinned	-0.4953	0.086	-5.73	<0.001	-0.6647	-0.3260
	Intercept	0.6713	0.067	10.08	<0.001	0.5408	0.8017
SOV	2015	0.0530	0.096	1.36	0.583	-0.1360	0.2420
	25% thinned	-0.1180	0.087	3.57	0.173	-0.2876	0.0516
	50% thinned	-0.4389	0.123	0.55	<0.001	-0.6801	-0.1976
	25% thinned:2015	0.0406	0.148	0.28	0.783	-0.2485	0.3297
	50% thinned:2015	0.3045	0.160	1.90	0.057	-0.0096	0.6185
BAS	Intercept	2.8961	0.066	44.03	<0.001	2.7672	3.0250
	2015	-0.0290	0.024	1.21	0.23	-0.0761	0.0181
	25% thinned	-0.6699	0.093	7.18	<0.001	-0.8528	-0.4871
VFT	50% thinned	-0.7848	0.094	8.38	<0.001	-0.9684	-0.6012
	Intercept	3.0090	0.176	17.13	<0.001	2.6022	3.4155
VFT	2015	-0.2421	0.034	-7.21	<0.001	-0.3080	-0.1763
	25% thinned	-0.0204	0.248	-0.08	0.935	-0.5955	0.5548
	50% thinned	0.1146	0.248	0.46	0.644	-0.4607	0.6892
	25% thinned:2015	0.3133	0.046	6.83	<0.001	0.2234	0.4033
	50% thinned:2015	0.0977	0.045	2.16	<0.001	0.0092	0.1862

GV: ground vegetation; MV: mid-story vegetation; SOV: sub-overstory vegetation; BAS: basal area; VFT: volume of felled trees.

**Table 3.** Results of generalized linear mixed models explaining variation in rodent species density (number of individuals per trapping station) using stands and year.

Species	Model	AICc	$\Delta$ AICc	$\omega_i$
<i>Apodemus agrarius</i>	[Intercept + Year]	740.88	0.00	0.51
	[Intercept + Stands + Year + Stands*Year]	740.98	0.10	0.49
<i>Apodemus peninsulae</i>	[Intercept + Stands + Year]	1091.80	0.00	1.00
	[Intercept + Year]	1569.00	0.00	0.41
<i>Myodes regulus</i>	[Intercept + Stands + Year]	1569.06	0.06	0.40
	[Intercept + Stands + Year + Stands*Year]	1570.46	1.46	0.20

Models were selected using Akaike Information Criterion with corrections for small sample size (AICc) ( $\Delta$ AICc < 2).

**Table 4.** Descriptive statistics from the selected models of stands and year explaining variation in rodent species abundances.

Species	Variable	$\beta$	S.E.	Z	p	95% C.I.	
						Lower	Higher
<i>Apodemus agrarius</i>	Intercept	-1.9484	0.278	7.00	<0.001	-2.4938	-1.4031
	2015	0.7345	0.273	2.69	0.007	0.1988	1.2702
	25% thinned	0.4258	0.455	0.94	0.349	-0.4656	1.3171
	50% thinned	-0.5520	0.533	1.04	0.301	-1.5973	0.4933
	25% thinned:2015	-0.2659	0.425	0.63	0.531	-1.0984	0.5666
<i>Apodemus peninsulae</i>	50% thinned:2015	0.9527	0.507	1.88	0.060	-0.0410	1.9464
	Intercept	-0.4116	0.209	-1.97	0.049	-0.9033	0.0583
	2015	0.3442	0.115	3.00	0.003	0.1198	0.5715
<i>Myodes regulus</i>	25% thinned	-0.5370	0.288	-1.87	0.062	-1.2045	0.1356
	50% thinned	-1.1189	0.302	-3.71	<0.001	-1.8032	-0.4274
<i>Myodes regulus</i>	Intercept	-0.2801	0.167	1.68	0.093	-0.6074	0.0472
	2015	0.5237	0.107	4.89	<0.001	0.3136	0.7337
	25% thinned	-0.4313	0.242	1.78	0.075	-0.9061	0.0434
	50% thinned	0.1224	0.243	0.50	0.615	-0.3547	0.5996
	25% thinned:2015	0.0383	0.228	0.17	0.866	-0.4079	0.4845
50% thinned:2015	-0.2706	0.197	1.37	0.170	-0.6574	0.1162	

than in 2014. The ground vegetation in 2014 was higher in the control than in the 50% thinned stand; however, opposite trend was observed in 2015. Furthermore, we found that mid-story and sub-overstory vegetation and the basal area of standing trees were reduced following tree thinning. Shrubs and grasses in the thinned stands may have benefited from improved sunlight conditions brought about by canopy removal (Chan et al. 2006). However, thinning results in mechanical damage to the ground in the first year

of tree thinning (Lindh and Muir 2004). In our study, mechanical damage was higher in the 50% thinned stand than in the other stands. Consequently, ground vegetation in the 50% thinned stand developed poorly in the first year after tree thinning, although it surged vigorously, the following year as the habitat stabilized and light condition improved. We observed that the volume of felled trees decreased over time. Further, the volume of felled trees in 2015 was the highest in the 25% thinned stand, followed by the 50% thinned

**Table 5.** Results of generalized linear mixed models explaining variation in rodent species density (number of individuals per trapping station) using microhabitat factors.

Species	Model	AICc	$\Delta$ AICc	$\omega_i$
<i>Apodemus agrarius</i>	[Intercept + GV + MV + SOV]	723.47	0.00	0.19
	[Intercept + GV + MV + SOV + BAS]	723.51	0.05	0.19
	[Intercept + GV + UV + MV + SOV]	724.38	0.91	0.12
	[Intercept + GV + UV + MV + SOV + BAS]	724.68	1.22	0.10
	[Intercept + GV + MV + SOV + VFT]	725.03	1.56	0.09
	[Intercept + GV + MV + SOV + OV + BAS]	725.05	1.58	0.09
	[Intercept + GV + MV + SOV + BAS + VFT]	725.19	1.73	0.08
	[Intercept + GV + MV + SOV + OV]	725.38	1.91	0.07
	[Intercept + GV + MV + BAS]	725.41	1.94	0.07
	<i>Apodemus peninsulae</i>	[Intercept + GV]	1095.37	0.00
[Intercept + GV + BAS]		1096.16	0.79	0.17
[Intercept + GV + UV]		1096.32	0.95	0.16
[Intercept + GV + VFT]		1096.89	1.52	0.12
[Intercept + GV + OV]		1097.10	1.73	0.11
[Intercept + GV + SOV]		1097.10	1.73	0.11
[Intercept + GV + MV]		1097.33	1.96	0.09
[Intercept + GV + SOV]		1579.42	0.00	0.42
<i>Myodes regulus</i>	[Intercept + GV]	1580.67	1.25	0.23
	[Intercept + GV + UV + SOV]	1580.96	1.54	0.20
	[Intercept + GV + MV + SOV]	1581.41	1.99	0.16

GV: ground vegetation; UV: understory vegetation; MV: mid-story vegetation; SOV: sub-overstory vegetation; OV: overstory vegetation; BAS: basal area; VFT: volume of felled trees.

Models were selected using Akaike Information Criterion with corrections for small sample size (AICc) ( $\Delta$ AICc < 2).

**Table 6.** Descriptive statistics from the selected models of microhabitat factors explaining variation in rodent species abundances.

Species	Variable	$\beta$	S.E.	Z	p	95% C.I.	
						Lower	Higher
<i>Apodemus agrarius</i>	Intercept	-1.6223	0.157	10.35	<0.001	-1.9296	-1.3150
	GV	0.5942	0.120	4.95	<0.001	0.3590	0.8294
	UV	0.0748	0.073	1.02	0.306	-0.0684	0.2180
	MV	-0.2300	0.095	2.43	0.015	-0.4153	-0.0448
	SOV	-0.1966	0.093	2.10	0.036	-0.3799	-0.0132
	OV	0.0533	0.097	0.55	0.582	-0.1364	0.2430
	BAS	-0.1586	0.111	1.43	0.154	-0.3768	0.0595
	VFT	0.0560	0.083	0.67	0.502	-0.1075	0.2194
<i>Apodemus peninsulae</i>	Intercept	-0.7898	0.217	3.64	<0.001	-1.2148	-0.3648
	GV	0.1935	0.067	2.88	0.004	0.0616	0.3254
	UV	0.0563	0.053	1.06	0.290	-0.0480	0.1606
	MV	0.0154	0.059	0.26	0.795	-0.1005	0.1313
	SOV	-0.0321	0.059	0.54	0.586	-0.1479	0.0836
	OV	-0.0320	0.059	0.54	0.587	-0.1476	0.0836
	BAS	-0.0706	0.064	1.10	0.271	-0.1962	0.0551
	VFT	0.0422	0.058	0.73	0.467	-0.0716	0.1560
<i>Myodes regulus</i>	Intercept	-0.0794	0.160	0.50	0.621	-0.3937	0.2349
	GV	0.2166	0.047	4.66	<0.001	0.1255	0.3077
	UV	-0.0319	0.046	0.70	0.487	-0.1218	0.0580
	MV	0.0101	0.047	0.05	0.830	-0.0820	0.1022
	SOV	0.0817	0.046	0.05	0.077	-0.0090	0.1724

GV: ground vegetation; UV: understory vegetation; MV: mid-story vegetation; SOV: sub-overstory vegetation; OV: overstory vegetation; BAS: basal area; VFT: volume of felled trees.

and the control stands. Various factors, such as sunlight, wind, and time may have affected the decay rate of felled trees (Radtke et al. 2009). The felled trees in the study site decomposed over time; furthermore, the 50% thinned stand, where lighting at ground level was higher than in the other stands, underwent a faster decay process of felled trees.

The rodent species under study included the major rodent species occurring in South Korea. These are forest-dwelling species (Choi and Cho 2007), and the structure of forest stands and bush layers determine their habitation and distribution (Rhim and Lee 2001). In this study, we observed that the densities of the three rodent species increased as the habitat stabilized over time. These rodent communities respond to human disturbance strongly, and their abundances are influenced by anthropogenic pressure (Lee et al. 2008).

We found that *A. agrarius* and *M. regulus* did not differ among stands, whereas *A. peninsulae* avoided the 50% thinned stand. Each rodent species shows species-specific habitat selection preference depending on its requirements for food and shelter (Radespiel et al. 2003). *Apodemus agrarius* and *M. regulus* primarily consume grass and seeds, whereas *A. peninsulae* prefers tree seeds and acorns (Jo 2015; Lee et al. 2020). Therefore, *A. peninsulae* did not show preference for the 50% thinned stand, where distance among trees is greater than that in the other stands.

Consistently with other studies, we found that the three small rodent species under study preferred microhabitats with dense ground vegetation (e.g. habitat generalist rodents of *A. agrarius* and ground-dwelling rodents of *M. regulus*). This pattern indicated that ground vegetation is a key factor for rodents while

selecting habitat in various environments (Coda et al. 2014; Lovera et al. 2019; Lee et al. 2020). This habitat preference of these species depends on the role of ground vegetation cover in providing food and shelter (Lee et al. 2019). Additionally, *A. agrarius* avoided dense mid-story and sub-overstory vegetation; probably because tree canopy in the stand negatively affected the growth of ground vegetation by reducing the amount of sunlight reaching the ground (Bolen and Robinson 2003).

Our results suggest that tree thinning, especially at a rate of 50%, negatively influenced small rodent populations, especially, that of *A. peninsulae*. Previous studies on long-term trends found that tree thinning and the associated mechanical disturbance improved light conditions and restored previous habitat conditions, which proved advantageous for rodent species (Kitagawa et al. 2018). Vegetation cover and felled trees provide shelter for rodents (Camp et al. 2012). The relationship between microhabitat factors and rodents will likely change continuously during successional processes. Long term-monitoring is needed to understand the microhabitat effects of tree thinning on rodents' populations at the *L. kaempferi* forests.

## Conclusions

Tree thinning altered microhabitat factors and severely, disturbed microhabitat conditions in the first year, particularly in the 50% thinned stand; this stand resulted in unsuitable habitats for *A. peninsulae*. However, the study sites stabilized over time. Microhabitat factors can be manipulated by different forest management practices. Moderate tree thinning such as 25% in this study may allow a convenient balance between biodiversity conservation and human demands for forest resources.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Funding

This work was supported by the National Research Foundation of Korea under Grant [2019R1F1A1059744].

## ORCID

Jae-Kang Lee  <http://orcid.org/0000-0001-6226-8676>  
 Hyun-Su Hwang  <http://orcid.org/0000-0001-7730-4027>  
 Tae-Kyung Eom  <http://orcid.org/0000-0002-2148-1814>  
 Shin-Jae Rhim  <http://orcid.org/0000-0003-3098-1148>

## References

Ares A, Berryman SD, Puettmann KJ. 2009. Understory vegetation response to thinning disturbance of varying complexity in coniferous stands. *Appl Veg Sci*. 12(4):472–487.  
 Bartoń K. 2016. MuMIn: multi-model inference. R package version 1.15.6. <https://CRAN.R-project.org/package=MuMIn>.

Bates D, Maechler M, Bolker B, Walker S. 2015. Fitting linear mixed-effects models using lme4. *J Stat Softw*. 67:1–48.  
 Bermejo T, Traveset A, Willson MF. 1998. Post-dispersal seed predation in the temperate rainforest of Southeast Alaska. *Can Field-Nat*. 112(3):510–512.  
 Bolen EG, Robinson W. 2003. *Wildlife ecology and management*. Upper Saddle River (NJ): Prentice Hall.  
 Burnham KP, Anderson DR. 2002. *Model selection and multi-model inference: a practical information-theory approach*. New York (NY): Springer.  
 Camp MJ, Rachlow JL, Woods BA, Johnson TR, Shipley LA. 2012. When to run and when to hide: the influence of concealment, visibility, and proximity of refugia on perceptions of risk. *Ethology*. 118(10):1010–1017.  
 Carey AB, Harrington CA. 2001. Small mammals in young forests: implications for management for sustainability. *For Ecol Manage*. 154(1–2):289–309.  
 Carrilho M, Teixeira D, Santos-Reis M, Rosalino LM. 2017. Small mammal abundance in Mediterranean *Eucalyptus* plantations: how shrub cover can really make a difference. *For Ecol Manage*. 391:256–263.  
 Chan SS, Larson DJ, Maas-Hebner KG, Emmingham WH, Johnston SR, Mikowski DA. 2006. Overstory and understory development in thinned and underplanted Oregon Coast Range Douglas-fir stands. *Can J for Res*. 36(10):2699–2711.  
 Choi TY, Cho HM. 2007. *Encyclopedia of wildlife field sign*. Paju: Dolbegae.  
 Coda J, Gomez D, Steinmann AR, Priotto J. 2014. The effects of agricultural management on the reproductive activity of female rodents in Argentina. *Basic Appl Ecol*. 15(5):407–415.  
 Converse SJ, Block WM, White GC. 2006. Small mammal population and habitat responses to forest thinning and prescribed fire. *For Ecol Manage*. 228(1–3):263–273.  
 Cummings J, Reid N. 2008. Stand-level management of plantations to improve biodiversity values. *Biodivers Conserv*. 17(5): 1187–1211.  
 Dawson RD, Bortolotti GR. 2000. Reproductive success of American kestrels: the role of prey abundance and weather. *Condor*. 102(4):814–822.  
 Durak T. 2012. Changes in diversity of the mountain beech forest herb layer as a function of the forest management method. *For Ecol Manage*. 276:154–164.  
 Escobar MAH, Uribe SV, Chiappe R, Estades CF. 2015. Effect of clearcutting operations on the survival rate of a small mammal. *PLoS One*. 10(3):e0118883.  
 Homyack JA, Harrison DJ, Krohn WB. 2005. Long-term effects of precommercial thinning on small mammals in northern Maine. *For Ecol Manage*. 205(1–3):43–57.  
 Ito S, Ishigami S, Mitsuda Y, Buckley GP. 2006. Factors affecting the occurrence of woody plants in understory of sugi (*Cryptomeria japonica* D. Don) plantation in a warm-temperate region in Japan. *J for Res*. 11(4):243–251.  
 Jo YS. 2015. *Mammals of Korea: conservation and management* [PhD dissertation]. Lubbock (TX): Texas Tech University.  
 Kalies E, Covington W, Chambers C, Rosenstock W. 2010. How do thinning and burning treatments in southwestern conifer forests in the United States affect wildlife density and population performance? *CEE Rev*. 09–005. SR66.  
 Kang JH, Son SH, Kim KJ, Hwang HS, Rhim SJ. 2013. Effects of logging intensity on small rodents in deciduous forests. *J Anim Vet Adv*. 12(2):248–252.  
 Kirkland GL, Kirkland JR. 1990. Patterns of initial small mammal community change after clearcutting of temperate North American forests. *Oikos*. 59(3):313–320.  
 Kitagawa R, Ueno M, Masaki T. 2018. Initial effects of thinning and concomitant disturbance on the understory woody community in Japanese cedar plantation. *J Res*. 23(2):120–128.  
 Korea Forest Service. 2012. *Characteristics of forest structure and wildlife caused by forest practices*. Seoul: Korea Forest Service.  
 Korea Forest Service. 2018. *Statistical yearbook of forestry*. Seoul: Korea Forest Service.

- Krojerová-Prokešová J, Homolka M, Barančková M, Heroldová M, Baňář P, Kamler J, Purchart L, Suchomel J, Zejda J. 2016. Structure of small mammal communities on clearings in managed European forests. *For Ecol Manage.* 367:41–51.
- Kuehne C, Weiskittel AR, Fraver S, Puettmann KJ. 2015. Effects of thinning-induced changes in structural heterogeneity on growth, ingrowth, and mortality in secondary coastal Douglas-fir forests. *Can J for Res.* 45(11):1448–1461.
- Lee JK, Hwang HS, Eom TK, Rhim SJ. 2018. Influence of tree thinning on abundance and survival probability of small rodents in a natural deciduous forest. *Turk J Zool.* 42(3):323–329.
- Lee JK, Hwang HS, Eom TK, Rhim SJ. 2019. Ecological factors influencing small rodents in a tree thinned Japanese larch *Larix kaempferi* plantation. *Pak J Zool.* 51:2153–2160.
- Lee JK, Hwang HS, Eum TK, Bae HK, Rhim SJ. 2020. Cascade effects of slope gradient on ground vegetation and small-rodent populations in a forest ecosystem. *Animal Biol.* 70(2):203–213.
- Lee EJ, Lee WS, Rhim SJ. 2008. Characteristics of small rodent populations in post-fire silvicultural management within pine forest. *For Ecol Manage.* 255(5–6):1418–1422.
- Lee EJ, Rhim SJ. 2016. Seasonal home ranges and activity of three rodent species in a post-fire planted stand. *J Vertebr Biol.* 65(2):101–106.
- Lindh BC, Muir PS. 2004. Understory vegetation in young Douglas-fir forests: does thinning help restore old-growth composition? *For Ecol Manage.* 192(2–3):285–296.
- Lovera R, Fernández MS, Cavia R. 2019. Small rodent species on pig and dairy farms: habitat selection and distribution. *Pest Manag Sci.* 75(5):1234–1241.
- National Institute of Forest Science. 2013. Characteristics of small mammal populations caused by forest practices. Seoul: National Institute of Forest Science.
- Newbold T, Hudson LN, Phillips HRP, Hill SLL, Contu S, Lysenko I, Blandon A, Butchart SHM, Booth HL, Day J, et al. 2014. A global model of the response of tropical and subtropical forest biodiversity to anthropogenic pressures. *Proc R Soc B.* 281(1792):20141371.
- R Core Team. 2017. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing.
- Radespiel U, Ehresmann P, Zimmermann E. 2003. Species-specific usage of sleeping sites in two sympatric mouse lemur species (*Microcebus murinus* and *M. ravelobensis*) in Northwestern Madagascar. *Am J Primatol.* 59(4):139–151.
- Radtke PJ, Amateis RL, Prisley SP, Copenheaver CA, Chojnacky DC, Pittman JR, Burkhart HE. 2009. Modeling production and decay of coarse woody debris in loblolly pine plantations. *For Ecol Manage.* 257(3):790–799.
- Rassi P, Hyvärinen E, Juslén A, Mannerloski I. 2010. Suomen lajien uhanalaisuus -punainen kirja 2010. Helsinki: Suomen Ympäristöministeriö & Suomen Ympäristökeskus.
- Rhim SJ, Lee WS. 2001. Habitat preference of small rodents in deciduous forests of north-eastern South Korea. *Mamm Study.* 26(1):1–8.
- Rhim SJ, Son SH, Hwang HS, Park BB, Sung JH, Park CR. 2013. Population dynamics of small mammals in a natural deciduous stand and a Japanese larch *Larix kaempferi* plantation stand. *J Anim Vet Adv.* 12(7):846–851.
- Rouvinen S, Kuuluvainen T. 2005. Tree diameter distributions in natural and managed old *Pinus sylvestris*-dominated forests. *For Ecol Manage.* 208(1–3):45–61.
- Son SH, Hwang HS, Lee JK, Eom TK, Park CR, Lee EJ, Kang JH, Rhim SJ. 2017. Influence of tree thinning on the abundance of mammals in a Japanese larch *Larix kaempferi* plantation. *Anim Cells Syst (Seoul).* 21(1):70–75.
- Sullivan TP, Sullivan DS, Lindgren PMF. 2000. Small mammals and stand-structure in young pine, seed-tree, and old-growth forest, Southwest Canada. *Ecol Appl.* 10(5):1367–1383.
- Thomas A, De Keersmaeker L, Van Calster H, De Schrijver A, Vandekerckhove K, Verstraeten G, Verheyen K. 2012. Diverging effects of two contrasting tree species on soil and herb layer development in a chronosequence of post-agricultural forest. *For Ecol Manage.* 278:90–100.
- Thompson I, Mackey B, McNulty S, Mosseler A. 2009. Forest resilience, biodiversity, and climate change. Montreal: Secretary of the Convention on Biological Diversity.
- Zuur AF, Ieno EN, Walker NJ, Saveliev AA, Smith GM. 2009. Mixed effects models and extensions in ecology with R. New York (NY): Springer.