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MANAGEMENT OF RED SQUIRREL FEEDING DAMAGE TO LODGEPOLE PINE BY STAND DENSITY MANIPULATION AND DIVERSIONARY FOOD

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ABSTRACT: The red squirrel (*Tamiasciurus hudsonicus*) feeds on the vascular tissues of sapling lodgepole pine (*Pinus contorta*) during spring periods in forests of interior British Columbia and Alberta, Canada. This damage may lead to mortality and reduced growth of crop trees in managed stands. Manipulation of stand density by pre-commercial thinning to densities <1,000 stems/ha is an effective method to lower squirrel populations and feeding damage. Lowering stand density enhances the growth of crop trees, and understory herbs and shrubs as wildlife habitat, while protecting trees from squirrel feeding. This approach has been successful in several forest ecological zones. An alternative management tool is provision of diversionary food (sunflower seed) for those stands susceptible to feeding damage, and where stand thinning has already been completed. Diversionary food can be applied aerially and is very cost effective for protecting managed stands. These techniques may be used to maintain or even enhance species diversity of small mammal communities in those forest stands requiring protection.

KEY WORDS: diversionary food, forest management, lodgepole pine, pre-commercial thinning, red squirrel, small mammals, species diversity, stand density, sunflower seeds, wildlife habitat

INTRODUCTION

Three species of squirrels inhabit forests of the Pacific Northwest (PNW) of North America. The Douglas squirrel or chickaree (*Tamiasciurus douglasii*) is restricted to the west coast from southwestern British Columbia south through the Sierras to northern Baja California. The red squirrel (*T. hudsonicus*) ranges throughout the inland PNW and across the boreal and sub-boreal forests of Canada and the northeastern U.S. (Banfield 1974). Both of these squirrels have similar habits and are active throughout the winter. The western grey squirrel (*Sciurus griseus*) is found in mixed coniferous-deciduous forests along both sides of the Cascade Range in western Washington, western Oregon and northern California (Carraway and Verts 1994).

All three species of tree squirrels strip bark from the boles of conifers to feed on the exposed sapwood (Lawrence et al. 1961; Baldwin et al. 1986; Sullivan and Sullivan 1982; Sullivan 1998). Trees in the 20- to 60-year age classes generally sustain the greatest injury. Squirrels remove small strips of bark and then feed on the vascular tissues on the exposed sapwood. The sapwood and short strips of discarded bark (3 by 8 cm) that accumulate on the ground under the injured tree may have scattered toothmarks. These bark strips readily distinguish squirrel work from similar crown-girdling injuries by porcupine (*Erethizon dorsatum*) and woodrat (*Neotoma cinerea*). Most barking damage by squirrels occurs in spring and early summer during the early part of the growing season. The red squirrel may seriously damage crop trees in pre-commercially thinned stands of lodgepole pine (*Pinus contorta*) in interior regions of the PNW (Brockley and Sullivan 1988; Sullivan et al. 1994).

HABITAT MODIFICATION

There are two major questions associated with the use of habitat modification or alteration as a tool to reduce wildlife damage in forest and agricultural areas:

1) Can we modify habitat to reduce damage?
2) Can habitat modification, which reduces damage by the target problem species, actually benefit other non-target species such that diversity of the overall wildlife community is maintained or enhanced?

Managing forests to produce a desirable mix of forest resources, including timber and wildlife, requires an understanding of how animals respond to habitat. Management strategies aimed at long-term population change are most likely to succeed if they alter habitat quality, quantity, or availability. Modification of habitat to reduce populations of one target species likely also changes habitat quality or quantity for other wildlife species (McComb and Hansen 1992).

Principal components of habitat for a given wildlife species include food quality and quantity, and cover for nesting (reproduction), thermal (maintenance of body temperature and physiology), and security (escape from predators) needs. Natural resource managers can manage habitat to control a problem species by reducing food quality, quantity, or availability while also reducing the quality, quantity or availability of cover. This strategy can lead to significant reductions in habitat quality for the pest species (McComb and Hansen 1992).

An alternative approach is to increase cover through enhancement of forest stand structure (e.g., snags and slash piles) to enhance predator abundance, and increase food by way of providing a diversionary food source. This latter approach is designed to temporarily satisfy part, or a majority, of the food requirements of a problem species in a localized area. Consequently, feeding damage should be reduced and the problem species should be attracted or concentrated away from the crop to be protected.

The major objective of this paper is to discuss the use of operational tools: 1) stand thinning (reduce food and cover); and 2) diversionary food (increase food), as

means of habitat modification to reduce feeding damage to lodgepole pine by red squirrels. A secondary objective is to describe responses of non-target small mammal communities to these treatments.

METHODS
Study Areas
The study areas for research and development of the use of: 1) variable stand density; and 2) diversionary foods, to manage red squirrels in young lodgepole pine forest, are described in Sullivan et al. (1996) and Sullivan and Klenner (1993), respectively.

Variable Stand Density
A low (500 stems/ha), medium (1,000 stems/ha), and high (2,000 stems/ha) density was investigated at each of the Penticton Creek, Kamloops, and Prince George study areas in the south-central interior of British Columbia, Canada. This operational scale experiment was initiated with pre-commercial thinning in the fall of 1988 (1989 at Kamloops) to test the influence of variable tree density on squirrel populations and feeding damage. All stands in these areas had a history of chronic damage by squirrels with mean values ranging from 43% to 70% of trees with feeding injuries. Squirrel populations were live-trapped at two-week intervals during May to August (damage period) 1989, 1990, and 1991 (1990 and 1991 at Kamloops). Feeding damage to sample crop trees was measured annually in August 1989 to 1993. See Sullivan et al. (1996) for details of methodology.

Diversionary Food
This operational experiment was conducted in 1990 at the Bigg Creek study area (Sullivan and Klenner 1993) to assess the influence of manually applied sunflower seed on squirrel populations and damage to lodgepole pine crop trees. Two control stands and two treatment stands were established at Bigg Creek with two additional control stands at McGregor Creek, two distinct study areas near Vernon, B.C. Sunflower seeds were distributed manually on the ground at 30 m intervals, with about 1 kg of seed in each pile, in the treatment stands on May 15 and June 16, 1990. Squirrel populations were live-trapped at two-week intervals from May to August 1990. Feeding damage to sample crop trees was measured in August 1990. See Sullivan and Klenner (1993) for details of methodology and Sullivan (1992) for details of operational aerial application of sunflower seed.

Small Mammal Communities
In each of the three stands in the variable stand density experiment and two additional stands (unthinned and old growth lodgepole pine, installed for comparative purposes) at each study area, and in each of the two control and two treatment stands in the diversionary food experiment, a 1 ha live-trapping grid with 49 (7 x 7) trap stations at 14.29 m intervals with one Longworth live-trap at each station was established. Small mammal populations were sampled at two-week intervals from May to August in 1990 and 1991 for the variable stand density experiment, and in 1990, for the diversionary food experiment. Traps were supplied with whole oats and coarse brown cotton as bedding. Traps were set on the

afternoon of day 1, checked on the morning and afternoon of day 2 and morning of day 3, and then locked open between trapping periods. All animals captured were ear-tagged and point of capture recorded. Small mammals were released on the grids immediately after processing. Population density of the common species was estimated using the Jolly-Seber model (Seber 1982) for the variable stand density data, and minimum number alive (MNA) for the one year of data in the diversionary food study. MNA was selected for the latter study because the generally preferred Jolly-Seber estimator became unreliable and impossible to calculate for species with low recaptures of previously marked animals (Krebs et al. 1986).

Small mammal species captured included the deer mouse (*Peromyscus maniculatus*), southern red-backed vole (*Clethrionomys gapperi*), northwestern chipmunk (*Tamias amoenus*), long-tailed vole (*Microtus longicaudus*), meadow vole (*M. pennsylvanicus*), shrews (*Sorex* spp.), and weasels (*Mustela* spp.).

Species diversity was measured by Simpson's index of diversity (Simpson 1949) which is sensitive to changes in the more abundant species. The Shannon-Wiener index of diversity (Pielou 1966) was also used because it is sensitive to changes in the rare species in a community sample. These diversity measures were calculated using Jolly-Seber (variable stand density) and MNA (diversionary food) population estimates for the common species and number of individuals captured for the less abundant species (shrews and weasels). These values were calculated for each trapping period and were then averaged for each summer.

Both studies used a randomized block experimental design with spatial and temporal replication for the regional replicates in the variable stand density study, and spatial replication for the site replicates in the diversionary food study. A randomized-block ANOVA (Zar 1984), which assumes no interaction between the blocks and the levels of treatment, was conducted to test differences in mean numbers of squirrels and feeding damage among treatments in the variable stand density study, and mean species diversity of small mammals among treatments in both studies. Mean numbers and 95% confidence limits were also been calculated for red squirrels and small mammal species (diversionary food study) for each summer in each stand.

RESULTS AND DISCUSSION
Variable Stand Density
Numbers of red squirrels were consistently higher in the medium and high density stands than in the low density stand at Penticton and Prince George (Figure 1). Both the low and medium density stands at Kamloops had significantly fewer squirrels in terms of average abundance than the high density stand (Sullivan et al. 1996). Feeding damage by red squirrels over the period 1989 to 1993 was significantly higher in the high density stands than in either the low or medium density stands (Table 1). Low-density stands appear to provide marginal conditions for these animals because of their reduced protective cover and a possible increased risk of predation. Similarly, reduction in understory shrub cover in young stands may also reduce the incidence of feeding

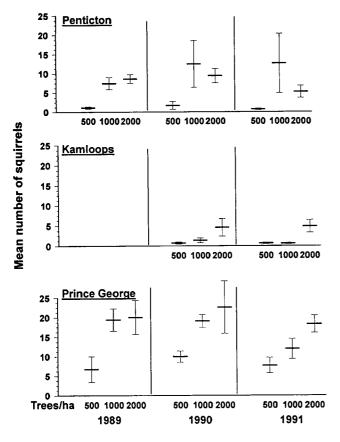damage by squirrels to pine crop trees (Sullivan et al. 1994).

Figure 1. Mean number of red squirrels and 95% confidence limits during each summer in the three stands at each study area for Jolly-Seber population estimates.

Diversionary Food

Red squirrel populations were higher in the treatment than control stands during the May to July feeding period. This difference was particularly pronounced when transient squirrels were included in the analysis, less so when only resident squirrels were considered (Sullivan and Klenner 1993). Squirrel populations in those stands with the diversionary food returned to control levels by August 1990. As discussed by Sullivan (1992) and Sullivan and Klenner (1993), feeding damage to crop trees was reduced significantly in the treatment stands.

This method has considerable potential to reduce damage with minimal disruption of habitat and wildlife. Historically, diversionary foods were perceived as being of limited utility and efficacy, with relatively high costs compared to other techniques. However, the approach is receiving renewed interest because of the movement away from lethal control methods towards more ecologically-based measures. In general, there has been relatively minor use of supplemental feeding for management of problem wildlife because of a lack of information and experimental results. Also, there is the perception that supplemental feeding may favor a local increase in the target population by increasing reproduction and survival, or it may change the behavior of the target animals.

The quality of supplemental food offered is of critical importance. Food should ideally be more palatable than the crop being protected and of similar or lower nutritive value than natural foods. A highly palatable and nutritious food could stimulate increased reproduction and immigration with consequent population increases beyond what the food supplementation program can support. Food must be presented in a way and place so as to be readily fed upon. Much research needs to be done on the quality, quantity, and placement of food. For example, the question of whether or not food should be placed or planted within a crop or reforested area depends on the preference ranking, abundance, and distribution of the supplemental food. It also depends on the feeding characteristics of the problem species and the average size of its natural home range.

The best candidate problem species are those that cause damage predictably and over relatively short periods of time (few weeks or months) because the crop is only susceptible for a short time, or the animal species are in the area or at pest status densities for a limited period. Examples are black bears (*Ursus americanus*) (Ziegltrum and Nolte 1997) and red squirrels which strip

Table 1. Average number of lodgepole pine trees per ha damaged by red squirrels over the period 1989 to 1993.

Study Area	Stand Density		
	500	1,000	2,000
Penticton	9	8	68
Kamloops	28	43	144
Prince George	19	40	74

bark from sapling-pole size timber to feed on vascular tissues during spring months. Other examples are conifer seed predation by the deer mouse (Sullivan and Sullivan 1984), and crop damage by voles (*Microtus* spp.) in no-till fields (Hines 1997), which also occur primarily in the spring. Each of these damage scenarios has an operationally viable diversionary food program to successfully reduce feeding damage to crop plants and trees.

Small Mammal Communities

Species diversity of the small mammal communities was significantly different between stand treatments in the variable stand density study for the Shannon-Wiener ($F_{4,20}$=4.00; P=0.02) and nearly so for Simpson's ($F_{4,20}$=2.50; P=0.08) diversity measurements. In terms of mean values and 95% confidence limits when comparing individual stands and years, there were no significant differences in small mammal diversity between stands at Penticton, except for the community in old growth which was significantly more diverse than that in the medium density stand in 1990 (Table 2). There were no differences between stands in 1991 at Penticton. At Kamloops, small mammal diversity was significantly higher in all thinned stands than in the unthinned and old growth stands in 1990. This trend of higher diversity continued in 1991 for the low and medium density stands. At Prince George, the low and medium density stands had a significantly higher diversity of small mammals than the high density or old growth stands in 1990. In the second year of sampling, all thinned stands tended to have higher diversity of small mammals than either of the unthinned or old growth stands (Table 2).

Evaluation of the response of small mammal communities to application of diversionary food indicated that, except for *M. pennsylvanicus*, there were no consistent differences in abundance between paired control and treatment stands (Table 3). Similarly, there was no difference between control and treatment stands for either Simpson's ($F_{1,1}$0.54; P=0.64) or Shannon-Wiener ($F_{1,1}$=0.62; P=0.62) diversity measurements. Simpson's diversity averaged 0.74 (control) and 0.65 (treatment) and Shannon-Wiener diversity averaged 1.85 (control) and 1.67 (treatment) in this diversionary food study (Table 3).

MANAGEMENT IMPLICATIONS
Stand Protection, Productivity, and Biodiversity

Habitat modification by manipulating stand density of lodgepole pine to <1,000 stems/ha by pre-commercial thinning is an effective method to reduce red squirrel populations and feeding damage in susceptible stands. Lowering stand density enhances growth of crop trees and the alteration of habitat appears to provide marginal conditions for squirrels in terms of protective cover and risk of predation. Thus, both stand protection and productivity can be achieved by stand density manipulation. Feeding damage by squirrels appears to decline as trees reach a dbh of 20 cm. This target dbh will be reached sooner in low density rather than in high density stands, since the widely spaced trees are responding with rapid diameter growth.

Enhancement of understory vegetation (herbs and shrubs) also occurs in heavily thinned stands and when combined with the appropriate crop tree average diameters (e.g., near 20 cm), may contribute to managing forests for biological diversity. This approach includes forestry practices that provide a variety of stand densities, successional stages, tree species, and stand structures in a mosaic of habitats across a landscape (Hunter 1990). Silvicultural practices that can provide a diversity of stand structures (habitats) could help meet the goals of managing for diversity.

Intensive management by stand density manipulation, to reduce squirrel damage, did not negatively affect small mammal communities in terms of species diversity. In fact, diversity of these communities tended to be highest in the low density stands. In addition, the thinned stands tended to have higher diversity overall than the unthinned stands of pine. This result suggests that stand structure in the thinned stands was growing in complexity and, hence, providing microhabitats and habitats for wildlife.

It is important to note that diversity measurements in this study were quantitative rather than qualitative. For example, each stand (or habitat) could have had a completely different set of species regardless of the qualitative measurements, which indicated that one stand had higher diversity than another. All of these communities of species are valuable and must be included in management plans.

Diversionary Food

As discussed by Sullivan (1992), operational application of sunflower seed as a diversionary food is an alternative management tool for those stands susceptible to feeding damage, where pre-commercial thinning or planting has already been completed. Such stands may be part of regular regeneration and silviculture programs, seed orchards, progeny sites, or other installations in a given forest operating unit. Diversionary food can be applied aerially and is very cost effective for protecting managed stands.

The operational cost at the start of this program in 1991 ranged from $40 to $45/ha per year. Since then, this technique has been used operationally to protect several thousand ha of managed stands in the Vernon and Kamloops Forest Districts in the southern interior of British Columbia. Costs have increased slightly to $45 to $50/ha per year, primarily due to fluctuating prices of sunflower seeds. Again, this technique is applied once per year, in the spring, prior to squirrel feeding damage in susceptible stands of lodgepole pine. For example, even if this protection was required annually for 10 years (from ages 15 to 25; up to approximately 20 cm dbh), the cost would be $450 to $500/ha to protect a managed stand investment of up to $3,000/ha.

Application of diversionary food reduced feeding damage by red squirrels with concurrent maintenance of small mammal abundance and diversity in managed stands of lodgepole pine. Similarly, both forest and wildlife objectives can be achieved when using variable stand density to solve a wildlife damage problem.

Table 2. Mean species diversity (Simpson's and Shannon-Wiener) of small mammal communities in the five stands at each area for the variable stand density study (95% confidence limits are given in parentheses).

Year and Study Area	Stand Density				
	500	1,000	2,000	Unthinned	Old Growth
Simpson's Diversity					
1990					
Penticton	0.46 (0.37-0.55)	0.40 (0.34-0.46)	0.40 (0.32-0.48)	0.47 (0.43-0.51)	0.55 (0.48-0.62)
Kamloops	0.64 (0.60-0.68)	0.64 (0.60-0.68)	0.60 (0.56-0.64)	0.33 (0.26-0.40)	0.52 (0.48-0.56)
Prince George	0.65 (0.60-0.70)	0.65 (0.62-0.68)	0.55 (0.53-0.57)	0.61 (0.53-0.69)	0.49 (0.42-0.56)
1991					
Penticton	0.51 (0.45-0.57)	0.53 (0.46-0.60)	0.46 (0.38-0.54)	0.46 (0.36-0.56)	0.58 (0.53-0.63)
Kamloops	0.71 (0.69-0.73)	0.70 (0.64-0.76)	0.56 (0.52-0.60)	0.54 (0.48-0.60)	0.47 (0.35-0.59)
Prince George	0.69 (0.66-0.72)	0.66 (0.62-0.70)	0.65 (0.62-0.68)	0.52 (0.46-0.58)	0.58 (0.52-0.64)
Shannon-Wiener Diversity					
1990					
Penticton	1.18 (0.98-1.38)	0.98 (0.87-1.09)	1.01 (0.83-1.19)	1.10 (1.02-1.18)	1.31 (1.14-1.48)
Kamloops	1.61 (1.44-1.78)	1.65 (1.53-1.77)	1.39 (1.32-1.46)	0.87 (0.73-1.01)	1.09 (1.02-1.16)
Prince George	1.60 (1.44-1.76)	1.55 (1.42-1.68)	1.32 (1.22-1.42)	1.52 (1.34-1.70)	1.22 (1.06-1.38)
1991					
Penticton	1.33 (1.21-1.45)	1.23 (1.05-1.41)	1.21 (1.02-1.40)	1.05 (0.84-1.26)	1.30 (1.17-1.43)
Kamloops	1.80 (1.73-1.87)	1.77 (1.59-1.95)	1.23 (1.12-1.34)	1.27 (1.15-1.39)	1.07 (0.82-1.32)
Prince George	1.63 (1.52-1.74)	1.58 (1.43-1.73)	1.54 (1.41-1.67)	1.28 (1.13-1.43)	1.35 (1.27-1.43)

Table 3. Mean abundance of small mammal populations per ha and species diversity (Simpson's and Shannon-Wiener) of small mammal communities in the control and treatment stands for the diversionary food study (95% confidence limits are given in parentheses).

Species and Variable	Stand			
	Control-1	Food-1	Control-2	Food-2
P. maniculatus	5.00 (2.25-7.75)	3.13 (0.55-5.71)	6.88 (4.04-9.72)	7.25 (3.16-11.34)
C. gapperi	3.25 (1.93-4.57)	0.00	0.50 (0.05-0.95)	0.38 (-0.05-0.81)
T. amoenus	1.88 (0.01-3.75)	3.00 (1.21-4.79)	4.13 (3.00-5.26)	1.75 (1.16-2.34)
M. pennsylvanicus	0.63 (0.20-1.06)	3.63 (1.36-5.90)	1.75 (0.59-2.91)	4.88 (3.58-6.18)
M. longicaudus	3.13 (0.22-6.04)	2.00 (-0.29-4.29)	0.25 (-0.14-0.64)	0.50 (-0.13-1.13)
Sorex spp.	2.88 (1.07-4.69)	2.00 (-0.28-4.28)	1.50 (0.50-2.50)	1.75 (-0.08-3.58)
Mustela spp.	0.00	0.25 (-0.14-0.64)	0.00	0.13 (-0.17-0.43)
Simpson's Diversity	0.78 (0.73-0.83)	0.58 (0.28-0.88)	0.69 (0.64-0.74)	0.72 (0.68-0.76)
Shannon-Wiener Diversity	1.96 (1.57-2.35)	1.54 (0.71-2.37)	1.74 (1.49-1.99)	1.79 (1.70-1.88)

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