UNIVERSITY OF ALBERTA

An examination of small mammal damage to juvenile stands of lodgepole pine in West-Central Alberta

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled An Examination of small mammal damage to juvenile stands of lodgepole pine in West-Central Alberta submitted by Kathryn Anré Friedmann in partial fulfillment of the requirements for the degree of M.Sc.

James Beck Jr.

Jack Heidt

Robert Hardin

Date Nov 30, 1992

I dedicate this thesis to:

My Late Father Dr. Gerhart Friedmann

My Mother Norma Friedmann

and David McIntosh

Thank you for your love and support

Abstract

Damage to lodgepole pine (*Pinus contorta*) through the removal of bark by small animals is having a severe impact on the survival and productivity of stands near Hinton, Alberta. 58% of the Forest Management Agreement Area is Lodgepole pine. This study was set up to address the following objectives 1) to determine what animal species is responsible for the damage of concern, 2) to determine when the damage occurs, 3) to determine the patterns of damage and characteristics of trees attacked and 4) to determine what characteristics make a stand vulnerable to attack.

Sixty-seven plots, located in four compartments were sampled from the end of May through August 1991. Damage began in early June and continued through mid July of 1991. Eighteen percent of the trees surveyed were subject to new damage, 68% of previously damaged trees were re-damaged, while only 32% of undamaged trees were damaged. Trees with previous damage were more likely to be re-attacked than undamaged trees. In order tc correctly identify the damaging animal, the timing, location, appearance and diameter of trees attacked were examined. The causal agent of the damage was red squirrels, not snowshoe hares as previously believed.

The last objective of this study was addressed through analysis of a large data set provided by Weldwood of Canada (Hinton Division). This data set was composed of information collected from 1988 to 1989 over the entire Forest Management Agreement Area. No differences were found between the characteristics of damaged and undamaged stands on either a

plot or block basis. This may be due to incomplete measurement of damage or information not included in the data set.

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The assistance of Bob Beck and Mike Bokalo in getting the RSI data formatted for SAS is appreciated. I thank Dr. T. Terrum of Computing and Network Services for the many hours he spent with me helping with SAS programs. I would also like to thank Rick Bonar for providing equipment for the field part of this study.

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Table of Contents

Chapter Page

List of Tables

List of Figures

I. Introduction and Problem Definition

Reduction in merchantable timber due to small mammal damage is becoming an increasing problem as forest management intensifies. Snowshoe hares (*Lepus americanus* Erxleben) and red squirrels (*Tamiasciurus hudsonicus* Erxleben) cause barking and browsing damage in stands of young lodgepole pine (*Pinus contorta* Dougl. *var.* latifolia Engelm.). Barking involves the removal of sections of bark and cambium from the tree stem, while browsing involves clipping of leaders and branches. In British Columbia, snowshoe hare and red squirrel damage in young stands of lodgepole pine has been the focus of numerous studies (Sullivan 1984, 1985, & 1987). However, in Alberta, there have been no studies focusing specifically on snowshoe hare and or red squirrel damage. On Weldwood of Canada's (Hinton Division) forest management agreement area, in the Hinton area of Alberta, some young stands of lodgepole pine contain high levels of barking damage. Company foresters believe that the heaviest damage is occurring on the better sites and that snowshoe hares are responsible (Rugg 1990).

To begin to develop strategies aimed at reducing levels of damage, four factors must be determined:

1). What animal species is responsible for the damage of concern?

2). When does the damage occur?

3). What are the patterns of damage and characteristics of the trees attacked?

4). What characteristics make a stand vulnerable to attack?

Animal Species Responsible for Damage

SNOWSHOE HARE HABITAT AND FOOD

Wolff (1980), Pietz and Tester (1983), and Sullivan and Sullivan (1983) found that hares prefer habitats with dense vegetative cover, particularly 1-2 m above the ground. This conclusion is supported by other researchers. Grange (1932) for example indicated hares are found in practically all forest types, but the amount of underbrush largely determines the attraction of any particular area. Overstocked pine stands can also provide optimum hare habitat (Adams 1959, Grange 1965, and Koehler *et al.* 1979). In Canada, young alder (*Alnus* spp. Mill) or low growing conifers provide the cover hares need in both upland and lowland habitats (Buehler and Keith 1982). Hare habitat use varies with the seasons. Both Wolff (1980) and Buehler and Keith (1982) attribute seasonal habitat use changes to a response to changes in the availability of food and cover.

RED SQUIRREL HABITAT AND FOOD

Red squirrels prefer habitats of mature stands of seed bearing trees such as white spruce (*Picea gluca* (Moench) Voss) (M. Smith 1968), black spruce (*Picea mariana* (Mill) BSP.) (Rusch and Reeder 1978) and jackpine (*Pinus banksiana* Lamb.) (Rusch and Reeder 1978). Seeds from these trees are the primary food source of red squirrels. Stands of juvenile lodgepole pine on cutover or burned land will also support red squirrel populations, often at densities comparable to mature stands, for short periods of time (Sullivan and Moses 1986). In these stands, squirrels often feed on cambium (Sullivan and Sullivan 1982a). Although mature conifer stands are excellent habitat for red squirrels, research by Sullivan and Sullivan (1982a), Sullivan (1990) and Klenner and Krebs (1991) has shown that in mature conifer stands red squirrel populations are limited by food supply.

Timing of Damage

SNOWSHOE HARES

Telfer (1974), Wolff (1980), de Vos (1964), Cook and Robeson (1945), and Grange (1932) found that during the winter months snowshoe hares feed on the buds, bark and foliage of certain hard and softwood trees in addition to some shrubs. Available succulent plant materials and cambium from pine are consumed during the summer months.

RED SQUIRRELS

Tree buds and flowers, fresh fruits, mushrooms, green cones, pollen and cambium are some of the seasonal foods eaten by red squirrels (Layne 1954, Rusch and Reeder 1978, Sullivan and Moses 1986). These foods can become so abundant during the spring and summer that in some areas seeds become an insignificant food source for short time periods (McKeever 1964). In British Columbia, during times of low seed availability, red squirrels have been found to rely on alternative food sources (Sullivan and Moses 1986). Cambium is an important food for red squirrels during late spring from May to June (McKeever 1964, Sullivan and Sullivan 1982a, and Sullivan and Vyse 1987). Early spring consumption of cambium corresponds to the early part of the growing season (Brockley and Sullivan 1988). An increase in the consumption of cambium is not due to a lack of other foods, according to Layne (1954).

Patterns of Damage and Characteristics of Trees Attacked

In British Columbia, the majority of trees attacked by snowshoe hares are less than 6 cm in diameter at breast height (DBH) while the majority of trees attacked by red squirrels are greater than 6 cm in DBH (Brockley and Elmes 1987, Sullivan and Sullivan 1982a).

Characteristics making stands vulnerable to attack

Vegetative and physical characteristics of damaged areas need to be identified to allow future high risk areas to be located. This will facilitate development and implementation of management practices aimed at minimizing damage levels. In British Columbia, snowshoe hares prefer densely socked stands and stands with dense cover 1-2 meters above the ground (Wolff 1980, Pietz and Tester 1983 and Sullivan and Sullivan 1983), while red squirrels prefer less dense stands of mature white spruce, black spruce or lodgepole pine (M. Smith 1968, Rusch and Reeder 1987, Sullivan and Sullivan, 1982a).

Study layout

From an extensive data set, collected by Weldwood in 1988-1989, areas damaged by the feeding of snowshoe hares and or red squirrels can be identified and located. This data set contains information (to be discussed in chapter three) which might be used to characterize damaged stands. Although it cannot reveal what animal species is responsible, when the damage is occurring, whether the damage occurs repeatedly on the same tree or whether certain trees are more susceptible to damage, the data set is useful as a sample platform to develop a field study to examine these questions.

The remainder of this study is organized in three main sections. Chapter two covers what animal species is responsible for the damage, when the damage is occurring, and patterns of damage and characteristics of trees attacked. Chapter three examines the Regenerated Stand Inventory (RSI) data set and attempts to determine what characteristics of an area are associated with damage. Chapter four discusses overall conclusions, possible management strategies and makes suggestions for areas for future work.

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II. Small mammal damage in stands of juvenile lodgepole pine:

Introduction

On Weldwood of Canada's, (Hinton division) forest management agreement (FMA) area (Province of Alberta 1988) in Alberta, young regenerated stands of lodgepole pine (*Pinus contorta* Dougl. *var.* latifolia Engelm.) are being severely damaged through the removal of portions of bark and vascular tissue from the stem. This damage, referred to as barking damage, has been attributed by managers at Weldwood to the feeding of snowshoe hares (*Lepus americanus* Erxleben) and is restricted to the snow free period of the year (Rugg 1990). Greatest levels of damage are thought to occur on the better pine sites (Rugg 1990). Forest managers at Weldwood predict that if the intensity of damage in some regenerated areas continues at its present level these areas will not be in a commercially viable state at the planned rotation age (Rugg 1990).

Objectives

To address the concerns indicated by Weldwood, and to aid managers in planning and implementing measures aimed at reducing barking damage, this study will investigate the following questions:

1). What animal species is responsible for the damage of concern?

2). When does the damage occur?

3). What are the patterns of damage and characteristics of the trees attacked?

Animal species responsible for damage

Red squirrels (*Tamiasciurus hudsonicus* Erxleben) have been shown to cause much of the barking damage in juvenile lodgepole pine stands in British Columbia (Sullivan and Sullivan 1982a, 1982b, & 1982c). Therefore, it is possible that much of the damage in the Hinton area, now attributed to snowshoe hares, might be due to red squirrels. However, there is some indication that barking damage peaks every 10 years in conjunction with peaks in the snowshoe hare cycle (Bella 1991). Although this may suggest that snowshoe hares are responsible, Sullivan (1992) states that red squirrel barking damage also peaks at times of snowshoe hare population peaks. Studies by Brockley and Sullivan (1988), Brockley and Elmes (1987), Sullivan (1984, 1985 & 1987), Sullivan and Sullivan (1982a & 1986) and Sullivan and Vyse (1987) in British Columbia document snowshoe hare and red squirrel feeding damage on lodgepole pine and other tree species. Thinning was found to increase the susceptibility of trees to snowshoe hare damage in the first few years after spacing but, as time progressed hare damage decreased (Sullivan 1984, Sullivan and Sullivan 1982b). Sullivan (1984) believes this decrease is due to a reduction in the quality of habitat for the snowshoe hares in the thinned stand. Red squirrel damage is higher in thinned and fertilized lodgepole pine stands than in untreated stands (Sullivan 1984, Brockley and Sullivan 1988, Sullivan and Sullivan 1982b, Sullivan and Vyse 1987). In addition, Sullivan and Sullivan (1982a) found that snowshoe hare damage increased with increasing tree density while red squirrel damage decreased with increasing stocking levels.

Rates of attack on juvenile lodgepole pine are not constant. Sullivan and Vyse (1987) found red squirrel damage was high in one year and low in the next. Fluctuation in the population levels of red squirrels and snowshoe hares are believed to account for some of this variation. Other factors determining the levels of damage may include availability of alternative foods (Sullivan and Sullivan 1982a) and condition of the tree cambium (Sullivan 1987). Cambium is an important food for red squirrels from May to July (McKeever 1964, Sullivan and Sullivan 1982a). Early spring consumption of cambium corresponds to the early part of the growing season (Brockley and Sullivan 1988).

The size of a red squirrel population is determined by the size of the spruce and lodgepole pine cone crops in the surrounding areas. Large cone crops are associated with large red squirrel populations (Sullivan and Vyse 1987, Klenner and Krebs 1991, Sullivan and Sullivan 1982b and Sullivan 1990). Juvenile lodgepole pine stands are thought to be sub-optimal red squirrel habitat (Sullivan 1987). Nevertheless, these stands may contain large numbers of red squirrels for short periods of time (Sullivan and Moses 1986). Despite fluctuations, red squirrel populations are stable enough that they can cause serious damage every year, while snowshoe hares tend to cause serious damage only during population peaks (Sullivan 1987).

Red squirrel and or snowshoe hare damage has not been the primary focus of any previous research in Alberta. However, feeding damage by snowshoe hares is mentioned in Bella (1985), Powell (1982) and Amirault and Pope (1989). Red squirrel damage is mentioned only by Amirault and Pope (1989).

Differentiating red squirrel and snowshoe hare damage

CHARACTERISTICS OF SNOWSHOE HARE DAMAGE ARE:

- trees attacked generally are less than 6 cm DBH
- scar edges are messy
- scars look gnawed and have teeth marks
- residual pieces of cambium remain inside the scar
- bark removed is consumed
- scars are irregularly shaped

CHARACTERISTICS OF RED SQUIRREL DAMAGE ARE:

- trees attacked are generally greater than 6 cm in DBH
- scar edges are neat
- bark seems to be peeled from inside the scar and no teeth marks are present
- no residual cambium inside the scar
- bark removed is not consumed and residual bark strips are found at the base of the tree
- scars are irregularly shaped but most are somewhat rectangular

When does damage occur?

Snowshoe hare feeding damage occurs primarily in the winter months (November to April), and will appear on a stem in accordance with increasing and decreasing depths of snow (Sullivan and Sullivan 1982a). Red squirrel feeding damage occurs primarily in the spring and early summer (May to June) and will occur on any part of the stem (Sullivan and Sullivan 1982a).

Patterns of Damage and Characteristics of trees attacked

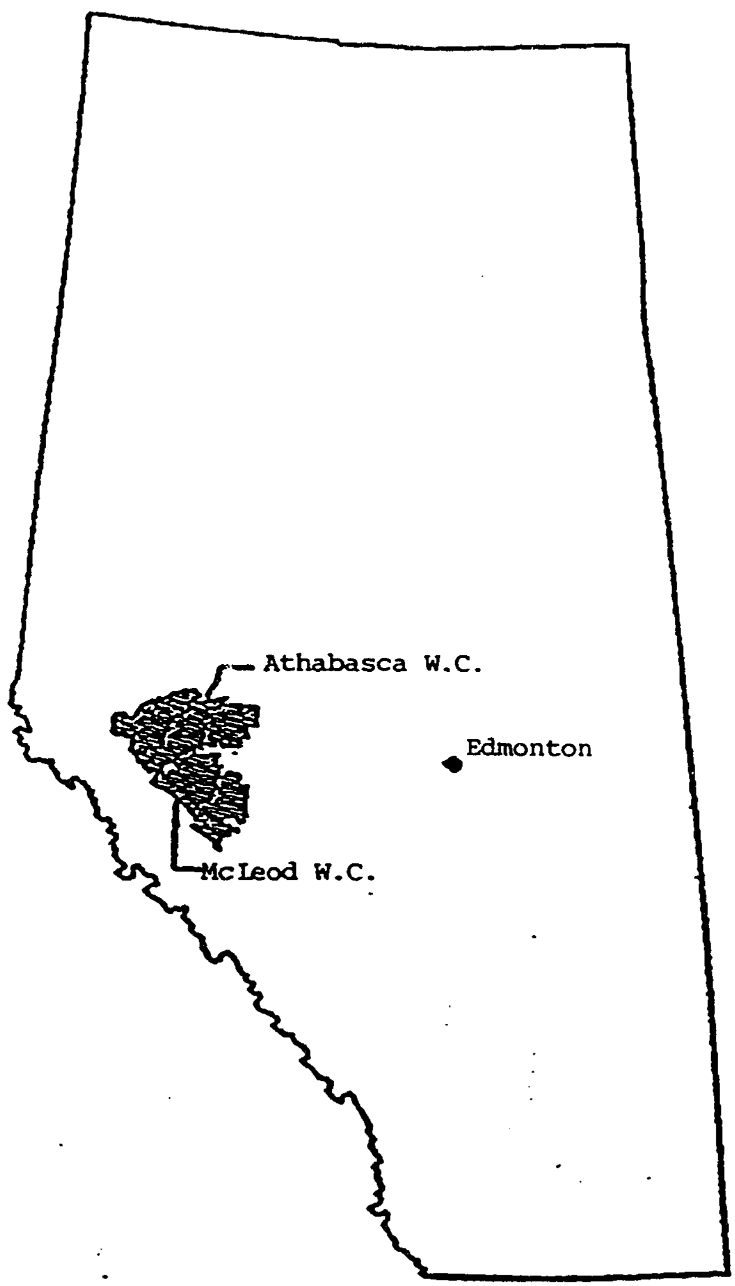
Snowshoe hares prefer to feed on trees less than 6 cm in diameter at breast height (DBH), while red squirrels prefer stems greater than 6 cm DBH (Brockley and Elmes 1987, Sullivan and Sullivan 1982a). Brockley and Sullivan (1988) believe the preference for larger trees may be due to greater amounts of nutrients in the cambium/phloem tissues.

Study Area

This study was conducted on Weldwood's FMA area (Province of Alberta, 1988) (Figure 1). The FMA is located on the eastern slopes of the Rocky Mountains, west of Jasper National Park in west central Alberta between 116° -118°, west longitude and 53°-54° north latitude (Dumanski *et al.* 1972). The FMA covers 1,012,119 ha (Weldwood *et al.* 1992). This area falls in the Cordilleran and Interior Plains physiographic regions, with elevations ranging from 850 to 2886 m (Weldwood *et al.* 1992). The boreal, montane and subalpine forest regions are all represented in the FMA (Weldwood *et al*. 1992). The eastern part of the FMA lies in the Boreal forest region; the Western part of the FMA lies in the Subalpine forest region (Rowe 1982). The Athabasca River Valley, West of Hinton, lies in the dry montane forest region at elevations of 1,000m to 1,200m (Weldwood *et al.* 1992).

Lodgepole pine is the most common coniferous tree species in this area. Aspen (*Populus tremuloides* Michx.) and balsam poplar (*Populus balsamifera* L.) are common deciduous tree species. In older stands not

Figure 1. Location of Weldwood's FMA in Alberta. Labeled Working Circles (W.C.) Contained Plots Established for the Field Study.



affected by fire or logging, white spruce (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Mill) BSP.) predominate. Subalpine fir (*Abies lasiocarpa* Mill.) can be found in some areas (Dumanski *et al.* 1972). Common shrubs in this area are buffalo-berry (*Shepherdia canadensis* Nutt.), hazelnut (*Corylus cornuta* Marsh.), alder (*Alnus* spp. Mill.), willow (*Salix* spp. L.), wild raspberry (*Rubus idaeus* L.), wild rose (*Rosa* spp. L.), labrador tea (*Ledum groenlandicum* L.), blueberry (*Vaccinium myrtillus* Michx.), bog cranberry (*Vaccinium vitis-idaea* L.), and bearberry (*Arctosaphylos uva-ursi* (L.) Spreg.). Common herbs and are twin-flower (*Linnaea borealis* L.), bunchberry (*Cornus canadensis* L.), bishop's-cap (*Mitella nuda* L.), indian paint-brush (*Castelleja* spp. Mutis *ex* L.f.), wintergreen (*Pyrola* spp. L.), wild strawberry (*Fragaria* spp. L.), vetch (*Vicia americana* L.) and fire weed (*Epilobium angustifolium* L.) (Dumanski *et al.* 1972).

The climate in this area is described as sub-humid continental with long cold winters and moderately mild summers. Warm chinook winds are common in the winter months. Peak rainfall occurs during June-August (50 cm). July is the hottest month of the year (Dumanski *et al.* 1972) with temperatures reaching an average high of 15° C.

Methods

PLOT SELECTION

Weldwood's Regenerated Stand Inventory (RSI) data base was used to select the location of sampling areas. The RSI data base consists of plots (22000) placed in a regular grid pattern in all cutblocks (8000) harvested from 1956 to 1981 (Weldwood 1989) and contains information on vegetation in the plots and physical characteristics of the cutblocks.

Concentrations of plots with damage were located by mapping all plots (Figure 2) having at least one lodgepole pine trees with browsing or barking damage. Selected plots were limited to the Athabasca and McLeod working circles due to vehicle travel time from Hinton. Plots to be used in this study were selected from the concentrations of damaged plots based on their proximity to a road or cutline, for ease of access. Due to travel time (vehicle) between area of damage concentrations and travel time (foot) between plots and time for plot measurement only 67 plots were selected. This permited the re-measurement of the plots every two weeks.

MEASUREMENTS MADE

Selected plots were initially established in May 1991 when all trees within a radius of 2.82m from the plot center were tagged and numbered, the damage status (damaged or undamaged) and diameter (DBH) were recorded. Photographs were taken of all existing damage in order to provide a basis from which to compare suspected incidence of new damage on subsequent visits.

Selected plots were regularly examined every two weeks from May to September 1991 to determine timing of damage, amount of new damage, amount and pattern of repeat damage and size of trees damaged. On every re-visit, all trees in the plot were examined for new damage. New instances of damage were photographed and recorded. When there was doubt as to whether damage was new, photographs of previous damage were examined. Plots were re-visited again in May 1992 to determine if any damage had occurred over the winter months.

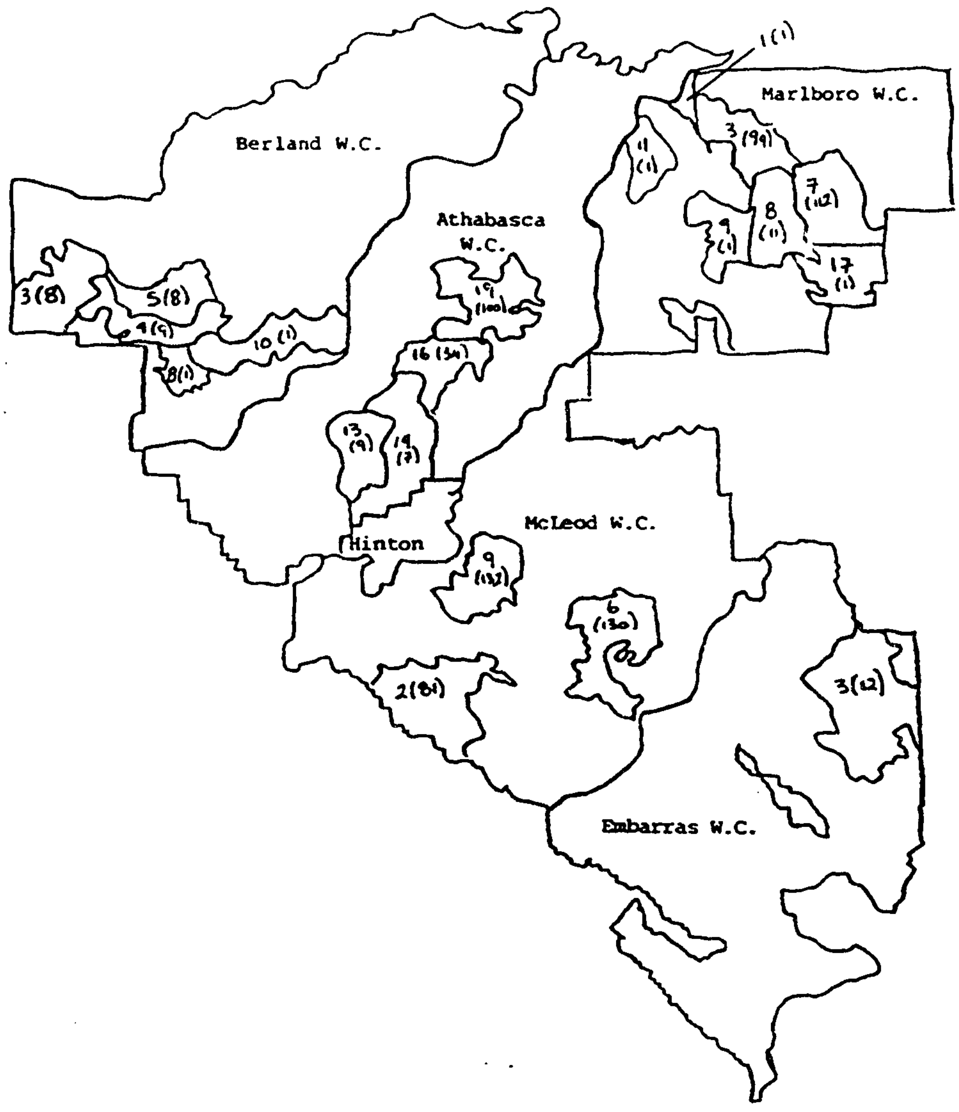


Figure 2. Map of Weldwood's FMA indicating the location of compartments containing damaged plots. Unbracketed numbers represent the compartment number. Numbers in brackets are number of plots with damage.

DETERMINATION OF DAMAGING ANIMAL SPECIES

In the field, scar appearance was used to determine which animal species was responsible for the damage. Scars with a messy, gnawed appearance and pieces of cambium present and teeth marks inside the scar borders were attributed to snowshoe hares. Scars somewhat rectangular in shape with clean borders and no residual cambium or teeth marks inside the scar border were attributed to red squirrels. In order to verify the ability to identify the animal species by scar appearance, approximately 100 samples of new damage were collected from outside the plots and taken to Dr. T. Sullivan at the University of British Columbia. He confirmed the scars were being correctly attributed to the appropriate animal species.

TIMING OF DAMAGE

Timing of damage was measured by the appearance of new scars on trees within the selected plots. If the damage was due to the feeding of snowshoe hares then a low frequency of new damage was expected because snowshoe hares primarily damage lodgepole pine during the winter months. If on the other hand, red squirrels were responsible for this damage, a large number of new attacks during the early spring and summer was expected. It was also expected that attacks would decrease to zero as late summer approached, because in British Columbia red squirrels primarily damage lodgepole pine during the spring and summer months (Sullivan and Sullivan 1982a).

PATTERNS OF DAMAGE AND CHARACTERISTICS OF TREES ATTACKED

The diameter of trees attacked helps to differentiate between snowshoe hare and re squirrel damage. If the majority of trees attacked was found to be less than 6 cm it would suggest snowshoe hares were primarily responsible (Brockley and Elmes 1987, Sullivan and Sullivan 1982a). If however, the majority of trees attacked was greater than 6 cm then it would suggest that red squirrels were primarily responsible (Brockley and Elmes 1987, Sulliv.ın and Sullivan 1982a).

Statistical analysis

Statistical analysis was conducted at the University of Alberta using SAS version 6.06 (SAS Institute 1988). Chi-square tests were used to determine the influence of old damage on the occurrence of new damage. Linear regression was used to determine the relationship between tree diameter and frequency of attack. A significance level of $P < 0.05$ was used in all analysis.

Results and Discussion

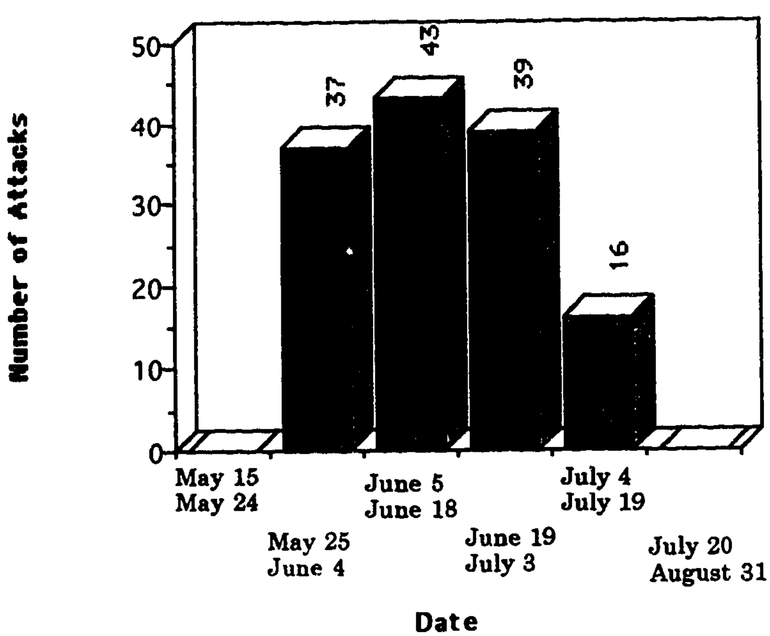
OBJECTIVE ONE: ANIMAL SPECIES RESPONSIBLE FOR THE DAMAGE

Using scar appearance to distinguish between snowshoe hare and red squirrel damage it was found that new damage observed on 65 plots (97% of plots, 99.5% of trees) was due to red squirrels; damage on the remaining 2 plots (3% of plots, 0.5% of trees) was due to snowshoe hares.

OBJECTIVE TWO: TIMING OF DAMAGE

In 1991, damage began in the first week of June and continued to mid July (Figure 3). In 1992, damage had already started when plots were re-visited in the middle of May. Damage observed was determined to be less than two weeks old based on the amount of pitch on the scars, and the fresh, undehydrated appearance of the residual bark strips caught on the tree and on the ground. Reasons for the earlier appearance of new damage in 1992 are not fully known, but may be due to a warm weather pattern in May of 1992 which did not occur in the year before.

Figure 3. Frequency of New Attacks During Sample Periods.



OBJECTIVE THREE: PATTERN OF DAMAGE AND CHARACTERISTICS OF TREES ATTACKED

On the 67 plots, 607 trees were measured and followed for this study. Figure 4. shows the distribution of trees per diameter class; 41 trees were below breast height and were assigned a diameter of 0 cm. The average diameter of all trees sampled was 5.05 cm; the average diameter of trees breast height or taller was 5.41 cm (n=569).

During the summer of 1991, there were 115 instances of new damage (18.85% of the trees examined); of these, 78 (68%) were on trees with previous damage and 37 (32%) were on previously undamaged trees. Multiple attacks were defined as the appearance of new damage on the same tree in more than one two week sample period. Eighteen (16%) of the 115 instances of new damage observed were multiple attacks; 14 (78%) of the 18 multiple attacks were on trees with old damage. See Table 1. for a summary of these findings.

Figure 4. Distribution of sample trees by diameter class

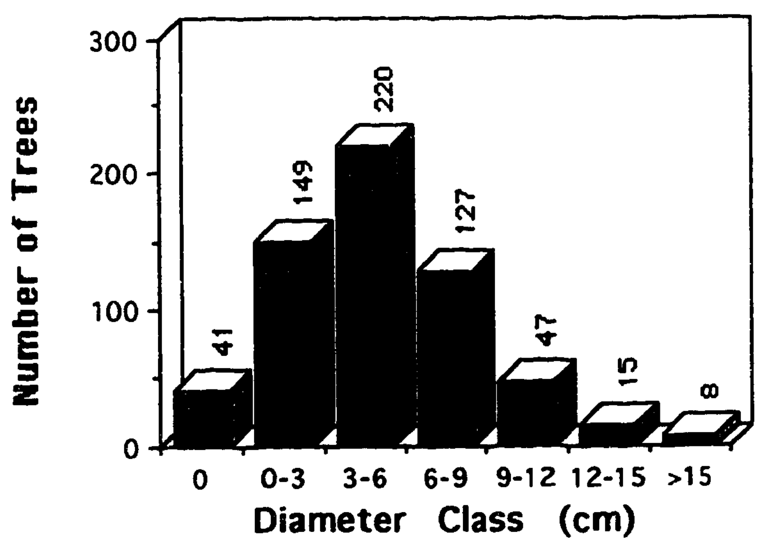


Table 1. Number of trees with no damage, old damage and old and new damage by diameter class. Percentages are in parenthesis.

Diameter Class (cm)	Number of Trees	Trees With Old Damage	Trees With New Damage	Trees With Both Old and New Damage	Trees With Only New Damage
0	41 (6.8)	2 (1.2)	0	-	-
>0-<3	149 (24.5)	11 (6.9)	8* 1** (7.8)	4* (5.1)	4* 1** (13.5)
>3-<6	220 (36.2)	50 (31.6)	28* 4** (27.8)	17* (21.7)	11* 4** (40.5)
>6-<9	127 (20.9)	53 (33.5)	44* 2** (40)	31* (39.7)	13* 2** (40.5)
>9-<12	47 (7.7)	29 (18.3)	18* (15.6)	17* (21.7)	1* (2.7)
>12-<15	15 (2.5)	8 (5.0)	4* (3.4)	4* (5.1)	0*
>15	8 (1.3)	5 (3.1)	6* (5.2)	5* (6.4)	1* (2.7)
Total	607	158	115	78	37

* Damage due to red squirrels.
** Damage due to snowshoe hares.

Linear regression analysis of diameter class in relation to damage indicates that proportionately more large trees were attacked than small trees (Y= proportion of trees damaged per diameter class; x= diameter class) (R^2 = 0.7882). Figure 5. illustrates the percentage of trees damaged in each diameter class. This preference for larger diameter trees is consistent with Sullivan's (1987 and 1985) findings that red squirrels prefer cambium from larger trees. Although exact reasons for this preference are not known, it suggests that trees will be vulnerable to barking damage for relatively long periods of time.

Figure 5. Percent of sample trees in each diameter class damaged.

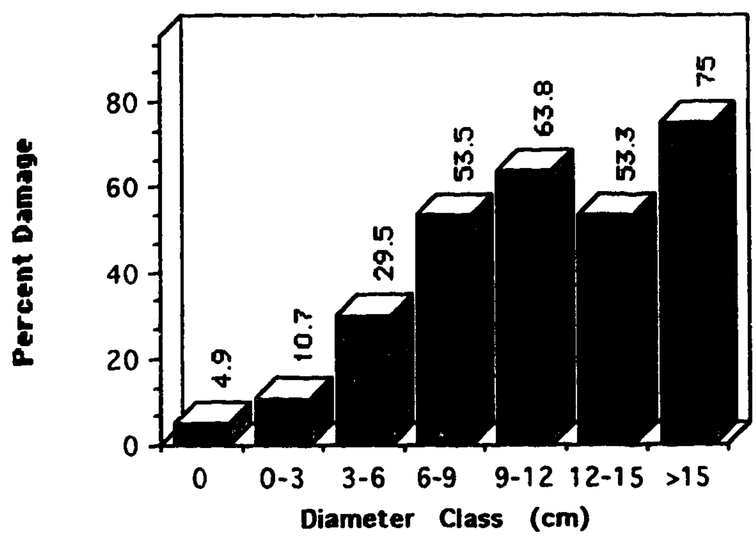


Table 2 is a contingency table of damage classes of sample trees. This table shows that trees with old damage will be subject to repeat damage at higher frequencies than trees with no old damage. A Chi-Square analysis of the relationship between old damage and the presence of new damage, indicates the difference in percent of trees attacked with old damage, verses those attacked with no old damage is significant (X^2= 128; $P < 0.05$). However, since larger trees are more likely to be attacked (above) the effect of diameter was controlled, by computing the association between row and column variables using the Copchran-Mantel-Haenszel test statistic option in SAS, and chi-square analysis repeated. Results still showed that old damage was still significant in influencing the presence of new damage (X^2= 130; $P < 0.05$). Reasons for the selection of trees with old damage are not known, but may be related to tree growth rate or secondary compounds (compounds produced by the tree to protect or heal itself from attack).

Table 2. Contingency table, showing number of trees in each of four damage categories

	No New Damage	New Damage
No Old Damage	412	37
Old Damage	80	78

Conclusions

The results of this study indicate that red squirrels are the primary cause of damage to juvenile stands of lodgepole pine in the Hinton area of Alberta. The timing of the onset of red squirrel barking damage is variable, but in general coincides with the onset of spring. This is consistent with findings from British Columbia of McKeever (1964), Sullivan and Sullivan (1982a), and Sullivan and Vyse (1988) that this type of damage is restricted to the beginning of the growing season. In addition, a larger proportion of trees greater than 6 cm DBH were attacked compared to trees less than 6 cm DBH, which support the conclusion above, of red squirrel being the primary damaging agent, and is consistent with patterns of damage reported in the literature.

The most significant finding of this study was that trees with previous damage were more likely to be re-attacked than trees with no damage. Further supporting this finding, during the re-survey of plots in May of 1992, new damage was restricted solely to trees with previous damage. This preference for damaged trees has not been previously reported in the literature. Reasons for this may be linked to the nutrient status of the tree or to secondary compounds. Research examining these attributes of damaged trees needs to be conducted in order to determine what is making damaged trees more susceptible to attack than undamaged trees.

Management Implications

If most of the damage in this area had been due to snowshoe hare feeding, then thinning, to reduce the amounts of ground cover, might have been appropriate as a means of reducing damage levels. However, most of the damage in this area is due to red squirrel feeding, thus thinning as a means of controlling for this damage is therefore not recommended. Literature suggests red squirrel damage may cease when trees reach a larger (> 20 cm) size (Sullivan 1984). A manager might contemplate fertilization of lodgepole pine stands to get trees to a "safe from attack" size sooner. However this is also not recommended. Fertilized and thinned stands are more vulnerable to red squirrel attack than untreated stands (Sullivan and Sullivan 1982b, Brockley and Sullivan 1987). Sullivan and Sullivan (1982b) found thinned stands had the second highest attack rate, next to fertilized stands. Further, they estimated fertilized stems had 3-4 times the tissue loss due to barking damage than stems not fertilized. Fertilization not only increased the number of attacks, but increases their severity, as measured by the amount of bark removed (Brockley and Sullivan 1987). If juvenile stand fertilization or thinning (spacing or cleaning) is contemplated it must be recognized that these actions may significantly increase the probability of red squirrel damage occurring in these treated stands. Significant numbers of crop trees are likely to be damaged and this damage will either kill the trees or result in a reduced growth rate, and in so doing reduce the stand's productivity.

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III. What characteristics make a stand vulnerable to attack.

Introduction

Young regenerated stands of lodgepole pine (*Pinus contorta* Dougl. *var.* latifolia Engelm.) are being severely damaged by the feeding of red squirrels (*Tamiasciurus hudsonicus* Erxleben) in the Hinton area of Alberta. This damage is termed barking damage and occurs when red squirrels remove portions of bark from trees in order to feed on the cambium. Degree of damage varies between stands, but it is believed that better site pine stands are most heavily damaged (Rugg 1990). Factors creating damage centers (areas with high levels of damage) are not clearly understood. In order for managers to predict the location of future damage centers, characteristics most correlated with damage need to be identified. This problem will be addressed through analysis of Weldwood of Canada's (Hinton division) regenerated stand inventory (RSI) data base (Weldwood 1989).

Red squirrel habitat

Mature stands of seed bearing trees, such as white spruce (*Picea gluca* (Moench) Voss) (M. Smith, 1968); black spruce (*Picea mariana* (Mill) BSP.) and jackpine (*Pinus banksiana* Lamb.) (Rusch and Reeder 1978) are preferred red squirrel habitats. Seeds from the cones of these conifers are the primary food source of red squirrels. Research by Klenner and Krebs (1991), Sullivan (1990) and Sullivan and Sullivan (1982) has shown that in mature conifer stands red squirrel populations are limited by food supply. Stands of juvenile lodgepole pine on cutover or burned land also support red squirrel populations often at densities comparable to mature stands, for short periods of time (Sullivan and Moses 1986). In these stands, squirrels often feed on vascular tissue (Sullivan and Sullivan 1982).

Seasonally available foods such as tree buds and flowers, fresh fruits, mushrooms, green cones, pollen and cambium are readily incorporated into red squirrel diets (Layne 1956, Rusch and Reeder 1978, Sullivan and Moses 1986). In some areas, these foods are so abundant that during the spring and summer seeds become an insignificant food source (McKeever 1964). In British Columbia, during times of low seed availability red squirrels have been found to rely on alternative food sources (Sullivan and Moses 1986).

Objectives

The objectives of this study were: to determine, through analysis of the RSI data set, what characteristics, physical and or vegetative, can be used as predictors of future damage in regenerated lodgepole pine stands and to determine if better sites are subjected to higher levels of damage.

RSI data base: Structure and contents

RSI data was collected in 1988 and 1989 from cutblocks harvested from 1956 to 1981 (n=8000) by Weldwood of Canada, Hinton division (Weldwood 1989). Plots (n=22000) were systematically established throughout the sample cutblocks at 100 or 200 meter intervals depending on the stocking status of the stand. Two sample crop trees, in each plot, were selected and the following information was collected:

tree species

damage status (damaged or undamaged)

height (meters)

root collar diameter (centimeters).

PLOT DATA

In addition to the sample tree information, the following data was gathered for each plot:

number of crop trees by species (coniferous species only greater than 25 cm tall)

total crop trees (coniferous species only)

number of non-crop conifers by species (less than 25 cm tall)

total non-crop conifers

number of deciduous trees by species

total deciduous trees

total number of non-crop trees (coniferous and deciduous trees)

total number of trees

average non-crop height

number of snags

number of residuals by species

site index (all site indexes in were set to 16 by Weldwood)

age in 1988.

In addition, understory cover data, collected on a plot basis, was divided into:

woody species one	non-woody species one
woody species two	non-woody species two
woody species three	non-woody species three

height woody species one	height non-woody species one
height woody species two	height non-woody species two
height woody species three	height non-woody species three
percent cover woody species one	percent cover non-woody species one
percent cover woody species two	percent cover non-woody species two
percent cover woody species three	percent cover non-woody species three

Some moss lichen information was also collected but not used in this study because of too many missing values in the data set.

BLOCK DATA

On a cutblock basis the following were recorded:

slope

aspect

harvest year

Methods

DEVELOPMENT OF THE RSI DATA SET

The RSI data set contains information on the physical and vegetative characteristics of all cutblocks harvested from 1956 to 1981. Information for each cutblock was collected from a series of sample plots established throughout each block. There are 8000 cutblocks and 22000 plots in the RSI data set. For this analysis only lodgepole pine cutblocks are needed. Therefore, the RSI data set was sorted so only those cutblocks with greater than 50% of their plots containing at least one lodgepole pine crop tree remained for analysis. The remaining data was examined for duplicate entries and entries with missing data, when found, were removed. All overstory and understory height measurements were converted to meters. Erroneous understory names and or unacceptable understory heights in the plot data were checked for and deleted. After these changes, 1627 cutblocks and 11241 plots remained. Sample tree heights in the remaining data were checked and for each age the maximum acceptable sample tree height was calculated as follows:

Maximum height = 0.5+0.5(age-4).

This allows for a maximum 7 year height of 2 meters and 0.5 meters of growth, maximum, for each additional year (Curry 1992). All plots with heights exceeding that allowed by the above formula for each age were deleted. The remaining data set, consisting of 1607 blocks and 10919 plots, was used in the analysis.

Parameters examined at the plot level were: number of crop trees by species, total crop trees, number of non-crop trees by species, total non-crop trees, number of deciduous trees by species, total deciduous trees, total tree density, average height of sample trees, age, percent woody understory cover, woody understory height, percent non-woody understory cover, non-woody understory height, and percent total cover.

Parameters examined at the block level were: slope, aspect, age, number of crop trees, number of non-crop conifers, number of deciduous trees, percent total understory cover, percent woody cover, percent non-woody cover, height of sample trees, number of crop trees by species, number of deciduous trees by species, number of non-crop trees by species, height of the woody understory cover, height of the non-woody understory cover, and total tree density.

Statistical Analysis

The RSI data set was analyzed on both the plot and block level. At the block level, analysis consisted of comparing damaged blocks to undamaged blocks. A block was considered damaged if at least one of its plots contained damage. On the plot level, plots were placed in to one of the following categories, based on damage status, for analyses:

- Damaged or undamaged (a plot is considered damaged if one or both the sample trees is coded for damage)
- 0% damage (neither sample crop tree damaged); 50% damage (one sample crop tree damaged), or 100% damage both sample crop trees damaged)
- Plots from undamaged blocks (i.e. undamaged plots), undamaged plots from damaged blocks and damaged plots from damaged blocks.

DISCRIMINANT ANALYSIS

Discriminant analysis, a multivariate procedure, uses a set of predictor variables to discriminate between predefined levels of an outcome variable. In this case, the outcome variable is the level of damage, either on a percentage basis or on a presence absence basis. The set of variables used to predict damage are those listed in the section RSI data base: structure and contents. The squared canonical correlation, in discriminant analysis, indicates the estimated relationship between the predictor variables and the outcome. A large squared canonical correlation indicates a high correlation between the predictor variables and the damage status of the plot or block. Conversely, a low squared canonical correlation indicates a low correlation between the predictors and the damage status of the plot or block. Discriminant analysis was run comparing:

- damaged plots to undamaged plots.
- plots with 0% damage to plots with 50% damage to plots with 100% damage.
- plots from undamaged blocks to undamaged plots from damaged blocks to damaged plots from damaged blocks.
- damaged blocks to undamaged blocks.

HEIGHT COMPARISONS

All site indexes in the RSI data set had been set to 16 by Weldwood. This unrealistically implies all lodgepole pine cutblocks and plots on the Weldwood FMA are the same site class. Thus, the site index variable in the RSI data set is useless in examining whether or not better sites are being attacked. Therefore, the only way in which to determine if better sites are subject to higher levels of damage was to compare heights of damaged and undamaged areas within each age group. Those plots or cutblocks with greater heights within an age group are on better sites. If damaged plots or blocks have greater heights than undamaged plots or blocks, it indicates that better sites are selected over poorer sites. In order to determine if site index is influencing the location of damage, the following height comparisons, by age group were made and statistically compared:

- damaged plots verses undamaged plots.
- undamaged plots from undamaged blocks verses undamaged plots from damaged blocks verses damaged plots from damaged blocks.
- damaged blocks verses undamaged blocks.

Results and discussion

DISCRIMINANT ANALYSIS

Comparison of means between damaged and undamaged plots indicated a low predictive ability (squared canonical correlation = 4.8%). Comparison of plots based on the damage status of the block and plot indicated a low predictive ability (squared canonical correlation = 9.5%). Comparison of the three levels of damage on a plot basis also indicated low predictive ability (squared canonical correlation = 6.0%). Comparison of damaged and undamaged blocks indicated a slightly better, but still poor predictive ability (squared canonical correlation = 13.6%). The low squared canonical correlations of the above analyses indicate that both on the plot and block level the ability to predict the damage status of the plot or block is low.

HEIGHT COMPARISONS

Plot comparisons

Comparing heights of damaged and undamaged plots, regardless of block damage status, by age showed that for the majority of ages the average height for damaged plots is higher than for undamaged plots (Figure 6). Comparing average heights of undamaged plots from undamaged blocks, undamaged plots from damaged blocks and damaged plots from damaged blocks, by age, showed that, in general, damaged plots have greater heights than both classes of undamaged plots. Mean heights of the three classes of plots were tested for significant differences. Table 3 summarizes the statistical testing of the differences of theses heights.

Mean heights of trees by age class from undamaged plots from undamaged blocks verses mean heights of trees by age class from undamaged plots from damaged blocks (column 1 verses column 2 of table 3).

Comparison of the mean tree heights, by age class, for these two classes of plots shows 13 positive differences, 10 negative differences and 3 cases of no difference. Of these 26 differences, only 7 are statistically significant (5 positive and 2 negative). In a practical sense this indicates tree heights of the undamaged plots seem about the same regardless of whether the plots occur on a damaged or undamaged cutblock. This would tend to indicate the site or site index of undamaged plots are similar.

Figure 6. Mean Heights of Plots within Blocks by Age.

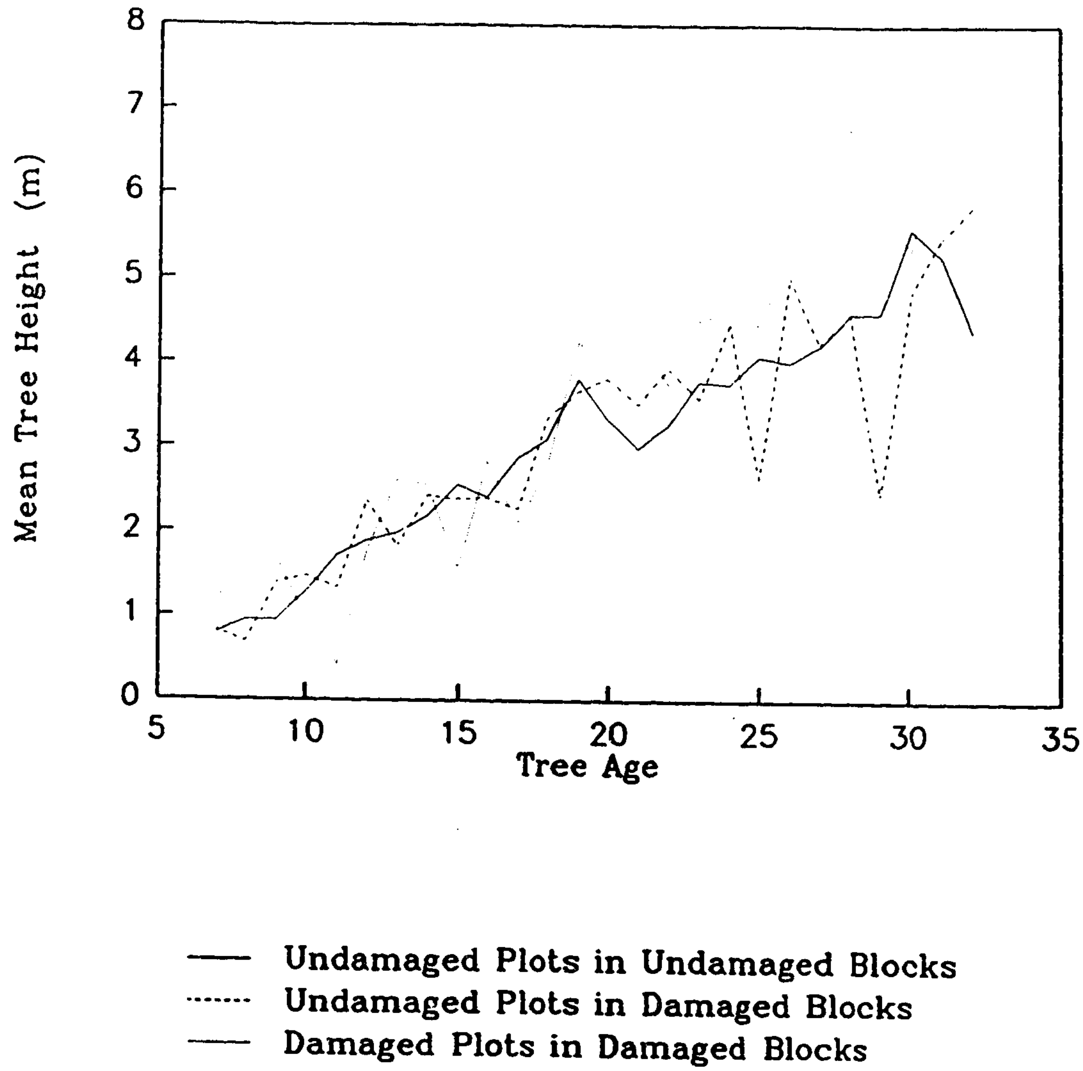

Table 3. Mean Heights of plots within blocks by age. Significant comparisons are marked.

Age	Mean Height of Un-damaged Plots from Undamaged Blocks (1)	Mean Height of Un-damaged Plots from Damaged Blocks (2)	Mean Height of Damaged Plots from Damaged Blocks (3)	Mean Height Differences (1) vs. (2)	Mean Height Differences (2)vs. (3)	Mean Height Differences (1) vs.(3)
7	0.80	0.83	1.30	0.03	0.47	0.50
8	0.95	0.69	1.09	-0.26	0.40	0.14
9	0.95	1.40	1.70	0.45	0.30	0.75
10	1.29	1.48	0.97	0.19	-0.51	-0.32
11	1.73	1.33	0.41	-0.40	-0.92	-1.32
12	1.90	2.39	1.77	0.49 **	-0.62	-0.13
13	1.99	1.84	2.64	-0.15	0.80 **	0.65 **
14	2.20	2.44	2.57	0.20	0.13	0.37
15	2.57	2.40	1.56	-0.17	-0.84 *	-1.01 **
16	2.42	2.41	2.86	-0.01	0.45 *	0.44 *
17	2.89	2.27	2.10	-0.62	-0.17	-0.79 **
18	3.11	3.35	2.76	0.24	-0.59 *	-0.35
19	3.82	3.68	4.27	-0.14	0.59 **	0.45 *
20	3.35	3.83	3.91	0.48	0.08	0.56
21	2.99	3.51	4.30	0.52 **	0.79 *	1.31 **
22	3.27	3.94	3.75	0.67	-0.19 **	0.48
23	3.78	3.58	4.52	-0.20	0.94 **	0.74 **
24	3.75	4.47	4.60	0.72 **	0.13	0.85 **
25	4.08	2.62	4.46	-1.46 **	1.84 **	0.38
26	4.00	5.02	5.37	1.02 *	0.35	1.37 **
27	4.20	4.23	5.80	0.03	1.57 **	1.60 **
28	4.58	4.57	6.84	-0.01	2.27 **	2.26 **
29	4.58	2.42	5.80	-2.16 **	3.38 **	1.22
30	5.59	4.82	5.34	-0.77	0.52	-0.25
31	5.26	5.47	6.90	0.21	1.43 *	1.64 **
32	4.36	5.86	6.73	1.50 **	0.87 *	2.37 **

* Significant at 0.01 $p < 0.05$.
**Significant at $p < 0.01$.

Mean heights of trees by age class from undamaged plots from undamaged blocks verses mean heights of trees by age class from damaged plots from damaged blocks (column 1 verses column 3 of table 3).

Comparison of the mean tree heights, by age class, for these two classes of plots shows 19 positive differences and 7 negative differences. Of these 26 differences, 13 are significantly different (11 positive and 2 negative). In general the mean heights of trees from damaged plots from damaged cutblocks tend to be taller by age class compared to the mean heights of trees from undamaged plots from undamaged cutblocks. This tends to indicate that the site or site index of damaged plots is higher than that of undamaged plots.

Mean heights of trees by age class from undamaged plots from damaged blocks verses mean heights of trees by age of damaged plots from damaged blocks (column 2 verses column 3 of table 3).

Comparisons of the mean tree heights, by age class, for these two classes of plots shows 19 positive differences and 7 negative differences. Of these 26 differences, 14 are significantly different (11 positive and 3 negative). In general the trees from damaged plots are taller than the trees from undamaged plots. In this case, this again implies the site or site index of damaged plots is higher than the undamaged plots. In addition it implies that site or site index varies within cutblocks and the damage is preferentially occurring on the best parts of the cutblocks.

Block comparisons

Comparing average heights between damaged and undamaged blocks, by age, showed that in general damaged blocks had greater average heights than undamaged blocks (Figure 7). Mean heights of damaged and undamaged blocks were tested for significant differences. Table 4 summarizes the statistical testing of these heights. Of the 26 age classes the mean tree height on damaged cutblocks is taller for 18 age classes, no different for one age class and shorter for 7 age classes. Thirteen of these 26 differences are statistically significant (9 positive and 4 negative). These results suggest that in general it is the better sites throughout the study area that are being damaged.

Figure 7. Mean Heights of Damaged and Undamaged Blocks by Age.

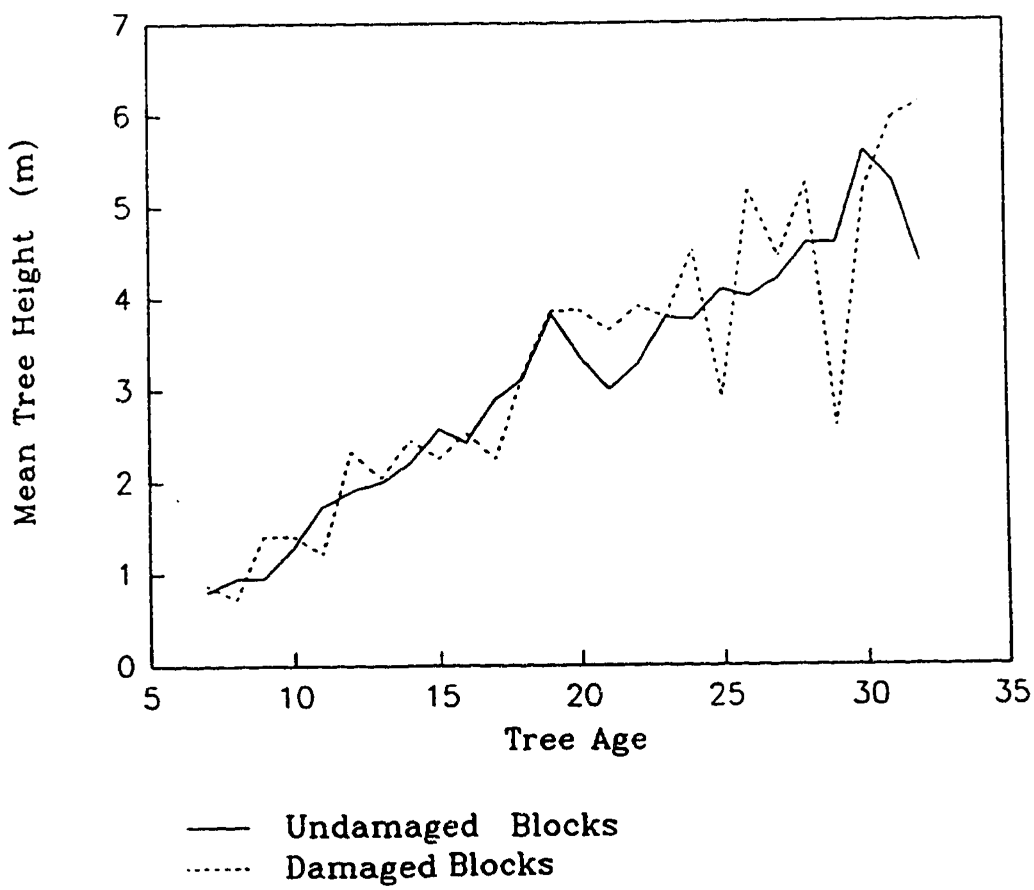

Table 4. Mean Heights of Damaged and Undamaged Blocks by Age, Significant Comparisons are marked.

Age	Mean Height of Undamaged Blocks (1)	Mean Height of Damaged Blocks (2)	Mean Height Differences (1) vs. (2)
7	0.80	0.87	0.07
8	0.95	0.73	-0.22
9	0.95	1.41	0.46
10	1.29	1.41	0.12
11	1.73	1.21	-0.52
12	1.90	2.33	0.43 *
13	1.99	2.04	0.05
14	2.20	2.45	0.25 *
15	2.57	2.25	-0.32 *
16	2.42	2.53	0.11
17	2.89	2.24	-0.65 **
18	3.11	3.15	0.04
19	3.82	3.85	0.03
20	3.35	3.86	0.51 *
21	2.99	3.64	0.65 **
22	3.27	3.90	0.63 **

23	3.78	3.78	0
24	3.75	4.52	0.77 **
25	4.08	2.91	-1.17 **
26	4.00	5.17	1.17 **
27	4.20	4.43	0.23
28	4.58	5.24	0.66 **
29	4.58	2.58	-2.00 **
30	5.59	5.16	-0.43
31	5.26	5.96	0.70
32	4.36	6.11	1.75 **

* Significant at 0.01 $p < 0.05$.
**Significant at $p < 0.01$.

CONCLUSIONS

Results of the discriminant analysis indicate that the information in the RSI data set is not sufficient to determine what characteristics of an area are making it susceptible to damage. Developing an equation to predict the susceptibility of an area to damage in the future is not possible with the existing information. Although it appears that damage occurs throughout the FMA, height comparisons indicate that better sites are more likely to be attacked than poorer sites. This supports Weldwood's belief that it is the better sites that are subjected to the most damage.

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IV. Conclusions

General

Damage in juvenile lodgepole pine stands in the Hinton area of Alberta is primarily due to the feeding of red squirrels during the late spring and early summer months. Within a stand, larger trees (DBH > 6 cm) are primarily attacked compared to smaller (DBH < 6 cm) trees. These findings are consistent with findings from British Columbia. Trees with previous damage are selected over trees with no damage. This fact has not been previously reported in the literature.

Analysis of the RSI data set indicates that the information contained in this data set was not sufficient to determine what factors make certain areas vulnerable to attack. Information not included in this data set may be needed in order to determine what characteristics separate damaged from undamaged areas. Two pieces of additional information that might be helpful are: 1). Proximity of damaged areas to mature stands of white spruce (*Picea gluca* (Moench) Voss) or lodgepole pine (*Pinus contorta* Dougl. *var.* latifolia Engelm.) in either uncut blocks or in buffer strips and or 2). Amount of coarse woody debris in the area.

Mature white spruce or lodgepole pine stands (preferred red squirrel habitat) provide cover from predators and therefore juvenile red squirrels may be moving into the surrounding young lodgepole pine stands each year from these stands. The use of Geographic Information System (GIS) may allow patterns between the location of mature timber and damaged areas to be identified. The amount of coarse woody debris may influence damage levels by providing ground hiding cover for red squirrels and their predators.

Possible management strategies

RSI analysis results do not lead to any suggestions on how management practices can be altered in order to minimize potentially high levels of future damage. General impressions from fieldwork and information in the literature lead to the following suggestions in which red squirrel damage in juvenile lodgepole pine stands may be minimized. It must be noted that none of the management strategies listed below have been tried in Alberta. Research trials are needed to determine their effectiveness.

1. SUPPLEMENTAL FEEDING

Supplemental feeding experiments have proved to be successful in reducing damage levels in British Columbia where, researchers have been experimenting with feeding sunflower seeds at the beginning of spring (Klenner and Krebs 1991, Klenner and Sullivan 1991, Sullivan 1992). In one study, damage levels were significantly reduced with the supplemental feeding (Sullivan 1992). To date, none of the red squirrel populations were permanently altered as a result of the availability of supplemental food (Klenner and Sullivan 1991, Sullivan 1992). Sullivan (1992) estimated costs from $40.67-$45.77 per ha. per year. According to Sullivan (1992) when trees reach DBH of > 20 cm they seem to be less susceptible to attack (this does not mean that they never will be attacked). Thus, feeding would need to occur from DBH < 6 cm to DBH = 20 cm. Whether or not supplemental feeding is financially feasible or will work in Alberta is not known.

2. DEVELOPMENT OF REPELLENT SPRAYS

Repellent sprays have been successfully used in the reduction of snowshoe hare feeding damage in the short term (Bryant 1980, Sullivan and Crump 1984, and Sullivan *et al.* (1985). Bryant (1980) used resins extracted from several trees species, while Sullivan and Crump (1984) used mustelid anal gland compounds and Sullivan *et al.* (1985) used predator feces, urine and anal gland odors. Similar repellents may be successful in controlling red squirrel damage. The short term effect of these repellents requires re-application on a yearly basis if continuing damage control is desired. No research has been reported in the literature on attempts to develop red squirrel repellents.

3. SQUIRREL REMOVAL

Removal of red squirrels from highly vulnerable areas will only serve to open up the area for re-habitation to transient individuals and is therefore not recommended. Price *et al.* (1986) and Klenner (1991) found that when territory holding individuals were removed, other individuals quickly took over the territory.

4. INTENTIONAL WOUNDING OF TREES

The preference of red squirrels for trees with previous damage suggests that these trees possess something attractive to red squirrels. This suggests that the tree itself may be the initial attractant or the presence of disease or infection may make the tree attractive. After the initial attack, the presence or absence of secondary compounds may continue to make the tree attractive to red squirrels. Intentional wounding of selected sacrifice trees may create conditions in the tree that make it attractive to red squirrels (Boutin 1992). The presence of sacrifice trees would not prevent undamaged trees from being damaged, but might reduce the likelihood of this occurring. If sacrifice trees are used, they should be evenly distributed over the area of concern. As previously mentioned, research trials are needed to test the validity of creating target trees as a means of controlling levels of red squirrel damage.

SUMMARY OF CONCLUSIONS

This study has examined the timing and characteristics of small mammal damage in juvenile stands of lodgepole pine and made suggestions on how to minimize damagc levels. Red squirrels were found to be responsible for the majority of the damage. Damage occurs in the late spring and early summer for a period of approximately eight weeks. Larger, damaged trees are more likely to be re-damaged than smaller, undamaged trees. Although analysis of the RSI data set did not determine what characteristics make certain areas damage centers it did indicated that better sites are subjected to higher levels of damage than poorer sites.

Further research

As previously indicated, research testing the effectiveness of the management strategies suggested in chapter three is needed. Nutrient status and secondary compound production in damaged and undamaged trees needs to be examined in order to determine why damaged trees are selected over undamaged trees. Further research is also needed to determine what characteristics of an area (physical and or vegetative) facilitate high levels of damage. Results from these studies may help in the selection of logical management actions to reduce damage levels to acceptable levels.

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