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Differences in small-mammal and stand structures between unburned and burned pine stands subjected to two different post-fire silvicultural management practices

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We examined the abundances of three small-mammal species, Korean field mice (*Apodemus peninsulae*), Korean red-backed voles (*Myodes regulus*), and striped field mice (*A. agrarius*), and a stand structure of unburned and burned stands resulting from two different post-fire silvicultural management practices within a pine forest in South Korea. The habitat structure changed dramatically depending on the post-fire silvicultural practices. Most measured variables of the stand structure and downed trees were significantly different among the differently-managed stands. We captured 776 animals of five species (1114 captures in total) in nine stands, each trapped during the two-year study period. The total abundances of captured small mammals did not differ significantly among the differently-managed stands. Mean Jolly–Seber estimates of the population density of *M. regulus* were 79%–291% higher in the post-burned untreated stand, whereas those of *A. agrarius* were 214%–491% higher in the post-burned Japanese red pine (*Pinus densiflora*) planted stand. The preferred stands for small mammal species were generated by forest fire and post-fire silvicultural practices. The values of understory vegetation, coarse woody debris, and downed trees were most strongly related to small-mammal abundance following post-fire silvicultural practices. Therefore, the effects of post-fire silvicultural practices on small-mammal populations should be considered in the post-fire management of a burned pine forest.

Introduction

Fire is a major agent of ecological disturbance in many biomes throughout the world, from grassy deserts to boreal forests (Briani *et al.* 2004). Usually, there is considerable variation within each fire. Fire and its effects depend on habitat conditions before burning as well as on the sustainability of a wide variety of different communities or species; the intensity, periodicity, and seasonality of fires; landscape context and unburned area, and numerous interactions (Dickson 2000, Baker 2006). The effects of fires on wildlife are frequently classified as either relatively short-term and direct, causing immediate mortality, or movement away from the fire or long-term and indirect (response to changes in habitat structure and post-fire plant succession) (Sullivan *et al*. 1990, Carey & Johnson 1995, Elkinton *et al*. 1996, Smith 2000).

Post-fire management alternatives are hindered to an extent by a lack of clear data on the efficacy of different alternatives (e.g., salvage logging *vs*. no silvicultural entry). Currently, we lack information on the quality of post-fire habitats or how resident wildlife species respond to fire-induced changes in the availability of altered structural elements (Bury *et al*. 2000). Since post-fire changes in mammal communities are generally associated with changes in vegetation structure and composition (Price & Waser 1984, Ojeda 1989), fire events may produce strong changes in populations as well as in the community structure of small mammals (Whelan 1995).

Small mammals must be considered whenever the maintenance of ecological values is a forest management goal (Converse *et al*. 2006). Striped field mice (*Apodemus agrarius*), Korean field mice (*A. peninsulae*), and Korean red-backed voles (*Myodes regulus*) are known as dominant small mammal species in Korea (Won 1967). These species play an important role in the forest ecosystem of Korea as prey for reptilian, avian, and mammalian predators (Baek & Sim 1999, Lee *et al*. 2010), and as consumers of plants and invertebrates (Yoon *et al*. 2004). *Apodemus agrarius* is a generalist in the Korean peninsula, whereas *M. regulus* and *A. peninsulae* prefer the forest as their habitat. Changes in habitat conditions, such as thinning, clear cutting, removal of woody debris, and loss of leaf litter, affect the composition and population dynamics of small mammal species (Rhim & Lee 2001, Lee 2005).

There have been several large-scale pine forests fires in South Korea since the late 1990s. Extensive post-fire silvicultural management practices, such as removal of snags, downed trees, woody debris, and plantation of Japanese red pine (*Pinus densiflora*), for regeneration have been implemented in most of the burned areas (Lee 2005). However, there remains a lack of information and data on changes in small mammal populations following post-fire silvicultural practices in pine forests in South Korea. While post-fire silvicultural management of stands can influence small mammal populations, it is unclear how management-related changes in habitat components influence small mammal populations.

In this study, we studied small mammals by utilizing capture–recapture methods to investigate the differences in small-mammal populations between unburned and burned stands subjected to two different post-fire silvicultural management practices (removal of snags, downed trees, and other debris, followed by planting of Japanese red pine; no removal of materials was followed by natural regeneration) in pine forests in South Korea. This study was designed to test the hypotheses that: (1) stand structure changes in accordance with post-fire silvicultural management practices (H1), and (2) small-mammal populations change in response to post-fire silvicultural management practices affecting stand structure (H2).

Methods

Study area and experimental design

Our study was carried out in a pine-forest area (37°13´N, 128°18´E) in Samchuck, Gangwon Province, South Korea. At this location, the elevation ranges from 250 to 400 m a.s.l., the mean annual temperature and precipitation were 11.8 °C and 1793 mm, respectively. Weather conditions during our study did not differ from the longer-term averages. The dominant tree species in the study area were Japanese red pine (*Pinus densiflora*), Mongolian oak (*Quercus mongolica*), and cork oak (*Q. variabilis*). There were human disturbances during the Korean War (1950–1953), such as cutting, forest fire, etc., that resulted in Japanese red pine being planted in this area. Before the forest fire in our study area, the age of the forest was about 50 years.

A fire in April 2000 burned thousands of hectares of pine forest in the study area. We selected three types of study stands: (1) an unburned stand, (2) post-burned Japanese red pine plantation stand, and (3) post-burned untreated stand. All trees were damaged and dead in both of the burned stands. The experimental design was a randomized-block design with replicate blocks of unburned and burned stands subjected to two different post-fire silvicultural management practices at each of the three locations (blocks) in the study area. These nine stands were selected on the basis of operational scale, proximity, and reasonable grouping into respective blocks based on their location and elevation. The stands within a block were spatially segregated in order to enhance statistical independence; in a given block, the three stands were 1.0–2.5 km apart. The forest conditions of unburned and both burned stands were similar before the fire. Further, whether or not the strands were burned as well as whether or not they were logged after burning did not depend on the inherent differences among the stands.

Stand structure

We measured the habitat conditions at each trapping station (100 stations/stand) within circles 5.56-m in diameter (0.01 ha). For each tree and snag within the circle, we recorded its species and the diameter at breast height (dbh). The number of downed trees and volume of downed coarse woody debris were also recorded in the circle. We classified vertical layers into understory (0–2 m), mid-story (2–5 m), and overstory (5–20 m) within the circles. Coverage was classified into the following four categories based on the percentage of cover of all vascular plants (trees, herbs, and shrubs) in each vertical layer, following Rhim and Lee (1999): 0 (0%), 1 (1%–33%), 2 (34%–66%), and 3 (67%–100%). The number of woody seedlings in each circle was also counted. We conducted the survey in July–August 2008.

We used the vegetation sampling data to construct four variables designed to assess: (1) management intensity, and (2) small mammal habitats. To assess management intensity, we calculated the number of standing trees per ha (TREE) and basal area (BASALAREA) per ha in each of the 100 habitat-survey circles within nine study stands. To assess small mammal habitats, we measured four variables: UNDERVEGE (understory vegetation), CWD (coarse woody debris), DOWNTREE (downed trees), and SEEDLING (woody seedlings). We constructed a coverage index of understory vegetation (UNDERVEGE) using mean coverage indices for each 5.56-m-diameter circle from the habitat survey. We constructed the variable CWD by measuring the volume of coarse woody debris. We calculated downed tree volume (DOWNTREE) from log measurements by assuming that logs were cylindrical and then averaging the volume of logs per study stand. We constructed the variable SEEDLING by calculating the average number of woody seedlings per 5.56-m-diameter circle in each study stand.

Small mammals sampling

We trapped small mammals over four consecutive nights every 2 months in each study stand from April 2007 to December 2008. Trapping grids (100 × 100 m) had 100 (10 × 10 array) trap stations at 10-m intervals with a Sherman live trap at each station (Rhim & Lee 2001). Traps were baited with peanuts and peanut butter, and they were checked in the morning. We recorded the following data: trap location, species, new or recapture, individual identity, and release conditions. All small mammals captured were ear-notched and toe-clipped for individual identification and immediately released at the point of capture (Saitoh 1991). On cold nights, cotton was added to the trap.

Data analysis

Abundance estimates for each sampling grid in each stand were obtained by analysing the mark–recapture data for each small mammal species using the Jolly–Seber stochastic model (Seber 1982). Abundance estimation was conducted using Program MARK 3.2 (White and Burnham 1999).

To analyze stand structure, a randomized-block ANOVA (Zar 1984) was carried out to compare the mean values of variables, including standing trees, basal area, number of downed tree, and woody seedling of the trees. As an additional part of this stand-structure analysis, we analyzed data using ANOVA to compare the mean volume of coarse woody debris and coverage of vegetation among the study stands. The abundance of small mammals was analyzed by repeated measures ANOVA, with 3 managed and 3 replicate stands for each management type and 10 measures through time. Duncan's multiple range test (DMRT) was used in post-hoc comparisons of mean values.

Throughout the analysis, we employed an information-theoretic philosophy of model selection with a focus on multi-model inference (Burnham and Anderson 2002). Tools employed included model selection based on Akaike's Information Criterion (AIC; Akaike 1973) corrected for small sample size (AIC_c; Hurvich & Tsai 1989). Relative importance values were calculated by summing the Akaike weights over all models (Burnham & Anderson 2002).

We modeled species abundance so that we could estimate the impacts of the management variables (TREE, BASALAREA, and TREAT) and habitat variables (UNDERVEGE, CWD, DOWNTREE, and SEEDLING) on population densities. We began by determining which of these factors should be included in the models for each species; thus, we first considered four models: intercept + management + habitat, intercept + management, intercept + habitat, and intercept. We used the top-ranked (based on AIC_c) of these four models to build the models. For each management and habitat effect in the analyses, we computed relative importance values (Burnham and Anderson 2002). Relative importance values were calculated by summing the Akake weight over all models in a balanced set, which included a given effect. We also calculated the model-average estimates of regression coefficients and their 95% confidence limits (Burnham and Anderson 2002). We based our inference on the management and habitat effects on the available evidence, including the AIC_c model selection rankings, relative importance value, and 95% confidence intervals of regression coefficients.

Results

All measured variables of stand structure and downed trees, except the number of standing trees and coverage of mid-story vegetation, were significantly different among the stands (Table 1), with the replanted Japanese red pine forest differing from the unburned and the post-fire untreated forests while the latter two appeared very similar (DMRT: $p = 0.05$).

During the study period, in the nine study stands we captured 776 animals belonging to five species (1114 captures in total) (Table 2). We caught large numbers of the three small-mammal species: 406 Korean field mice (*Apodemus peninsulae*), 321 Korean red-backed voles (*Myodes regulus*), and 355 striped field mice (*A. agrarius*). Amur hedgehog (*Erinaceus amurensis*) and lesser white-toothed shrew (*Crocidura suaveolens*) were only occasionally caught (32 captures).

Of the three major species, the abundance of *A. peninsulae* was higher in the unburned and post-burned untreated stands, whereas its lowest numbers were in the post-burned Japanese red pine planted stand. *Myodes regulus* abundances differed significantly among the stands (repeated measures ANOVA: $F_{2,4} = 10.35$, $p = 0.01$), with the highest numbers recorded in the post-burned untreated stand (DMRT: $p = 0.05$). Abundances of *A. agrarius* also differed significantly among the stands ($F_{2,4} = 5.32$, $p = 0.03$), with the highest number found in the post-burned Japanese red pine planted stand (DMRT: $p = 0.05$). Total abundance of all captured small mammals did not differ significantly among the stands ($F_{2,4} = 1.46$, $p = 0.08$) (Table 2).

Probability of capture (P_c) (Jolly & Dickson 1983) tended to vary among the species, with overall mean values being 45.7% for *A. peninsulae*, 37.3% for *M. regulus*, and 40.1% for *A. agrarius* (Table 3). In our study area, *Apodemus peninsulae*, *M. regulus*, and *A. agrarius* were the principal members of the forest-floor small-mammal communities. Estimates of trappability for the three small mammal species did not differ significantly among the stands ($F_{2,4} = 0.24$, $p = 0.11$).

Mean population densities (indiv. ha^{-1}) obtained from Jolly–Seber estimates of *M. regulus* ($F_{2,18} = 20.49$, $p = 0.001$) and *A. agrarius* ($F_{2,18} = 9.34$, $p = 0.01$) differ significantly among the stands. Whereas, the densities of *A. peninsulae* did not differ among the stands ($F_{2,18} = 0.21$, $p = 0.24$). The overall, combined densities of the three small mammals in the studied stands were not significantly different during two-year study period ($F_{2,18} = -2.58$, $p = 0.43$) (Table 4 and Fig. 1).

The top-ranked model ($r^2 = 0.82$) for explaining the density of *A. peninsulae* was 0.44[intercept] + 0.31[BASALAREA] + 0.28[DOWNTREE]. The secondary-ranked model ($r^2 = 0.64$) was 0.37[intercept] + 0.24[BASALAREA] (Table 5). Of the variables in the top model, the variable with the largest relative importance was basal area (0.51), followed by downed trees (0.43). These two variables were the most impor-

Table 1. Summary of the stand-structure attributes (density, basal area, and coverage), characteristics of downed trees (volume and number of trees), and woody seedlings for the studied stands together with results of a randomized-block ANOVA.

Variables	Stand			*F*	df	*p*
	Unburned (*n* = 3 stands)	Post-burned Japanese red pine planted (*n* = 3 stands)	Post-burned untreated (*n* = 3 stands)			
Number of standing trees per ha	435.7 ± 130.6[a]	42.3 ± 17.0	389.4 ± 108.2	3.02	2,4	0.08
Basal area (m² ha⁻¹)	5.4 ± 2.5	0.5 ± 0.2	3.7 ± 1.8	4.17	2,4	0.02
Coverage of overstory (8–20 m) vegetation	2.1 ± 0.4	–	0.4 ± 0.3	26.41	2,4	0.001
Coverage of sub-overstory (2–8 m) vegetation	1.8 ± 0.6	–	2.1 ± 0.5	16.12	2,4	0.005
Coverage of mid-story (1–2 m) vegetation	1.3 ± 0.4	1.0 ± 0.5	2.1 ± 0.9	3.63	2,4	0.06
Coverage of understory (< 1 m) vegetation	1.1 ± 0.4	2.4 ± 0.6	1.6 ± 0.5	14.16	2,4	0.007
Volume of downed cwd[b] (m³ ha⁻¹)	1.1 ± 0.8	3.3 ± 1.1	5.7 ± 1.4	18.81	2,4	0.005
Number of downed trees per ha	157.6 ± 54.2	33.5 ± 15.3	501.1 ± 120.2	26.12	2,4	0.001
Number of woody seedlings per ha	2435.9 ± 922.4	5853.7 ± 3105.0	4162.6 ± 2623.3	18.69	2,4	0.005

[a] Mean ± S.E. [b] cwd = coarse woody debris.

Table 2. The total numbers of small mammals captured in the studied stands together with the numbers of captured individuals and numbers of times recaptured (in parentheses).

Species	Stand			Total
	Unburned (*n* = 3 stands)	Post-burned Japanese red pine planted (*n* = 3 stands)	Post-burned untreated (*n* = 3 stands)	
Apodemus peninsulae	162 (85, 77)	69 (37, 32)	175 (138, 37)	406 (260, 146)
Myodes regulus	52 (35, 17)	101 (72, 29)	168 (126, 42)	321 (233, 88)
Apodemus agrarius	99 (67, 32)	214 (157, 57)	42 (27, 15)	355 (251, 104)
Erinaceus amurensis	1 (1, 0)	–	–	1 (1, 0)
Crocidura suaveolens	6 (6, 0)	7 (7, 0)	18 (18, 0)	31(31, 0)
Total	320 (194, 126)	391 (273, 118)	403 (309, 94)	1114 (776, 338)

tant with regards to density. All other variables had relative importance values < 0.40 (Table 6).

The top-ranked model (r^2 = 0.73) explaining density of *M. regulus*, was 0.51[intercept] + 0.74[CWD] + 0.29[DOWNTREE]. The second-ranked model (r^2 = 0.60) was the model explaining the density 0.42[intercept] + 0.26[DOWNTREE] + 0.31[UNDERVEGE] (Table 5). Both coarse woody debris (0.57) and downed trees (0.50) were the most important variables with regards to density of *M. regulus*. If there is a 50% increase in coarse woody debris, the modeled relationship for the top model predicted a 37% increase in the density of this species. The number of standing trees had a negative regression coefficient (Table 6).

In the analysis of *A. agrarius* densities, the top-ranked model (r^2 = 0.78) explaining density was 0.69[intercept] + 0.71[SEEDLING] + 0.34[UNDERVEGE]. The second-ranked model (r^2 = 0.52) was 0.53[intercept] + 0.48[UNDERVEGE] (Table 5). The relative importance value for the seedling variable was 0.72, whereas for the understory vegetation variable, it was 0.53 (Table 6). All other variables had relative importance values < 0.40.

Discussion

Fire and post-fire silvicultural management practices examined in this study resulted in changes in small mammal habitat components, stand-structure attributes, characteristics of downed trees, and woody seedlings. Coverage of understory vegetation responded positively to forest

Table 3. Jolly trappability estimates (mean values and 95% confidence limits) for the three small-mammal species captured in the studied stands.

Stand	*Apodemus peninsulae*		*Myodes regulus*		*Apodemus agrarius*	
	Mean (%)	95%CL	Mean (%)	95%CL	Mean (%)	95%CL
Unburned						
1	38.4	18.9–57.8	39.6	23.9–55.3	44.3	9.8–78.8
2	46.0	19.1–73.0	28.4	17.3–39.5	44.8	12.5–77.1
3	52.5	32.9–72.2	41.4	19.7–63.0	38.9	8.5–69.4
Post-burned Japanese red pine planted						
1	40.4	10.7–70.1	43.4	20.0–66.8	38.4	25.8–50.9
2	37.3	20.2–54.3	38.8	19.3–58.2	46.6	36.0–57.2
3	48.9	27.2–70.6	49.0	24.3–49.0	51.7	39.4–64.1
Post-burned untreated						
1	47.2	29.3–65.0	32.6	11.6–53.7	26.4	0.0–56.7
2	43.4	28.2–58.6	25.2	8.7–41.7	38.4	3.8–73.0
3	57.4	43.0–71.8	37.3	11.8–62.9	31.5	3.2–59.9

Table 4. Jolly–Seber population estimates of density (mean ± SE, indiv. ha^{-1}) of small-mammal species in the studied stands together with results of a repeated-measures ANOVA.

Species	Stand			*F*	df	*p*
	Unburned (*n* = 3 stands)	Post-burned Japanese red pine planted (*n* = 3 stands)	Post-burned untreated (*n* = 3 stands)			
Apodemus peninsulae	6.2 ± 1.5	2.2 ± 0.6	6.5 ± 1.3	0.21	2,18	0.24
Myodes regulus	2.6 ± 0.6	4.2 ± 1.0	7.5 ± 1.7	20.49	2,18	0.001
Apodemus agrarius	3.6 ± 1.1	7.7 ± 2.7	1.6 ± 0.4	9.34	2,18	0.01

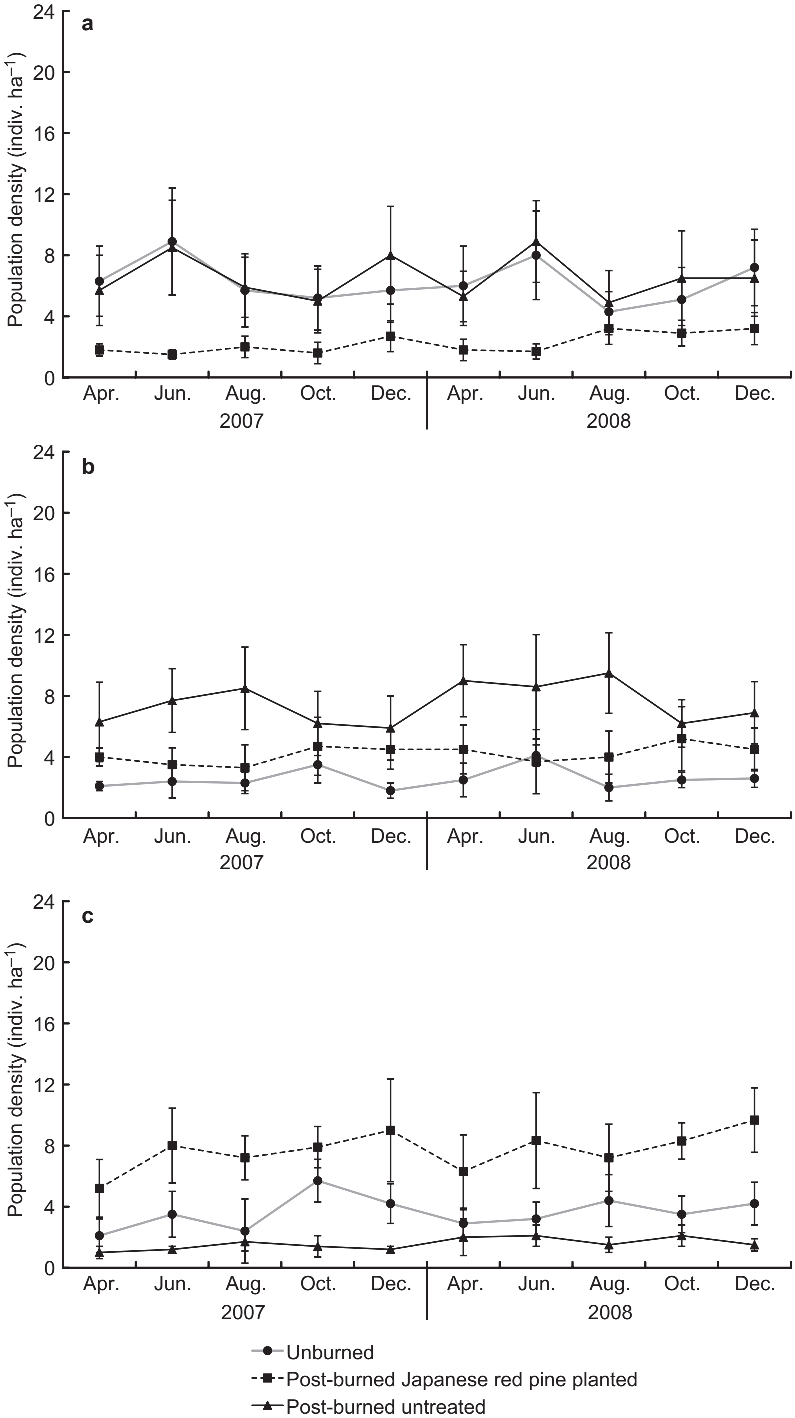

Fig. 1. Population densities (indiv. ha^{-1}) from Jolly–Seber estimates of (**a**) *Apodemus peninsulae*, (**b**) *Myodes regulus* and (**c**) *Apodemus agrarius* in the study stands (three replicate stands for each management).

fire and post-fire silvicultural practices. Cutting of severely damaged trees leads to a high level of coarse woody debris, which can produce a high-quality habitat for species dependant on understory coverage in the post-burned Japanese red pine planted stand (Rhim & Lee 2001, Greenburg 2002, Lindenmayer *et al*. 2008). Changes in vegetation structure due to silvicultural practices were predicted based on vegetation development in gaps and openings in the forest, which provided spatial variability in microhabitats and resources (Halpern & Spies 1995, Sullivan *et al.* 2001, Homyack *et al.* 2004). Clearly, significant differences in habitat variables among the stands supported H1, specifically, that stand structure attributes change in accordance with post-fire silvicultural practices.

A higher number of small mammals were captured in the post-burned untreated stand, which had a higher volume of downed coarse woody debris. Coarse woody debris has been recommended as an element of forested stands that is necessary to maintain small mammal populations (Hagan & Grove 1999, Bowman *et al.* 2000, Fuller *et al.* 2004). Downed and dead woody material has been suggested to provide a habitat for invertebrates, an escape cover from predators (Hayes & Cross 1987), a growing surface for fungi (Hagan & Grove 1999), and a microclimate by retaining moisture (Fraver *et al.* 2002).

Management and habitat variables influence abundances of small mammals, as each of the variables can be manipulated by forest managers through silvicultural practices. We found that the number of downed trees, volume of coarse woody debris, and coverage of understory vegetation were the habitat components most strongly related to small-mammal abundances. However, we also found that additional practices caused variation in abundances, as evidenced by basal areas per ha and the number of woody seedlings. An important determinant of small-

Table 5. Top-ranked (based on AIC_c) models explaining abundance of each of three small-mammal species based on model selection results from weighted regression analysis of small rodent densities as function of block, management, and habitat variables.

Species	Top-ranked model	AIC_c	ΔAIC_c	Akaike's weights (ω_i)
Apodemus peninsulae	Density {intercept + BASALAREA + DOWNTREE}	574.3	0	0.5
	Density {intercept + BASALAREA}	576.3	1.9	0.3
	Density {intercept + DOWNTREE}	577.5	3.2	0.1
Myodes regulus	Density {intercept + CWD + DOWNTREE}	428.7	0	0.6
	Density {intercept + DOWNTREE + UNDERVEGE}	430.1	1.4	0.5
	Density {intercept + DOWNTREE}	433.1	4.4	0.2
	Density {intercept + CWD}	434.6	5.9	0.1
Apodemus agrarius	Density {intercept + SEEDLING + UNDERVEGE}	310.4	0	0.5
	Density {intercept + UNDERVEGE}	312.0	1.6	0.2
	Density {intercept + SEEDLING}	313.0	2.6	0.1

Table 6. Estimated relative importance values (RI), model-averaged effect sizes, and 95% confidence limits (CL) from weighted regression for management (TREE, BASALAREA, and TREAT) and habitat (UNDERVEGE, CWD, DOWNTREE, and SEEDLING) effects on small-mammal abundances.

Variable	*Apodemus peninsulae*		*Myodes regulus*		*Apodemus agrarius*	
	RI	Effect (95%CL)	RI	Effect (95%CL)	RI	Effect (95%CL)
TREE	0.21	0.01 (–0.02 to 0.03)	0.29	–0.25 (–0.93 to 0.43)	0.33	0.04 (–0.13 to 0.21)
BASALAREA	0.51	0.40 (0.03 to 0.76)	0.17	0.45 (0.07 to 0.83)	0.21	0.03 (–1.02 to 1.07)
TREAT	0.34	0.43 (–0.99 to 1.85)	0.31	0.09 (–0.03 to 0.20)	0.25	0.05 (–0.01 to 0.10)
UNDERVEGE	0.31	0.15 (–0.07 to 0.32)	0.36	0.24 (–0.44 to 0.92)	0.53	0.39 (0.02 to 0.76)
CWD	0.37	0.02 (–0.05 to 0.09)	0.57	0.03 (–0.01 to 0.06)	0.38	0.09 (–0.39 to 0.57)
DOWNTREE	0.43	0.33 (0.03 to 0.62)	0.50	0.28 (–0.09 to 0.65)	0.30	0.64 (–0.57 to 1.85)
SEEDLING	0.31	0.03 (–0.03 to 0.10)	0.31	0.07 (0.03 to 0.12)	0.72	0.06 (–0.01 to 0.12)

mammal abundances in this study appeared to be related to post-fire silvicultural practices. Thus, our H2 that small mammal populations change in response to post-fire silvicultural practices was supported with regard to total abundance, trappability, and population density.

Of the habitat variables examined, basal area appeared to have power as a predictor of *A. peninsulae* densities. *Apodemus peninsulae* populations have been positively linked with the availability of downed trees (Lee *et al*. 2008). The amounts of downed trees were different among our stand types. Our population data on *A. peninsulae* indicated an association with the unburned and post-burned untreated stands.

Myodes regulus prefers habitats with a higher volume of coarse woody debris and number of downed trees interspersed by post-fire silvicultural practices. Coarse woody debris was the best predictor of *M. regulus* densities. A positive relationship between *M. regulus* density and coarse woody debris was expected, based on the species' movements, as well as nesting, and feeding behavior (Won 1967, Yoon *et al*. 2004). Downed trees were also an important predictor of *M. regulus* densities. Lower density of standing trees was related to higher *M. regulus* density.

Compared with the post-burned untreated stand, the post-burned Japanese red pine planted stand provided a suitable habitat for *A. agrarius*. This species prefers dense understory ground cover (Won 1967). The number of woody seedlings was the best predictor of *A. agrarius* densities, and coverage of understory vegetation also had power as a predictor. Positive relationships between *A. agrarius* and woody seedlings (Lee 2011) as well as understory vegetation (Lee *et al*. 2008) have previously been documented.

Our results indicate that dense understory coverage may increase the abundance of small mammal populations in the post-fire silvicultural managed stands. There were higher small-mammal abundances in the post-burned untreated stand than in the post-burned Japanese red pine planted stand. Further, our results suggest that retention of coarse woody debris and downed trees may have a critical impact on small-mammal abundances (Mosses & Boutin 2001).

The response to fire and post-fire silvicultural practices by small mammals is likely to vary depending on a plethora of factors, making generalization difficult. This study took place 7–8 years after the fire, and the plants, invertebrates, and vertebrates had had nearly a decade to respond to the fire disturbance. Successional processes will continue to change these post-fire habitats, and thus, this study was but a snapshot in time. There is a need to carefully assess the ecological effects of post-fire silvicultural practices over longer time periods. This study suggests that retaining of the understory cover, woody debris, and downed trees may promote small mammal populations.

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