The Effect of Simulated Bark Stripping by Moose on Scots Pine Height Growth: an Experimental Treatment

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Abstract

The damage caused by large herbivores feeding on forest trees is considerable. This study was carried out to determine the reaction of Scots pine (*Pinus sylvestris* L.) trees to mechanical bark stripping that imitates the damage to tree stems caused by moose (*Alces alces* L.). There was a significant difference between the height increment of control and damaged trees during first year after treatment. However, damaged trees quickly recovered and resumed growth. The differences among damage treatments (removing 30, 60, and 90% bark) were not significant. Tree size affects tree growth, which means that the growth reduction after bark stripping will be compounded over future tree growth and may determine the competition interrelations in stands.

Key words: bark stripping, damage, height growth, moose, Scots pine

Introduction

Herbivores can alter the successional patterns of forests by selectively browsing preferred species (Gill and Beardall 2001, Rooney 2001, Akashi 2009). If the preferred browse species are predominantly early-successional or seral in character, then browsing may result in a reduction of light demanding species (Horsley et al. 2003, Månsson 2009). In boreal and hemiboreal ecosystems, herbivory by moose may be a major reason for composition shifts as indicated by studies in different parts of western Russia (Abaturov and Smirnov 2002). Kuznetsov and Lozinov (1992) report the 20-year-long impact of moose (*Alces alces* L.) that led to gradual replacement of pine by hardwood species and Norway spruce (*Picea abies* (L.) Karst) in Valdai Hills region of Russia. These changed patterns of vegetation have also been reported by Connor et al. (2000) and Edenius et al. (2001) who studied moose in the boreal zone.

Moose is the most important and the largest ungulate in Estonia. The moose population peaked at the end of the 1970s in Estonia when the medium population density of moose was estimated at more than 10 individuals per 1000 ha (Tõnisson and Randveer 2003). The situation was similar in Finland where the highest densities in southern Finland occurred during the winter of 1977-1978 with average densities in some districts exceeding 11 moose per 1000 ha (Lavsund et al. 2003). In Sweden the peak densities were even higher, reaching 30-40 animals per 1000 ha in the mid-1970s and early 1980s (Cederlund and Markren 1987).

Although it is difficult to estimate the financial impact of such dense moose populations on the forestry sector, one attempt in Sweden (Lavsund 1987) estimated an economic value of the damage at 20-50 million US dollars per year. This represents 2-5 % of the total value of the annual harvest of lumber and pulpwood. Glöde et al. (2004) reported that the annual income loss due to pine browsing by moose in Sweden is predicted to be increased in the future to about 70-190 million US dollars (500-1300 million SEK). In Estonia, moose damage in young Scots pine (*Pinus sylvestris* L.) stands is significant (Örd and Tõnisson 1986, Vahter and Kaimre 2009) and the most prevalent form of damage is browsing of young shoots. Bark stripping, while occurring less frequently, can nevertheless cause substantial damage. Bark stripping by large ungulates has caused serious damage to several tree species worldwide (Gill 1992, Parks et al. 1998, Keith and Pellow 2005). For example, in Sweden, where stands of Scots pine are subject to bark stripping, almost 5% of all trees are affected each year (Faber 1996, Faber and Edenius 1998). In Estonia, bark stripping by moose is more common in middle-aged Norway spruce stands than in pine stands (Randveer and Heikkilä 1996). Nonetheless, the potential for damage to one out of every twenty pine trees is a significant issue in Estonian forests and warrants investigation.

In order to determine the effect of bark stripping, we simulated moose damage by mechanically removing bark from Scots pine trees in Estonia. We hypothesized that bark stripping significantly reduced tree height increment. We tested the effects of wound size and repeated wounding on height growth to examine the hypothesis that reduced height increment is a function of recent-year and cumulative stripped bark area.

Materials and methods

Estonian forests are in the hemi-boreal forest zone (Ahti et al. 1968). The study was established in a Scots pine stand in southern Estonia (58°09'N, 27°07'E). Scots pine forests are not uncommon component of the region's forests, usually situated on sites that contain excessively well-drained sandy soils. The stand was established in 1993 by direct seeding on podzols. These are medium fertility soils in Estonian conditions (site index H_{100} = 25 m). The study area was 250 m^2. All trees were numbered and the experimental area was fenced in order to avoid external influences.

Treatments were applied randomly to trees within the fenced exclosure. Three treatments were applied in March 2004: stripping the bark at breast height with wounding 30, 60 and 90% of the stem perimeter, representing the full range of potential damage. The level of damage corresponds to variation of damage in real forest stand, where the degree of damage can vary by its extent. An adjacent, untreated area was used as a reference site to plan the treatments. A knife was used to remove the bark to a vertical length of 20 – 30 cm. The bark was stripped but the xylem was not affected by treatment. Bark stripping damage was imitated on the trees with a height between 2-3 meters, believed to be the most attractive to moose (Bergqvist et al. 2001). Furthermore, the time of wounding – April and May – matched the damage peak under natural conditions (Faber 1996). We used visual estimation to ensure that trees with comparable size were in each damage class; subsequent analysis found no significant difference in heights between the control and treatment populations (data not shown). In the spring of 2005, an additional 30% of bark was removed on two-thirds of the trees in 30% treatment and on half of the trees in 60%, a continuous debarked area. The trees receiving this second treatment were designated 30+30% and 60+30%. Table 1 provides a summary of the treatment classes. The original number of trees selected for different treatments (Control, 30%, 60% and 90%) was 55-60. The final number of trees is somewhat different, because during the selection and marking of trees some of the trees died, primarily among the 90% treatment class.

Table 1. Number of trees (n) and mean height (H) before treatment at 2004 (with standard error) in different treatments of bark stripping experiment

	Control	30%	60%	90%	30+30%	60+30%
n	59	21	28	52	40	27
H (cm)	287.1	276.8	268.6	276.1	266.9	273.4
SE	± 7.0	± 11.3	± 8.8	± 4.8	± 7.2	± 6.7

Total tree heights were measured with a telescopic measuring rod (1 cm precision) at the beginning of the study and after treatments each year in early spring before the growing season for a total of five years. Diameter was not used as a response variable because it is confounded by stand density and the simulated browsing-induced measurement inaccuracy.

Tree height and height increment by measurement year were analyzed with the general linear model (GLM) procedure of SAS software (version 9.1; SAS Institute, Cary, NC). In the statistical analysis one-way ANOVA and ANCOVA models were used with the following formulas:

$$y_{ij} = m + t_i + e_{ij}, \quad (1)$$
$$y_{ij} = m + t_i + bh_{ij} + e_{ij}, \quad (2)$$

where *m* denotes the intercept of model, t_i denotes effect of i^{th} treatment, h_{ij} denotes initial height of j^{th} tree for i^{th} treatment in year 2004, b denotes the common slope for covariate h_{ij}, e_{ij} denotes the error term, assumed to be an independent normal random variate with zero mean.

Results

There was a significant difference between the height increment of the control and damaged trees (average of all treatments). The analysis without initial tree height (Model 1) showed significantly higher height increment values (4.87 ± 1.60 cm in 2004, $P < 0.05$ and 4.78 ± 2.00 cm in 2005, $P < 0.05$) for the control trees compared to the average of all treatments during first two years after treatment (Table 2).

Table 2. Effect of bark stripping on annual tree height increment (control vs. average of all treatments) in case of Model 1 (without initial tree height – 2004)

Year	Estimate (cm)	Standard error of estimate (cm)	*t*-value	*P*-value
2004	4.87	1.60	3.05	0.0026
2005	4.78	2.00	2.39	0.0180
2006	2.92	1.91	1.53	0.1273
2007	0.84	2.69	0.31	0.7551
2008	0.81	3.22	0.25	0.8029

When the initial tree height was included in the analysis (Model 2) there were significantly greater height-increment values (3.21 ± 1.32 cm in 2004, $P < 0.05$) for the control trees during the first year after treatment (Table 3). However, damaged trees quickly recovered and resumed growth. The differences between damage treatments (removing 30, 60, and 90% bark) were not significant. Furthermore, the repeated bark stripping did not result in significant differences in height increment.

Table 3. Effect of bark stripping on annual tree height increment (control vs. average of all treatments) in case of Model 2 (with initial tree height – 2004)

Year	Estimate (cm)	Standard error of estimate (cm)	*t*-value	*P*-value
2004	3.21	1.32	2.44	0.0157
2005	2.73	1.81	1.51	0.1329
2006	1.73	1.85	0.93	0.3527
2007	-0.09	2.66	-0.03	0.9727
2008	0.81	3.24	0.25	0.8027

The analysis of treatments on first year height increment in 2004 (Model 1) revealed significant differences ($P < 0.05$) between the height increment of the control and damaged trees (Table 4). Bark stripping was found to have a significant relationship with the height increment but not between the different levels of damage. When analysis with the initial tree height (Model 2) was applied (Table 5), the first year height increment on the control trees was significantly higher than the increment on trees with bark damaged at the 60% (3.32 ± 1.62 cm, $P < 0.05$) and 90% (4.16 ± 1.61 cm, $P < 0.05$) levels. There was no significant difference in the first year height increment between the different treatments.

Table 4. Effect of treatments on first year height increment by Model 1 (different variants without initial tree height – 2004)

Parameter	Estimate (cm)	Standard error of estimate (cm)	*t*-value	*P*-value
control vs. 30%	4.15	1.92	2.16	0.0318
control vs. 60%	5.30	1.96	2.70	0.0075
control vs. 90%	5.45	1.96	2.78	0.0060
30% vs. 60%	1.15	1.95	0.59	0.5567
30% vs. 90%	1.29	1.95	0.66	0.5072
60% vs. 90%	0.15	1.99	0.07	0.9417

Table 5. Effect of treatments on first year height increment by Model 2 (different variants with initial tree height – 2004)

Parameter	Estimate (cm)	Standard error of estimate (cm)	*t*-value	*P*-value
control vs. 30%	2.62	1.58	1.66	0.0983
control vs. 60%	3.32	1.62	2.05	0.0413
control vs. 90%	4.16	1.61	2.59	0.0103
30% vs. 60%	0.70	1.60	0.44	0.6615
30% vs. 90%	1.54	1.59	0.97	0.3336
60% vs. 90%	0.84	1.63	0.52	0.6049

Although the height of the control trees was greater than the height of wounded trees, the differences were not significant (data not shown). The height increment of wounded and the control trees increased from year to year, as evidenced by significant differences within a treatment between tree heights in consecutive years. Thus, our simulated bark stripping of Scots pine did not result in a significant reduction in the height increment of later years (data not shown).

The repeated damage influence was analysed by comparing the height increments between treatment years (Figure 1). Repeated wounding of the same tree in a subsequent year did not affect the tree height

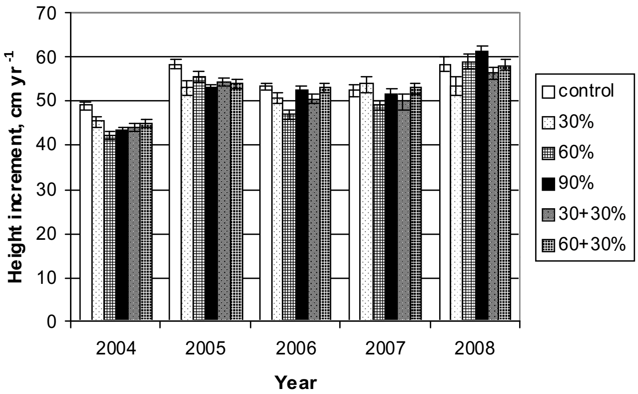

Figure 1. Height increment of trees with different bark stripping treatments during observation period 2004-2008

increment when the total damage was 60% or 90%. Nonetheless, a year effect could still be detected.

The relationship between the initial tree height influence and the first year height increment as a function of different treatments is displayed in Figure 2. Initial height of the tree was not of overwhelming importance; including it in the model only eliminated significant differences between the control and the 30% damage level (Table 5).

Our study was confined to individual tree observations on a medium site. Damage can be worse on poor sites as was demonstrated by shoot browsing simulation studies (Danell et al. 1991). In addition, trees on sites with different water regimes may exhibit differing susceptibility to damage risk by moose (Heikkilä and Härkönen 1993).

Trees can react to herbivory by compensatory physiological mechanisms in the case of browsing

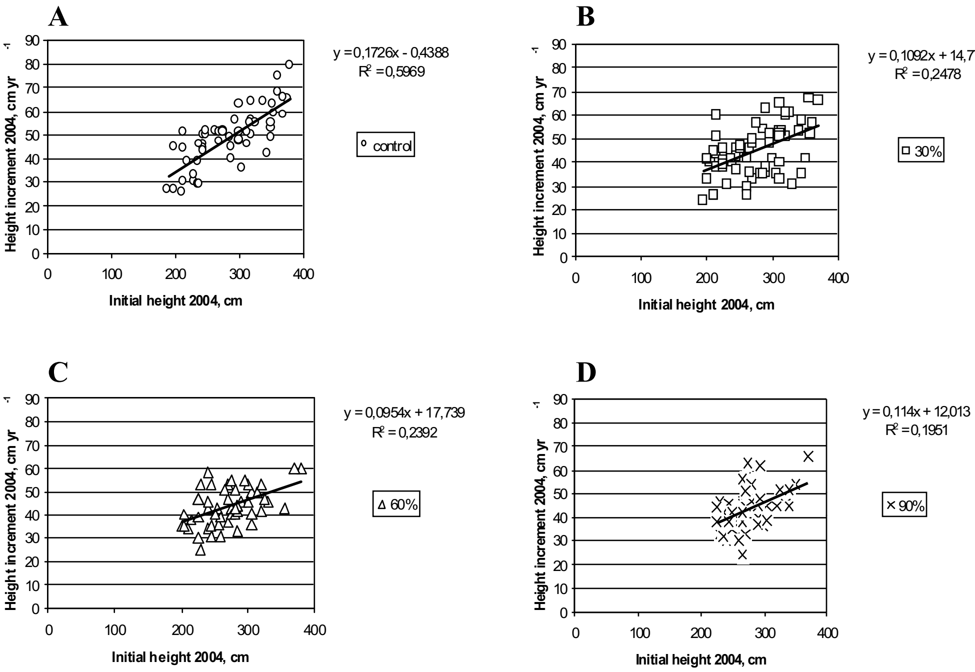

Figure 2. The effect of initial tree height in 2004 to first year height increment in 2004.
A – control, B – 30% damage of bark, C – 60% damage of bark, D – 90% damage of bark

Discussion

Our results with Scots pine suggest that the effect of bark stripping by moose was not great in terms of tree growth during the observation period. As was stated above, the simulated damage mimicked the height and seasonality of natural bark stripping by moose. One possible difference between our simulated browsing and natural browsing damage was that our study limited damage to the phloem and browsing under natural conditions may cause damage into the xylem. Although the wounded trees demonstrated reduced growth, the differences were relatively small and temporary. Most surprisingly, the effect on the height increment of trees with 60+30% treatment did not differ significantly from the controls. Spatially defined locations were not available for the study trees, but the selection was random and the sample size was large, so neighbor influences should not have been an influential factor.

wounds such as bark stripping. Wounds that completely encircle a tree (complete girdling) usually kill the tree (Gill 1992, Cōté et al. 2004). Simulating the browsing of Scots pine shoots resulted in no significant effect on height increment within three years of treatment (Persson et al. 2005). The effect of bark stripping is not only a loss of phytomass but also may cause a reallocation of carbon from the height increment to defence. Forest pathogens can attack trees by infecting the exposed sapwood after mechanical wounding of the cambial zone (Johansson et al. 2004) and cause lowered wood quality by stain and rot (Welch and Scott 2008). However, small wounds can be quite effectively closed by callus tissue, which protects the sapwood and contributes to formation of new cambium (Oven and Torelli 1999). Scots pine can be relatively resistant in regard of infections through wounds (Vasiliauskas 2001); largely through resin flow over the wound that protects the tree. At the same time resin flow can cause considerable carbon cost to the tree.

A repeated browsing study was reported by Bergqvist et al. (2003) where they found that bark stripping was positively correlated with height of the trees and length of the apical leader, a surrogate for height growth. Although the height increment in our study was not greatly affected, the effect of bark stripping may be a trigger for competitive differentiation of trees. Size-growth relationships have been included in basic tree and stand development models (Jõgiste 1998) where often the disturbance component related to herbivores or pathogens is responsible for such a triggering impulse. In our study, the initial height influenced growth of first and following periods more than the treatment.

The age structure of tree populations within a region is influenced by silvicultural strategies and management activities. Such data are recommended to be considered in forest and landscape conservation planning. In addition natural disturbances shape stand structure and forestry decisions made after disturbances can have complex interrelationships with animal populations (Krueger and Peterson 2006, de Chantal and Granström 2007). Altered food acquisition patterns of herbivores have been related to long-term population processes of the animals and stand development patterns of the trees (Faber and Thorson 1996, Bergqvist et al. 2001). The differences between food supply in naturally and artificially regenerated stands are considerable. The main reason for bark stripping has been attributed to food quality of forage and animal needs in terms of their biochemical background (Edenius 1993, Jia et al. 1995, Faber 1996, Bergqvist et al. 2003).

Our results do not allow the economic evaluation of moose damages. At the same time it is possible to include the results of the study in the analysis of necessity of protection investments.

In conclusion, simulated moose browsing had a significant effect on the first year height increment after treatment. However, the differences among damage intensities were not significant. Furthermore, the repeated damage did not result in significant differences in the height increment. The first year differences disappeared in subsequent years, regardless of whether or not the trees were treated.

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ВЛИЯНИЕ ПОВРЕЖДЕНИЙ КОРЫ СОСНЫ ОБЫКНОВЕННОЙ ЛОСЕМ НА ПРИРОСТ ПО ВЫСОТЕ: ЭКСПЕРИМЕНТАЛЬНЫЙ ПОДХОД

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Резюме

Ущерб, наносимый лесным насаждениям кормлением крупных растительноядных достигает больших размеров. Данное исследование было проведено для определения реакции сосны обыкновенной (*Pinus sylvestris* L.) на механическое удаление коры, имитирующие повреждение стволов деревьев лосем (*Alces alces* L.). Значительная разница прироста по высоте наблюдается между поврежденными и контрольными деревьями в течение первого года после повреждений. Несмотря на это, поврежденные деревья быстро восстанавливались и продолжали рост. Различие между степенью повреждений (удаление 30, 60 и 90% коры) было незначительно. Поскольку размер дерева влияет на его рост, замедление роста после удаления коры повлияет на последующий прирост и может обусловить конкуренцию в древостоях.

Ключевые слова: удаление коры, повреждение, прирост по высоте, лось, сосна обыкновенная