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Impacts of Moose (*Alces alces*) Browsing on Paper Birch (*Betula papyrifera*) Morphology and Potential Timber Quality

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Although moose browsing effects on the growth and morphology of birch are well studied, effects of moose browsing on potential timber quality of birch have received little attention. Here, an assessment was made of the impacts of moose (*Alces alces* L.) damage to Paper Birch (*Betula papyrifera* Marsh.) trees from a 20-year old clear cut area in a sub-boreal spruce forest within the Aleza Lake Research Forest, near Prince George, British Columbia, Canada. Specifically, differences in overall tree architecture and in the internal characteristics of trees that had been severely damaged and suppressed by moose winter browsing were compared to birch trees that had not been damaged by moose in this way and were considered free-to-grow. The average stem diameter, number of annular growth rings, and height of stem breaks made by moose on suppressed birches at the point of breakage was 17.9 ± 6.6 mm, 4.6 ± 1.2, and 141.8 ± 32.0 cm, respectively. Stem diameters and the heights above-the-ground of stem breaks made by moose during sequential breakage events were not significantly different (all $p \geq 0.05$) from one another. Decay was significantly (all $p \leq 0.001$) more extensive in trees where branches had been broken off by moose than in trees with no breaks or where breaks were from unknown agents. Suppressed birches were significantly ($p = 0.048$) more exposed (farther from their nearest tree neighbor) when compared to birches that were free-to-grow. The distance from birch trees to species-specific neighbors (of any species) did not differ (all $p \geq 0.05$) between suppressed and free-to-grow birches. Suppressed birches damaged from intense browsing and stem breakage were significantly ($p \leq 0.001$) farther away from other birches showing signs of slight to moderate browsing than free-to-grow birches were from similar conspecifics. Because moose appear to impact the potential wood quality of birch, forest managers should consider the impacts that browsing and stem breakage can have on birch timber where these trees co-occur with and are eaten by moose.

Keywords browse damage, deciduous, forestry, hardwood, silviculture, ungulate, wood quality
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1 Introduction

Moose are recognized as an agent of severe damage to forest stands throughout many parts of their circumpolar range (Bergerud and Manuel 1968, Jalkanen 2001, De Jager and Pastor 2008). Which trees in a forest stand are sought out and browsed by moose varies according to regional differences in moose preferences and tree species availability (Peek 1998, Persson et al. 2000). Although moose damage to conifer stands throughout Scandinavia is commonly reported (Danell et al. 1991, Heikkilä and Härkönen 1996), similar levels of damage to conifers are rarely reported from western North America (Rea and Child 2007). Here, hardwoods such as willow and birch – not pine or other softwoods – tend to comprise the majority of the moose winter diet (Renecker and Schwartz 1998).

Interactions between moose and broadleaved deciduous tree species such as birch have been well studied (Renecker and Schwartz 1998), particularly in Scandinavia (Bergström and Danell 1987, Danell and Bergström 1989, Danell et al. 1997, Persson et al. 2005, Persson et al. 2007, DeJager and Pastor 2008). However, the direct impacts of moose on the ability of birch to become part of the merchantable segment of a forest stand and the impact of moose damage on birch growth and wood quality per se has received little attention (Härkönen et al. 2009).

The impacts of moose on birch tree autecology in the Aleza Lake Research Forest (ALRF) of British Columbia, Canada was examined to determine the ability of moose to impact directly the ability of paper birches to mature naturally. Determining whether or not moose suppress birch recruitment into later seral stages and how such suppression affects the growth and potential lumber quality of birch was the primary objective of the research.

2 Methods

2.1 Study Area

The study site was located within the Aleza Lake Research Forest (approximate latitude of 54°07´ North, and longitude of 122°04´ West at an elevation of 600–750 m asl) in north central British Columbia. The research forest is a 9000 ha university-based outdoor research facility and working forest ~60 km east of Prince George, BC, Canada. The research forest is located in the Upper Fraser River basin, on the eastern edge of the Central Interior Plateau, near the foothills of the northern Cariboo and Rocky Mountain ranges and is described by Jull and Karjala (2005).

Situated in the Wet Cool (SBSwk1) subzone of the Sub-boreal Spruce biogeoclimatic zone (Pojar et al. 1987), the research forest typifies a montane transitional zone between a climate of drier plateau forests to the west, and the wet, snowy mountain forests in the nearby Interior Cedar Hemlock (ICH) and Engelmann spruce-subalpine fir (ESSF) forests to the east (Jull and Karjala 2005). About 85% of the ALRF is composed of gently rolling to gullied terrain that is covered by upland spruce-fir forests and wetlands with some hardwoods. The remaining 15% is composed of the Bowron River floodplain which is a complex mosaic of alluvial sites, ranging from old river channels, alluvial wetlands and freshly-deposited gravel bars and higher terraces (Jull and Karjala 2005). Moose densities in the surrounding area in the years preceding our assessments and when moose would have been browsing on birches that we evaluated were 0.45–0.60 moose/km^2 (Heard et al. 1999, Heard et al. 2001).

2.2 Field Work

Data from birches were collected from an ~30 ha area of a hybrid white spruce (*Picea glauca* [Moench] Voss. × *englemannii* [Parry ex Engelm.] T.M.C. Taylor)/subalpine fir (*Abies lasiocarpa* Hook.[Nutt.]) forest area that had been clear-cut and planted with spruce approximately 20 years prior to the present study. Early successional, mid-sized shrubs and trees growing in the study area included alder (*Alnus* spp.), birch (*Betula papyrifera*), willow (*Salix* spp.) and aspen (*Populus tremuloides* Michx.). The study area was selected based on whether or not a mix of birches could be found that were: 1) suppressed as a result of repeated heavy browsing and multiple stem breakage events by moose and 2) growing freely above the reach of moose.

Fifty eight birch saplings were selected from within the study area for evaluation. Old roads and log decking landings were used to gain access to different parts of the study area. Birches were selected from across the stand type and were located within the stand between 50 and 400 meters from haul roads. Selection procedures were based on damage to birches. Birches that showed signs of heavy and repeated browse use by moose, had multiple stem breaks and were obviously suppressed in growth (n = 24) were selected for evaluation and characterization. Birches that were characterized by a distant history of no or slight to moderate browse use by moose, but at survey time appeared free-to-grow (n = 35), with robust main stems and mature leaders well beyond the reach of browsing moose were selected for comparative purposes.

The majority of birches that were selected were assessed exclusively in the field. However, 24 trees were also selected for removal from the stand and transport back to the Enhanced Forestry Laboratory at the University of Northern British Columbia for closer inspections of the impact of browsing and breakage on internal tree attributes. For those trees assessed exclusively in the field, measurements recorded included: tree height, base diameter at ~30 cm above the ground, diameter at breast height (~1.3 m above the ground), distance to the nearest tree species that was as tall or taller and as thick or thicker in diameter at the trunk than the birch being assessed and, distance to the nearest birch that had a canopy within the reach of moose and not classified as either suppressed or free-to-grow, but that showed signs of slight to moderate (in some cases no) browsing. Trees that were not taken back to the lab were cored in the field (at ~30 cm above the ground) for age determinations. Twenty birches were aged using cores and disks to cross-validate the two techniques. Each birch selected for assessment was photographed in the field.

2.3 Lab Work

Twenty-four of the trees that we transported back to our lab had been repeatedly and extensively browsed by moose over their life time as evidenced by their hedged form and stunted vertical growth. We photographed each tree brought to the lab against a light-colored backdrop to enhance contrast (Fig. 1).

Fig. 1. A typical suppressed birch damaged by moose in the Aleza Lake Research Forest and taken from the study area for assessment at the Enhanced Forestry Lab.

A 2–3-cm thick disk was cut from the bottom of the main stem of each birch and sanded on one side so that the annular rings could be counted to determine the tree age at ~30 cm above the ground. An ~1-cm thick disk was also cut and sanded from the three most recent breakage points on each tree so that a determination of the mean stem age at breaks created by moose during winter browsing events could be made (see Telfer and Cairns 1978). The chronological order of breaks was assessed by evaluating their position on the tree and the amount and age (using the number of current annual growth scars) of shoots arising from below the breakage. Also recorded were the height and stem diameter at each break. The morphometry or “hedgedness” of each tree was also assessed by measuring and averaging the length of branches from trunk center out to the branch tips along two sides of each birch from the base of the tree to the top in 5-cm increments.

Finally, the degree of internal decay within the main stem of trees that came from branch breakage events caused by moose and other agents on trees brought into the lab was evaluated. Decay was assessed by bandsawing birches through portions of the stems from which both broken and healthy branches originated. Bandsawing exposed the origins of branches and revealed portions of the tree affected by decay that had invaded stems from break points on branches. The width of the branch collar where each branch was attached to the main stem was recorded, as was the average width and length of the decay core and the average width of the main stem in which the decay was detected. From these measurements, indices of decay were developed using:

DECAY INDEX 1 = ADCD * ADCL
DECAY INDEX 2 = ADCD * ADCL / SW
DECAY INDEX 3 = (ADCD * ADCL / SW) / BCD

where
ADCD = average decay core diameter (width),
ADCL = average decay core length, SW = stem width, and BCD = branch collar diameter (width).

2.4 Statistical Analyses

To test differences in the diameter, age, age/diameter relationship and breakage height above the ground of the last 3 breaks made by moose on birch stems and the distance from suppressed and free-to-grow birch trees to the nearest neighbor (any tree species) and specifically to the nearest birch that was slightly to moderately browsed, analysis of variance (ANOVA; Tabachnick and Fidell 2007) was used. ANOVAs were also used to test for differences in the amount of internal decay caused by branch breakage from moose browsing and other factors. Homogeneity of variances for all ANOVA comparisons were tested using a Levene’s test (Milliken and Johnson 1984). A Kolmogorov-Smirnov test was used to test assumptions of normality (Gotelli and Ellison 2004). Linear regression analysis (Gould and Gould 2002) was used to test the relationship of tree height to age and height to base diameter between suppressed and free-to-grow birches. All analyses were conducted in Statistica 9 (Statsoft 2009).

3 Results

Varying significantly from unbrowsed, free-to-grow birches (which were effectively branch-free up to and beyond the reach of browsing moose), suppressed birches were, multi-stemmed, branched and more hedged in appearance (Fig. 1).

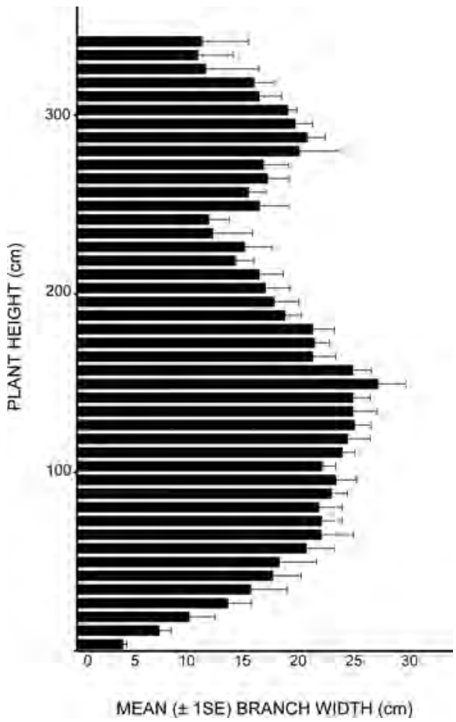

Fig. 2. The relationship of the mean (± 1SE) branch width (from the main stem center line to the tip of the longest branch) to plant height of birch trees (n = 23) browsed by moose at the Aleza Lake Research Forest. Imagining the Y-axis as the midline of the main stem of the tree allows for a visualization of how wide the widest branches of trees were on average at 5-cm intervals up and along one side of the tree from bottom to top (~3.5 m high).

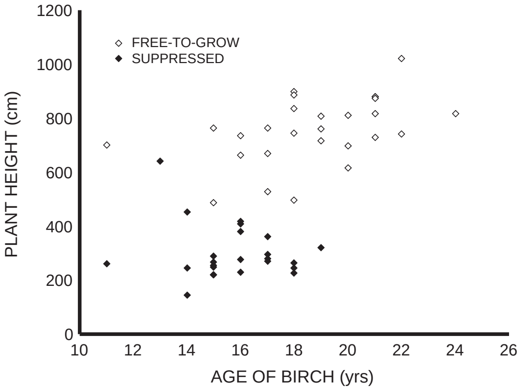

Fig. 3. Relationship between the age and height of birches that have been suppressed (n = 24) through repeated moose browsing and those that were free-to-grow (n = 27).

On average, birches were just under 3.5 m tall and had a morphology or silhouette which could be described as hour glass-shaped with the longest lateral branches occurring at 1.5 and 2.8 m above the ground (Fig. 2).

The average base diameter and age of trees assessed in lab was 59.5 ± 10.9 mm and 12.5 ± 1.8 years, respectively. Suppressed birches were shorter at a given tree age (TREE HEIGHT = 440.23 – 8.91AGE) than free-to-grow birches (TREE HEIGHT = 166.47 + 32.25AGE; Fig. 3). Similarly, suppressed birches were shorter at a given base diameter (TREE HEIGHT = 129.27 + 25.44BASE-DIAMETER) than free-to-grow birches (TREE HEIGHT = 452.13 + 34.69BASEDIAMETER). No differences (P = 0.560) existed between suppressed and free-to-grow birches in the density of annuli per given basal stem diameter (age to diameter relationship).

The average number of breaks (not bites) on trees assessed in lab was 6.54 ± 3.59 breaks. The average diameter, number of annuli and height of breaks made by moose on birches assessed in lab (n = 24) was 17.9 ± 6.6 mm, 4.6 ± 1.2 annuli (range of 3 to 8 annuli), and 141.8 ± 32.0 cm, respectively. There was no significant difference in the diameter ($F(1,2) = 0.330$, $p = 0.720$), age ($F(1,2) = 1.28$, $p = 0.285$) or break height above the ground ($F(1,2) = 0.359$, $p = 0.700$) of the last 3 breaks made by moose on the main/collateral stems of birches.

Fig. 4. A sagittal section of a young birch tree showing evidence of the original apical meristem having been browsed by moose (white arrow). Topping of the birch by moose created a response in the plant which allowed the birch to continuing growing – apparently facilitated by a lateral meristem assuming apical control. Dieback of the mainstem, however, appeared to create an entry point for the formation of decay which can be seen in the center of the birch and which continued down the length of the birch (but which is not seen in the image due to how the plant was sectioned).

All indices of decay assessed indicated that decay (Fig. 4) was significantly (all $p \leq 0.001$) more extensive in sections of trees where branches had been broken off by moose than in tree sections where breaks were from unknown agents (Fig. 5), or where branches were healthy and unbroken (causing no decay at all).

Birch trees suppressed by moose were significantly ($F(1,1) = 4.083$, $p = 0.048$) more exposed

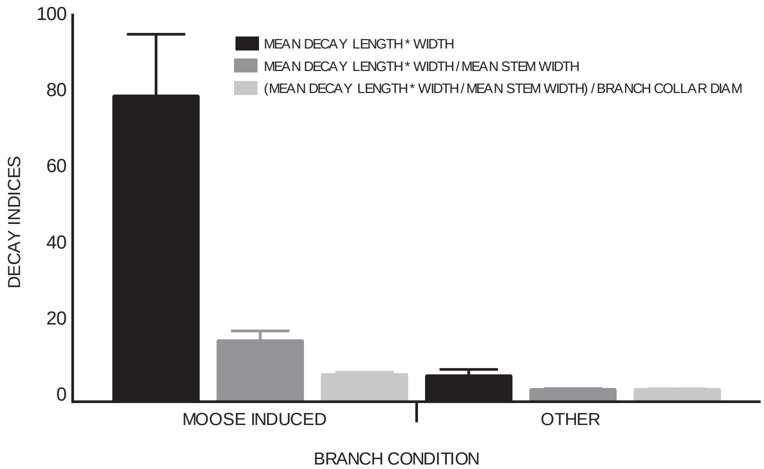

Fig. 5. Mean (± 1SE) decay index scores for three different indices of decay caused by branch breakage from moose (n = 39 intrusions) or other unknown agents (n = 14 intrusions). Black is the mean length of wood decay cores found in the inner stem of suppressed trees and originating from the breakage point multiplied by the mean width of the decay core. Dark grey is the index in black divided by the mean width of the stem through which the core of decay is contained. Light grey is the dark grey index divided by the diameter of the branch collar in the branch in which the break occurred. Note: Most unbroken branches showed no signs of decay where the branches originated from the main stem. Therefore, only those branches that were not broken by moose (but by other agents or had cracks at their base) but showed some signs of decay at their origins were assessed for any contribution of decay to individual birches brought into the lab and sectioned.

(farther from their nearest tree neighbor) when compared to birches that were free-to-grow. There were no significant differences (all $p \geq 0.05$) in the distance to specific tree species neighbors (conifers or hardwoods) from birches (either suppressed or free-to-grow). Suppressed birches, however, were significantly farther away from other birches showing signs of slight to moderate browse history than free-to-grow birches were from similar conspecifics ($F(1,1) = 12.573$, $p \leq 0.001$).

4 Discussion

Many of the young birch trees growing in the study area were repeatedly damaged by moose from winter browsing and breakage events and were hedged and stunted in growth. Such multi-stemmed, twisted and bushy birches with low branching looked very different than other single-stemmed, free-to-grow birches of the same age that contained branches high in the crown of the tree, well above the reach of moose.

Although we selected suppressed and free-to-grow birches for comparison, a full range of damage levels to birches could be found in the study area. Some birches appeared to have never been browsed by moose while others with light, moderate and severe levels of damage existed in a heterogeneous mix among the conifers and other hardwoods in the stand.

Not surprisingly, suppressed birches were shorter at a given age and given base diameter than free-to-grow birches. Tree forming birches were similarly affected in Sweden in response to intense simulated winter browsing by moose (Bergstrom and Danell 1987) with trees being 40% (*Betula pendula)* and 57% (*B. pubescens)* shorter on average than controls. Additionally, the number of annuli per given stem diameter did not vary between suppressed and free-to-grow birches, suggesting that moose damage had no effect on tree girth or the way in which annular rings were laid down in the tree trunk. That the stem diameter to annuli ratio in this study was not affected by browsing appears counterintuitive given the extensive remodeling and gross morphological alterations to the upper portions of the tree. Bergstrom and Danell (1987) reported smaller annual increases in stem diameters when comparing 5–8 years old browsed to unbrowsed birches over a 3 year period, but diameter to annuli ratios were not specifically assessed and most trees increased in diameter significantly during the study period, regardless of clipping intensity. Danell and Huss-Danell (1985), however, reported no differences in the age or stem diameters of birches that showed a history of moderate when compared to slight browsing and Schatz et al. (2008) reported no changes to the stem diameters of *Betula pendula* following pruning. Together, such findings suggest that birch is extremely tolerant to mechanical damage and that cambial growth in the trunk is neither suppressed nor is it accelerated in response to heavy browsing and/or stem breakage.

Of the birches selected for assessment, suppressed birches generally showed signs of heavy and repeated use. These birches were not only thoroughly browsed, but on average had main and collateral stems that had been broken by moose to access shoots above their reach (Telfer and Cairns 1978) a total of 6 or 7 times over the life of the birch, or about once every two years. Repeated use of shrubs and trees by moose from year to year has been reported by others and may suggest a preference by moose for individual trees (Löyttyniemi 1985, Bergqvist et al. 2003).

Stem breaks occurred at predictable places on birches at about 1.5 meters above the ground where stems were 15–20 mm in diameter. Although some breaks occurred on older, thicker stem sections and above this height, moose appeared to limit breakage to stems that, at breast height (~ 1.3 meters), contained 4 to 5 years of growth. Once leaders were above the browse line – enough that mainstems at breast height contained 8 to 9 annular rings – they appeared to be free-to-grow and presumably too thick for moose to snap. Branches growing from the lower portions of the trees, if present, were rebrowsed extensively regardless of whether the tree was suppressed or free-to-grow.

Breakage events by moose not only affected the morphology of the tree and its ability to grow into the tree layer, but subjected each birch to large and upward facing wounds that provided entry points for moisture and pathogens, presumably similar to those described by Lilja and Heikkilä (1995). Sectioning of birches revealed that all breaks on trees, aside only from the most recent, resulted in decay. Decay and the associated discoloration of heartwood was typically extensive (on average was 40% of the tree interior for the length of the section in which decay occurred) in those trees inspected and, therefore, of substantial consequence where timber quality is valued. These findings appear to correspond with those of Härkönen et al. (2009), where they recorded flaws in stem form as well as pith and wood discoloration/decay in European white birch (*B. pubescens*) and silver birch (*B. pendula*) as a result of moose damage. Similar color defects were also reported by Schatz et al. 2008 in silver birch following pruning.

Birches suppressed by moose damage tended to be farther away from other trees (birches as well as other tree species) than those that were undamaged by moose. Proximity to other trees has been found to be related to the degree of damage incurred by trees from herbivores (Milchunas and Noy-Meir 2002) since trees in the open are less concealed by neighboring vegetation and easier to feed upon. Because tree neighbors (of any species other than birch neighbors studied) shorter and presumably younger than study birches were not considered to have had an influence on levels of moose damage to birch, only trees that were as tall as or taller than each study tree were assessed for nearest neighbor measurements.

Theoretically, it should have been easier to find trees taller than suppressed trees (i.e., these neighbors should be more abundant than trees taller than free-to-grow birches) for taking nearest neighbor measurements. Despite this potential bias, nearest neighbor trees were always significantly farther from suppressed than free-to-grow trees – suggesting free-to-grow trees grew in denser patches while suppressed trees were more exposed. This relationship held true for all non-birch nearest neighbors, regardless of tree species.

The distance between suppressed birches and the nearest birch neighbor that was neither suppressed nor free-to-grow, but within the reach of moose and possibly showing signs of use was also greater when compared to the distance between these birches and those classified as free-to-grow. Together, these data appear to support the Associational Avoidance Hypothesis (Milchunas and Noy-Meir 2002) which suggests that plants growing in the open (such as suppressed birches) are less likely to be protected from herbivores in search of food than those adjacent to and mixed within neighboring plant complexes.

5 Management Implications

Overall, these findings suggest that moose impact birch by altering its ability to compete with surrounding vegetation and to be successfully recruited into the tree layer. Suppression was not characteristic of all birch within the stand. Instead, some birches growing farther from other trees – in more open parts of the stand – appeared to be targeted by moose repeatedly and caught in some type of feeding loop as described by De Jager and Pastor (2010), from which they appeared unable to escape. This does not imply that all birches growing within the open were as subjected to repeated browsing as those measured, rather an open habitat was more characteristic of where suppressed birches could be found when compared to free-to-grow birches. In short, suppressed and malformed birches were rarely seen growing in more densely forested parts of the study area.

A measurement specifically of distance to the nearest birch neighbor currently growing amongst suppressed and free-to-grow birches and within the reach of moose may be an irrelevant metric given current browse pressures on younger trees would have had no past influence on older birches acquiring free-to-grow status. Nevertheless, surrounding birch densities (as with other tree species) may continue to influence the rebrowsing of suppressed trees and such documentation may be of value to managers interested in how moose may perceive and use neighboring birches in relation to suppressed and free-to-grow trees. Interestingly, data from nearest neighbor birch assessments indicated that some level of browsing continues on birches within the reach of moose in both open and less open portions of the study area, albeit to what degree such birches were browsed was not specifically measured.

The damage to birch incurred by moose has two important implications to forest managers interested in cultivating birch. First, birches repeatedly targeted as a food resource by moose tended to be hedged, multi-stemmed, extensively branched and stunted in vertical growth. Such browsing may help to reduce birch densities and/or vigor and the competitive effects of birch on coniferous crop trees (Mielikäinen 1980, 1985), but also leads to the growth of birches that are crooked, twisted-grained, discolored and knotty – resulting in lower wood quality. Second, browse and breakage events imposed by moose on birches predisposed plants to internal decay formation. This decay weakens the tree (birches with rotten boles that appeared to have been snapped by wind or snow loading events were found in the study area) and reduces the potential lumber quality of the tree and, therefore, its merchantability.

Although birch trees do not currently comprise a significant component of industrialized forestry throughout western Canada, this is not true in places such as Fennoscandia where moose and birch also co-occur (Härkönen et al. 2009). Additionally, local changes to forest stand dynamics (e.g., mountain pine beetle epidemics) and changes in world economics may lead to the opening and expansion of markets where birch is in higher demand. To meet any such demands, forest managers tending stands for future merchantability must begin now, while young birches are within the reach of moose and while cleaning and thinning operations are being planned, to consider the impacts that moose may have on the quality of birch timber realized at harvest time.

Given that birches growing farther from their nearest neighbors at Aleza Lake were more heavily browsed than those less exposed, minimizing such exposure through innovative silvicultural and stand tending techniques may help to reduce damage. Such treatments may only be considered, however, within a regionally-specific context where considerations are made not only for tree species composition, the larger-scale distribution of food resources and moose densities, but for trade-offs between current browse abundance and range quality and hypothetical future gains from high quality birch.

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