Pakistan J. Zool., vol. 51(6), pp 2153-2160, 2019. DOI: http://dx.doi.org/10.17582/journal.pjz/2019.51.6.2153.2160

Ecological Factors Influencing Small Rodents in a Tree Thinned Japanese Larch *Larix kaempferi* Plantation

Jae-Kang Lee, Hyun-Su Hwang, Tae-Kyung Eom and Shin-Jae Rhim*

School of Bioresource and Bioscience, Chung-Ang University, Ansung 17546, South Korea

ABSTRACT

We used a capture-recapture method to investigate the ecological factor influencing small rodents in a tree thinned Japanese larch *Larix kaempferi* plantation in Mt. Maehwa, Hongcheon, South Korea. The mid-story, understory and ground vegetation coverage, the number of standing and downed trees ha^{-1} and the volume of downed trees ha^{-1} were significantly different between the pre- and post-thinning sessions. Mean density of *Apodemus agrarius*, *A. peninsulae,* and *Myodes regulus* were significantly different between sessions. Monthly captured adults and juveniles of *A. agrarius* and *A. peninsulae* were significantly higher in the post- than in the pre-thinning session. Population sizes were dramatically increased in the post-thinning session. Ground and understory vegetation coverage and number of downed trees ha^{-1} positively influenced the density. The overstory vegetation coverage negatively influenced the density. Tree thinning resulted in well-developed ground and understory vegetation and increasing downed trees might be an important method for forest management and biodiversity conservation.

Article Information
Received 14 August 2018
Revised 12 May 2019
Accepted 09 July 2019
Available online 16 August 2019

Authors' Contribution
JKL and SJR designed the study and wrote the manuscript. HSH and TKE performed field work and analyzed the data.

Key words
Downed tree, Ground vegetation, Population size, Small rodents, Understory vegetation

INTRODUCTION

Many forests are managed for human usage worldwide (Carry and Johnson, 1995). Management can ultimately affect the habitat resources of species in forest ecosystems (Moses and Boutin, 2001; Etcheverry *et al*., 2005; Rebbah et al., 2019). In many cases, habitats are damaged by removing the standing trees and understory vegetation according to forest practices (Franklin *et al*., 2002). There are a variety of silvicultural forest practices ranging from clear-cutting to single tree selection (Sullivan and Sullivan, 2001). The well-known responses of crop trees to thinning include an increase in the stem diameter, crown size, and volume of trees, and a decrease in the mortality of trees (Homyack *et al*., 2004). However, the effect of these tree thinning patterns on small rodents is not clear.

Small rodents represent a huge amount of the faunal biomass in forest ecosystems (Moreira-Arce *et al*., 2015). Moreover, they play important roles as consumers, prey and dispersers of fungi and plants. Rodents prey on the seeds of trees, and can limit natural generation (Levey *et al*., 2002; Lee, 2012). They have been considered indicator species in their habitat (Ausden, 2007), and might be influenced by the habitat elements contributing to habitat complexity, such as standing trees, snags, understory cover and downed trees (Fontúrbel, 2012; Moreira-Arce *et al*., 2015).

Small rodents comprise an essential component of managed coniferous forests (Zabel and Anthony, 2003; Sollmann *et al*., 2015). Moreover, forest management practices could be an influencing factor for mammals in coniferous plantations (Sullivan and Sullivan, 2001; Korea Forest Service, 2012). For example, the post-management changes that occur in habitat variables might affect the on-ground cover, used for nesting and shelter from predators (Homyack *et al*., 2004; Kang *et al*., 2013a).

Silviculture of plantations of Japanese larch *Larix kaempferi* has been performed on a national scale in South Korea since the 1960s. Tree thinning of overstocked Japanese larch plantation has been practiced increasingly to increase the growth rate of trees and reduce competition among them. However, changes in habitat characteristics with thinning of coniferous plantations are poorly understood. Moreover, forest managers have an interest in biological conservation as the basis for sustainable forest management (Homyack *et al*., 2004; Korea Forest Service, 2012).

There is a lack of information on the response of small rodents to tree thinning in the silvicultured Japanese larch plantations in South Korea. This information is essential for the conservation and management of biodiversity and habitat in these plantations. We hypothesized that habitat variables, such as vegetation coverage, standing trees, and downed trees, might be affected by tree thinning, and an

* Corresponding author: sjrhim@cau.ac.kr
0030-9923/2019/0006-2153 $ 9.00/0
Copyright 2019 Zoological Society of Pakistan

increase in the densities and population of small rodents might be observed because they are influenced by these habitat changes. Here, we used the capture-recapture method to investigate small rodent populations close to habitat features that have been changed by tree thinning in a Japanese larch plantation.

MATERIALS AND METHODS

This study was carried out from May to November in 2014 and 2015 in a Japanese larch *Larix kaempferi* plantation (37°40′03″–37°40′17″ N, 127°52′07″–127° 52′13″ E) in Mt. Maehwa, Hongcheon, South Korea. The annual mean temperature was 10.8°C (range 35.7 to –19.6°C) and annual precipitation was 828 mm. The altitude of the study area ranged from 170 – 260 m above sea level. The dominant tree species was Japanese larch, which were planted in 1960. We selected four 90 × 90 m study plots, each of which were divided into a grid pattern, consisting of a 15 × 15 m array for trapping and habitat surveying. Each study plot was spatially separated from the other plots by a distance of 500 m, based on the estimated home range of small rodents (range 1743 to 14692 m^2) in South Korea (Lee and Rhim 2016). There was no small rodent caught on neighboring plots in this study. We divided the study period into pre-thinning (May to November 2014) and post-thinning (May to November 2015) sessions. The trees were thinned in January 2015 in this area.

Habitat variables were measured at each trap station within circles of radius 5.64 m. In each circle, we recorded the species and number of standing trees and the number and volume of downed trees. Within the 5.64–m radius circles, we classified a vertical layer into ground (0–1 m), understory (1–2 m), mid-story (2–8 m), sub-overstory (8–20 m), and overstory (20–30 m) regions. Based on the percentage of cover in each vertical layer, the vegetation coverage was classified into the following four categories: 0 (percent coverage = 0%), 1 (1–33%), 2(34–66%) and 3 (67–100%) (Lee *et al*., 2012; Rhim *et al*., 2012).

We trapped small mammals in each study plot on three consecutive nights per month from May to November in 2014 and 2015. Each study plot (100 × 100 m) had 49 (7 × 7 array) trap stations at 15 m intervals. A Sherman live trap (7.62 × 8.89 × 22.86 cm, LFA trap) was installed at each station. The traps were baited with peanuts and checked each morning (Kang *et al*., 2013a). During the trapping sessions, we recorded the trap location, rodent species, if the individual was new or recaptured, individual identity, and age class. Rodent species were identified by morphometric and fur parameters. Age class was distinguished by tooth wear, sexual organs, pregnancy, and lactation. All captured small rodents were toe-clipped for individual identification and immediately released at the captured trap station (Lee *et al*., 2008; Kang *et al*., 2013b).

For habitat variable and small rodent population analysis, a Mann-Whitney *U* test (Zar, 2010) was carried out to compare the vegetation coverage (ground, understory, mid-story, sub-overstory and overstory), number of standing trees ha^{-1}, number of downed trees ha^{-1}, volume of downed trees ha^{-1}, and monthly captured adult and juvenile small rodents between the pre- and post-thinning sessions. Density (number of individuals ha^{-1}) estimates in each plot were obtained by analyzing the mark-recapture data for each small rodent species using POPAN analysis of the Jolly-Seber stochastic model (Seber, 1982; Lee *et al*., 2012). Means of the 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). Population density estimations were conducted using the MARK 8.0 program. Estimated monthly mean densities of small rodent species were compared using the Kruskal-Wallis test.

We assessed which habitat variables might be sharing small rodent densities by using a generalized linear mixed model (GLMM; Zuur *et al*., 2009) to account for the spatially and temporally nested data (four densities estimated per site × two seasons). First, we ran a normality test (Zar, 2010) on all candidate independent variables. Then, we evaluated the multicollinearity of the parameters by calculating the Spearman correlation coefficient (r) and, for each highly correlated pair (correlation ≥ 0.7; Fowler *et al*., 1998). The parameters with r > 0.7 were excluded from further analysis. We performed a GLMM analysis (R packages: lme4; Density = habitat variable 1 + habitat variable 2 + · · · + [1|plot] + [1|year]) using the trap ID as a random factor, and all possible combinations of the independent variables (Bates *et al*., 2014). The trap ID was used as a random factor because all small rodent individuals can be independently captured in all traps. For every mode, MARK processed the Akaike information criterion (AIC) corrected for a small sample size (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 GLMM. Values were considered statistically significant at $P < 0.05$.

RESULTS

Coverage of mid-story, understory, and ground vegetation were significantly different between the pre- and post-thinning sessions. Coverage of vegetation in the vertical foliage layers, except for the coverage of ground vegetation, was decreased by tree thinning. However, the coverage of ground vegetation was dramatically increased in the post-thinning session. The number of standing trees ha^{-1}, number of downed trees ha^{-1} and volume of downed trees ha^{-1} were significantly different between the pre- and post-thinning sessions in the Japanese larch plantation. The number of standing trees ha^{-1} was decreased by tree thinning. However, the number and volume of downed trees ha^{-1} were higher in the post- than in pre-thinning session (Table I).

During this study, we captured 306 small rodents belonging to three species (438 captures in total): 218 *Apodemus agrarius*, 60 *A. peninsulae,* and 28 *Myodes regulus* individuals. *Apodemus agrarius* was the dominant species in the study area. During the pre-thinning session, only two small rodent species (*A. agrarius* and *A. peninsulae*) were captured in the study area. However, during the post-thinning session, study species (*A. agrarius*, *A. peninsulae*, and *Myodes regulus*) were captured.

The number of monthly captured adults of *A. agrarius* and *A. peninsulae* were significantly higher in the post-thinning than in the pre-thinning session. Moreover, the number of monthly captured juveniles of *A. agrarius* and *A. peninsulae* were significantly different between the pre- and post-thinning sessions (Table II).

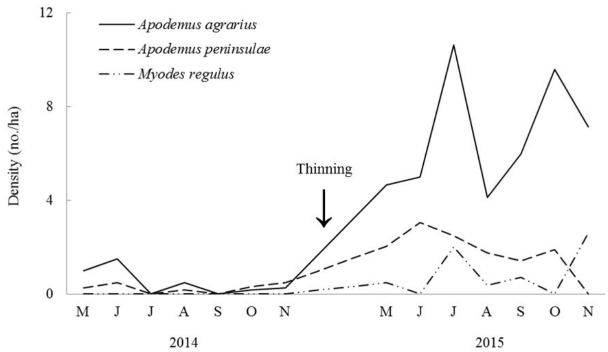

Fig. 1. Mean density (Jolly-Seber) of small rodents during tree thinning in a Japanese larch *Larix kaempferi* plantation from May to November in 2014 and 2015. Letters indicate months from May to November.

Table I.- Differences in habitat variables between pre-thinning and post-thinning sessions in a Japanese larch *Larix kaempferi* plantation resulted with a Mann-Whitney U test. Values are means±SE.

Variable	Session		Z	p
	Pre-thinning	Post-thinning		
Coverage of overstory vegetation (20–30 m)	0.54±0.08	0.37±0.06	–1.37	0.170
Coverage of sub-overstory vegetation (8–20 m)	1.28±0.07	1.13±0.06	–1.02	0.308
Coverage of mid-story vegetation (2–8 m)	2.41±0.07	1.39±0.09	–7.53	<0.001
Coverage of understory vegetation (1–2 m)	1.45±0.08	0.99±0.05	–4.42	<0.001
Coverage of ground vegetation (0–1 m)	1.67±0.08	2.21±0.08	–4.47	<0.001
No. of standing trees ha^{-1}	869.39±37.55	459.73±32.50	–7.24	<0.001
No. of downed trees ha^{-1}	275.84±28.68	1339.33±87.83	–9.75	<0.001
Volume of downed trees ha^{-1} (m^3)	12.33±1.97	18.22±1.86	–4.71	<0.001

Table II.- Differences in the number of monthly captured adults and juveniles of small rodents between the pre-thinning and post-thinning sessions in a Japanese larch *Larix kaempferi* plantation resulted with a Mann-Whitney *U* test. Values are means±SE, represented in ind ha^{-1}.

Age	Species	Session		Z	P
		Pre-thinning	Post-thinning		
Adult	*Apodemus agrarius*	1.07±0.21	5.64±0.98	–3.72	0.001
	Apodemus peninsulae	0.64±0.13	2.14±0.51	–2.15	0.039
	Myodes regulus	-	0.71±0.30	2.41	0.114
Juvenile	*Apodemus agrarius*	0.21±0.07	4.14±0.22	–3.20	0.002
	Apodemus peninsulae	-	0.64±0.15	–2.69	0.050
	Myodes regulus	-	0.43±0.13	2.12	0.210

The estimated mean density of the three species studied were significantly different during the study period in the Japanese larch plantation (Kruskal-Wallis test, $\chi^2 = 12.45$, $p = 0.002$) (Fig. 1). The density of captured *A. agrarius* (Mann-Whitney U test, $Z = -4.10$, $p < 0.001$) and *A. peninsulae* ($Z = -2.60$, $p = 0.011$) individuals were significantly different, but higher in the post-thinning session. However, we found no significant difference in the density of *M. regulus* individuals between the pre- and post-thinning sessions. The overall density for study species significantly increased from 1.93 ind ha^{-1} in the pre-thinning session to 13.71 ind ha^{-1} in the post-thinning session (Mann-Whitney *U* test, $Z = -4.17$, $p < 0.001$).

The estimated densities of *A. agrarius* and *A. peninsulae* in the pre-thinning session were 9.00 and 4.00 ind ha^{-1} respectively. In the post-thinning session, the estimated densities of these species were over 3-6 times greater than those in the pre-thinning session. Moreover, the estimated density of *M. regulus* dramatically increased from 0 ind ha^{-1} in the pre-thinning session to 7.00 ind ha^{-1}

Table III.- Estimation of the densities (no. ha^{-1}) of small rodent species between the pre-thinning and post-thinning sessions in a Japanese larch *Larix kaempferi* plantation resulted with POPAN analysis of the Jolly-Seber stochastic model. Values are means±SE, represented in ind ha^{-1}. 95% CI: 95% confidence interval.

Species	Session			
	Pre-thinning		Post-thinning	
	Size	95% CI	Size	95% CI
Apodemus agrarius	9.00±0.00	9.00–9.00	61.22±7.14	53.46–85.86
Apodemus peninsulae	4.00±0.00	4.00–4.00	13.12±1.90	11.47–20.51
Myodes regulus	-	-	7.00±0.00	7.00±0.00
Total	13.00±0.00	13.00–13.00	83.84±7.93	74.25–108.56

Table IV.- Models based on the correlated Akaike information criterion (AIC$_c$) built to explain the density of the small rodent species ranked by the △AIC$_c$ value resulting from the generalized linear mixed model.

Species	Models	AIC$_c$	△AIC$_c$	ω_i
Apodemus agrarius	[intercept + coverage of ground + coverage of understory + coverage of overstory + No. of trees ha^{-1}]	442.40	0.00	0.14
	[intercept + coverage of ground + coverage of understory + No. of trees ha^{-1}]	442.46	0.06	0.14
	[intercept + coverage of ground + coverage of understory + coverage of mid-story + No. of trees ha^{-1}]	443.32	0.92	0.09
	[intercept + coverage of ground + coverage of understory + coverage of mid-story + coverage of overstory + No. of trees ha^{-1}]	443.52	1.11	0.08
	[intercept + coverage of ground + coverage of understory + coverage of sub-overstory + coverage of overstory + No. of trees ha^{-1}]	444.17	1.76	0.06
	[intercept + coverage of ground + coverage of understory + coverage of overstory + No. of trees ha^{-1} + volume of downed trees]	444.30	1.90	0.05
	[intercept + coverage of ground + coverage of understory + coverage of sub-overstory + No. of trees ha^{-1}]	444.38	1.98	0.05
Apodemus peninsulae	[intercept + No. of trees ha^{-1}]	252.03	0.00	0.07
	[intercept + coverage of mid-story + No. of trees ha^{-1}]	252.16	0.13	0.07
	[intercept + coverage of mid-story]	252.48	0.45	0.06
	[intercept + coverage of understory + coverage of mid-story + No. of trees ha^{-1}]	253.93	1.90	0.03
	[intercept + coverage of understory + No. of trees ha^{-1}]	253.97	1.94	0.03
	[intercept + coverage of sub-overstory + No. of trees ha^{-1}]	253.99	1.96	0.03

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

Species	Variables	Coefficient	SE	Z	P	95% CI
Apodemus agrarius	Intercept	0.2763	0.4730	0.58	0.559	-0.6507–1.2033
	Coverage of ground vegetation	0.3447	0.1074	3.21	0.001	0.1343–0.5552
	Coverage of understory vegetation	-0.3050	0.1264	2.41	0.116	-0.5527–-0.0573
	Coverage of mid-story vegetation	-0.1051	0.0987	1.06	0.287	-0.2986–0.0885
	Coverage of sub-overstory vegetation	-0.0681	0.1259	0.54	0.588	-0.1786–0.3149
	Coverage of overstory vegetation	-0.2095	0.1462	1.43	0.152	-0.4960–0.0770
	No. of standing trees ha^{-1}	-0.0015	0.0003	4.98	<0.001	-0.0021–-0.0009
	Volume of downed trees ha^{-1}	0.0022	0.0044	0.50	0.620	-0.0107–0.0064
Apodemus peninsulae	Intercept	-0.8668	0.5757	1.51	0.132	-1.9951–0.2616
	Coverage of understory vegetation	0.0953	0.1989	0.48	0.632	-0.2945–0.4851
	Coverage of mid-story vegetation	-0.2807	0.1744	1.61	0.108	-0.6225–0.0610
	Coverage of sub-overstory vegetation	-0.0832	0.2348	0.35	0.723	-0.5433–0.3770
	No. of standing trees ha^{-1}	-0.0009	0.0005	1.84	0.066	-0.0018–0.0001

in the post-thinning session. The total estimated densities of small rodents were larger in the post-thinning session (Table III).

The best model of density of small rodent species in a Japanese larch plantation had an Akaike weight (ω) of 0.03–0.14. Seven models fulfilled the criteria defined as best models ($\triangle AIC_c < 2$) for *A. agrarius*. Moreover, six models were defined for *A. peninsulae* (Table IV). The ground and understory vegetation coverage were highly positive correlated, and the number of standing trees ha^{-1} were highly negative correlated with the density of *A. agrarius* (Table V).

DISCUSSION

In this study, study species shared the same forest ecosystem. The three captured species are the most common and dominant small rodent species in the forests of South Korea. These species exhibit low forest-type specificity, have a broad diet, and are associated with abundant understory cover (Yoon, 1992; Lee *et al*., 2008). The densities of small rodents were different between the pre and post-thinning sessions, suggesting that individual species were influenced by tree thinning in the studied Japanese larch plantation.

Dramatic changes in the density of small rodents were observed in the post-thinning session in this study. In general, forest management changes the habitat structure by removing vegetation (Hunter, 1999). The conservation and management of biodiversity can be achieved by a combination of forest practices that provide a diverse forest age, class, structure, and function (Kang *et al*., 2013b; Hwang *et al*., 2014). Human-induced changes, such as thinning in silvicultured plantations, have direct influences on animal populations (Schmid-Holmes and Drickamer, 2001).

The changes in habitat variables and structure that result from tree thinning will likely positively affect some animal species (Homyack *et al*., 2004). Especially, small rodents are frequently positively related with more dense habitats, which are characterized by a high understory cover (Greenberg *et al*., 2006; Knapp *et al*., 2013). Higher canopy coverage might limit important resources for small rodents by reducing the understory structure and vegetation (Sollmann *et al*., 2015). Downed trees are also an important habitat factor, as they support food resources and provide cover from predators (Ecke *et al*., 2002; Vanderwel *et al*., 2010).

In this study, *Apodemus agrarius* was positively associated with ground vegetation and downed trees. Thinning resulted in a substantially denser coverage of ground vegetation in the post-thinning session than in the pre-thinning session. Moreover, the volume of downed trees was dramatically increased by tree thinning (Table 1). The denser ground vegetation and higher volume of downed trees provides a suitable microhabitat for food resources, such as lichen, fungi, and insects (Zabel and Anthony, 2003). However, the volume of downed trees was not a significant predictor of the best model in this study. Moreover, the number of standing trees ha^{-1} was negatively associated with the density of *A. agrarius*. This suggests that the decrease of number of standing trees ha^{-1} caused by thinning would be beneficial to the species.

An area with a high amount available resource could affect the survival and reproduction of animals (Lindström, 1999). Our study supported the prediction that animal reproduction is affected by tree thinning. Based on the number of juveniles, reproduction in the study species was significantly higher in the post- than in pre-thinning session. Given the response in small rodents to tree thinning, as well as the increase in ground vegetation and decrease of standing trees ha^{-1} in the studied Japanese larch plantation, it is possible that the small rodent populations in this landscape could benefit from tree thinning to increase their survival and reproduction.

The presence of relatively higher ground cover after tree thinning could explain the increased presence of these species, considering that ground cover is an ecologically important habitat variable for them (Amacher *et al*., 2008; Moreira-Arce *et al*., 2015); it provides a substrate for the maintenance of food and shelter (Sullivan and Sullivan, 2001). Moreover, there could be potential increase in the damage to plantations caused by the thinning increasing the small rodent density in post-thinning (Lee *et al*., 2017).

We conclude that small rodent populations will respond to changes in habitat caused by tree thinning. Japanese larch plantation managed with well-developed ground vegetation and a high volume of downed trees could sustain small rodents. An increase in the density of small rodents might be positively related to the density of predators. Therefore, if these habitat variables are enhanced in these man-made habitats, tree thinning might be regarded as an important forest management method for the conservation of biodiversity in Japanese larch plantations.

ACKNOWLEDGEMENTS

This study was supported by the Forest Science and Technology Project (Grant No: S121315L140100) of the Korea Forest Service, Republic of Korea. This research was supported by the Chung-Ang University Graduate Research Scholarship in 2017.

Conflict of interest statement

We declare that we have no conflict of interest.

REFERENCES

Amacher, A.J., Barrett, R.H., Moghaddas, J.J. and Stephens, S.L., 2008. Preliminary effects of fire and mechanical fuel treatments on the abundance of small mammals in the mixed-conifer forest of the Sierra Nevada. *Forest Ecol. Manage*., **255**: 3193–3202. https://doi.org/10.1016/j.foreco.2007.10.059

Ausden, M., 2007. *Habitat management for conservation: A handbook of techniques.* Oxford University Press, UK. https://doi.org/10.1093/acprof:oso/9780198568728.001.0001

Bates, D., Maechler, M., Bolker, B. and Walker, S., 2014. *Lme4: Linear mixed-effects models using Eigen and S4*. R package version 1. 1-7. http:CRAN.R-project.org/package=lme4

Burnham, K.P. and Anderson, D.R., 2002. *Model selection and multi-model inference: A practical information-theory approach*. Springer, USA.

Carry, A.B. and Johnson, M.L., 1995. Small mammals in managed, naturally young and old-growth forests. *Ecol. Appl*., **5**: 336–352. https://doi.org/10.2307/1942026

Ecke, F., Löfgren, O. and Sörlin, D., 2002. Population dynamics of small mammals in relation to forest age and structural habitat factors in northern Sweden. *J. appl. Ecol*., **39**: 781–792. https://doi.org/10.1046/j.1365-2664.2002.00759.x

Etcheverry, P., Ouellet, J.P. and Crête, M., 2005. Response of small mammals to clear-cutting and precommercial thinning in mixed forests of southeastern Quebec. *Can. J. Forest Res.*, **35**: 2813–2822. https://doi.org/10.1139/x05-208

Fontúrbel, F.E., 2012. Does habitat degradation cause changes in the composition of arboreal small mammals? A small-scale assessment in Patagonian temperate rainforest fragments. *Lat. Am. J. Conserv*., **3**: 68-73.

Fowler, J., Cohen, L. and Jarvis, P., 1998. *Practical statistics for field biology.* John Wiley & Sons, USA.

Franklin, J.F., Spies, T.A., van Pelt, R., Carey, A.B., Thornburgh, D.A., Berg, D.R., Lindenmayer, D.B., Harmon, M.E., Keeton, W.S., Shaw, D.C., Bible, K. and Chen, J., 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecol. Manage.,* **155**: 399–423. https://doi.org/10.1016/S0378-1127(01)00575-8

Greenberg, C.H., Otis, D.L. and Waldrop, T.A., 2006. Response of white-footed mice (*Peromyscus leucopus*) to fire and fire surrogate fuel reduction treatments in s southern Appalachian hardwood forest. *Forest Ecol. Manage*., **234**: 355–362. https://doi.org/10.1016/j.foreco.2006.07.022

Homyack, J.A., Harrison, D.J. and Krohn, W.B., 2004. Structural differences between precommercially thinned and unthinned conifer stands. *Forest Ecol. Manage*., **194**: 131–143. https://doi.org/10.1016/S0378-1127(04)00132-X

Hunter, M.L., 1999. *Maintaining biodiversity in forest ecosystems.* Cambridge University Press, UK. https://doi.org/10.1017/CBO9780511613029

Hwang, H.S., Son, S.H., Kang, H. and Rhim, S.J., 2014. Ecological factors influencing the winter abundance of mammals in temperate forest. *Folia Zool.,* **63**: 296–300. https://doi.org/10.25225/fozo.v63.i4.a9.2014

Kang, J.H., Son, S.H., Kim, K.J., Hwang, H.S. and Rhim, S.J., 2013a. Effects of logging intensity on small rodents in deciduous forests. *J. Anim. Vet. Adv*., **12**: 248–252.

Kang, J.H., Son, S.H., Kim, K.J., Hwang, H.S. and Rhim, S.J., 2013b. Characteristics of small mammal populations in thinned and clearcut stands in Japanese larch (*Larix leptolepis*) plantations. *Forest Sci. Tech*., **9**: 151–155. https://doi.org/10.1080/21580103.2013.802658

Knapp, E.E., Skinner, C.N., North, M.P. and Estes, B.L., 2013. Long-term overstory and understory change following logging and fire exclusion in a Sierra Nevada mixed-conifer forest. *Forest Ecol. Manage*., **310**: 903–910. https://doi.org/10.1016/j.foreco.2013.09.041

Korea Forest Service, 2012. *Characteristics of forest structure and wildlife caused by forest practices.* Korea Forest Service, Korea.

Lee, D.K., 2012 *Ecological management of forests.* Seoul National University Press, Korea.

Lee, E.J., Lee, W.S. and Rhim, S.J., 2008. Characteristics of small rodent populations in post-fire silvicultural management stands within pine forest. *Forest Ecol. Manage*., **255**: 1418–1422. https://doi.org/10.1016/j.foreco.2007.10.055

Lee, E.J. and Rhim, S.J., 2016. Seasonal home ranges and activity of three rodent species in a post-fire planted stand. *Folia Zool*., **65**: 101–106. https://doi.org/10.25225/fozo.v65.i2.a5.2016

Lee, E.J., Rhim, S.J., Son, S.H. and Lee, W.S., 2012. Differences in small-mammal and stand structures between unburned and burned pine stands subjected to two different post-fire silvicultural management practices. *Ann. Zool. Fenn.,* **49**: 129–138. https://doi.org/10.5735/086.049.0301

Lee, W.S., Park, C.R., Rhim, S.J., Hur, W.H., Chung, O.S., Choi, C.Y., Park, Y.S. and Lee, E.J., 2017. *Wildlife ecology and management*. 2nd edn. Life Science Publishing, Korea.

Levey, D.J., Silva, W.R. and Galetti, M., 2002. *Seed dispersal and frugivory: ecology, evolution and conservation.* CABI, UK.

Lindström, J., 1999. Early development and fitness in birds and mammals. *Trends Ecol. Evol.,* **14**: 343–348. https://doi.org/10.1016/S0169-5347(99)01639-0

Moreira-Arce, D., Vergara, P.M., Boutin, S., Simonetti, J.A., Briceño, C. and Acosta-Jamett, G., 2015. Native forest replacement by exotic plantations triggers changes in prey selection of mesocarnivores. *Biol. Conserv.,* **192**: 258–267. https://doi.org/10.1016/j.biocon.2015.09.015

Moses, R.A. and Boutin, S., 2001. The influence of clear-cut logging and residual leave material on small mammal populations in aspen-dominated boreal mixedwoods. *Can. J. Forest Res.* **31**: 483–495. https://doi.org/10.1139/cjfr-31-3-483

Rebbah, A.C., Menaa, M., Telailia, S., Saheb, M. and Maazi, M.C., 2019. Effect of habitat types on breeding bird assemblages in the Sidi Reghis Forests (Oum El Bouaghi, North-Eastern Algeria). *Pakistan J. Zool.,* **51**: 433-447. http://dx.doi.org/10.17582/journal.pjz/2019.51.2.433.447

Rhim, S.J., Kim, K.J., Son, S.H. and Hwang, H.S., 2012. Effect of forest road on stand structure and small mammals in temperate forest. *J. Anim. Vet. Adv.,* **11**: 2540–2547. https://doi.org/10.3923/javaa.2012.2540.2547

Schmid-Holmes, S. and Drickamer, L.C., 2001. Impact of forest patch characteristics on small mammal communities: a multivariate approach. *Biol. Conserv.,* **99**: 293–305. https://doi.org/10.1016/S0006-3207(00)00195-6

Seber, G.A., 1982. *The estimation of animal abundance and repeated parameters.* Charles Griffin & Company, USA.

Sollmann, R., White, A.M., Gardner, B. and Nanley, P.N., 2015. Investigating the effects of forest structure on the small mammal community in frequent-fire coniferous forests using capture-recapture models for stratified populations. *Mammal. Biol.,* 80: 247–254. https://doi.org/10.1016/j.mambio.2015.03.002

Sullivan, T.P. and Sullivan, D.S., 2001. Influence of variable retention harvests on forest ecosystems diversity and population dynamics of small mammals. *J. appl. Ecol.,* **38**: 1234–1252. https://doi.org/10.1046/j.0021-8901.2001.00674.x

Vanderwel, M.C., Malcolm, J.R., Caspersen, J.P. and Newman, M.A., 2010. Fine-scale habitat associations of red-backed voles in boreal mixedwood stands. *J. Wildl. Manage.,* **74**: 1492–1501. https://doi.org/10.1111/j.1937-2817.2010.

tb01276.x

Yoon, M.H., 1992. *Wildlife*. Daewonsa Publishing Company, Korea.

Zabel, C.J. and Anthony, R.G., 2003. *Mammal community dynamics: management and conservation in the coniferous forests of Western North America.* Cambridge University Press, UK. https://doi.org/10.1017/CBO9780511615757

Zar, J.H., 2010. *Biostatistical analysis.* Prentice Hall, USA.

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A. and Smith, G.M., 2009. *Mixed effects models and extensions in ecology with R.* Springer, USA. https://doi.org/10.1007/978-0-387-87458-6