



Natural browsing repellent to protect Scots pine *Pinus sylvestris* from European moose *Alces alces*

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ABSTRACT

A major problem within forestry is winter browsing on young Scots pine (*Pinus sylvestris*) by European moose (*Alces alces*). Moose are selective foragers and make foraging decisions on many scales, for example, they avoid trees with high levels of plant defensive compounds, which reduce digestibility. Bark extract from Norway spruce (*Picea abies*) is known to have high levels of such defensive compounds. The aim of this study was to evaluate the effects of Norway spruce bark extract as a repellent to European moose. Spruce bark was extracted in a conventional way with ethanol as the solvent, creating a solution that was applied to the apical leader of young pine trees in planted forests. In two field trials in northern Sweden (winter 2017–2018 and winter 2018–2019), the apical leader of young pine trees (height 1–2.5 m) were sprayed with bark extract from Norway spruce. A total of 5247 pine trees were included in the study. The field trials showed that spruce bark extract lowered the number of browsed apical leader of pine trees, and directed moose to browse less valuable lateral shoots, and neighboring trees. During the first field trial, apical leaders were treated every second meter along transects with a concentration of the spruce bark extract of 2.8% by dry weight. The level of browsed apical leaders changed from 15.1% to 6.8% of all apical leaders. During the second field trial, apical leaders were treated in circular plots, in which all main stems inside the circle were treated with a concentration of the spruce bark extract of 5.0% by dry weight. The level of browsed apical leaders changed from 19.5% to 4.7% of all apical leaders. Hence, results show that spruce bark extract (a non-toxic forest byproduct) can function as an efficient repellent. The bark extract can control browsing to a level that is considered acceptable – generally a maximum of 5% of all apical leaders browsed every year. This would result in approximately 7 out of 10 trees, in treated small scale areas, having unbrowsed apical leaders when the trees reach a height at which the apical leaders are safe from moose browsing.

1. Introduction

The strong focus on Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) in forest regeneration, in conjunction with a homogenization of the landscape structure resulting from clearcutting and soil preparation, has favored moose and increased their available food resources in the form of young trees of pine and birch (*Betula pubescens* and *B. pendula*) (Edenius et al., 2002; Hörnberg, 2001; Swedish forest agency, 2019). As a result, the population of moose in Sweden has increased tenfold since rotational forest regimes were introduced in the mid-1900 s (Edenius et al. 2002).

The Swedish boreal forests have been intensively managed for wood production over decades and are dominated by two tree species: Pine with 39.3% of wood biomass and spruce with 40.4% of wood biomass

(Official Statistics of Sweden, 2019). Spruce is one of the least preferred species as a food-source for moose, while the animals exhibit an intermediate preference for pine (Bergström & Hjeljord, 1987; Edenius et al., 2002). The deciduous species in Sweden (rowan (*Sorbus aucuparia* L.), aspen (*Populus tremula* L.), willows (*Salix* spp.) and birch are ranked among the most preferred species (Hörnberg 1995). It is known that browsing (herbivory) by moose is highly selective and target to balance the demand of nutritional value, fiber and energy (Felton et al., 2018). Hence, moose selectively choose between different tree species, different individual of trees, and even between different parts of a specific tree to satisfy their demands (Danell et al., 1991; Stolter et al., 2009; Sunnerheim-Sjöberg & Hämäläinen, 1992). By that said, changing the preference of a tree pointing to a lower nutritional value can be an effective way of steering herbivory by moose.

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Because of the conifer dominated forest landscape, the preferred deciduous trees occur at low volumes and thus, pine is quantitatively the most important winter food species for moose in Sweden (Bergström & Hjeljord 1987; Bergqvist et al., 2018). In winter, moose mainly feed on woody plants, such as pine (Bergström & Hjeljord, 1987; Edenius et al., 2002; Felton et al., 2018) and intense browsing on pine results in large economic losses due reductions in wood quality, growth rate and increased tree mortality (Gill, 1992; Honkanen et al., 1994; Nilsson et al., 2016; Pettersson et al., 2010). In particular, damage to the apical leader greatly reduces timber quality and value (Bergström & Hjeljord, 1987; Gill, 1992; Nilsson et al., 2016). Hence, this study focuses specifically on protecting the apical leader.

A range of actions have been taken to prevent moose browsing based on their selectivity. These include the use of commercial repellents with a bitter taste and/or smell, only some of which have been scientifically tested. The results are sometimes promising, but the ingredients can be expensive and may have undesirable side effects in the ecosystem (Stutz et al., 2017). However, bitter-tasting non-toxic products have proved less effective over time (Nolte, 1999). This phenomenon is called “post-ingestive learning” and means that the animals learn that the bitter taste is not followed by consequences such as digestive problems, nausea etc. They learn to overcome the taste and continue to feed on treated trees (Alm Bergvall, 2009; Provenza, 1995).

Compared to bitter-tasting repellents that are commercially available, natural defensive compounds produced by plants (for example tannins) have a true repellent effect. This means that the browsing animals have learned that the compounds not only taste and smell bad, but also inhibit their digestion and therefore act as natural browsing repellent to protect susceptible plants and trees (Alm Bergvall 2009; Provenza 1995).

In a recent study, Stutz et al. (2017) tested the repellent effect of birch bark extract and achieved promising results. However, birch is moderately preferred as a food source for moose (Hörnberg 1995), and accounts for only 12.5% of the total wood biomass in Sweden (Official statistics of Sweden, 2019). Therefore, a more promising possibility is to take advantage of tree species that are less preferred by moose, and readily available in large quantities at sawmills, such as spruce.

Spruce bark is characterized by large proportions of defensive compounds such as phenolics, flavonoids and tannins (Kempainen et al. 2014; Miranda et al. 2012; Neiva et al. 2018; Palo 1984). Spruce is one of the least preferred tree species by moose and is available in large amounts (Hörnberg 1995; Official Statistics of Sweden, 2019). Ethanol extraction of spruce bark from Finland resulted in solutions containing 18.74% extractives (as a % of dry mass) and contained high proportions of phenolic compounds (851 mg gallic acid equivalents/g_{Extract}), of which tannins constituted 360 mg catechin equivalents/g_{Extract} (Neiva et al., 2018).

This study evaluates whether an ethanol extract of spruce bark acts as a browsing repellent for moose and reduces the browsing damage to apical leaders of pine in plantations. In contrast to other browsing-repellent studies based on plant defensive chemistry (Belovsky & Schmitz, 1994; Alm Bergvall et al., 2013; Stutz et al., 2017; Sunnerheim et al., 1988), we tested this in young pine forests with wild moose populations, allowed to exhibit their natural behavior without fencing or added food source.

By applying a repellent to the apical leader, the appeal of the apical leader will be reduced for the herbivore. Treating the apical leader with repellent may protect the whole tree from herbivory including the lateral shoots by reducing the appeal of the whole tree. If so, less protected lateral shoots will gain protection from the treated apical leader if moose are making a choice between different individuals or patches of trees (associational refuge) (Atsatt & O'Dowd, 1976; Pietrzykowski et al., 2003; Stutz et al., 2017; Smit et al., 2006). Alternatively, the opposite effect may be observed if herbivores choose primarily between different parts of the same tree. Untreated lateral shoots may then be more vulnerable to herbivores due to their higher palatability relative

to the treated apical leader (associational neighbor contrast susceptibility; Alm Bergvall et al., 2006). Therefore, we studied browsing damage to both apical leaders and lateral shoots of the trees.

The overall aim of the current study was to examine whether the use of spruce bark extracts applied to apical leaders of pine in small scale areas can reduce the browsing damage on apical leaders caused by moose in young pine forests. We also wanted to examine whether moose choose primarily between different trees (associational refuge), or between different parts of one tree (associational neighbor contrast susceptibility). More specifically, we aimed to answer the following questions:

Can we lower the level of browsed pine apical leader to an acceptable level, max 5%, (Swedish forest agency, 2019) by applying repellent?

Does treating the apical leader with repellent have any impact on the browsing pattern on the lateral shoots?

2. Methods and materials

2.1. Study area

The experimental area was located in central Sweden in the middle boreal zone (Ahti et al., 1968), 10 km NE of Junsele, Västernorrland county (63°46'05.2"N 17°00'38.7"E).

The chosen area has a high density of young pine forests and a high density of moose during the winter. The area consists of approximately 100 000 ha of forest dominated by young trees of pine. The landscape is typical of the boreal region in Scandinavia with pine and spruce being the dominant tree species. Birch and aspen are the most common deciduous tree species but, in managed stands, they rarely constitute more than a small proportion of the standing volume. The study area supports only few roe deer (*Capreolus capreolus*), and deer browsing is insignificant compared to moose.

We selected 10 study sites in pine-dominated young forest with a tree height between 1 and 2.5 m, five study sites for each year of the field trial. The average age of the trees was 7 years across all the study sites. All study sites were located in the same valley and within a distance of 10 km of each other. The two field trials were established in the periods 16-19th of January 2018, and 12-14th of January 2019. We measured the height of all trees in the experiment in decimeters.

2.2. Repellent

Fresh spruce bark was collected in November each year at a local sawmill. The bark was dried at room temperature for 10 days, to 90% dry mass. Pieces of sapwood contaminating the bark were manually removed. The bark extraction routine was similar in the two years, but twice the volume was collected in the second year, resulting in the repellent containing twice the concentration of extractives in field trial 2 compared to field trial 1.

Extraction routines were the following: 10 kg bark was refluxed in 50 L ethanol (95.5%) for 4 h. A total of approximately 30 L was obtained. The dry weight was 2.8–3.1%. The solution was cooled to room temperature, filtered and decanted. No further extraction was done in 2018, and the extract was stored cool in closed plastic bottles prior to being used in the field trials. In 2019, the extraction was made twice by washing the bark residues from the first extraction with 10 L ethanol, the washing ethanol contained 1 dry weight %. Another 11.3 kg bark was refluxed in 5 L ethanol (95.5%) plus the two extracts (35 + 10 L) for 4 h. A total of 32 L were then obtained with 5.2 dry weight %. This final extract was stored cool in closed plastic bottles prior to being used in the field trials. Bottles were shaken vigorously immediately before use in the field.

As we wanted to control for the potential repellent effect of the ethanol itself, we used both the repellent (extract with ethanol) and pure ethanol (95.5%) later in the field trial. The field trials hence included three different treatments: 1: repellent, 2: ethanol (95.5%) and

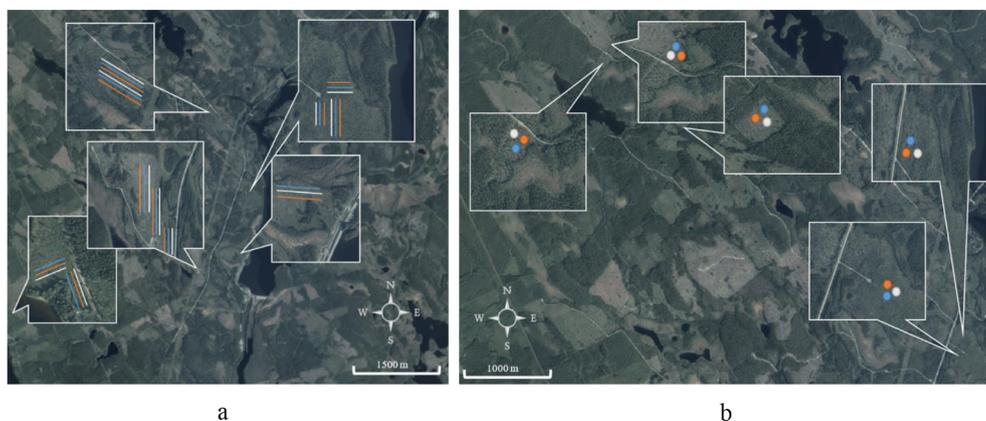


Fig. 1. Map showing the two different experimental designs for field trial 1 (1a) and field trial 2 (1b). Apical leader of trees (1–2.5 m tall) was treated with three different treatments: White line/dot = control, blue line/dot = ethanol, orange line/dot = repellent. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3: untreated control.

2.3. Field trial and experimental design

2.3.1. Field trial 1

In the first trial we tested the effect of repellent application to the apical leader of pine trees in transects (Fig. 1a). Transects were used to ensure that a large area in each site was treated with the available amount of repellent, and hence to increase the probability of moose visits (compared to aggregated plots, covering a smaller area; Fig. 1b).

Five study sites were chosen in which tree species composition (over 85% pine), tree density (1800–2600 trees per hectare) and tree height (mean height of 1.5 m) were similar. The average size of each study site was 2.8 ha (ranging from 1.9 to 3.8 ha). One site held 3 transects, two held six transects and two held nine transects with 55–147 trees per transect, depending on the spatial configuration of the site. The study sites were part of a large complex with several young pine forest and the transects covered approximately 10–20% of the total area of study sites (Fig. 1a).

The first transect in each study site started 10 m from a randomly selected corner of the site, and 10 m were left between transects to minimize the risk of a cross-over effect from the different treatments (Fig. 1a). Within the transect, one tree (1–2.5 m tall) every second meter was treated, a normal inter-tree distance between main stems in planting schemes. In the majority of all transects, trees stood closer together and therefore we left untreated trees between. In a few patches with sparsely distributed stems, trees stood more distant and we treated the closest neighbor along the transect (approximately 5% of all pines). Trees that already had old browsing damage on apical leader or any fresh browsing damage (winter season 2017–2018) was excluded. The selection procedure were the same for all treatments and study sites.

The apical leader was sprayed with a hand-pressurized sprayer (Solo 456–5 Litre Hand-held Sprayer). An average of 10 ml per tree was applied, irrespective of the length of the apical leader. All trees in the experiment were marked on the stem, as close to the forest floor as possible, with spray markers with different colors for the three treatments.

2.3.2. Field trial 2

In the second trial, we wanted to test the effect of repellent application on the apical leader of pine trees in circular plots with clusters of trees (Fig. 1b). All main stems in the circular plot were treated. This design better reflects potential future use in forestry, where all main stems in a site are likely to be treated. After the first year of the field trial, it was evident that moose are present all over the study area, so we considered it safe to use aggregated plots even though the design covered a smaller total area. In the circular plots, the apical leader of all main stems of pine with no fresh browsing damage and in the height range 1–2.5 m were treated. If the tree already had fresh browsing

damage (winter season 2018–2019), it was excluded from the experiment.

Five new study sites were chosen, with similar tree species composition (over 85% pine), tree density (1800–2600 trees per hectare) and tree height (mean height of 1.5 m). The average size of each treated plot in each of the study site was 0.3 ha (ranging from 0.2 to 0.45 ha). Thus, the treated area covered about one ninth the area in field trial 1. The study sites were part of the same large complex with young pine forests. The circular plots covered approximately 3–5% of the total area of the study sites.

All five study sites had three circular plots, one per treatment. The position of the center of the circle was always randomly placed, except that the outer perimeter of the circle was not closer than 10 m from other circles to minimize cross-over effects (Fig. 1b). The circular plots contained 176–341 treated trees, and the diameter ranged between 30 and 45 m depending on the size of the study site, but always including minimum 150 trees.

All treated trees in the experiment were marked on the stem, as close to the forest floor as possible, with spray markers with a different color for each treatment.

Field trial 1 (1a): Transects: Each line represents one treatment, with treated trees every second meter. The transects run parallel to each other with 10 m between. Transects contained 55–147 trees per transect.

Field trial 2 (2b): Circular plots: Each plot represents one treatment, with all main trees (1–2.5 m tall) treated. The plots had a diameter of 30–45 m and contained 176–341 trees and minimum 10 m between outer perimeters.

2.4. Recorded damage

We revisited the field trials in the following spring/summer (May 2018 and July 2019). All trees included in the experiment were examined. The marked stems were easy to identify and the winter browsing damage was easily distinguished from old browsing damage that had happened during previous winters or recent summer browsing. Old browsing damage appeared dried and dead, and fresh browsing damage from the on-going growing season appeared bushy with newly sprouted shoots (Faber and Lavsund, 1999). This allowed us to record only new browsing damage during wintertime (January–April). All trees were placed into one of three categories: apical leader browsing, only lateral shoots browsing, or no new browsing damage (unbrowsed). Some of the trees with apical leader browsing also suffered lateral shoots browsing, but yet, it was classified as an apical leader browsing. All of the trees classified as “lateral shoots browsing” had unbrowsed apical leader.

2.5. Statistics

Results from trial 1 and trial 2 were analyzed separately. We calculated the proportion of pine individuals with browsed apical leader, browsed lateral shoots or unbrowsed trees for each of the three treatments at each study site, giving five different proportions per year for each treatment. The proportions, after arcsine-square root transformation, were analyzed in R (R Core and Team, 2018) using a one-way ANOVA and Welch F-test not assuming equal variances, to determine whether there was any significant difference between the treatments. The variances were significantly higher in the ethanol and control groups compared to repellent-treated trees. The five study sites were considered independent since we assume that they are sufficiently far apart to represent several moose individuals visiting them during the winter. During winter, moose home ranges are usually less than 10 km² and significantly smaller than summer home ranges (Cederlund and Okarma, 1988; Olsson et al., 2011). The chosen area have a dense moose population, with approximately 7–10 individuals per 1000 ha (Swedish forest agency, 2019).

The different treatments within the same study site were not considered to be independent and no statistical analysis was conducted within the same study site.

3. Results

3.1. Field trial one

A total of 1589 trees at the 5 study sites were included in the experiment. All sites were visited by moose during the experimental period (January–May 2018) and the browsing pressure was overall very high; 46% of all control trees showed evidence of fresh browsing damage by moose (Table 1).

Although not statistically significant, this field trial showed that spraying apical leader with the repellent resulted in lower levels of moose browsing damage to apical leader from 13.7% (\pm 9.5%) to 6.6% (\pm 3.4%) (Fig. 2a; Table 1). It is known that moose tend to take more than one bite of the same tree, to minimize their energy consumption (Edenius, 1991). This was evident also in our results: Of the repellent-treated trees with browsed apical leader, 63% also had browsed lateral shoots. The corresponding number for ethanol-treated trees was 69% and for control trees 72%.

No treatment effect was found with respect to the number of trees with only browsed lateral shoots, with browsing affecting around 32% of the trees regardless of treatment, but with lower variability among the repellent-treated trees (Table 1; Fig. 2b). None of the treatments was statistically significantly different due to high variability in browsing pressure between the five study sites (Table 2). This was particularly evident for the control and ethanol-treated apical leader (Fig. 2a), while browsing was consistently low for apical leaders treated with repellents. We, therefore, consider the observed differences to be biologically relevant as they suggest a clear effect of the repellent,

Table 1

Sample tree data and browsing in field trials 1 and 2. Means and standard deviation based on the five sample plots for each year. (* = trees with browsing damage only on the lateral shoots and no apical leader browsing).

Treatment	Sample tree		Browsing (%)							
	Total N	Height (m) Mean \pm SD	Apical leader Mean \pm SD		Lateral shoots* Mean \pm SD		Unbrowsed Mean \pm SD			
Trial no.	1	2	1	2	1	2	1	2	1	2
Repellent	572	1265	1.54 \pm 0.14	1.47 \pm 0.06	6.59 \pm 3.78	4.88 \pm 2.83	32.32 \pm 6.26	19.23 \pm 3.30	61.09 \pm 8.71	75.89 \pm 5.90
Ethanol	532	1190	1.52 \pm 0.17	1.46 \pm 0.05	8.09 \pm 9.27	18.67 \pm 8.50	33.90 \pm 7.18	20.59 \pm 6.50	58.01 \pm 16.19	60.74 \pm 9.86
Control	485	1203	1.56 \pm 0.16	1.47 \pm 0.13	13.67 \pm 9.45	19.51 \pm 5.68	32.36 \pm 10.38	17.69 \pm 9.09	53.97 \pm 16.47	62.33 \pm 9.73
Total Average	1589	3658	1.54	1.47						

especially so in light of the results from field trial two.

Field trial one also indicated a potentially lower level of number of browsing-damaged trees treated with ethanol compared to the control (from 13.67 (\pm 9.45) % to 8.09 (\pm 9.27) %, while the number of browsed apical leader of ethanol-treated trees was slightly higher than repellent-treated trees (6.59 \pm 3.78%) (Table 1). Again, the results was not significant and the variation between study sites was large.

3.2. Field trial two

A total of 3658 trees at five study sites were included in this experiment. Moose were present at all sites during the experimental period (January–July 2019) and the browsing pressure was somewhat lower than in the first field trial but generally high; 37% of all control trees had evidence of fresh browsing damage by moose (Table 1).

By spraying the apical leader with repellent in aggregated circular plots, the level of browsing damage to apical leaders caused by moose changed from 19.5% (\pm 5.7%) to 4.9% (\pm 2.8%) of all apical leader (Fig. 3a; Table 1). The difference was highly significant (p-value = 0.0018; Table 2). Similar to field trial 1, 68% of repellent-treated trees with browsed apical leader, also had browsed lateral shoots. The corresponding number for ethanol-treated trees was 63% and for control trees 71%.

Similar to the first field trial there was no significant difference in trees with only browsing damage to lateral shoots (Fig. 3b) with browsing of around 20% of the trees regardless of treatment, but with less variability among the repellent-treated trees (Table 1; Fig. 3b). Given the clear effect on apical leader browsing, the fraction of totally unbrowsed trees was significantly higher on repellent-treated trees (Table 2). The number of totally unbrowsed trees was 75.9% (\pm 5.9%) compared to 62.3% (\pm 9.7%) for control trees. The difference was significant with a p-value of 0.028 (Table 2).

In contrast to the indication in the first field trial, ethanol did not seem to provide any repellent effect. A comparison between the ethanol-treated and the control trees show no statistical difference in browsing damage to apical leader (19.5% (\pm 5.7%) for control trees and 18.7% (\pm 8.5%) for ethanol-treated trees).

4. Discussion

With high browsing pressure from wild herbivores and with limited high-quality food available, there is a need for manual protection of economically valuable trees (Bergqvist et al., 2001; Nilsson et al., 2016). Ideally, the practice should be to protect the most valuable trees, use a forest regime that ensures available food of good quality for browsing mammals and direct the animals to less economically valuable trees.

The overall conclusion from our study is that bark extract from spruce can act as a browsing repellent, deterring moose from browsing the apical leader of pine. Our study shows that it is possible (at least with a high concentration and with an aggregated application scheme)

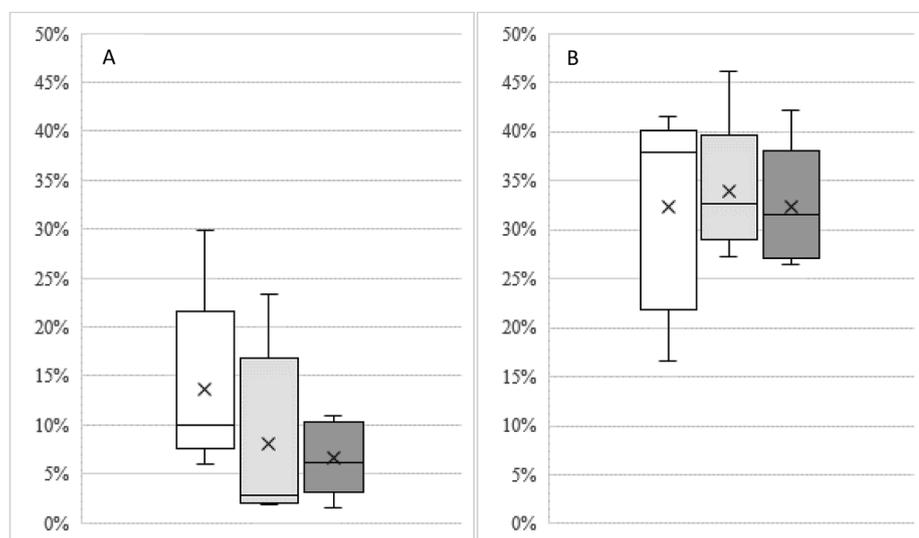


Fig. 2. Results from field trial one. Box and whisker plot of the proportion of browsed apical leaders (A) and proportion of trees with only lateral shoots browsed (B). The y-axis shows % of total number of trees in the study areas per treatment. The figure shows mean, median, upper and lower quartiles as well as maximum and minimum (N = 5). “x” indicates the mean. White = Control, Light grey = Ethanol, Dark grey = Repellent.

Table 2

ANOVA examining the effects of treatments on browsed apical leader, browsed lateral shoots and unbrowsed trees in the two field trials. Sample size N = 5 for both trials and data was arcsine-square root transformed prior to analysis and, based on the Welch-test, does not assume equal variances. Treatments in bold indicate the treatments where there were significant differences (p-value less than 0.05).

	Sum of squares	Df	F-value	p-value
Apical leader browsing				
Field trial 1				
Treatment	0.0427	2	1.31	0.3062
Residuals	0.1956	12		
Apical leader browsing Field trial 2				
Treatment	0.1762	2	11.53	0.0018
Residuals	0.0917	12		
Lateral shoots browsing				
Field trial 1				
Treatment	0.0011	2	0.072	0.9235
Residuals	0.0942	12		
Lateral shoots browsing				
Field trial 2				
Treatment	0.0052	2	0.734	0.8245
Residuals	0.0982	12		
Unbrowsed trees				
Field trial 1				
Treatment	0.0132	2	0.312	0.7167
Residuals	0.2569	12		
Unbrowsed trees				
Field trial 2				
Treatment	0.0822	2	5.027	0.0278
Residuals	0.0981	12		

to affect the feeding behavior of moose and thereby protect the economically valuable apical leader of pine trees grouped together in fairly small groups. We have shown that it is possible to lower the level of apical leader browsing down to acceptable levels around 5%, even in areas, like for this field trial, with high browsing pressure. This supports the results of previous research on bark extracts, in which birch bark extract acted as a repellent to fallow deer and moose (Alm Bergvall et al., 2013; Stutz et al., 2017). We did not see any relation between treated apical leader and unbrowsed lateral shoots. As shown in the results: If the apical leader was left unbrowsed, the probability of the lateral shoots being browsed was 20–30%, regardless of whether the apical leader were treated with repellent. However, if an apical leader was browsed, the probability of the lateral shoots also being browsed changed to 60–70% regardless of treatment (Table 1). This is probably

due to feeding behavior where the moose tend to take more than one bite per tree after making a decision to feed (Edenius, 1991). If a moose overcomes the repellent effect, they remain at that tree and continue to eat, on both the lateral shoots and the apical leader. Earlier studies that have examined patterns of moose browsing in Sweden show that the most important explanatory variable for the risk of browsing damage to a specific tree is previous damage to the same tree (Wallgren et al., 2013). This may explain why the repellent does not always work: moose always strive for saving energy and tend to remain in the place where they started browsing and do not move until they have obtained a sufficient amount of high-quality food in that location (Wallgren et al., 2013).

This indicates that we can protect apical leader efficiently, without limiting the available food source in the form of lateral shoots. It also shows that, for the small proportion of trees where we were unable to protect the apical leader, the moose probably stayed at the same tree and continued to eat the lateral shoots and might leave the neighboring trees unbrowsed to a higher extent.

The novelty in this study lies in the use of bark extract from spruce combined with field trials involving wild, non-captive, moose exhibiting natural behavior. This work is important because changing from current browsing repellents to more natural and environmentally friendly treatment is important for the forest industry (Jakl et al., 2016; Stutz et al., 2017). The spruce bark extract is based on inexpensive raw material obtained from by-products from the same industry it aims to help.

The first field trial, where we set up the experiment in long transects over a large area, and using a repellent at a relatively low concentration, produced somewhat unclear results. The transect design was intended to ensure that a large area was covered, and thereby to increase the chance of moose visits. Earlier studies have had trouble analyzing the results due to limited presence of animals (Alm Bergvall et al., 2013), therefore we were initially concerned that moose visits would be rare. That concern turned out to be unwarranted and there was high browsing pressure at all study sites, thus allowing us to use a more relevant field trial design in year two with circular plots and groups of trees.

It should be noted that in the first field trial, browsing of apical leaders treated with the repellent showed limited variation between the five sites, while the variations in browsing of the apical leader treated with ethanol and the untreated control were large (Table 1). Nevertheless, we saw 52% lower browsing on apical leaders, suggesting that the repellent did decrease browsing at all study sites, but that general browsing pressure happened to be lower at some of the sites, resulting in low browsing also in the two other treatments. The variance in

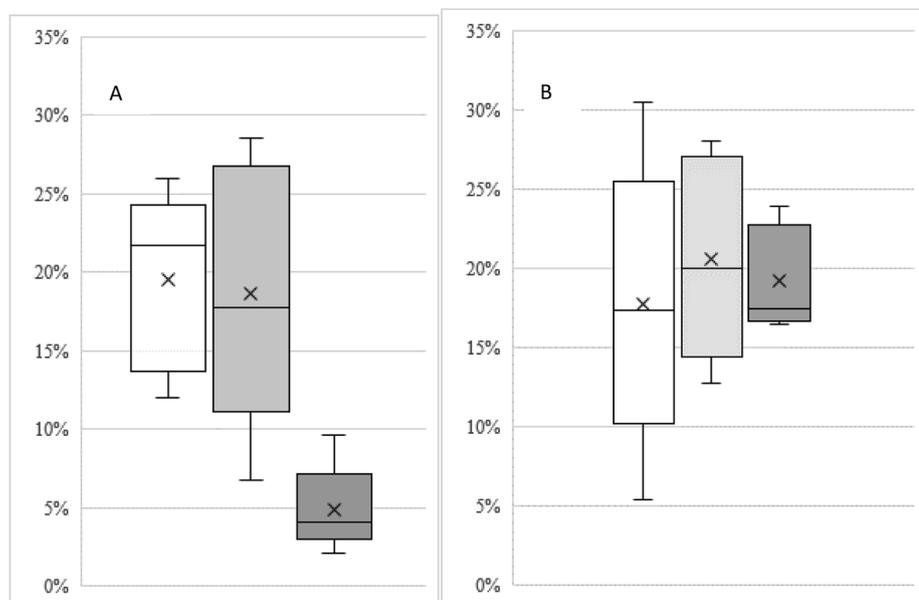


Fig. 3. Results from field trial two. Box and whisker plot of the proportion of browsed apical leaders (A) and proportion of trees with only lateral shoots browsed (B). The y-axis shows % of the total number of trees in the study areas per treatment. The figure shows mean, median, upper and lower quartiles as well as maximum and minimum (N = 5). "x" indicates the mean. White = Control, Light grey = Ethanol, Dark grey = Repellent.

browsing on control and ethanol-treated apical leader may, therefore, reflect actual variation in the moose population for that specific site at the time of the field trial, and not a treatment effect. In addition, 2018 was a year with very deep snow, approximately 120 cm, and some trees may have been covered by snow and thus escaped browsing (SMHI, 2020). In addition, the first field trial involved around half of the number of trees compared to the second field trial, which could have effected on the accuracy of estimating the browsing level (Table 1).

The second field trial provided much clearer results, with the repellent being associated with a strong decrease in browsing-damaged apical leaders. The second field trial also included almost twice as many trees as the first trial, thus improving the reliability of the results. This trial was set up in the same valley, with comparable browsing pressure. The design of the second field trial increased the spatial concentration of application (in terms of treated apical leader/hectare). This would have made the repellent more noticeable inside the circular plots and this may have strengthen the effect. In the circular plots, all main stems were treated, and only secondary stems, with lower economic value, were left in between the treated trees. In the second field trial, we did not observe any indication of an effect of ethanol on apical leader browsing and hence we attribute the low browsing at some sites in the first field trial to effects of the design, varying moose density and effects of snow cover.

The second field trial also represents a more likely way of using repellents in real situations; we treated the apical leader on all main stems of economic value, within reachable height for moose. We did not treat secondary stems of lower quality, and of low economic value. The secondary stems ensure available food for the moose population, and may act as effective protection from browsing damage to highly economically valuable trees because there is a higher probability that moose will leave the apical leader unbrowsed when other palatable untreated pines are present. Earlier studies on browsing repellents for mammals showed higher efficiency if a palatable alternative was available (Kimball et al., 2002; Provenza, 1995; Wallgren et al., 2013). This design dramatically increased the number of treated trees/hour and resulted in an acceptable (Swedish forest agency, 2019) and very significant decrease in browsed apical leader, down to approximately 4–5% of all apical leader.

Earlier studies using bitter-tasting repellents showed clear effects over concentration gradients, with higher concentrations being associated with higher repellent effects (Andelt et al., 1994; Andelt et al., 1992). In our first field trial, the concentration of the repellent was only

half that in the second trial. Nevertheless, we did not observe a biologically significant difference in browsing level of repellent-treated trees in our two field trials. It is therefore, likely that the lower concentration of the repellent is sufficient to deter moose from browsing. Further studies are needed to determine whether the field design or the concentration of the repellent, or both, is the most critical factor.

Our repellent applied to the apical leader did not protect the whole tree from browsing (associational refuge). However, we did not see the reverse effect, i.e. that the lateral shoots were browsed more on treated trees (associational neighbor contrast susceptibility). Lateral shoots were browsed to the same extent, no matter the treatment (Table 1). The protection of apical leader is local; the moose are still present in the area and still eat the pines. Earlier studies of repellents for browsing mammals have shown both associational refuge (Stutz et al., 2017) and associational neighbor contrast susceptibility (Alm Bergvall et al., 2006), but none of these studies was conducted with wild moose under natural conditions. Our study show that browsing repellents that suggest lower food quality should be applied to all trees, and all parts of the tree that you want to protect, due to the very local effect to the treated parts of the specific tree.

Our result shows that no matter if the apical leader of the tree indicating low quality food, the moose primarily choose between different parts of trees, irrespective of whether the apical leader is treated or not. This is novel information because this is the first study to compare repellent-treated apical leader browsing with browsing of untreated lateral shoots on the same tree. Earlier studies, under natural conditions with no repellents involved have shown the opposite: that moose choose between individual trees, and not between different parts of the same tree as long as the tree is within reachable height (Bergqvist et al., 2001).

We draw the conclusion that the repellent effect from our treated trees came from the active compounds in the bark extract, and was not related to the solvent ethanol. This is clearly confirmed in the second field trial (where both the concentration and treatment pattern are more relevant for practical application). We also draw the conclusion that our repellent act by smell. Our repellent did not have any visual cues (colour, structure etc.) but still influenced browsing without the moose having to take a bite and taste. Repellents acting by smell hence has a big advantage as it leaves treated parts of trees totally unbrowsed.

For applied purposes, it may be appropriate to use a different solvent in the production of the repellent. One solution could be to use CO₂-reduction or just water extraction. Reducing the volume of ethanol

needed would lower the costs and decrease the environmental impacts of production. From an applied point of view, it would also be beneficial not to transport large volumes of flammable ethanol solution. It may also be important for treating other vulnerable tree species which may be negatively affected by the application of ethanol. We expect that the extract would also be effective against roe deer browsing (both in forest land and gardens) because roe deer have been shown to exhibit the same main browsing preference patterns as moose (Hörnberg, 2001).

4.1. Management implications

This study showed that spruce bark extract can be used as an effective protection of pine apical leader at least within smaller plantation areas. We assume that the effect would remain even if whole stands were treated. However, more research is needed on the effect at larger scale.

In this study, the application of the repellent was performed manually with a hand sprayer. The time consumption is relatively small with approximately 400 treated trees per hour. As long as you only want to treat the apical leader, manual application is needed. Large-scale, mechanized, application by UAV/helicopter might be useful, but more research is needed to evaluate a total-cover effect of the repellent. The advantage of manual application is that small volume of repellent is needed, and a low-cost equipment, which probably overcome the potential economic advantage of large-scale application.

By protecting the apical leader, there is a need for repeated treatments, as the tree will grow a new apical leader every year. How many years there is a need for application is depending on the growth rate of the tree; in our study region approximately 5–10 years.

While using repellents, it is important to make sure that the moose have alternative trees available. To avoid browsing damages in neighboring forests, we recommend to leave less valuable pines untreated. This will increase the chance that the moose stay in one, limited, area, leave treated trees unbrowsed, while returning to the untreated and already browsed trees in later years.

4.2. Conclusion

Our results demonstrate that spruce bark extract functions as an efficient moose repellent, reducing browsing of the apical leader of young pines to a level that is considered acceptable (5%), at least at the spatial scale studied. At the low concentration levels used, the extract can be seen as non-toxic and it is a low-cost byproduct from the local forest industry. Based on visual observations, it appears to cause no harm to the trees. This makes it a promising method of protection for vulnerable trees and a potential solution for forest owners to deal with the currently high browsing pressure.

CRedit authorship contribution statement

Matilda Lindmark: Conceptualization, Investigation, Data curation, Writing - original draft. **Kerstin Sunnerheim:** Conceptualization. **Bengt Gunnar Jonsson:** Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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