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Moose Browsing Tends Spruce Plantations More Efficiently Than a Single Mechanical Release

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Abstract: Forest vegetation management can improve planted seedling survival and growth and is thus widely used in plantation silviculture. In some jurisdictions, mechanical release using brushsaws has replaced the traditional use of chemical herbicides for forest vegetation management purposes. However, its associated costs and the increasing difficulty of finding qualified labor represent a challenge. The browsing of competition by large herbivores may represent an alternative to mechanical release when planted seedlings are resistant to browsing. Here, we compare the efficacy of moose browsing relative to mechanical release in controlling competing vegetation and in promoting white spruce growth in plantations. In a high moose density region, we used an experimental design consisting of four pairs of moose exclosures and unfenced plots; fifty percent of both the access-restricted and unrestricted study areas received a mechanical release treatment. Moose browsing was more efficient than mechanical release in diminishing the sapling density and basal area of competing species. Mechanical release only reduced the sapling density of taller competitors (height > 201 cm), whereas browsing reduced the sapling densities of competitors across a greater size range (height > 130 cm). These effects of moose browsing on competition translated into a greater positive effect of moose browsing on the basal area of planted spruces. We attribute the higher effectiveness of moose browsing relative to mechanical release to its chronic nature. Moose browsed continuously throughout the year and for multiple years, whereas mechanical release was applied only one time between the second and fourth years after planting. Our results suggest that pairing wildlife management and silviculture decisions could be in the best interest of both the hunting and forestry industries in regions where plantations are frequent and use browse-resistant crop trees. Favouring browsers in controlling the density of competing species could increase the hunting experience and income, while providing an effective, cost-free, and socially acceptable forest vegetation management service.

Keywords: vegetation control; silviculture; competition; *Alces alces*; *Picea*; herbivore; ungulate

1. Introduction

Plantations can be used for various purposes, such as fibre production, the restoration of degraded sites, and carbon sequestration [1,2]. In many cases, planted seedlings are mainly subjected to competition from surrounding shade-intolerant trees, shrubs, and herbs that impacts their growth and survival [3,4]. Forest vegetation management to reduce competing vegetation effects on target trees species is thus common [5]. It can include preventive approaches, such as site preparation, seedling culture, and cover crops, as well as forest cleaning approaches, such as broadcast, spot, or injection herbicide treatments; motor manual cutting; girdling; and grazing [6]. While the application of chemical herbicides is often a more effective and cost-efficient method to control competition [7–10], their use raises issues related to social acceptance and land certification [11]. As a result, many jurisdictions are reducing or banning herbicide use for forestry purposes (e.g., [12]). In Quebec (Canada), forest vegetation management strategies rely on the use of motor-manual mechanical release treatments combined with the planting of large stock seedlings [13]. While this forest cleaning approach has a higher social acceptability [11] and has proven effective in reducing competition and enhancing seedling growth on a wide variety of site conditions [14–16], it is expensive and generally less effective than herbicides [17]. Moreover, increasing difficulties in finding a qualified workforce are challenging for forest managers, especially at a time characterized by a general shortage of skilled labour [18]. The forestry sector in Quebec is expected to be 15,000 workers short by 2022 [19]. We thus need to seek alternative methods to control competing vegetation that can generate added value for society.

While chronic browsing by cervids such as moose can hinder the economic and ecological value that can accrue from forest management [20–22], it could also provide ecosystem services in the context of plantation forestry when the crop-tree species is avoided by browsers or when competing vegetation is relatively more susceptible to browsing than the crop-tree species [23,24]. Yearly, a single moose (*Alces alces* (L.) Miller) consumes around 10,000 kg of vegetation [25], the bulk coming from deciduous leaves and herbs during summer, and deciduous twigs and balsam fir (*Abies balsamea* (L.) Mill.) during winter in North America [26,27]. Since white spruce (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Mill.) BSP) are generally not part of their diet [28–30], browsing by moose could represent an efficient alternative to mechanical release in spruce plantations at a reduced cost, if the level of browsing is high enough to control the competing vegetation and if the browse-resistant species does not replace the initial competitors. Numerous studies have shown how high densities of moose and ungulates in general can significantly reduce the abundance of preferred trees, shrubs, and herbs and modify forest plant communities [31–34]. Moreover, in a recent study Stokely and Betts [35] analyzed the combined effect of deer (*Cervidae* family) browsing and herbicide use and showed that the ability of deer to provide an ecosystemic service in plantations depends on the management (herbicides in their study) intensity and on the palatability of the planted crop-tree. However, it remains to be seen how ungulate browsing alone compares to other forest cleaning methods, such as mechanical release, in terms of competition control and effect on spruce growth.

Our objective was thus to compare moose browsing with mechanical release using motor-manual brushsaws and test their single and interactive effects on the competing vegetation and growth of planted white spruces, a species generally avoided by moose. To do so, we used a design which compared a browsing exclusion treatment (unbrowsed/browsed) and a forest cleaning treatment (no release/mechanical release) in four experimental white spruce plantations in a high moose density region. We expect both mechanical release and browsing to reduce competition. However, the effect of browsing is chronic and the competing species in our systems are light-demanding tree species with a relatively high palatability to moose. Consequently, we also predict that browsing will be more effective at reducing the saplings' density and the height and basal area of competing species than mechanical release applied once during an experimental period of seven growing seasons. Browsing should thus have a greater positive effect than mechanical release on white spruce growth. We expected this positive effect to reflect more strongly on the spruce basal area than on spruce height, as vertical growth is generally not strongly affected by the release of competition in early years after establishment [16,36].

2. Materials and Methods

2.1. Study Area

The experiment was based in the Matane Wildlife Reserve in the Gaspésie peninsula in Quebec (Canada). This region is located within the eastern balsam fir–paper birch (*Betula papyrifera* Marsh.) bioclimatic domain [37] and is characterized by cold winters with abundant snowfall and rainy, cool summers with an annual mean temperature of 1 °C [38]. Balsam fir and paper birch are the dominant tree species. With white spruce as a companion species, they represent the main commercial species. Past forest management practices have been detrimental to the abundance of spruce within balsam fir stands in this region [39], partly because of their impact on natural regeneration processes [40,41]. Because of its fiber quality and productivity, white spruce plantations are common in this area [42,43]. In addition to paper birch, fast-growing deciduous species, such as rowan (*Sorbus americana* Marsh.); pin cherry (*Prunus pensylvanica* L.f.); and, to a lesser extent, trembling aspen (*Populus tremuloides* Mich.) and willows (*Salix* spp.), are common and can densely populate openings following perturbations such as clear-cutting [44]. Their relative abundance varies with the site productivity. Rowan, trembling aspen, and willow are more common in sites with a high relative productivity, while sites with a low productivity will almost exclusively contain paper birch in the deciduous category. These deciduous thus represent the bulk of the competition for white spruce in this region, but they are also all consumed by moose, with rowan, birch, and pin cherry being the favoured species [45]. Moose densities are high in the Matane Wildlife Reserve (3.3 moose/km^2; [46]), while the white-tailed deer (*Odocoileus virginianus* Zimm.) densities are negligible.

2.2. Experimental Design and Data Collection

We selected four mesic forest sites (~6 km to ~42 km distant) characterized by null or low slope that had been clear cut during the fall of 2010 or the early spring of 2011. At each site, the logging debris was removed using mechanical site preparation (screefing and windrowing). In June 2011, we obtained large stock seedlings of white spruce in containers of 25 cells with a 310 cm^3 container volume. These seedlings were produced over 2 years in a regional tree nursery (Somival, Lac-au-Saumon, QC, Canada) from a local seed source. We planted the seedlings in a 2 m × 2 m grid in June 2011, a few days before the exclosure construction. The initial seedling height (assessed immediately after planting) varied between 30 and 45 cm. We built an exclosure of 400 m^2 (28.5 m × 14 m) at each site using a high tensile fence. Every exclosure was paired to an unfenced plot of the same dimension accessible to moose, located within 50 m of the spruce plantation. Half of the area of each unbrowsed and paired browsed plot received a forest cleaning treatment (either no release or mechanical release) in July–August 2014 during their third growing season after planting. We performed the mechanical release with motor-manual brushsaws according to standard operational procedures in Quebec; all competing ligneous and herbs species were cut at a height of 10–15 cm. Our experiment was arranged in a split-plot design and thus comprised the forest cleaning treatment (no release/mechanical release) nested within the browsing exclusion treatment (unbrowsed/browsed). Due to human error, one of the paired browsed plots received a mechanical release treatment on its whole surface. Consequently, all the combinations of treatments levels were replicated on four sites, with the exception of the no release + browsed treatment, which was replicated on three sites only. This led to a total of 15 experimental units (plots). Although some initial seedling mortality and some natural seedling establishment did occur, the number of planted spruces did not differ across treatments (*t*-test: $p > 0.15$ for all combinations, see Supplementary Material 1). While there is no guarantee in browsing experiments involving wildlife that the regenerating area is used uniformly, the vegetation in the small plantations (~0.2–2.0 ha) of this study was uniformly dominated by white spruce, with clear evidence of browsing on deciduous stems (pers. obs.).

Competitors' density, height, and size represent different components of competition structure. As competition for light is the main factor affecting planted spruces' growth in the studied region [47,48], greater competitor densities, taller competitors, or both can all directly reduce the light availability for spruce [47,49]. In 2018, we thus counted and identified at the species level (except for *Salix* spp.) every sapling other than spruce, hereafter called "competitors", of height ≥ 130 cm high and classified them within three height classes (130–200, 201–300, and >301 cm). We maintained a 1.5 m buffer zone along the fences. We measured the competitors' and spruces' diameters at breast height and classified them in 2 cm DBH classes (class 0 (0–2 cm); class 2 (2–4 cm); class 4 (4–6 cm); class 6 (6–8 cm); class 8 (8–10 cm)). To better integrate the component related to the competitors' size and the planted seedlings' responses, we calculated their respective basal area (cm^2/ha). We witnessed no browsing on white spruce, except for a few instances of hare (*Lepus americanus* Erxleben) browsing, which are distinguishable by the sharp angular cut they leave.

2.3. Statistical Analyses

To investigate the effects of moose and mechanical release on competitors (total density, density per height class, and basal area), we used generalized linear mixed models with a negative binomial distribution family (glmmTMB package, [50]). We investigated the effect of moose and mechanical release on planted spruce seedlings (seedling height, seedling basal area) using linear mixed models (nlme package, [51]). For the spruce basal area, we first verified that the treatment did not have an effect on the number of spruces taller than 130 cm to make sure that any effect on the basal area would not be an artefact of the number of spruces (Supplementary Material 2). For all models, we included the forest cleaning treatment nested within the browsing exclusion treatment nested within the site as a random factor. When significant interactions were found, we used protected least-squares-means to contrast the different levels of treatments (emmeans package, [52]). For the competitors' analyses, randomly replacing the competitor density from 0 to 1 individual/ha in 50% of the cases for the >301 cm height class allowed computing valid estimates without affecting the results. For negative binomial models, we tested for overdispersion. For the linear mixed models, we tested the normality of the residuals along with the homoscedasticity using standard graphical procedures. Due to the small number of replicates and to the naturally high variability of the studied phenomenon, we used $\alpha = 0.10$ as a threshold for statistical significance. Errors are reported as 95% confidence intervals. All the analyses were performed using the R statistical environment (version 3.6.0, [53]).

3. Results

Both the browsing exclusion and the forest cleaning treatments affected the density (*n*/ha) of competitors (Table 1). The density of competitors was higher in the exclosures (mean = 7762 [1012–59,542]) than in the browsed plots (326 [33–3256]) and in plots that were not released (2170 [371–12,684]) compared to those that were mechanically released (1479 [249–8774]). Hence, browsing reduced mean competitors density by 7436 stems / ha and mechanical release by 691/ha (Figure 1).

Table 1. Results of models analysing the effects of browsing exclusion (unbrowsed/browsed) and forest cleaning (no release/mechanical release) on the competition and growth of the planted white spruces. "MR" stands for mechanical release. All the models included the forest cleaning treatment nested within the browsing exclusion treatment, nested within the site as a random factor. For competitor variables, we used general linear mixed models with a negative binomial distribution. For spruce variables, we used linear mixed effects models with a gaussian distribution. Significant fixed effects and contrasts are in bold. Asterisk (*) represent interaction between fixed effects. We used $\alpha = 0.1$ as a threshold for statistical significance.

Response Variable	Fixed Effect	F/χ2	*df*	*p*-Value	Contrast	*t*	*df*	*p*-Value
Competitors density	**Browsing exclusion**	χ2 = 8.4	1	**0.004**				
	Forest cleaning	χ2 = 5.3	1	**0.02**				
	Browsing exclusion * Forest cleaning	χ2 = 1.5	1	0.23				
Competitors density (per height class)	**Browsing exclusion**	χ2 = 8.0	1	**0.005**				
	Forest cleaning	χ2 = 1.9	1	0.17				
	Height class	χ2 = 27.5	2	**<0.001**				
	Browsing exclusion * Forest cleaning	χ2 = 2.7	2	0.10				
	Browsing exclusion * Height class	χ2 = 7.0	2	**0.03**	height class = 130–200 cm:			
					Unbrowsed/Browsed	2.4	29	**0.02**
					height class = 201–300 cm:			
					Unbrowsed/Browsed	4.2	29	**<0.001**
					height class = >301 cm:			
					Unbrowsed/Browsed	3.0	29	**0.006**
	Forest cleaning * Height class	χ2 = 10.6	2	**0.005**	height class = 130–200 cm:			
					No Release/MR	−0.2	29	0.86
					height class = 201–300 cm:			
					No Release/MR	−2.4	29	**0.02**
					height class = >301 cm:			
					No Release/MR	−2.2	29	**0.04**
	Browsing exclusion * Forest cleaning * Height class	χ2 = 4.2	2	0.12				
Competitors basal area	**Browsing exclusion**	χ2 = 9.5	1	**0.002**				
	Forest cleaning	χ2 = 26.8	1	**<0.001**				
	Browsing exclusion * Forest cleaning	χ2 = 3.2	1	**0.08**	**Unbrowsed/Unbrowsed + MR**	−5.2	7	**0.001**
					Unbrowsed/Browsed	2.7	7	**0.03**
					Unbrowsed/Browsed + MR	−3.7	7	**0.008**
					Unbrowsed + MR/Browsed	2.1	7	**0.08**
					Unbrowsed + MR/ Browsed + MR	3.1	7	**0.02**
					Browsed/Browsed + MR	−5.2	7	**0.001**

Table 1. *Cont.*

Response Variable	Fixed Effect	F/χ2	*df*	*p*-Value	Contrast	*t*	*df*	*p*-Value
Spruces basal area	Browsing exclusion	F = 5.1	1	0.11				
	Forest cleaning	F = 4.0	1	0.10				
	Browsing Exclusion * Forest cleaning	F = 9.8	1	**0.02**	Unbrowsed/Unbrowsed + MR	−2.0	5	0.10
					Unbrowsed/Browsed	−2.3	5	**0.07**
					Unbrowsed/Browsed + MR	−1.5	5	0.20
					Unbrowsed + MR/Browsed	−1.7	5	0.16
					Unbrowsed + MR/Browsed + MR	−0.9	5	0.43
					Browsed/Browsed + MR	2.3	5	**0.06**
Spruces height	Browsing exclusion	F = 1.2	1	0.36				
	Forest cleaning	F = 1.0	1	0.38				
	Browsing exclusion * Forest cleaning	F = 4.1	1	0.10	Unbrowsed/Unbrowsed + MR	−1.0	5	0.38
					Unbrowsed/Browsed	−1.1	5	0.33
					Unbrowsed/Browsed + MR	−0.2	5	0.83
					Unbrowsed + MR/Browsed	−0.7	5	0.55
					Unbrowsed + MR/Browsed + MR	0.2	5	0.84
					Browsed/Browsed + MR	1.9	5	0.12

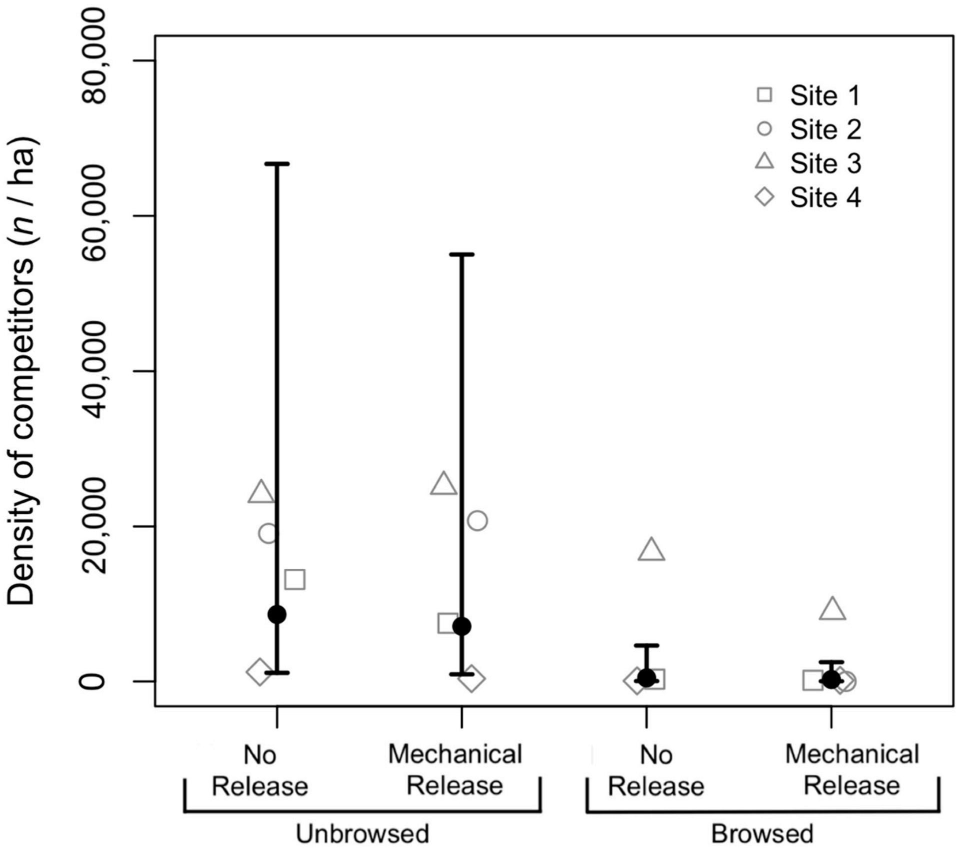

Figure 1. Density of the competing tree saplings in four white spruce plantations receiving combinations of browsing exclusion (unbrowsed or browsed) and forest cleaning (no release or mechanical release) treatments. Predicted values were estimated from a generalized linear mixed model with a negative binomial distribution and with the forest cleaning treatment nested within the browsing exclusion treatment, nested within the site, as a random factor. Error bars are 95% confidence intervals. Raw averages are shown in gray. Both the browsing exclusion and the forest cleaning treatments significantly lowered the competitors' density. Although their interactive effect was not statistically significant, the present figure gives a better picture of their relatives effects.

Breaking up the competitors' density per height class shows that browsing exclusion affected the competitor density throughout a wider range of height classes than the forest cleaning treatment (Table 1). Specifically, browsing reduced the density of all the height classes (Figure 2A), while mechanical release reduced the density of the 201–300 cm and >301 cm competitors, but not of the 130–200 cm competitors (Figure 2B). There was a tendency for browsing to be slightly more effective at reducing the competitors' density, irrespective of height class, when combined with mechanical release.

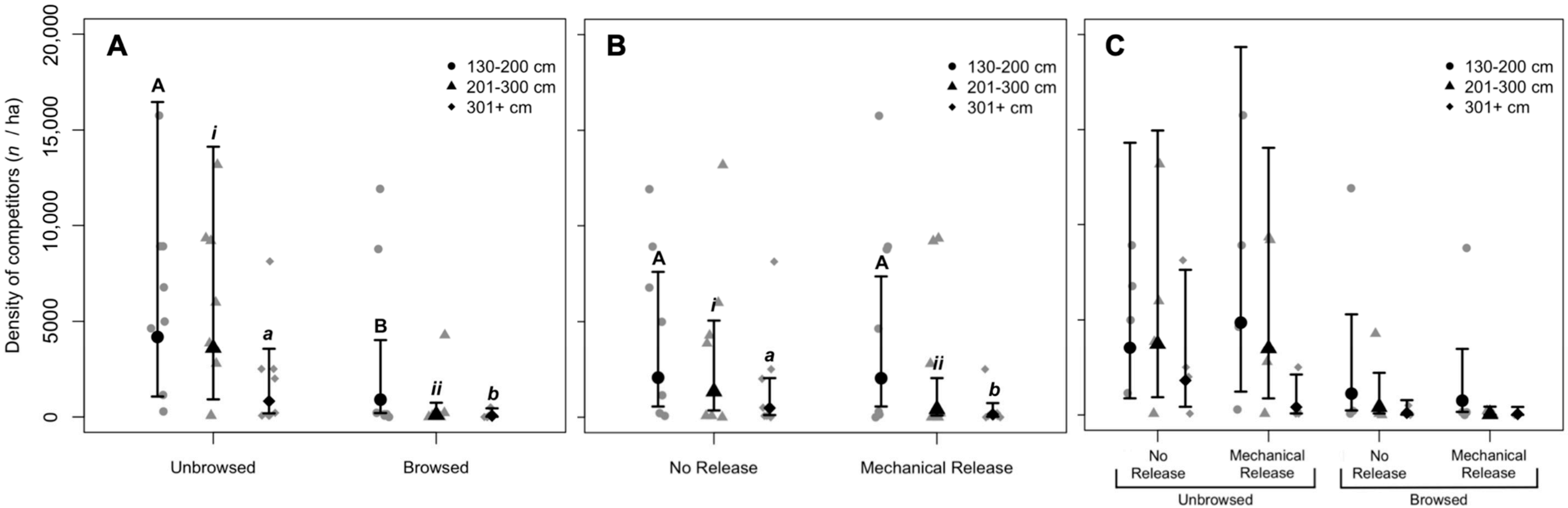

Figure 2. Density of the competing tree saplings per height class in four white spruce plantations receiving combinations of (**A**) browsing exclusion (unbrowsed or browsed) and (**B**) forest cleaning (no release or mechanical release) treatments. The non-significant interaction between browsing exclusion, forest cleaning, and height is shown in (**C**) to visually compare the effect size of all the treatments. Predicted values were estimated from a generalized linear mixed model with a negative binomial distribution and with the forest cleaning treatment nested within the browsing exclusion treatment, nested within the site, as a random factor. Error bars are 95% confidence intervals. Raw averages are shown in gray. In (**A**,**B**), contrasts between the treatments levels were made within each height class: caps letters represent contrast results for the 130–200 cm class, i and ii for the 201–300 cm class, and lowercase letters for the >301 cm class. Different letters/symbols represent significant effects of treatment on the density of the height class at $p = 0.1$. See Table 1 for statistical contrast results.

Overall, browsing was more effective than mechanical release at reducing competitors' basal area. Mechanical release reduced the competitors' basal area, but its effect was smaller in browsed plots compared to in unbrowsed plots (Table 1, Figure 3). This is mainly due to the fact that the basal area of competitors was lower in the browsed plots compared to the unbrowsed plots, irrespective of the forest cleaning treatment. The combination of browsing and mechanical release was significantly more effective than all the other treatments, but the difference with browsing alone was smaller than the difference with the other unbrowsed treatments (Figure 3).

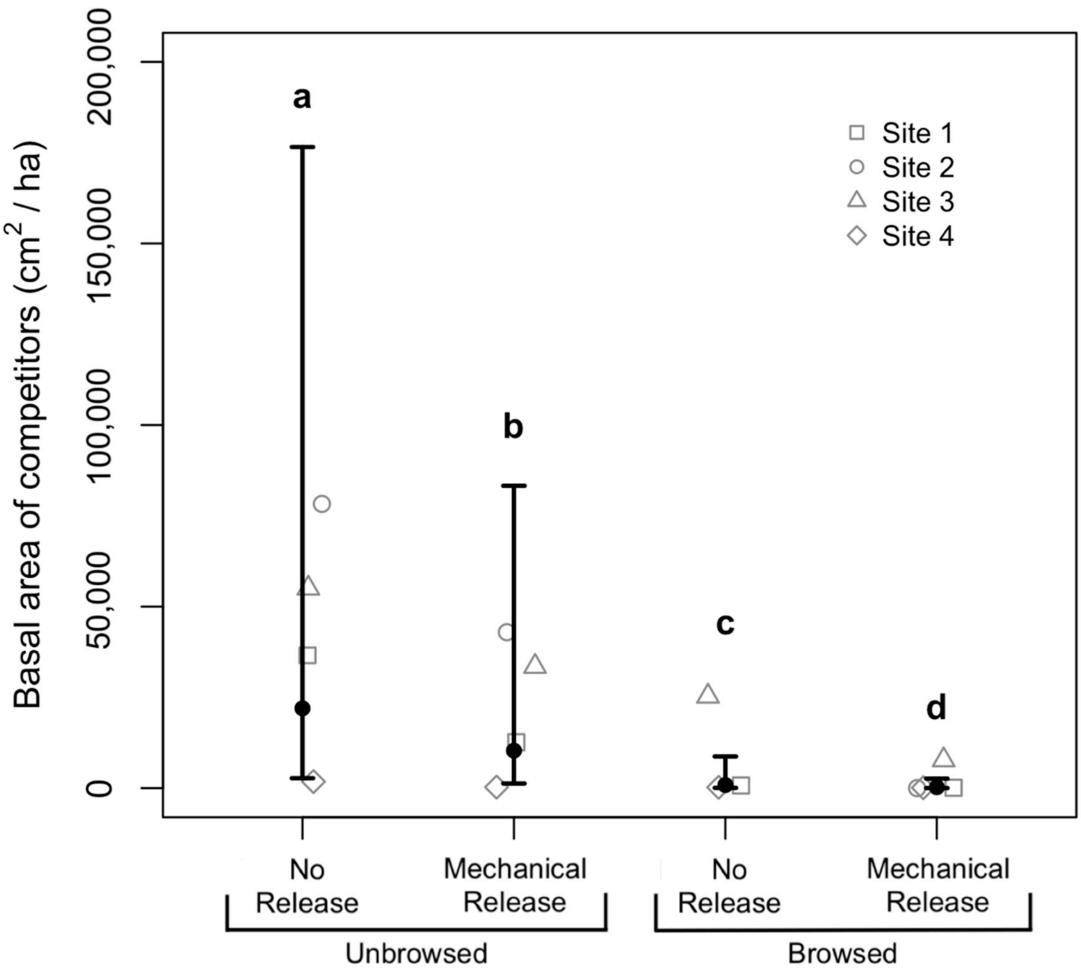

Figure 3. Basal area of the competing tree saplings in four white spruce plantations receiving combinations of browsing exclusion (unbrowsed or browsed) and forest cleaning (no release or mechanical release) treatments. Predicted values were estimated from a generalized linear mixed model with a negative binomial distribution and with the forest cleaning treatment nested within the browsing exclusion treatment, nested within the site, as a random factor. Error bars are 95% confidence intervals. Raw averages are shown in gray. Treatments that do not share at least one similar letter are significantly different at $p = 0.1$.

The basal area of the planted spruces was higher in the browsed than in the unbrowsed plots, although forest cleaning interacted with this result (Table 1, Figure 4). Mechanical release alone tended to increase the spruces' basal area, but its combination with browsing led to a lower basal area when compared to the browsed plots with no release (Table 1, Figure 4). Despite a trend for an interactive effect of browsing exclusion and forest cleaning on height (Supplementary Material 3), we found no significant post hoc comparison among the combinations of browsing exclusion and forest cleaning levels (Table 1).

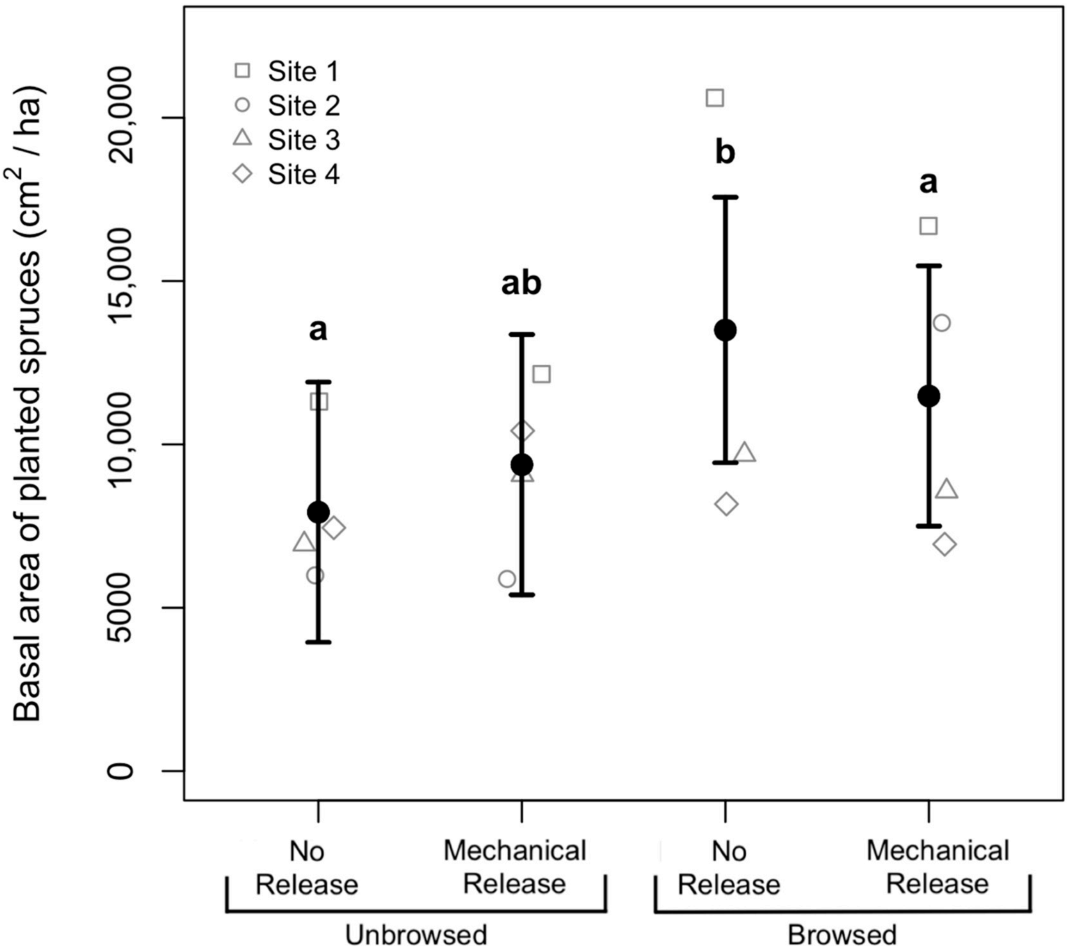

Figure 4. Basal area of the planted white spruces in four plantations receiving combinations of browsing exclusion (unbrowsed or browsed) and forest cleaning (no release or mechanical release) treatments. Predicted values were estimated from a linear mixed effects model with the forest cleaning treatment nested within the browsing exclusion treatment, nested within the site, as a random factor. Error bars are 95% confidence intervals. Raw averages are shown in gray. Treatments that do not share at least one similar letter are significantly different at $p = 0.1$.

4. Discussion

As predicted, both moose browsing and the use of mechanical release reduced competition when compared to unbrowsed plots with no release, but browsing was overall more effective than mechanical release seven years after plantation establishment. The stronger effect of browsing on competitors relative to mechanical release resulted in a higher basal area of planted spruce seedlings in browsed plots, while spruce height was, as predicted, unaffected by the treatment.

Moose browsing was effective at reducing all three components of competitive structure that we measured (competitor density, density by height class, and basal area). In comparison, the use of mechanical release alone only slightly reduced the density of competing saplings >201 cm and reduced the basal area of competitors, but to a much lower extent than browsing. We attribute the stronger effect of moose compared to mechanical release to the chronic and year-round nature of browsing, whereas mechanical release was performed once during the third growing season after planting [13]. Many competing shade-intolerant tree species, such as birch, rowan, and aspen, are aggressive re-sprouters that can grow back to 100+ cm in height after a few years following a punctual release treatment [54–56]. Our results reflect this, as mechanical release reduced the density of competitors 201–300 cm in height and >301 cm in height, but not of competitors 130–200 cm in height when compared to unbrowsed plots with no release. In comparison, moose browsing also kept the

130–200 cm competitors at significantly lower densities. Other studies have compared mechanical release with continuous clipping, the latter leading to a more effective control of competition [57] and enhancing planted seedlings' survival [58].

In addition to the negative effect competing vegetation has on resource availability (mainly light) for planted spruces, it may also increase spruce susceptibility to hare, whose browsing can be detrimental to spruce seedlings in some cases [47,59]. Consequently, reducing competition density may provide a service of reduced damage to planted seedlings from hare browsing over the first few years following plantation [60]. In our study, such service may have been fulfilled by moose browsing, but not by mechanical release, as moose were overall more effective at reducing competitors density. Additionally, only moose browsing was effective in reducing the density of smaller competitors (130–200 cm), characteristic of habitat preferred by hare [61]. Moreover, as moose browsing operated from the onset of plantation establishment, it may have reduced the susceptibility of the newly planted seedlings to hare browsing early in the plantation scenario. Early vegetation control is part of the optimum environment for establishing white spruce [62].

Treatment effects on competition density translated into observable effects on planted spruces. The stronger response of basal area relative to height was to be expected, as, in the short-term, reduced competition for light is mainly characterized by increased cambial growth relative to apical growth [16,36,63]. As has been observed elsewhere [15,64], mechanical release alone tended to increase the spruce total basal area. However, moose browsing was the treatment that most improved the spruce growth overall, a suspected result of its chronic effect on competition.

As both browsing and mechanical release had positive effects on planted spruce, one surprising result was that their combination reduced the basal area of planted spruce when compared to the effect of browsing alone. Although hardwoods, shrubs, and herbaceous species generally have negative impacts on planted conifer growth, they can also have facilitative effects [65]. For example, shrubs may protect young spruce from frost damage [66], vegetation cover may protect spruce seedlings from excessive water loss [67], and a certain degree of shading may be beneficial to young spruce [68]. This may explain why mechanical release tended to increase spruce total basal area and spruce height compared to unbrowsed plots with no release, but reduced them when combined with browsing. The observed benefits of the reduced competition under browsing alone would have been counterbalanced by the negative effects of the more open conditions, resulting from the reduced densities of competitors, found under the combination of browsing and mechanical release. The invasion of these plots by red raspberry (*Rubus idaeus* L.), a fast growing, shade-intolerant shrub that can form a dense cover, might also explain this result [69–72]. These two explanations are not mutually exclusive, as the absence of hardwood or fir competition could lead to frost damage in winter and to increased red raspberry abundance, and thus competition, in summer.

Management Implications

By keeping competitors at low densities and in lower height classes and by reducing their basal area, moose browsing may provide an ecosystem service in spruce plantations. Obviously, the capacity of moose to fulfill this ecosystem service depends on their regional densities and browsing pressure. Even though several abiotic and biotic factors, such as habitat quality, natural predation, and climate, are important factors driving moose population dynamics [73,74], management through hunting is the primary element regulating moose populations [75]. Adopting wildlife management objectives that favour high moose densities may be of interest for both the forest and the hunting industries in regions characterized by intensive forest management practices including spruce plantations. In these regions, reaching a moose density sufficiently high to control competing vegetation would likely improve both recreational and hunting experience and their associated income, increase the supply of a quality food source from game meat [76], and provide a silvicultural service related to forest vegetation management. Avoiding mechanical release or other forest cleaning treatments would reduce forest management costs; increase browsing availability; and help to maintain moose populations and the ecosystem services they provide [77], as well as their relational values such as cultural identity, social cohesion, and land stewardship [76]. As such, the pairing management of wildlife game, such as moose, and the management of forests could be effective, cost efficient, and socially acceptable, as long as high cervid densities do not have a detrimental effect on the ecosystem or managers are able to control on a fine-scale those densities [78,79]. Care should, however, be taken to ensure that the target herbivore density will not result in detrimental impacts on the ecosystems surrounding the plantations. For example, having too many large herbivores in naturally regenerating forests can modify plant communities by favoring browse-resistant species and can reduce biodiversity [80,81].

The capacity of large wild herbivores to provide an ecosystem service related to forest vegetation management in plantations requires that the crop-tree is not consumed by the browsers or that the browse damage does not reduce or limit plantations' productivity, as is reported for plantations of Scots pine (*Pinus sylvestris* L.) damaged by moose in Scandinavia [20,82]. There could still be a benefit of keeping moderate herbivore density when the crop-tree species is relatively less susceptible to browsing than the competing vegetation or if the crop-tree is able to compensate browse damage without significant quality loss or growing delay. While the suggested combination of forest plantations with managed browser densities for controlling competing vegetation appears to be well suited to the studied region, we think that anywhere with browse-resistant crop-trees, browsed competition, and managed large herbivore populations may benefit from joint forest and wildlife management.

5. Conclusions

This study used an experimental design consisting of paired fenced and unfenced plots to verify if moose browsing could provide an ecosystem service related to forest management in white spruce plantations. Chronic browsing by moose was more effective at controlling competing vegetation than a single mechanical release, resulting in an increased spruce basal area in the unfenced treatment. This could be particularly useful for forest managers, as there is a shortage of skilled labor to conduct mechanical release and as herbicides are banned in several jurisdictions due to low social acceptance. This also provide an opportunity for the hunting industry, which could benefit from higher moose densities. Getting the most from this type of ecosystem service involves the strong integration of forest and wildlife management decisions.

Supplementary Materials: The following are available online at http://www.mdpi.com/1999-4907/11/11/1138/s1. Supplementary material 1: Table S1: Total number of spruces by site/treatment after 8 growing seasons. The same number of spruces was planted initially, but seedling mortality, natural seedling establishment or treatments effects resulted in variation in the number of spruces per site/treatment. Due to a human error site, 2 received a mechanical release on its whole browsed surface. Hence, there is no "Browsed/No release" treatment for this site. Table S2: Number of spruces taller than 130 cm by site/treatment after 8 growing seasons. The same number of spruces was planted initially, but seedling mortality, natural seedling establishment or treatments effects resulted in variation in the number of spruces per site/treatment. Due to a human error, site 2 received a mechanical release on its whole browsed surface. Hence, there is no "Browsed/No release" treatment for this site. Supplementary material 2: Table S3: Results of a linear mixed effects model with gaussian distribution analysing the effects of browsing exclusion (Unbrowsed / Browsed) and forest cleaning (No release / Mechanical release) on the quantity of white spruces taller than 130 cm. The model included the forest cleaning treatment nested within the browsing exclusion treatment, nested within the site as a random factor. Supplementary material 3: Figure S1: height of planted white spruces in four plantations receiving combinations of browsing exclusion (unbrowsed/browsed) and forest cleaning (no release/mechanical release) treatments.

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