Journal of Animal and Veterinary Advances 11 (14): 2540-2547, 2012
ISSN: 1680-5593

Effect of Forest Road on Stand Structure and Small Mammals in Temperate Forests

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Abstract: Researchers examined changes in habitat structure and abundance of three small mammal species, Korean field mice (*Apodemus peninsulae*), Korean red-backed voles (*Myodes regulus*) and striped field mice (*A. agrarius*) between 1st year (the 1st trapping session in 2005) and 4th year (the 2nd trappings session in 2008) after forest road construction within deciduous and coniferous stands in Jincheon, Chungbuk province, South Korea. Forest structure differed significantly between forest edge and interior areas in both stands. Number of standing wood, basal area, coverage of understory vegetation and volume of coarse woody debris were higher in deciduous than in coniferous stands. Researchers captured 5 species of small animals, 1196 times in 4 sites during the 2 trapping sessions. The abundances of the three small mammals varied according to the habitat, generally higher in deciduous stands than in coniferous stands and higher in interior areas than in edge areas. In the 2nd trapping session, the abundance of *A. peninsulae* and *M. regulus* had increased and that of *A. agrarius* had decreased in the forest edge compared with the 1st trapping session. Understory vegetation and woody seedlings were the habitat components most strongly related to small mammal abundance at the edge of forest road. Long-term experiments are needed to elucidate the potential effects of forest road on small mammal species.

Key words: Coniferous forest, deciduous forest, forest road, population, small mammals

INTRODUCTION

Habitat loss is perhaps the major threat to forest dwelling species (Fahrig, 2002). Habitat structure has been postulated to be the strongest habitat influence on small mammal diversity and abundance (Dueser and Porter, 1986; Fuller *et al*., 2004). For many species, forest habitat near edges may not be as suitable as interior forest (Murcia, 1995; Harrison and Bruna, 1999). It is accepted that habitat loss has the most severe influence on wildlife, relegating fragmentation to a subordinate role at the landscape scale (Betts *et al*., 2006; St-Laurent *et al*., 2007). Forest roads precipitate fragmentation by dissecting previously large patches into smaller ones and in so doing they create edge habitat along both sides of the road, potentially at the expense of interior habitat (Reed *et al*., 1996; Forman *et al*., 2003). Forest road networks differ greatly in how they developed through time and how they are laid out over terrain (Chung *et al*., 2008). The geographic patterns of roads in forest landscapes differ substantially from place to place with commensurate differences in environmental effects (Spellerberg, 1998; Gucinski *et al*., 2001).

Forest roads and their adjacent road-related environment can be considered as a distinct habitat with impacts at the species, population and landscape scales (Forman and Alexander, 1998). Because some species avoid areas near roads and other are attracted to those areas, animal species composition is affected by habitat fragmentation caused by the presence of forest roads (Vos and Opdam, 1993).

Small mammals are important components of forest ecosystems and function as predators (Maxson and Oring, 1978), prey (Chubbs and Trimper, 1998; Dawson and Bortolotti, 2000), seed dispersers (Ostfeld *et al*., 1997; Bermejo *et al*., 1998) and dispersers of hypogenous fungi spores (Kirkland, 1990). Small mammals are also important herbivores and may significantly influence plant communities and communities of other herbivores. Therefore, small mammals have been considered to be ecological indicators of the effects of forest management practices (Lautenschlager *et al*., 1997). Habitat selection by small mammals is strongly influenced by factors that provide food and/or shelter either directly or indirectly (Morris, 1995; Hansson, 1997; Ecke *et al*., 2002).

In this study, Researchers focus on the effects of forest roads on populations of small mammals in temperate forests of South Korea. Researchers compared small mammal abundances and forest structure between forest edge and interior areas of deciduous and coniferous stands to better understand how forest road

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influences forest structure and the communities of small mammals. This study was designed to test the hypotheses that: stand structure attributes will change in accordance with forest road construction (H1) and characteristics of small mammal populations will change in response to forest road (H2) between forest edge and interior area in 1st and 4th years after forest road construction.

MATERIALS AND METHODS

Study area: The study area was located in the National Forest (36°54'N, 127°18'E) at Baekgok Myeon, Jincheon County, Chungbuk province, South Korea. The elevational range was 300-330 m. The mean annual temperature was 13.2°C and the mean annual precipitation was 1,800 mm. The most dominant tree species were loose flower hornbeam (*Carpinus laxiflora*) and serrata oak (*Quercus serrata*) in deciduous stands and pitch pine (*Pinus rigida*) in coniferous stands. The forest age was about 30-50 years due to human disturbances during the Korean War (1950-1953). After these disturbances, natural regeneration occurred in the deciduous stands and pitch pine was planted in the coniferous stands in this area.

Two sites were established in each of deciduous and coniferous forest along the forest road, a one lane unpaved road of low traffic volume (40-60 vehicles/day). The four study sites consisted of 5 m wide gravel surface and 2 m wide shoulders including drainage ditches on either side. The forest road was constructed in 2004 by the Korean Forest Service. At the forest road sites, the gravel surface, shoulders and ditches were of similar dimensions and road clearing had allowed light to penetrate.

Stand structure: Researchers measured the characteristics of habitat conditions at each trapping station (120 stations/site) within 5.56 m diameter circles (0.01 ha). For each tree and snag within the circle, researchers recorded species and diameter at breast height (dbh). The number of downed woods and volume of downed coarse woody debris also were recorded in the circle. Researchers classified vertical layers into understory (0-1 m), mid-story (1-2 m), sub-overstory (2-8 m) and overstory (>8 m) within the circles. The coverage was classified into the following 4 categories, based on the percentage of cover of all vascular plants (trees, herbs and shrubs) in each vertical layer following Rhim and Lee (2003), 0 (coverage percentage = 0%), 1 (1-33%), 2 (34-66%) and 3 (67-100%). The number of woody seedlings was also counted in each circle. Researchers conducted the surveys in August 2005 and 2008.

Small mammal sampling: Trapping was conducted over 5 consecutive nights in July to September, for both trapping sessions (2005 and 2008). A trapping grid (230×90 m) incorporating 120 trap positions was established at each site. On each side of the road, the grid consisted of 6 rows running parallel to the road at distances of 10, 20, 30, 90, 100 and 110 m from the center of the road. Each row consisted of 10 Sherman live traps placed 10 m apart with 1 trap per position. On each night 120 traps were set.

Traps were baited with peanuts and peanut butter and checked in the morning. Researchers recorded the following data: trap location, species, new or recapture, individual identity, age class (adult and juvenile), sex, body mass and release condition. All small mammals captured were ear-notched for individual identification and immediately released at the point of capture (Rhim and Lee, 2003; Lee *et al*., 2008).

Data analysis: For the analysis of stand structure attributes (standing wood density, basal area and coverage) and characteristics of downed trees (volume and number of trees) and woody seedlings between forest edge (10-30 m from the forest road) and interior (90-110 m from the forest road), Mann-Whitney U-test was conducted to compare with the median value of each variable during the 1st and 2nd trapping sessions in both deciduous and coniferous stands. Also, Researchers analyzed data using one-way ANOVA to compare mean variables of stand structure and small mammal populations of forest edge and interior areas in both stands.

Data analyses used the number of individuals Known To Be Alive (KTBA) as the response variable, i.e., individuals captured in a trapping session or captured subsequently after being captured in a previous trapping session. The effects of location (Table 1) on the number of individuals KTBA of *Apodemus peninsulae*, *Myodes regulus* and *A. agrarius* were examined using ANOVA. Recaptures of *Tamias sibiricus* and *Crocidura suaveolens* were insufficient to be considered in data analysis. Data were pooled over the three sampling times in July-September for both trapping sessions (2005 and 2008). Data collected from traps were pooled into 4 locations (forest edge and forest interior) at each site

Table 1: Effect of location

Location	Side of road	Distance from center of road (m)
Forest edge	Northern	10, 20, 30
Forest interior	Northern	90, 100, 110
Forest edge	Southern	10, 20, 30
Forest interior	Southern	90, 100, 110

Table 2: Summary of stand-structure attributes (density, basal area and coverage), characteristics of downed trees (volume and number of trees) and woody seedlings between forest edge (10-30 m from the forest road) and interior (90-110 m from the forest road) together with results of Mann-Whitney U-test for deciduous stands during the 1st (2005) and the 2nd (2008) trapping sessions in Jincheon and Chungbuk province, South Korea

	Edge			Interior		
Variables	2005	2008	p-value	2005	2008	p-value
No. of standing woods/ha	392.49±60.27[a]	409.42±54.81	0.58	443.52±90.96	451.93±98.26	0.69
Basal area (m^2 ha^{-1})	4.24±0.58	4.31±0.61	0.43	5.01±1.04	5.19±0.87	0.51
Coverage of overstory (>8 m) vegetation	1.49±0.39	1.68±0.64	0.23	2.31±0.45	2.37±0.51	0.84
Coverage of sub-overstory (2-8 m) vegetation	1.52±0.41	1.61±0.45	0.43	1.74±0.72	1.83±0.93	0.21
Coverage of mid-story (1-2 m) vegetation	1.35±0.35	1.30±0.41	0.29	1.49±0.51	1.51±0.62	0.71
Coverage of understory (<1 m) vegetation	0.89±0.09	2.31±0.74	0.01	1.37±0.49	1.29±0.32	0.45
Volume of downed CWD[b] (m^3 ha^{-1})	3.27±0.95	3.12±1.02	0.52	1.49±0.39	1.56±0.38	0.42
No. of downed trees/ha	263.12±48.92	252.87±50.42	0.61	103.45±21.43	122.46±34.95	0.31
No. of woody seedlings/ha	1894.45±94.21	4374.53±248.67	0.01	1284.67±99.32	1143.45±104.97	0.39

Table 3: Summary of stand-structure attributes (density, basal area, coverage), characteristics of downed trees (volume and number of trees) and woody seedlings between forest edge (10-30 m from the forest road) and interior (90-110 m from the forest road) together with results of Mann-Whitney U-test for coniferous stands during the 1st (2005) and the 2nd (2008) trapping sessions in Jincheon, Chungbuk province, South Korea

	Edge			Interior		
Variables	2005	2008	p-value	2005	2008	p-value
No. of standing woods/ha	324.58±38.43[a]	318.32±32.68	0.73	357.432±43.16	364.45±35.54	0.64
Basal area (m^2 ha^{-1})	3.54±0.23	3.62±0.32	0.38	4.12±0.68	4.23±0.49	0.32
Coverage of overstory (> 8 m) vegetation	1.48±0.45	1.51±0.31	0.43	2.45±0.43	2.48±0.42	0.74
Coverage of sub-overstory (2-8 m) vegetation	1.24±0.32	1.31±0.39	0.52	1.32±0.54	1.30±0.42	0.78
Coverage of mid-story (1-2 m) vegetation	1.11±0.23	1.29±0.31	0.42	1.26±0.76	1.35±0.32	0.46
Coverage of understory (<1 m) vegetation	0.47±0.04	1.75±0.37	0.01	0.97±0.08	1.01±0.14	0.6
Volume of downed CWD[b] (m^3 ha^{-1})	2.47±1.08	2.32±0.87	0.36	1.04±0.99	1.13±0.64	0.75
No. of downed trees/ha	246.36±62.45	276.32±80.67	0.45	97.87±10.67	106.76±53.24	0.42
No. of woody seedlings/ha	967.24±132.42	3451.98±104.92	0.01	1248.28±102.95	1314.32±176.32	0.28

[a]Mean±SE; [b]CWD: Coarse Woody Debris

defined by distance from the road (10, 20, 30 m and 90, 100 and 110 m). Data collected from traps were pooled into 4 locations at each site defined by distance from the road as shown in Table 2 and 3.

Aggregated data were transformed to achieve constant variance within groups using $\log_{10}(x + 0.1)$. Three orthogonal contrasts were used to partition the three degrees of freedom associated with the location effects and to determine the major contributions to those effects. The contrasts examined were:

- Forest edge vs. interior
- Northern vs. Southern side
- The difference between forest edge and interior on Northern side of the forest road vs. the equivalent difference on Southern side the proportions of *Appodumus peninsulae*, *Myodes regulus* and *A. agrarius* during each trapping session were examined by χ^2-tests. In all analyses, the level of significance was at least p = 0.05

RESULTS AND DISCUSSION

In the 1st trapping session, stand structure attributes and characteristics of downed trees such as number of standing woods (ANOVA, $F_{1,3} = 16.37$, $p<0.05$), basal area ($F_{1,3}$ = 7.98, <0.05), coverage of understory vegetation ($F_{1,3} = 14.53$, $p<0.05$) and volume of coarse woody debris ($F_{1,3} = 9.14$, $p<0.05$) were significantly higher in deciduous stands than in coniferous stands. Also, number of standing woods ($F_{1,3} = 17.52$, $p<0.05$), basal area ($F_{1,3}$ = 8.26, $p<0.05$) and volume of coarse woody debris ($F_{1,3}$ = 12.74, $p<0.05$) were significantly higher in deciduous stands than in coniferous stands during the 2nd grid-trapping session.

The coverage of understory vegetation was significantly higher in the 2nd trapping session (2008) than in the 1st (2005) within the forest edge of both types of stand (Mann-Whitney U-test, deciduous stands, U = 12.94, $p<0.01$; coniferous stands, U = 13.642, $p<0.01$) and number of woody seedlings (deciduous stands, U = 10.35, $p<0.01$; coniferous stands, U = 14.12, $p<0.01$). There were no significant differences in number of standing woods, basal area, coverage of overstory, sub-overstory, mid-story of vegetation, volume of downed coarse woody debris and number of downed trees between 2005 and 2008 in the forest edge. There were also no significant differences in all variables between 2005 and 2008 for the forest interior areas in both stands (Table 2 and 3).

The 4 sites were grid-trapped for a total 14400 trap-nights during the 1st (July to September 2005) and the 2nd trapping sessions (July to September 2008). Five

Table 4: Number of individuals KTBA (Known To Be Alive), number of captures and trappability of small mammals pooled over the 1st (2005) and the 2nd (2008) grid-trapping sessions at both sides of forest road for deciduous and coniferous stands, Jincheon, Chungbuk province, South Korea (Trappability: No. of captures per individual per trip, -: insufficient data)

Species	Stands	No. of ind. KTBA	No. of captures	Trappability (SE)
Apodemus peninsulae	Deciduous	59	217	2.48 (0.08)
	Coniferous	15	42	1.19 (0.16)
Myodes regulus	Deciduous	41	130	1.87 (0.09)
	Coniferous	6	17	2.33 (0.76)
Apodemus agrarius	Deciduous	27	71	1.56 (0.10)
	Coniferous	14	59	1.12 (0.13)
Tamias sibiricus	Deciduous	4	9	2.25 (-)
	Coniferous	1	2	2.00 (-)
Crocidura suaveolens	Deciduous	3	4	1.33 (0.33)
	Coniferous	1	3	1.50 (-)
Apodemus peninsulae	Deciduous	85	284	2.95 (0.07)
	Coniferous	17	49	1.21 (0.19)
Myodes regulus	Deciduous	52	197	2.06 (0.10)
	Coniferous	10	29	1.69 (0.42)
Apodemus agrarius	Deciduous	19	35	1.42 (0.13)
	Coniferous	10	31	1.05 (0.42)
Tamias sibiricus	Deciduous	5	11	2.30 (-)
	Coniferous	1	2	2.00 (-)
Crocidura suaveolens	Deciduous	3	4	1.45 (0.50)
	Coniferous	0	0	0.00 (-)

species of small mammals were trapped (Table 4). In the 1st trapping session, researchers recorded 554 captures of small mammals and 642 captures in the 2nd trapping session.

The species composition of the small mammals caught in the forest edge (10, 20 and 30 m) did not differed from forest interior areas in both deciduous and coniferous stands and for the 1st and 2nd trapping sessions. However, the number of captures of *Apodemus peninsulae* (Mann-Whitney U-test, 1st trapping session, $U = 10.68$, $p<0.05$; 2nd trapping session, $U = 8.24$, $p<0.05$) and *Myodes regulus* (1st trapping session, $U = 7.23$, $p<0.05$; 2nd trapping session, $U = 5.36$, $p<0.05$) were significantly higher in deciduous than in coniferous stands during both trapping sessions. The abundance of small mammals was significantly higher in deciduous than in coniferous stands ($U = 9.68$, $p<0.05$) (Table 4).

Small mammals were more abundant in the forest interior than in edge areas. This significant trend was more noticeable in *A. peninsulae* for both trapping sessions (Table 5). However, a comparison of the proportion of small mammal species in the 2 trapping sessions shows that during the 2nd trapping session, the individual KTBA for *M. regulus* increased significantly at the forest edge in deciduous (from 14.6-36.5%) and coniferous (from 33.3-0.0%) stands (χ^2-test, $\chi^2 = 34.57$, df = 1, $p<0.005$) with *A. agrarius* decreasing in both deciduous (from 33.3-21%) and coniferous (from 28.6-10.0%) stands ($\chi^2 = 21.03$, df = 1, $p<0.05$) compared with those of the 1st trapping session (Table 5). The structure of the small mammal community in forest edge differed to that of interior areas, for both trapping sessions.

Table 5: Differences in number of individuals KTBA (Known To Be Alive) of small mammals pooled over two sites at each of two stands-deciduous and coniferous at two locations: forest edge (10-30 m from the forest road) and interior (90-110 m from the forest road) during the 1st (2005) and the 2nd (2008) trapping sessions in Jincheon, Chungbuk province, South Korea

	Deciduous		Coniferous	
Species	Edge	Interior	Edge	Interior
Apodemus peninsulae	11	48	3	12
Myodes regulus	6	35	2	4
Apodemus agrarius	9	18	4	10
Apodemus peninsulae	32	52	7	10
Myodes regulus	19	33	7	3
Apodemus agrarius	4	15	1	9

Table 6: Three-way χ^2 analysis of the effects of forest type (deciduous and coniferous stands) and location (forest edge 10-30 m from the forest road and interior 90-110 m from the forest road) on the proportion of individuals KTBA of *Apodemus peninsulae*, *Myodes regulus* and *A. agrarius* and tests for partial independence of the three factors during the 1st (2005) and the 2nd (2008) trapping sessions in Jincheon, Chungbuk province, South Korea

Model	χ^2	df	p-value
Species, Forest type, Location	37.329	7	<0.001
Species (Forest type + Location)	24.297	6	<0.001
Locations (Species + Forest type)	31.176	5	<0.001
Forest type (Species + Location)	19.482	5	<0.005
Species Forest type, Location	26.853	7	<0.001
Species (Forest type + Location)	21.532	6	<0.005
Locations (Species + Forest type)	25.131	5	<0.001
Forest type (Species + Location)	14.759	5	<0.005

Three-way χ^2 analysis (Table 6) showed that the proportion of *A. peninsulae*, *M. regulus* and *A. agrarius* were dependent on forest type (deciduous and coniferous stands) and location (forest edge and interior). Tests of partial independence of the 3 factors (species, forest type and location) showed that none of the 3 factors were independent of the others during both trapping sessions.

The effects of proximity to the forest edge on the abundance of the 3 small mammal species for which sufficient data in the 1st and the 2nd trapping sessions were available (for ANOVA) is shown in Table 7 and 8. Upon partitioning the degrees of freedom using 3 orthogonal contrasts this significant location effect was found to be due to distance from the forest road rather than to side of the forest road effect. For individual KTBA of *A. peninsulae*, forest type, location and contrast between forest edge and interior were significant in the 1st and the 2nd trapping sessions. There were no significant effects of forest type and location for *M. regulus* and *A. agrarius* in both trapping sessions. For the abundance of *M. regulus*, the interaction between forest type and location and the contrast between forest edge and interior were significant. The main contribution to the significant location effect for *A. agrarius* was the contrast between forest edge and interior in the 2nd trapping session (Table 7 and 8).

Forest structure was significantly different between forest edge and interior areas in both deciduous and coniferous stands. The number of standing woods, basal area, coverage of understory vegetation and volume of coarse woody debris were significantly different between stands (Table 2 and 3). Standing trees were cut and forest canopy was opened by the forest road construction. In

Table 7: Effects of forest type (deciduous and coniferous) and location (forest edge on either side and interior on either side) on the number of individuals KTBA of *Apodemus peninsulae*, *Myodes regulus* and *A. agrarius* resulted by ANOVA testing in the 1st trapping session (2005) in Jincheon, Chungbuk province, South Korea

Species	Source of variance	df	MS	F-value	p-value
A. peninsulae	Forest type	1	0.01	16.02	0.007
	Location	3	0.02	6.95	0.010
	Forest type x location	3	0.21	1.27	0.280
	Contrast between forest edge and interior	1	0.03	7.42	0.009
	Contrast between on one side of the road and the other side	1	0.18	1.58	0.210
	Contrast between forest edge and interior on one side of forest road and equivalent difference on other side	1	0.08	0.45	0.530
M. regulus	Forest type	1	0.11	3.75	0.060
	Location	3	0.07	2.78	0.120
	Forest type x location	3	0.03	14.98	0.003
	Contrast between forest edge and interior	1	0.12	5.43	0.010
	Contrast between on one side of the road and the other side	1	0.07	1.24	0.290
	Contrast between forest edge and interior on one side of forest road and equivalent difference on other side	1	0.09	4.64	0.090
A. agrarius	Forest type	1	0.08	1.26	0.130
	Location	3	0.13	0.91	0.390
	Forest type x location	3	0.17	2.54	0.150
	Contrast between forest edge and interior	1	0.03	4.79	0.050
	Contrast between on one side of the road and the other side	1	0.04	0.32	0.640
	Contrast between forest edge and interior on one side of forest road and equivalent difference on other side	1	0.11	1.31	0.310

Table 8: Effects of forest type (deciduous and coniferous) and location (forest edge on either side and interior on either side) on the number of individuals KTBA of *Apodemus peninsulae*, *Myodes regulus* and *A. agrarius* resulted by ANOVA testing in the 2nd trapping session (2008) in Jincheon, Chungbuk province, South Korea

Species	Source of variance	df	MS	F-value	p-value
A. peninsulae	Forest type	1	0.16	7.07	0.030
	Location	3	0.08	5.64	0.009
	Forest type x location	3	0.09	1.51	0.250
	Contrast between forest edge and interior	1	0.00	5.34	0.010
	Contrast between on one side of the road and the other side	1	0.14	0.54	0.470
	Contrast between forest edge and interior on one side of forest road and equivalent difference on other side	1	0.07	3.09	0.080
M. regulus	Forest type	1	0.13	2.58	0.080
	Location	3	0.06	2.74	0.070
	Forest type x location	3	0.10	5.97	0.009
	Contrast between forest edge and interior	1	0.09	1.21	0.020
	Contrast between on one side of the road and the other side	1	0.14	1.98	0.140
	Contrast between forest edge and interior on one side of forest road and equivalent difference on other side	1	0.06	2.09	0.120
A. agrarius	Forest type	1	0.09	2.32	0.110
	Location	3	0.21	0.54	0.470
	Forest type x location	3	0.17	1.49	0.230
	Contrast between forest edge and interior	1	0.08	5.27	0.010
	Contrast between on one side of the road and the other side	1	0.11	1.25	0.220
	Contrast between forest edge and interior on one side of forest road and equivalent difference on other side	1	0.05	0.27	0.610

the forest edge area, coverage of understory vegetation and number of woody seedlings were significantly higher in the secondary than in the 1st trapping session probably due to secondary succession. The indirect effects of logging and biomass removal by forest road construction have led to considerable microhabitat and microclimatic changes in neighboring areas.

Clearly, significant differences in habitat variables between stands support H1 that stand structure attributes have been changed between the forest edge and the interior areas, suggesting the influence of forest road construction.

This study demonstrates that the presence of a forest road can alter the small mammal community in deciduous and coniferous stands. The data supported the Hypothesis (H2) that the abundance of forest small mammals is influenced by the presence of a forest road. Abundances of small mammals were low in the edge areas around forest road.

Edge effects can be defined as the alternation of environmental conditions by the presence of a boundary between a forest and a non-forest area (Pickett *et al*., 1997). Others have described this phenomenon as significance of edge influence (Chen *et al*., 1995). Edge theory is largely empirically based and focuses on boundaries between forest and patches of contrasting, shorter vegetation within this theoretical domain, the most important tacit assumption has been that the changes in environment between the edge and the interior of the forest take place within the forest patch (Matlack, 1993; Murcia, 1995; Pickett *et al*., 1997).

In this study, *A. peninsulae* and *M. regulus* colonized the edges of the forest road, particularly in the 2nd trapping sessions when trappable numbers almost tripled in comparison with the 1st. Much of the increase in trappable both mammals during the 2nd experiment occurred in the rows closer to the forest edge, particularly at the deciduous stands (Table 5). The increase in small mammal abundance was positively correlated with the understory coverage and woody seedlings. This increase in abundance of *A. peninsulae* and *M. regulus* at the close to the forest road in the 2nd trapping session is a similar pattern to attraction to higher ground cover and understory vegetation at the anthropogenic edge by forest fire as shown in previous studies (Lee *et al*., 2008).

The abundance of *A. agrarius* was negatively correlated with *A. peninsulae* and *M. regulus* at the forest edges. If competition among *Apodemus* sp. and *M. regulus* were determined by their relative abundance their occurrences should always be negatively correlated. A competitive cause would dictate that increased abundances of trappable *A. peninsulae* and *M. regulus* in the 2nd trapping session, particularly near the forest edge would have resulted in a concomitant decrease in *A. agrarius.*

Understory vegetation and coarse woody debris have been recommended as an element of forested stands that is necessary to maintain small mammal communities (Homyack *et al*., 2005; Lee *et al*., 2010). Understory vegetation likely provides small mammals with sufficient cover, travel routes and substrate for fungal growth within stands (Fuller *et al*., 2004). Downed and dead woody material has been suggested to provide subnivian accesses in winter, habitat for invertebrates, escape cover from predators (Hayes and Cross, 1987), growing surface for fungi (Hagan and Grove, 1999) and to mediate microclimate by retaining moisture (Fraver *et al*., 2002). The reduced canopy closure in forest edge areas promoted abundant understory vegetation which probably benefited voles a nd mice by providing cover (Lee *et al*., 2008).

Avoidance of road edges has also been recognized for many mammals (Allen and Sargent, 1993; Lovallo and Anderson, 1996) and temperate birds (Reijnen and Foppen, 1995; Gill *et al*., 1996). In these cases the avoidance was related to the amount of disturbance from traffic on busy highways and secondary roads. In the study, however, traffic was minimal (40-60 vehicles per day) with almost no vehicles using the forest road after dark when these small mammals are active, so traffic disturbance should not be considered as a causative factor of forest road edge avoidance. Instead, habitat changes at the forest edge appear to result in edge avoidance by small mammals.

All individuals trapped were species recognized as preferring temperate forest habitats in South Korea (Lee *et al*., 2008, 2010). In the study, *A. peninsulae* avoided edges in both trapping sessions. This species is known as predominantly a forest dwelling species (Rhim and Lee, 2001; Yoon *et al*., 2004). *M. regulus* avoided the edge in the 1st trapping session but colonized the edges of the forest road, particularly in the 2nd trapping session. As the coverage of understory vegetation and number of woody seedlings increased significantly in the edge areas of both stands. Because understory coverage is easily affected by forest road construction and responds quickly relative to shrubs or other habitat components (Lee, 2007), the stand structure of forest edge changed through succession as the years passed after forest road construction. The small mammal community could have been influenced by this change in stand structure.

For existing roads that cannot be decommissioned, the best management option for small mammals would be to maintain canopy closure over the road surface or to re-establish canopy closure by rehabilitation plantings along the road verge. The concomitant reduction in clearing and edge effects should moderate forest road effects for small mammals close to the forest edge. There is a need to carefully assess the ecological effects of forest roads over longer time periods. With increasing application of forest road management, information concerning forest road effects on all elements of biotic communities for long-term scales becomes increasingly important.

CONCLUSION

Researchers conclude that abundance of small mammals is higher in the interior than in the forest edge. Forest roads transform the physical conditions on and adjacent to the forest, creating edge effects with consequences that extend beyond the time of forest road's construction (Trombulak and Frissell, 1999).

ACKNOWLEDGEMENTS

Researchers appreciate J.E. Swenson for his constructive comments on earlier draft of this study and thank J.Y. Lee, M.J. Kim, N.R. Kim and E.J. Lee for assistance with field work. This research was supported by the Chung-Ang University Research Scholarship Grants in 2011.

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