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

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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.

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.) Carriére (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-Prokesová 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. 2000; Converse et al. 2006; Lee et al. 2008). The study scale, proximity, location, and elevation (Sullivan 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 km². 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 ≥ 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;
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-understory, 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-understory 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.
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 2. Descriptive statistics from the selected models of stands and year explaining variation in microhabitat factors.

| Microhabitat factor | Variable | $\beta$ | S.E. | Z     | p    | Lower | Higher |
|---------------------|----------|--------|------|-------|------|-------|--------|
| GV                  | Intercept| 0.7085 | 0.110 | 6.47  | <0.001 | 0.4654 | 0.9452 |
| 2015                |          | 0.3531 | 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:2015    |          | -0.5949| 0.168 | -3.55 | <0.001 | -0.9512 | -0.2361 |
| 50% thinned:2015    |          | 0.0867 | 0.131 | 0.53  | 0.599 | -0.1875 | 0.3251 |
| MV                  | Intercept| 0.6723 | 0.054 | 12.48 | <0.001 | 0.3655 | 0.9342 |
| 25% thinned         |          | -0.0814| 0.078 | -1.05 | 0.294 | -0.2335 | 0.0706 |
| 50% thinned:2015    |          | -0.4953| 0.086 | -5.73 | <0.001 | -0.6647 | -0.3260 |
| SOV                 | Intercept| 0.6713 | 0.067 | 10.08 | <0.001 | 0.5408 | 0.8017 |
| 2015                |          | 0.0530 | 0.096 | 1.36  | 0.383 | -0.1360 | 0.2420 |
| 25% thinned         |          | -0.1180| 0.087 | 3.57  | 0.173 | -0.2876 | 0.0516 |
| 50% thinned:2015    |          | -0.4389| 0.123 | 0.55  | <0.001 | -0.6801 | -0.1976 |
| 50% thinned:2015    |          | 0.0406 | 0.148 | 0.28  | 0.783 | -0.2485 | 0.3297 |
| 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 | 0.0081 |
| 25% thinned         |          | -0.6699| 0.093 | 7.18  | <0.001 | -0.8528 | -0.4871 |
| 50% thinned:2015    |          | -0.7848| 0.094 | 8.38  | <0.001 | -0.9684 | -0.6012 |
| VFT                 | Intercept| 3.0090 | 0.176 | 17.13 | <0.001 | 2.6022 | 3.4155 |
| 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:2015    |          | 0.1146 | 0.248 | 0.46  | 0.644 | -0.4607 | 0.6892 |
| 50% 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 | $\omega_a$ |
|------------------|---------------------------------|------|--------------|------------|
| Apodemus agrarius| [Intercept + Year]              | 740.88 | 0.00 | 0.51 |
|                   | [Intercept + Stands + Year + Stands-Year] | 740.98 | 0.10 | 0.49 |
| Apodemus peninsulae| [Intercept + Stands + Year]     | 1091.80 | 0.00 | 1.00 |
| Myodes regulus    | [Intercept + Year]              | 1569.00 | 0.00 | 0.41 |
|                   | [Intercept + Stands + Year + Stands-Year] | 1569.06 | 0.06 | 0.40 |

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    | Lower | Higher |
|------------------|----------|--------|------|-------|------|-------|--------|
| Apodemus agrarius| 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 |
| 50% thinned:2015 |          | 0.9527 | 0.507 | 1.88  | 0.060 | -0.0410 | 1.9464 |
| Apodemus peninsulae| 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 |
| 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 |
| Myodes regulus   | 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 |
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 habitat 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...

| Species            | Variable  | β      | S.E.     | Z      | p     | Lower 95% C.I.  | Higher 95% C.I. |
|--------------------|-----------|--------|----------|--------|-------|----------------|-----------------|
| **Apodemus agrarius** | 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       | 0.1336  | 0.111    | 1.43   | 0.154  | -0.3768        | 0.0095          |
|                    | VFT       | 0.0560  | 0.083    | 0.67   | 0.502  | -0.1075        | 0.2194          |
| **Apodemus peninsulae** | 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        | 0.0134  | 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          |
| **Myodes regulus**  | Intercept | -0.0794 | 0.160    | 0.50   | 0.521  | -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.
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. peninsulare. 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. peninsulare. 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.

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