

## Effects of cattle grazing on young spruce trees in boreal production forest

Mélanie Spedener<sup>a,\*</sup>, Karen Marie Mathisen<sup>a</sup>, Josh Hauer<sup>a</sup>, Rémi Héroult<sup>a</sup>, Gunnar Austrheim<sup>b</sup>, Morten Tofastrud<sup>c</sup>, Barbara Zimmermann<sup>a</sup>

<sup>a</sup> Faculty of Applied Ecology, Agricultural Sciences and Biotechnology, Department of Forestry and Wildlife Management, Inland Norway University of Applied Sciences, Koppang, Norway

<sup>b</sup> Department of Natural History, NTNU University Museum, Norwegian University of Science and Technology, Trondheim NO-7491 Norway

<sup>c</sup> Faculty of Applied Ecology, Agricultural Sciences and Biotechnology, Department of Agricultural Sciences, Inland Norway University of Applied Sciences, Hamar, Norway

### ARTICLE INFO

#### Keywords:

Forest grazing  
Beef cattle  
Browsing  
*Picea abies*  
*Bos taurus*

### ABSTRACT

The compatibility of forest livestock grazing with timber production is disputed, as livestock can damage young trees through browsing and trampling. At the same time, livestock grazing might reduce the growth of competing vegetation and thereby enhance conifer forest regeneration. We investigated the effects of cattle (*Bos taurus*) on young spruce (*Picea abies*) trees in boreal production forest. We compared data from young spruce plantations within and outside of the grazing area, and during and off the cattle grazing season. Overall, stocking rates were 0.01 cows per hectare across the grazing areas. Cattle did not distribute equally, but concentrated their area use to young spruce plantations, leading to locally high densities during periods of the grazing season. Cattle removed vegetation competing with young spruce trees: Within the grazing area, the sward height of the field layer vegetation was lower, and young willow (*Salix spec.*) and downy birch (*Betula pubescens*) trees were browsed more than outside the grazing area. The annual height growth of spruce increased once the spruce grew above sward height. Spruce trees surrounded by many competing trees grew slower than those surrounded by few trees. Bent spruce trees grew slower than undamaged spruce trees. Yet, no difference in annual spruce growth was found between inside and outside the cattle grazing area. In contrast, we found a higher spruce mortality risk inside than outside the cattle grazing area. This mortality risk was very low and positively correlated with a given spruce tree's bark being damaged. Cattle did not increase the risk of damaged stem bark. This study did not succeed in pointing out the mechanism by which cattle might increase spruce mortality risk. Interestingly, the probability of being browsed and the probability of being bent were higher after winter than after summer, indicating that wild ungulates and snow might have a stronger effect on young spruce trees than summer grazing cattle at these stocking rates. In conclusion, cattle had minor effects on young spruce trees. This study suggests that at low stocking rates, forestry and livestock production in boreal production systems are compatible.

### 1. Introduction

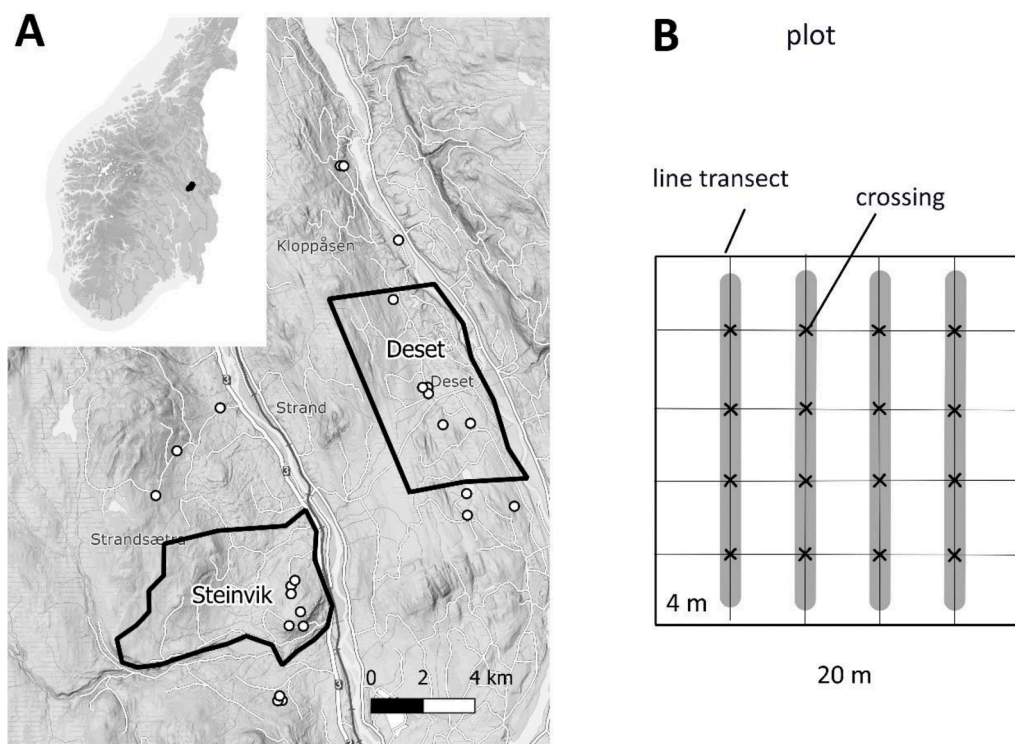
Forest grazing by livestock is a controversial management practice around the world, increasingly restricted in many countries over the past 250 years (Adams, 1975; Varga et al., 2020). Arguments given against forest grazing are damages on ditches, decreased water quality, soil packing and erosion as well as damages on both adult and young trees (Adams, 1975; Bjor and Graffer, 1963; Eissenstat and Mitchell, 1982; Hjeljord et al., 2014). On the other hand, positive effects such as fire risk reduction due to biomass removal and decreased tree sapling

competition with other vegetation for water, light and nutrients have been documented (Adams, 1975; Belsky and Blumenthal, 1997; Hancock et al., 2010; Popay and Field, 1996; Tohiran et al., 2019). By hindering the growth of competing vegetation, livestock grazing can be considered as a good tool for the establishment of conifer forests (Doescher et al., 1987). Cattle (*Bos taurus*) at high densities are found to reduce the density of deciduous trees, such as rowan (*Sorbus aucuparia*) and willows (*Salix spp*) on Norway spruce plantations in Norway (Bjor and Graffer, 1963; Hjeljord et al., 2014). Similarly, wild ungulates have been shown to reduce competing vegetation. In Canada, for example,

\* Corresponding author at: campus Evenstad, Anne Evenstads vei 80, 2480 Koppang, Norway.

E-mail address: [melanie.spedener@inn.no](mailto:melanie.spedener@inn.no) (M. Spedener).

<https://doi.org/10.1016/j.tfp.2024.100596>



**Fig. 1.** A. Location of the two cattle grazing areas included in this study. For each study area, we selected six young spruce plantations within the grazing area, three north of it and three south of it (white circles). B. On each plantation, we installed a plot of 20 x 20 m, marked with edge poles. Along 1 m wide transects (grey) spaced at 4 m intervals, we assessed browsing on young trees. At every intersection of the 4 x 4 m grid (black crosses), we measured sward height, and marked the closest spruce tree smaller than 2 m. On those spruce trees we registered height, growth and browsing and trampling signs.

moose (*Alces alces*) browsing on white spruce (*Picea glauca*) plantations was more efficient in diminishing the sapling density and basal area of competing species than mechanical release (De Vriendt et al., 2020). Similarly, excluding moose on post-harvested clearcuts in central Norway resulted in mediated succession trajectories: After 7 years, the exclosures were dominated by deciduous trees, whereas the open plots subject to moose impacts (browsing, trampling, defecation) were dominated by economically important coniferous trees (Kolstad et al., 2018). At low herbivore densities, the animals might forage in patches, leaving a large part of the vegetation untouched (Doescher et al., 1987). High numbers of large herbivores can lead to more uniform biomass removal, thus uniformly reducing the growth of competing vegetation (Doescher et al., 1987). At the same time, such high densities might increase the risk of trampling damages (Adams, 1975; Bjor and Graffer, 1963). Below a certain herbivore density threshold, tree regeneration is not negatively affected (Hester et al., 2000).

In Norway, only about 3 % of the land area is suited for agriculture (SSB, 2023c) and summer grazing in the outfields, such as forests, has a tradition of thousands of years (Sjögren et al., 2015). It is still of importance for Norwegian agriculture today, and beef cattle grazing in the outfields has been increasing in recent years (SSB, 2023b). Indeed, a recent study in the forested areas in the lowlands of South-Eastern Norway shows that it is possible to achieve acceptable weight gain for cattle summer grazing in boreal production forest, given suitable breeds are used at moderate stocking densities (Tofastrud et al., 2020). The forested areas in the lowlands of South-Eastern Norway are mainly production forests shaped by clear-cutting practices and dominated by patches of even-aged stands of either Norway spruce (*Picea abies*) or Scots pine (*Pinus sylvestris*) (Kuuluvainen et al., 2012; Aasetre and Bele, 2009). Spruce is the most common tree species in Norway, dominating 34.8 % of the forested area in 2017, followed by boreal deciduous trees (33 %) and Scots Pine (29 %) (Hysten et al., 2022). Furthermore, spruce realizes the highest prices and makes up the largest part of the harvested

timber (74 % in the first quarter of 2024) (SSB, 2024). Given that timber production is a primary goal of forest owners, there is a prevailing concern about potential economic losses resulting from damage to their spruce plantations caused by cattle. The aim of this study is to clarify to what extent cattle affect spruce plantations and thereby to facilitate the collaboration between forest and cattle owners. We focussed on young spruce trees under 2 m height, due to i) spruce being of high economical interest for forest owners, ii) our assumption of young trees being most exposed to ungulate damages and iii) cattle's considerable time spent in young spruce plantations (Tofastrud et al., 2019).

Cattle are not the only large herbivores in the studied system. Cervids densities have increased drastically between 1949 and 2015 (Speed et al., 2019), with today's moose densities in southeastern Norway ranging among the highest worldwide (Jensen et al., 2020). Ungulates are often characterized by their diet and placed along a gradient from strictly grazing to strictly browsing. Grazing is typically referred to as foraging on graminoids, including true grasses (Poaceae), sedges (Cyperaceae) and rushes (Juncaceae), and browsing as foraging on woody and nonwoody dicotyledonous plants (Janis, 2008), i.e., herbs, forbs, and leaves and twigs of woody plants (Clauss et al., 2008). Along the grazing-browsing gradient in our study system in the boreal forest, cattle are mainly grazing (Spedener et al., 2024). The cervids moose and roe deer (*Capreolus capreolus*) are typical browsers, and red deer (*Cervus elaphus*) is often characterized as intermediate feeder (Bergquist et al., 2003; Mysterud, 2000; Wam and Hjeljord, 2010; Zweifel-Schielly et al., 2012). In our study system, both grazers (summer) and browsers (whole year) are affecting young spruce trees, but their combined effect is rarely studied.

We investigated possible positive and negative effects of cattle in combination with cervids and wanted to know whether the positive or the negative effects predominated. We expected cattle grazing to have a positive effect on the annual height growth of young spruce trees by removing competing vegetation, such as graminoids, herbs and woody

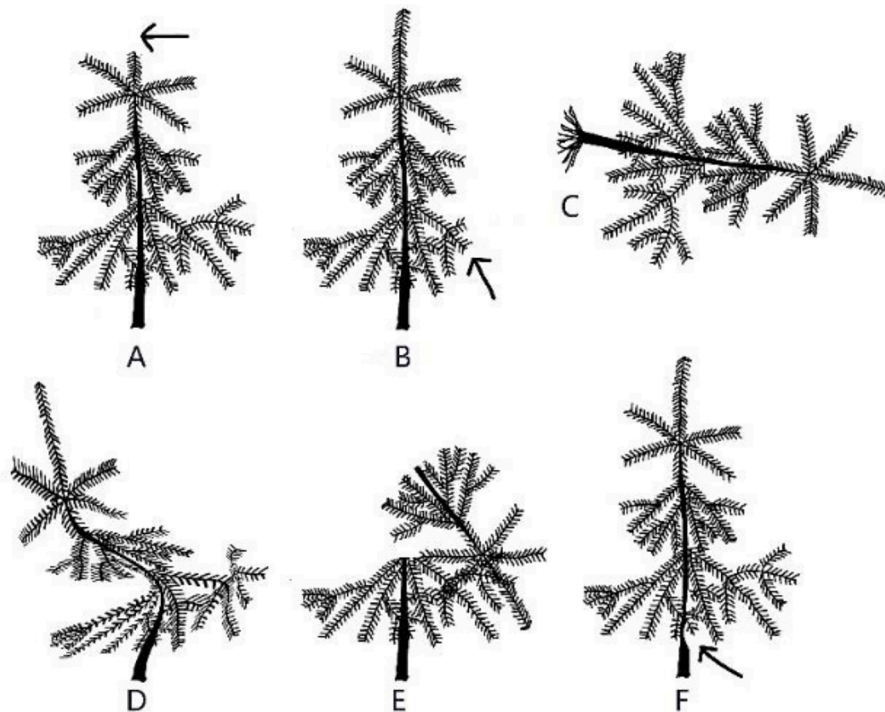


Fig. 2. Signs recorded on young spruce trees in boreal production forest with and without cattle. Browsing signs in the top row: “browsed on the top shoot” (A), “browsed on a side shoot” (B), “torn out of the ground” (C). Trampling and bedding signs (referred to as trampling signs in this paper) in the bottom row: “bent” (D), “broken” (E), “stem bark damaged” (F).

plants. As a contrast, we expected cattle to negatively affect young spruce trees through trampling and bedding (referred to as trampling signs in this article), leading to bent and broken trees as well as trees with damaged stem bark. We expected spruce trees with trampling signs to be at higher mortality risk and to grow slower than undamaged trees.

## 2. Methods

### 2.1. Study areas and sampling plots

To isolate the effects of cattle summer grazing we compared data from inside and outside cattle grazing areas during summer. In addition, we compared data from summer, when both cattle and cervids had access to the spruce plantations, with data from winter, when wild ungulates are the only large herbivores present inside the grazing area.

We collected data inside and outside two grazing areas, in Deset and Steinvik situated in South-Eastern Norway (Fig. 1A) in 2021–2023. Both areas are east facing slopes between 250 and 600 m above sea level covered with boreal production forest dominated by Norway spruce and Scots pine. The dominating forestry practices are based on age-class structured stands and clear-cutting, also known as even-aged forestry (Kuuluvainen et al., 2012). The cattle grazing areas are each about 35 km<sup>2</sup> and delimited by virtual fencing technology Nofence (Nofence, 2022). When approaching the virtual fence, the animals get an audio warning from their collar and if they do not respect this warning, they are given a mild electric pulse. The absence of physical fences allows wildlife to freely enter and leave the grazing area. Beef cattle of the breeds Hereford, Limousin and Charolais were grazing in the area from the end of May to the end of September all three years. The cattle stocking densities (Appendix 1) varied between 0.006 and 0.017 cows per ha, which corresponds to about 30 % of the grazing capacity for this area, estimated based on vegetation maps (Rekdal, 2006). Rekdal determined the approximate grazing value for cattle of each mapped vegetation type, grouped them into the three foraging classes “Less Good”, allowing for 0.05–0.08 beef cows per ha, “Good”, allowing for

0.08–0.12 beef cows per ha and “Very Good”, allowing for 0.12–0.17 beef cows per ha, and from that derived the grazing capacity of the area. Cattle did not distribute equally in our study area, as they select for grass-rich young forest stands with open canopy, especially when foraging (Tofastrud et al., 2019). On a national level, young forest stands with open canopy make up 23 % of the productive forest area, with 3% being recently logged and ready for planting and 20 % being young plantations (SSB, 2023a).

In each study area, we chose six young spruce plantations within and six outside the cattle grazing areas (Fig. 1B), which sums up to 24 plantations in total. To minimize the variation between plantations, we selected plantations in bilberry spruce forest (as described by Fremstad (1997)) with spruce trees below 2 m in height (in spring 2021). This forest type is very common in the study area and has shown to be preferred by free-ranging cattle in boreal production forest (Tofastrud et al., 2019). All these young plantations are part of the same forest system, which covers the slopes of these valleys for many tens of kilometres. We selected plantations close to forestry roads. This was practical for fieldwork and increased the probability of cattle using the plantations, as free-ranging cattle in boreal production forest are known to use forestry roads for travelling (Tofastrud et al., 2019).

In each of the 24 plantations, we established a plot of 20 x 20 m that we marked with edge poles (Fig. 1B). To avoid stand edge effects, the plots were placed in the middle of the plantations. We extracted forest productivity classes for our plots from publicly available maps, namely AR50 (NIBIO, 2023). The three productivity classes in our data are “good and very good” (expected roundwood harvest of 5 m<sup>3</sup> of per ha and year), “medium” (expected roundwood harvest of 3–5 m<sup>3</sup> of per ha and year) and “low” (expected roundwood harvest of 1–3 m<sup>3</sup> of per ha and year). As we only had one plot of class “low”, we grouped “medium” and “low” together.

### 2.2. Field measurements

On all 24 plots, we marked 16 young spruce trees (under 2 m height)

**Table 1**

List of all fitted models, with their response and explanatory variables, the number of observations, degrees of freedom used and the resulting AICc. For each response variable, the best model (most parsimonious within  $\Delta AICc < 2$ ) is marked in bold. (Hartig, 2022)). “Year” was included as random effect in A, D, E & F. “Plantation” was included as random effect in C-F. The model marked in grey and with # could not be fitted as there was no occurrence of browsed top shoot outside the grazing area during summer.

Response variables	Explanatory variables	df	AICc	
Competing vegetation	A.Sward height	Grazing_area (inside/outside) + plant_group + productivity + grazing_area:plant_group + grazing_area:productivity	10 7	1639.7 <b>1641.2</b>
		<b>Grazing_area (inside/outside) + plant_group + productivity 1</b>	3	1650.3
	B.Density of young trees	Grazing_area (inside/outside) + tree_species + grazing_area + tree_species:grazing_area	13 8	954.9 <b>951.4</b>
Young spruce trees	C.Browsing on young trees	<b>Grazing_area (inside/outside) + season (spring/fall) + height_class + tree_species + grazing_area:season + height_class:season + tree_species:grazing_area + season:tee_species</b>	23	<b>2079.3</b> 2110.6
		Grazing_area (inside/outside) + season (spring/fall) + height_class + tree_species 1	11 2	3012.2
	D1.Browsed on the top shoot	Grazing_area (inside/outside) + season (spring/fall) + height + height:season + grazing_area:season #	6 3	<b>416.1</b> 455.1
Young spruce trees	D2.Browsed on a side shoot	<b>Grazing_area (inside/outside) + season (spring/fall) + height 1</b>	8 6 3	<b>708.8</b> <b>709.8</b> 830.1
		Grazing_area (inside/outside) + season (spring/fall) + height + height:season + grazing_area:season 1		
	D3.Being bent	<b>Grazing_area (inside/outside) + season (spring/fall) + height + height:season + grazing_area:season</b>	8 6 3	<b>1428.7</b> 1435.4
		Grazing_area (inside/outside) + season (spring/fall) + height 1		1635.3
	D4.Damaged stem bark	Grazing_area (inside/outside) + season (spring/fall) + height + height:season + grazing_area:season	8 6 3	498.9 <b>500.2</b>
		<b>Grazing_area (inside/outside) + season (spring/fall) + height 1</b>		514.1
	E.Death	Browsed_top + browsed_side + bent + stem_bark_damaged + height + browsed_top:height + browsed_side:height + bent:height + stem_bark_damaged:height	12 8	196.2 <b>195.0</b>
F.Annual height growth		<b>Browsed_top + browsed_side + bent + stem_bark_damaged + height 1</b>	3	260.9
		Grazing_area (inside/outside) + season (spring/fall) + height + height:season + grazing_area:season	8 6 3	247.1 <b>244.4</b>
		<b>Grazing_area (inside/outside) + season (spring/fall) + height 1</b>		260.9
		<b>Browsed_top + browsed_side + bent + stem_bark_damaged + height + productivity + density_competing_trees + sward_height + sward_height*height + competing_trees*height + browsed_top*height + browsed_side*height + bent*height + stem_bark_damaged*height</b>	18	<b>6696.0</b> 6751.7
		Browsed_top + browsed_side + bent + stem_bark_damaged + height + productivity + density_competing_trees + sward_height 1	12 4	7694.0
	<b>Height*bonitet + grazing_area*bonitet + grazing_area*height</b>	10 7	<b>6812.3</b> 6830.8	
	Height + bonitet + grazing_area 1	4	7671.5	

in spring 2021, selecting the tree standing closest to the  $4 \times 4$  meter grid intersection (Fig. 1B). We visited these trees before and after the grazing seasons 2021, 2022 and 2023. This resulted in 384 marked spruce trees, visited 6 times each. In addition, we marked a new spruce whenever i) a marked tree died ( $n = 26$ ), ii) a marked tree could not be found ( $n = 24$ ) and iii) a marked tree grew higher than 2 m ( $n = 13$ ). This resulted in 63 additional marked trees. On each visit, we recorded if the tree could be found (yes/no), if the tree was alive (yes/no), tree height (in cm), annual height growth (top shoot length, in cm), occurrence of browsed top shoot ( $n = 54$ ), occurrence of browsed side shoot ( $n = 121$ ), the tree being torn out of the ground ( $n = 3$ ), bent ( $n = 297$ ), broken ( $n = 21$ ) or visibly damaged on the stem bark ( $n = 64$ ), as illustrated in Fig. 2. The sign classes with less than 25 occurrences in total (“torn out of the ground” and “broken”) were excluded from further analyses.

On all 24 plots, we recorded browsing on young trees along 4 transect lines, placed at 4-meter intervals (Fig. 1B). We walked these 192 transects after the grazing season in 2021 and before the grazing season in 2022. At 0.5 m on each side of the line, we recorded all trees shorter than 2 m, their species identity, height class (0–0.5 m, 0.5–1 m, 1–1.5 m, 1.5–2 m) and whether they were browsed on current annual shoots or not. We defined browsing as missing shoot tip or leaf stripping. To avoid model convergence problems in the further analyses, species with less than 250 observations in total (*Populus tremula*, *Ribes spec.*, *Sambucus racemose* and *Pinus sylvestris*) were excluded from the analysis. Retained were *Betula pendula* ( $n = 280$ ), *Betula pubescens* ( $n = 548$ ), *Picea abies* ( $n = 1056$ ), *Salix spec.* ( $n = 385$ ) and *Sorbus aucuparia* ( $n = 450$ ). Tree density per species was derived per plot as the number of trees counted along all four transects. Tree density of competing species was derived as the sum of all tree densities of all species except for spruce.

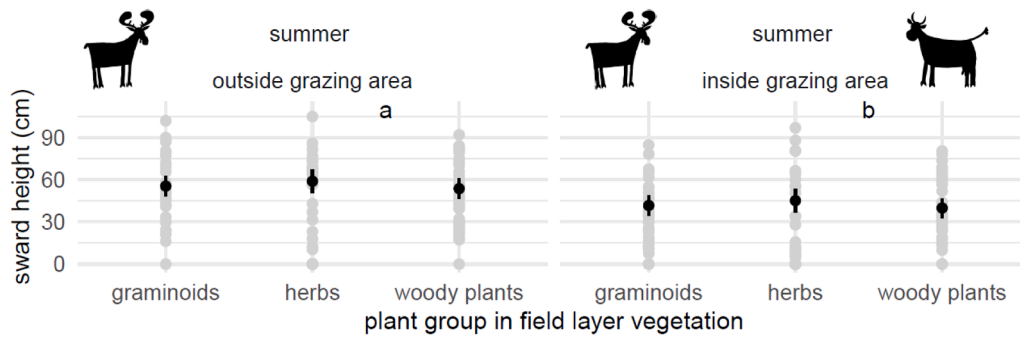
On all 24 plots, we registered the height of the field layer vegetation, called sward height, following a  $4 \times 4$ -meter grid (Fig. 1C), resulting in 16 measurements per plot. This was done in the middle of the grazing season in July 2021, 2022, and 2023. The field layer vegetation was divided into the three plant groups “graminoids”, “herbs” and “woody plants” and for each measurement of sward height, the most abundant

plant group on this spot was linked to the measurement. Sward height was averaged per plant group, plot, and year.

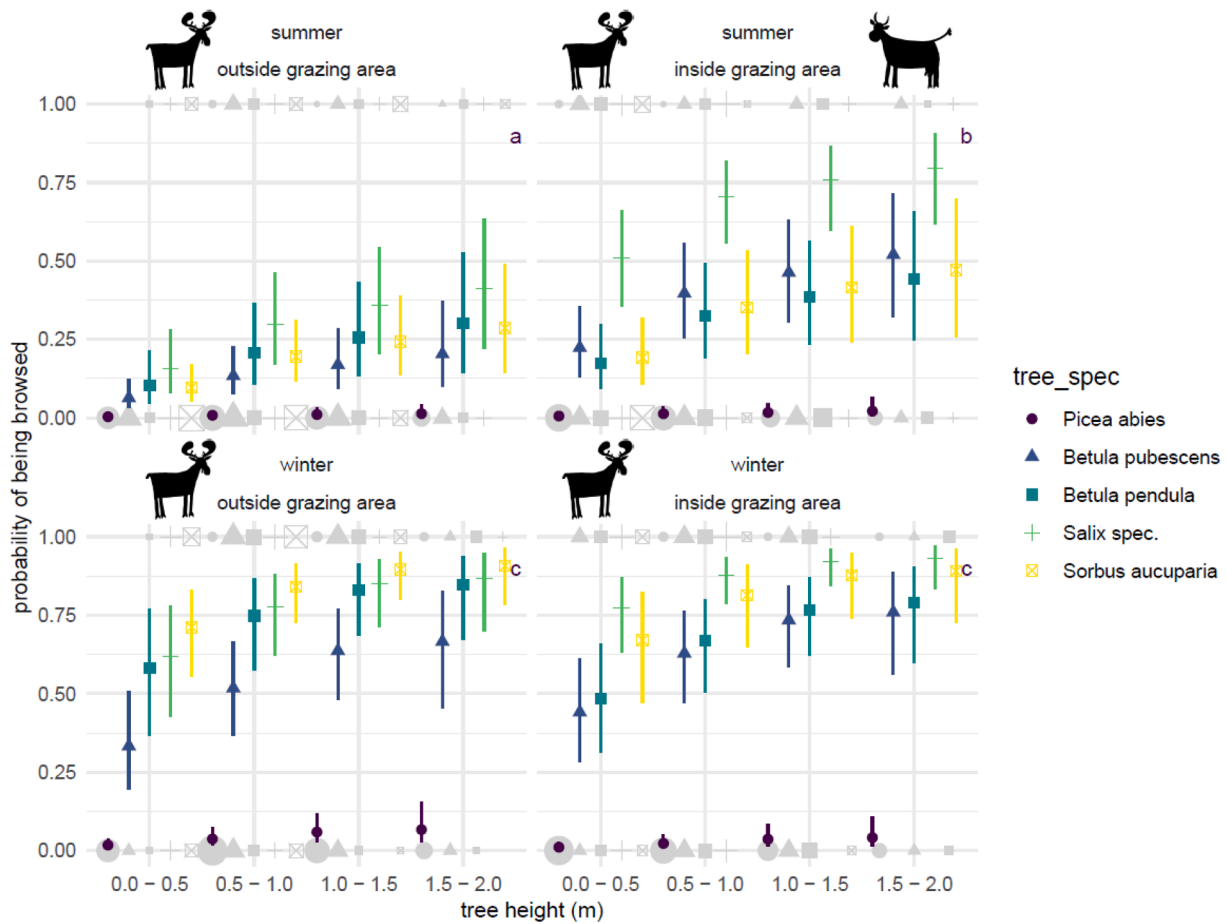
### 2.3. Data analyses

We modelled sward height, density of young trees, probability of browsing on young trees, as well as probability of browsing and trampling signs, mortality risk and annual height growth of young spruce in relation to grazing area and season. In addition, we modelled death risk and annual height growth of young spruce trees in relation to sward height, density of young trees, as well as browsing and trampling signs on the individual spruce tree. All analyses were done in R version 4.3.1 (R Core Team, 2022), R Studio (RStudio Team, 2022). We built generalized linear models GLMs and generalized linear mixed models GLMM (Bolker et al., 2009) using the package glmmTMB (Brooks et al., 2017). Where appropriate, we included year and plantation as random effects in the models. For units and sample sizes see Appendix 2 and for a list of all fitted models, see Table 1.

For each response variable we created i) a full model with all explanatory variables and their two-way interactions as far as they were ecologically plausible, ii) a model with all explanatory variables without interactions and iii) a null model. For each response variable, we compared the goodness of fit of these three models with the Akaike Information Criterion corrected for young sample sizes (AICc: Burnham & Anderson (2002)) using the “model.sel” function within the MuMIn library (Barton, 2022). Among the best models within delta AICc < 2, we picked the most parsimonious one. The best family and link-function for each response variable was determined based on the models’ diagnostic plots (DHARMA package, Hartig (2022)). For A and F, we used a Gaussian GLMM with an identity link function. For B, we used a negative binomial GLMM with a log link function. For C-E, we used a binomial GLMM with a logit link function. To avoid overfitting, we confirmed that we had at least 10 observations per degree of freedom used by the model. The DHARMA package (Hartig, 2022) was used to assess the goodness of fit and rule out overdispersion in the final model by



**Fig. 3.** Model predictions (mean and 95 % confidence intervals) for the best model of sward height in relation to cattle grazing area. The model included plant group and forest productivity as fixed effects and year as random effect. The data that the model is built on are displayed in grey. Significant contrasts between groups (here: inside versus outside grazing area) are marked with small letters. For groups with the same letter, the difference between the means is not significantly different from 0.



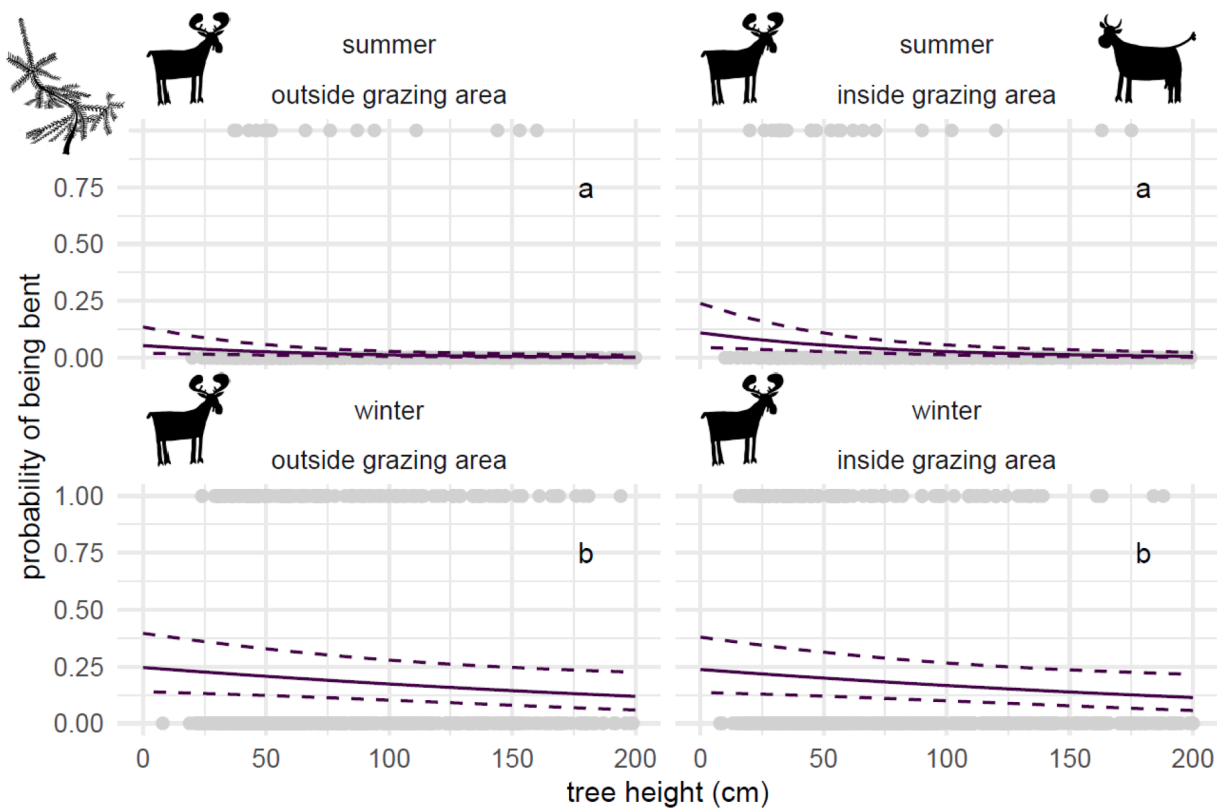
**Fig. 4.** Model predictions (mean and 95 % confidence intervals) for the best model of the probability of young trees being browsed in relation to grazing area (inside/outside) and season (summer/winter). The model included tree species and height class as fixed effects and plantation as random effect. The data that the model was built on are displayed in grey, with the symbol size representing sample size. Significant contrasts between groups (here: inside versus outside grazing area, and during versus off grazing season) are marked with small letters. For groups with the same letter, the ratio between the means is not significantly different from 1.

inspecting simulated quantile residuals against the predicted values. Model predictions were generated with the package *ggeffects* (Lüdtke, 2018) and plotted using *ggplot2* (Wickham, 2016). We estimated contrasts between factors using the package *modelbased* (Makowski et al., 2020).

### 3. Results

#### 3.1. Browsing on young trees other than spruce and reduction of sward height

Sward height was lower inside the cattle grazing area than outside, independent of plant group or forest productivity (Table 1, Appendix 5A, Fig. 3). Similarly, summer browsing was more probable inside than outside the grazing area for downy birch (*Betula pubescens*) ( $p = 0.043$ )



**Fig. 5.** Model predictions (mean and 95 % confidence intervals) for the best model of the probability of being bent for young spruce trees in relation to grazing area (inside/ outside) and season (summer/winter). The model included tree height as fixed effect and plantation and year as random effects. The data that the model was built on are displayed in grey. Significant contrasts between groups are marked with small letters. For groups (here: inside versus outside grazing area, and during versus off grazing season) with the same letter, the ratio between the means is not significantly different from 1.

and willows (*Salix spec.*) ( $p = 0.009$ ), but not for silver birch (*Betula pendula*) nor rowan (*Sorbus aucuparia*) (Table 1, Appendix 5B, Fig. 4). However, winter browsing was more probable than summer browsing for all competing tree species within the grazing area, i.e. silver birch ( $p < 0.001$ ), downy birch ( $p = 0.004$ ), willows ( $p = 0.002$ ) and rowan ( $p < 0.001$ ) (Table 1, Appendix 5B, Fig. 4). While the density of young trees differed between species, it did not differ between inside and outside the grazing area for any species (Table 1, Appendix 5C).

### 3.2. Probability of browsing and trampling signs of young spruce trees

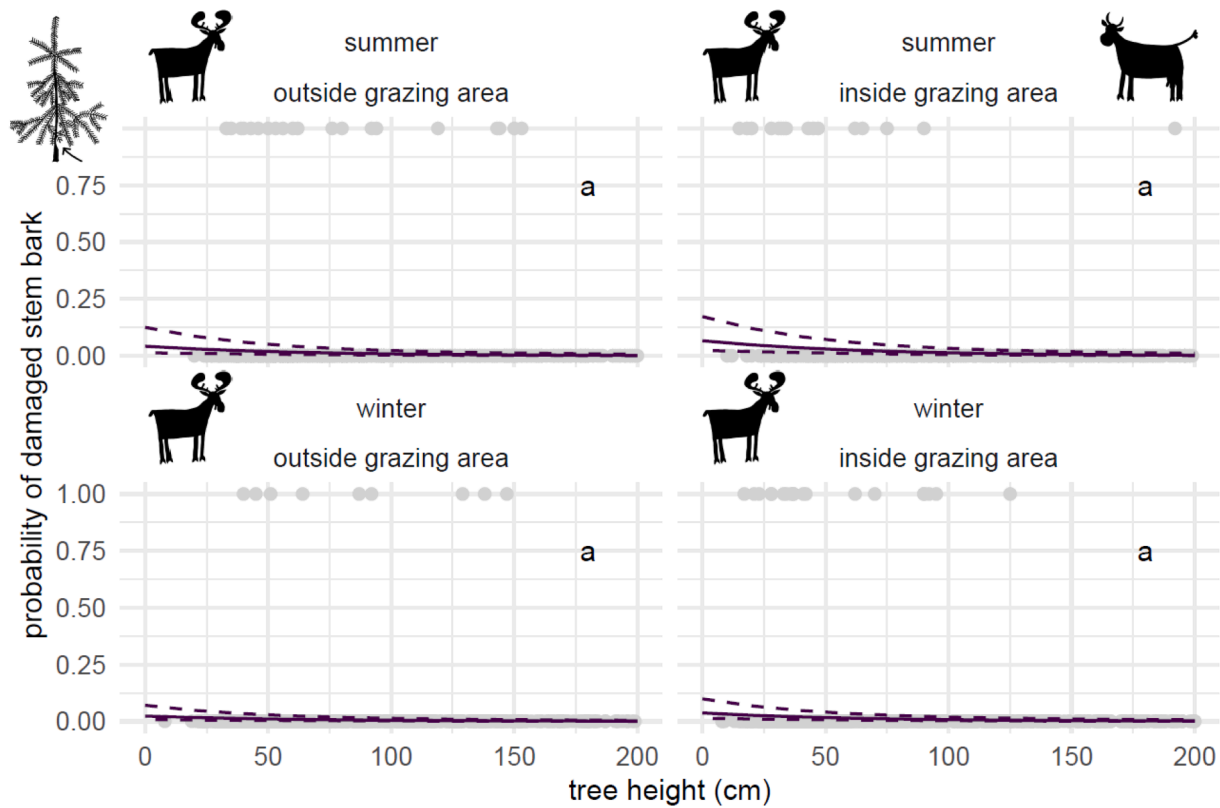
A total of 54 out of 2117 spruce trees (2.5 %) were browsed on the top shoot and 121 out of 2117 (5.7 %) were browsed on a side shoot, and the probabilities of these signs to occur did not differ between inside and outside the grazing area (Table 1, Appendix 5D-E, Appendix 3-4). Moreover, the probabilities of top and side shoot being browsed were significantly higher during winter than during summer (Table 1, Appendix 5D-E, Appendix 3-4). Due to low occurrence (3 out of 2117 trees, 0.1 %), the browsing sign “torn of the ground” was excluded from the analyses. Among trampling signs, being bent was most common. A total of 297 out of 2117 spruce trees (14 %) were bent and the probability of this sign did not differ between inside and outside the grazing area during summer ( $p = 0.291$ , Table 1, Appendix 5F, Fig. 5). The probability of being bent was higher after winter than after summer ( $p < 0.001$ , Table 1, Appendix 5F, Fig. 5). A total of 64 out of 2117 spruce trees (3 %) had damaged stem bark and the probability of this sign did not differ between inside and outside the grazing area during summer (Table 1, Appendix 5G, Fig. 6) and was more probable during summer than during winter (Table 1, Appendix 5G, Fig. 6). Due to low occurrence (21 out of 2117 trees, 1 %) the browsing sign “broken” was excluded from the analyses.

### 3.3. Mortality risk of young spruce trees

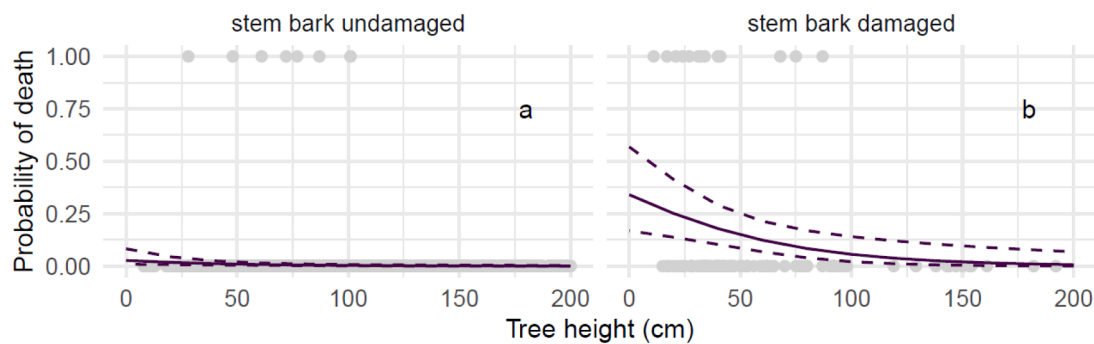
A total of 26 out of 2117 spruce trees (0.01 %) died. The best model linking spruce mortality risk to the condition of a spruce tree showed that the probability of death was higher for spruce with damaged stem bark (Table 1, Appendix 5H, Fig. 7). However, none of the other signs (i.e. browsed on the top shoot, browsed on a side shoot, bent) was correlated with mortality risk (Table 1, Appendix 5H). The probability of death decreased with spruce height (Table 1, Appendix 5H, Fig. 7). The best model linking spruce mortality risk to cattle grazing directly showed that spruce inside the grazing area were at higher mortality risk than those outside the cattle grazing area, both during summer and winter (Table 1, Appendix 5I, Fig. 8). Again, the probability of death decreased with spruce height (Table 1, Appendix 5I, Fig. 8).

### 3.4. Annual height growth of young spruce trees

The best model linking annual height growth to a given spruce's condition and its surrounding vegetation showed that the annual height growth of young spruce trees was correlated with an interaction between spruce height with the density of competing trees, an interaction between spruce height with sward height and an interaction between spruce height with the spruce being bent (Table 1, Appendix 5J, Fig. 9). Annual height growth was negatively correlated with the density of competing trees, and the strength of this correlation increased with spruce height (Appendix 5J, Fig. 9). In other words, the annual height growth was negatively correlated with the density of competing trees for taller, and less for smaller spruce trees. Annual height growth was positively correlated with the sward height, and the strength of this correlation increased with spruce height (Appendix 5J, Fig. 9). In other words, annual height growth was positively correlated with the sward



**Fig. 6.** Model predictions (mean and 95 % confidence intervals) for the best model of the probability of damaged stem bark on young spruce trees in relation to grazing area (inside/ outside) and season (summer/winter). The model included tree height as fixed effect and plantation and year as random effects. The data that the model was built on are displayed in grey. Significant contrasts between groups (here: inside versus outside grazing area, and during versus off grazing season) are marked with small letters. For groups with the same letter, the ratio between the means is not significantly different from 1.



**Fig. 7.** Model predictions (mean and 95 % confidence intervals) for the best model of the probability of spruce mortality in relation to browsing and trampling signs during the past year. The model included tree height as fixed effect and plantation and year as random effects. The data that the model was built on are displayed in grey. Significant contrasts between groups (here: damaged versus undamaged) are marked with small letters. For groups with the same letter, the ratio between the means is not significantly different from 1.

height of taller, but less for smaller spruce trees. Furthermore, annual height growth was negatively correlated with the spruce tree being bent, and the strength of this correlation increased with spruce height (Appendix 5J, Fig. 9). In other words, annual height growth was negatively correlated with the spruce trees being bent for taller, but less for smaller spruce trees. The best model linking annual height growth to cattle grazing directly showed no difference between inside and outside the grazing area (Table 1, Appendix 5K).

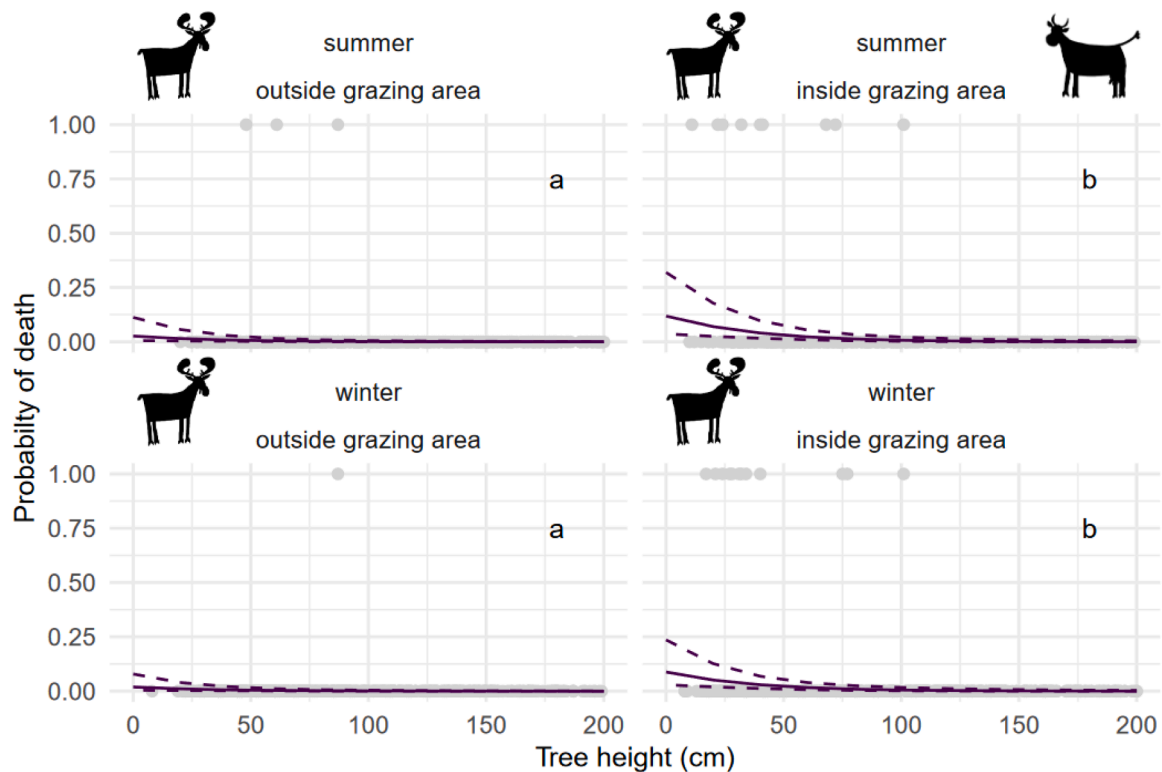
#### 4. Discussion

The aim of this study was to examine whether the positive or the negative effects of cattle on young spruce trees predominated in a

silvopastoral system in boreal production forest in Norway. We will first discuss our finding on positive effects, thereafter those on negative effects, and bring them together at the end.

##### 4.1. Positive effects of cattle on young spruce trees

We expected cattle grazing to have a positive effect on the annual height growth of young spruce trees by removing competing vegetation, such as graminoids, herbs and woody plants. Indeed, cattle reduced the height of the field layer vegetation and browsed on deciduous trees, namely willows and downy birch. These findings are in accordance with cattle diet in boreal production forest studied in an area located about 30 km further south (Spedener et al., 2024). Moreover, we found that the



**Fig. 8.** Model predictions (mean and 95 % confidence intervals) for the best model of the probability of spruce mortality relation to grazing area (inside/ outside) and season (summer/winter). The model included tree height as fixed effect and plantation and year as random effects. The data that the model was built on are displayed in grey. Significant contrasts between groups (here: inside versus outside grazing area, and during versus off grazing season) are marked with small letters. For groups with the same letter, the ratio between the means is not significantly different from 1.

density of competing trees was negatively correlated with annual height growth for taller, but not for smaller spruce trees. This indicates that from a certain height onward, spruce trees may be negatively affected by competing trees. The sward height of the field layer vegetation was positively correlated with annual height growth for taller, but not for smaller spruce. We can think of two explanations for this. First, the environmental conditions favourable for spruce trees might also be favourable for the field layer vegetation. We tried to account for this by including forest productivity in our models. However, this variable might not be the best one to explain good growing conditions for field layer vegetation and young spruce trees, as it was estimated from the incremental growth of older trees. Second, the observed positive correlation between sward height and annual spruce growth only occurred for trees that had grown above the sward height. This means that small spruce trees surrounded by field layer vegetation higher than themselves grew at a similar rate as those of the same height but at low sward height – even though we would expect them to grow faster, due to the better soil quality leading to a higher sward. We interpret these findings as competition between small spruce trees and the surrounding field layer vegetation.

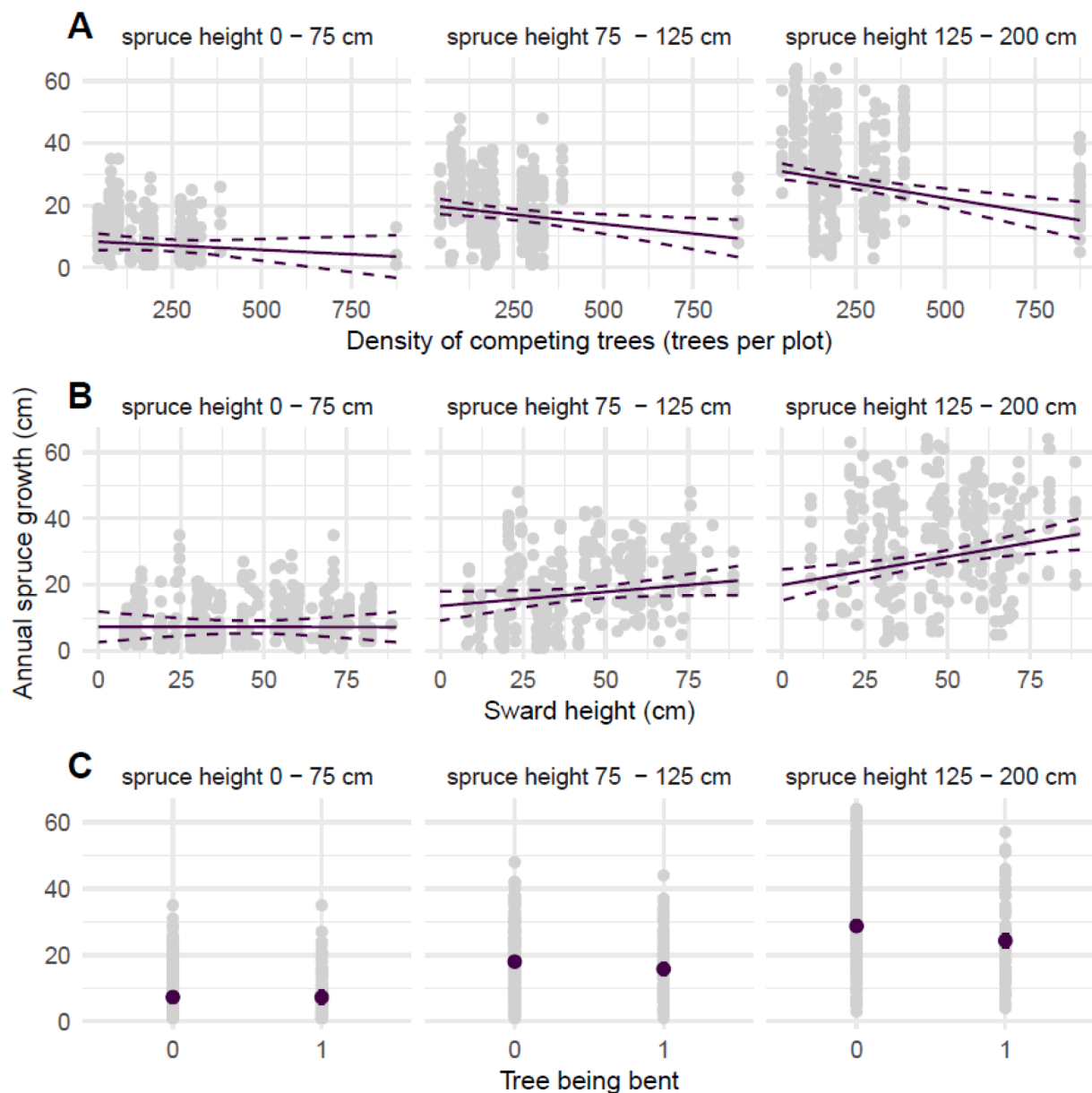
We should note the following points when interpreting the positive effects of cattle grazing shown in this study: Even though cattle browsed on competing trees, we did not see differences in the density of competing trees between inside and outside the grazing area. One could argue that our study period might have been too short to detect changes in tree densities, but cattle used to graze in this area before we carried out this study. Furthermore, all deciduous trees were browsed significantly more during winter than during summer. This indicates a much stronger weeding effect by cervids, which are mainly browsers (Austrheim et al., 2011; Bergquist et al., 2003; Wam and Hjeljord, 2010; Zweifel-Schielly et al., 2012), than by cattle, which are typical grazers (Spedener et al., 2024). In contrast, Bjor & Graffer (1963) found a strong

effect of cattle grazing on the density of deciduous trees in their extensive study of cattle forest grazing in Norway. They established exclosures and compared the density of deciduous trees inside and outside the exclosures after a couple of years. This could be due to higher cattle densities in their study areas, or to the fact that they not only excluded cattle, but also other large herbivores, such as cervids from their plots, and that they excluded those during both summer and winter. Even though cervid densities were very low in the 1960s, when that study was carried out, we wonder if the difference they found could be due to cervid browsing, especially during winter, which our study shows to be more important than cattle browsing during summer. In summary, we found that cattle reduced vegetation competing with spruce: They browsed on competing trees, and they reduced sward height. In addition, we found that the density of competing trees reduced annual spruce growth and our findings suggest that sward height reduces annual spruce growth of trees below sward height. These results indirectly suggest that cattle may have a positive effect on growth of small spruce trees. However, we did not find any differences in annual height growth between spruce inside and outside the grazing area. The possible positive effect of cattle on spruce growth might have been too weak to be picked up at these cattle stocking rates.

#### 4.2. Negative effects of cattle on young spruce trees

While we had not expected cattle to browse on spruce trees, we expected cattle to negatively affect young spruce trees through trampling, increasing risk of trampling signs, and thereby increasing mortality risk and reducing annual height growth. Indeed, there was no difference in browsing signs during the grazing season between inside and outside the grazing area. In contrast to our expectations, we did not find differences between inside and outside the grazing area for trampling signs neither. This implies that cattle grazing in this study did not lead to an increased





**Fig. 9.** Model predictions (mean and 95 % confidence intervals) for the best model of annual spruce growth in relation to density of competing trees, sward height and browsing and trampling signs during the past year. The model included tree height and forest productivity as fixed effects and plantation and year as random effects. The data that the model is built on are displayed in grey. A shows annual spruce growth in relation to density of competing trees and spruce height. B shows annual spruce growth in relation to sward height and spruce height. C shows annual spruce growth in relation to the spruce being bent (0 = not bent, 1 = bent) and spruce height.

risk of any type of browsing or trampling signs. Interestingly, the signs “browsed on the top shoot”, “browsed on a side shoot” and “bent” were more probable during winter than during summer, indicating that wildlife winter behaviour and snow had a stronger effect on young spruce trees than wildlife and cattle during summer. Investigating the link between browsing and trampling signs and spruce mortality risk and annual height growth, we found that most of the browsing and trampling signs affected neither mortality risk nor annual height growth. We should note that only 26 out of 2117 spruce trees (0.01 %) died. This small number of occurrences might weaken our models, but at the same time, it is a finding in itself: the overall mortality risk was very low in our study. The probability of death was increased only by the trampling sign “damaged stem bark” and the annual height growth was only reduced by the trampling damage “bent”. Butt rot is a main defect in Norway spruce trees and causes large economic losses for forest owners (Noordermeer

et al., 2023). Even though we did not find evidence for this in our study, cattle grazing might damage the bark of stem and roots. Thereby, cattle grazing might increase the risk of fungi infection (f.ex. *Heterobasidion parviporum*) and wood decay. In addition, as shown in this study, young spruce trees with damaged stem bark are at higher death risk. A long-term study would be needed to follow up spruce trees with stem bark damages caused by cattle to investigate the risk of fungi infection and wood decay.

This study shows that spruce with trampling signs have a reduced annual height growth and increased death risk, but that cattle did not increase the risk of such trampling risks, indicating that cattle would not have a negative effect on annual height growth and death risk of small spruce trees. However, we found higher spruce death risk inside than outside the cattle grazing area, both during summer and winter. It could be by coincidence that cattle inside the cattle grazing area experiences

higher death risks, caused by local pest outbreaks, local drought or small-scale differences in snow conditions. Or indeed, cattle grazing caused these higher death risks, either directly or indirectly. Our results suggest that direct cattle effects, such as browsing and trampling, can be excluded as mechanism. Alternative mechanisms could be changes in soil structure and composition or altered site use by spruce affecting wildlife. Again, we must keep in mind the small number of occurrences of spruce death, which might weaken our models. An earlier study in the same silvopastoral system in an area close by found a much higher proportion of damaged trees inside than outside the grazing area (Hjeljord et al., 2014). The most plausible explanation is the difference in cattle stocking rates. Rekdal et al. (2018) estimated the grazing capacity of the study area in Hjeljord et al. (2014) to be about the same as in our study area, but instead of 0.01 cattle per ha, the stocking density in Ringsaker was 0.08 cattle per ha, in addition to 0.6 sheep per ha. As cattle are known to select for spruce plantations due to higher forage availability, we can assume the cattle densities in the spruce plantations in our study to be above 0.01, but we consider them still considerably lower than in Hjeljord et al. (2014). Higher stocking rates could also be the reason for the higher mortality and damage risks documented by Bjor & Graffer (1963) all over Norway. However, their study also included areas where drought was the main mortality factor for spruce saplings, not cattle. Interestingly, they found that cattle caused more trampling than browsing damages, which is in accordance with our expectations.

## 5. Conclusion

The aim of this study was to investigate whether negative or positive effects of cattle on young spruce trees predominated in a silvopastoral system in boreal production forest in Norway. In conclusion, cattle neither had a clear positive nor clear negative effect. Even though we found no difference in spruce growth between inside and outside the cattle grazing area, cattle may possibly have a minor positive effect, as they reduced competing vegetation, and as competing vegetation had a negative effect on annual spruce growth. On the other hand, we found a higher spruce mortality risk inside than outside the cattle grazing area. This mortality risk was very low and positively correlated with the given spruce tree's bark being damaged, a damage type that was not increased by cattle grazing. This study did not succeed in pointing out the mechanism by which cattle might increase spruce mortality risk. Hester et al. (2000) pointed out the existence of herbivore density thresholds below which tree regeneration is not negatively affected. We might be facing cattle densities close to such a threshold in this study, as other studies in the same silvopastoral system, but with higher cattle densities, have reported high proportions of damages on and risks of death for small

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.tfp.2024.100596](https://doi.org/10.1016/j.tfp.2024.100596).

## Appendix

[Appendix 1](#), [Appendix 2](#), [Appendix 3](#), [Appendix 4](#), [Appendix 5](#)

### Appendix 1

Cow numbers and cow densities (per ha) released for summer grazing in the areas Deset and Steinvik during the years of this study. Most cows had a calf with them.

	2021		2022		2023	
	Cows	Cows per ha	Cows	Cows per ha	Cows	Cows per ha
Deset	21	0.006	23	0.007	34	0.01
Steinvik	47	0.013	60	0.017	60	0.017

spruce trees. This study suggests that at low stocking rates, forestry and livestock production in boreal production systems are compatible.

## Ethical statement

All applicable institutional and national guidelines for the care and use of animals were followed.

## CRediT authorship contribution statement

**Mélanie Spedener:** Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Karen Marie Mathisen:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Conceptualization. **Josh Hauer:** Writing – review & editing, Methodology, Investigation. **Rémi Héroult:** Investigation, Formal analysis. **Gunnar Austrheim:** Writing – review & editing, Validation, Supervision, Methodology. **Morten Tofastrand:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Conceptualization. **Barbara Zimmermann:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

## 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.

## Data availability

Data and R-script are available at Mendeley Data, doi: [10.17632/8hb9d9cdxs.1](https://doi.org/10.17632/8hb9d9cdxs.1) (Spedener et al., 2024).

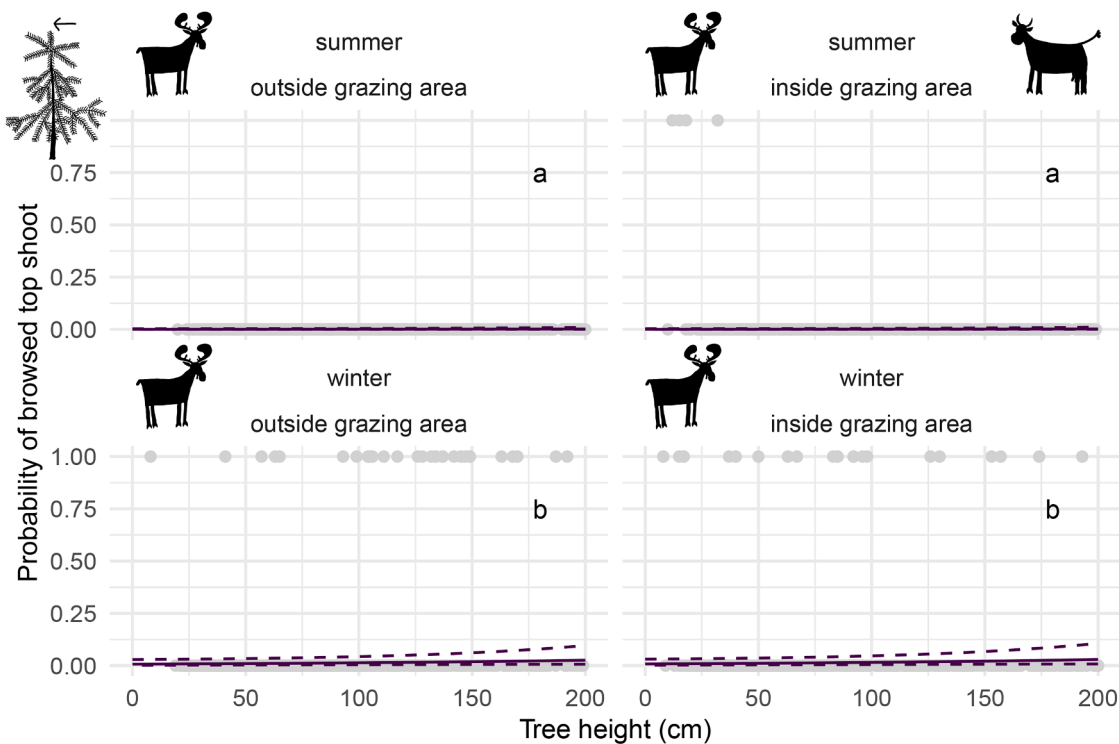
## Acknowledgements

We would like to thank the cattle and forest owners for their goodwill and cooperation in the implementation of this study, May Britt Trydal, Sari Dötterer, Amund Bratlien, Lisa Smit, Juliette Helbert, Saskia Wulff, Giulia Cenzi, Mathijs Megens, Alexandre Goudier, Ines Drozg and Victor Dalmagne for carrying out fieldwork, Olivier Devineau for statistical advice and 2 anonymous reviewers for their thorough and constructive comments on the manuscript. This study is part of the CarniForeGraze project which is funded by the Norwegian Research Council (project number 302674).

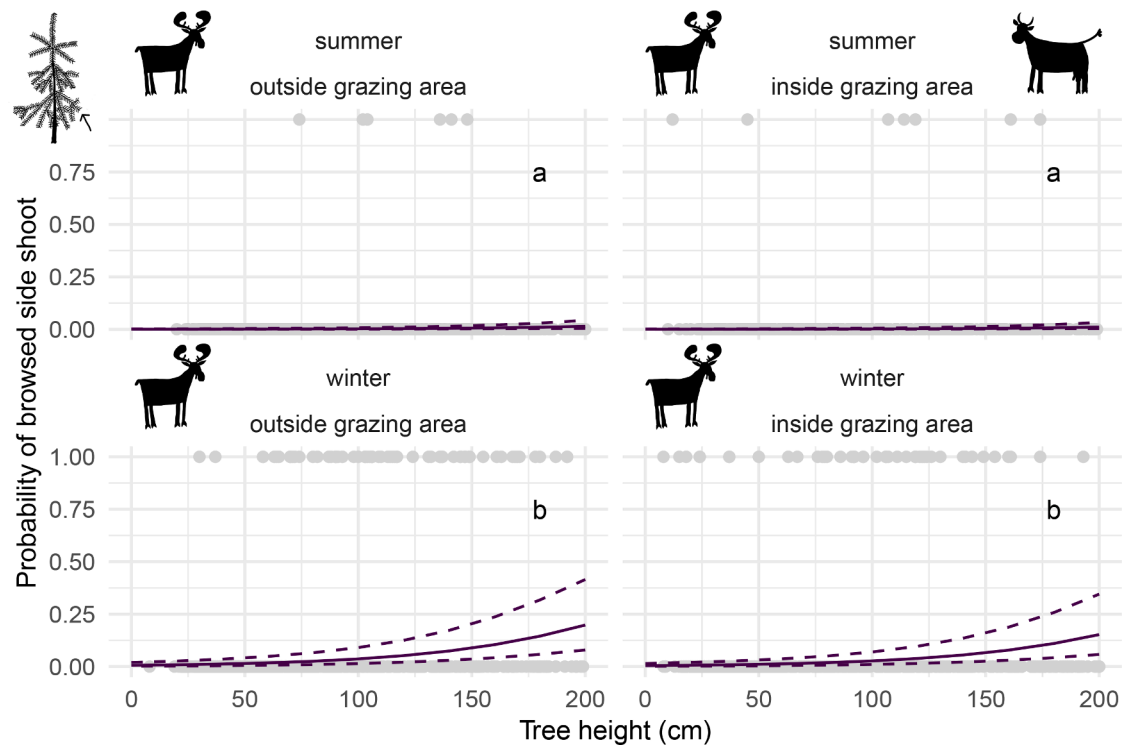
**Appendix 2**

Overview of the response variables and their sample sizes and sampling units.

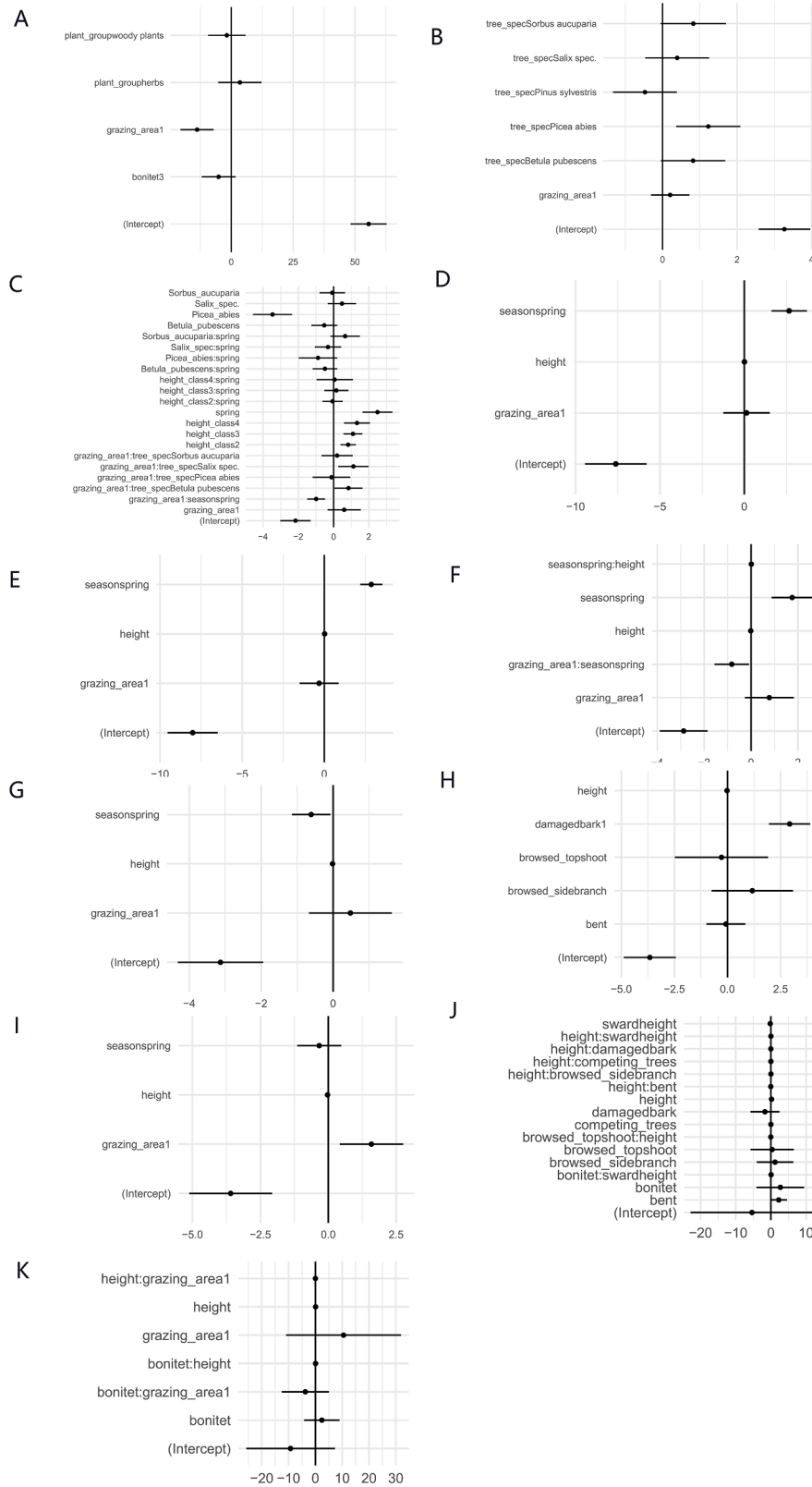
Response variables	Sample size	Unit	
<b>Competing vegetation</b>	Browsing on young trees Density of young trees Sward height	$\pm 63 \text{ trees} * 24 \text{ plots} * 1 \text{ year} * 2 \text{ rounds/year} = 2950$ $24 \text{ plots} * 6 \text{ tree species} * 1 \text{ year} * 1 \text{ rounds/year} = 144$ $24 \text{ plots} * 3 \text{ plant groups} * 3 \text{ years} * 1 \text{ round/year} = 216$	Yes/no Number of trees per species per plot cm
<b>Young spruce trees</b>	Browsed top shoot Browsed side shoot Being bent Damaged stem bark Death Annual growth	$\pm 16 \text{ trees} * 24 \text{ plots} * 3 \text{ years} * 2 \text{ rounds/year} = 2117$ $\pm 16 \text{ trees} * 24 \text{ plots} * 3 \text{ years} * 2 \text{ rounds/year} = 2117$ $\pm 16 \text{ trees} * 24 \text{ plots} * 3 \text{ years} * 2 \text{ rounds/year} = 2117$ $\pm 16 \text{ trees} * 24 \text{ plots} * 3 \text{ years} * 2 \text{ rounds/year} = 2117$ $\pm 16 \text{ trees} * 24 \text{ plots} * 3 \text{ years} * 2 \text{ rounds/year} = 2117$ $\pm 16 \text{ trees} * 24 \text{ plots} * 3 \text{ years} * 1 \text{ rounds/year} = 1152$	Yes/no Yes/no Yes/no Yes/no Yes/no cm



**Appendix 3.** Model predictions for the best model for probability of browsed top shoot on young spruce trees in relation to grazing area (inside/ outside) and season (summer/winter). The model included tree height as fixed effect and plantation and year as random effects. The data that the model was built on are displayed in grey. Significant contrasts between groups (here: inside versus outside grazing area, and during versus off grazing season) are marked with small letters. For groups with the same letter, the ratio between the means is not significantly different from 1.



Model predictions for the best model of the probability of browsed side shoot(s) on young spruce trees in relation to grazing area (inside/ outside) and season (summer/winter). The model included tree height as fixed effect and plantation and year as random effects. The data that the model was built on are displayed in grey. Significant contrasts between groups (here: inside versus outside grazing area, and during versus off grazing season) are marked with small letters. *For groups with the same letter, the ratio between the means is not significantly different from 1.*



**Appendix 5.** Model estimates (coefficient estimates and 95 % confidence intervals) for the best models modelling A) sward height, B) density of competing trees, C) browsing on young trees, D) the probability of young spruce trees being browsed on the top shoot, E) the probability of young spruce trees being browsed on a side shoot, F) the probability of young spruce trees being bent, G) the probability of young spruce trees being damaged on the stem bark, H) & I) the probability of death for young spruce trees and J) & K) the annual height growth of young spruce trees. For A and I, we used a Gaussian GLMM with an identity link function. For B, we used a negative binomial GLMM with a log link function, which means that its estimates are on log scale. For C–H, we used a binomial GLMM with a logit link function, which means that their estimates are on logit scale.

## References

- Aasetre, J.R., Bele, B., 2009. History of forestry in a central Norwegian boreal forest landscape: examples from Nordli, Nord-Trøndelag. *Norsk Geografisk Tidsskrift-Nor. J. Geogr.* 63 (4), 233–245.
- Adams, S.N., 1975. Sheep and cattle grazing in forests: a review. *J. Appl. Ecol.* 143–152.
- Austrheim, G., Solberg, E.J., Mysterud, A., 2011. Spatio-temporal variation in large herbivore pressure in Norway during 1949–1999: has decreased grazing by livestock been countered by increased browsing by cervids? *Wildl. Biol.* 17 (3), 286–298.
- Barton, K., 2022. MuMIn: Multi-Model Inference (1.46.0) [Programvare]. <https://CRAN.R-project.org/package=MuMIn>.
- Belsky, A.J., Blumenthal, D.M., 1997. Effects of livestock grazing on stand dynamics and soils in upland forests of the interior west. *Conserv. Biol.* 11 (2), 315–327. <https://doi.org/10.1046/j.1523-1739.1997.95405.x>.
- Bergquist, J., Bergström, R., Zakharenka, A., 2003. Responses of young Norway Spruce (*Picea abies*) to winter browsing by Roe Deer (*Capreolus capreolus*): effects on height growth and stem morphology. *Scand. J. For. Res.* 18 (4), 368–376. <https://doi.org/10.1080/0282758031005431>.
- Bjør, K., Graffer, H., 1963. Beiteundersøkelser På skogsmark: Investigation on Grazing in Woodland. Mariendals Boktrykkeri.
- Bolker, B.M., Brooks, M.E., Clark, C.J., Geange, S.W., Poulsen, J.R., Stevens, M.H.H., White, J.-S.S., 2009. Generalized linear mixed models: a practical guide for ecology and evolution. *Trends Ecol. Evol. (Amst.)* 24 (3), 127–135.
- Brooks, M.E., Kristensen, K., van Benthem, K.J., Magnusson, A., Berg, C.W., Nielsen, A., Skaug, H.J., Maechler, M., Bolker, B.M., 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *R. J.* 9 (2), 378–400. <https://doi.org/10.32614/RJ-2017-066>.
- Burnham, K.P., Anderson, D.R., 2002. Avoiding pitfalls when using information-theoretic methods. *J. Wildl. Manage.* 66 (3), 912–918. <https://doi.org/10.2307/3803155>.
- Clauss, M., Kaiser, T., Hummel, J., 2008. The Morphophysiological Adaptations of Browsing and Grazing mammals. I *The Ecology of Browsing and Grazing*. Springer, pp. 47–88 s.
- De Vriendt, L., Thiffault, N., Royo, A.A., Barrette, M., Tremblay, J.-P., 2020. Moose browsing tends spruce plantations more efficiently than a single mechanical release. *Forests* 11 (11), 11. <https://doi.org/10.3390/f11111138>. Artikkell.
- Doescher, P.S., Tesch, S.D., Alejandro-Castro, M., 1987. Livestock grazing: a silvicultural tool for plantation establishment. *J. For.* 85 (10), 29–37. <https://doi.org/10.1093/jof/85.10.29>.
- Eissenstat, D.M., Mitchell, W.W., 1982. Trampling damage by cattle on Northern Idaho forest plantations. *Rangel. Ecol. Manag./J. Range Manag. Arch.* 35 (6), 715–716.
- Fremstad, E., 1997. *Vegetasjonstyper i Norge*. NINA•NIKU Stiftelsen for Naturforskning Og Kulturminneforskning. <http://hdl.handle.net/11250/2837231>.
- Hancock, M.H., Summers, R.W., Amphlett, A., Willi, J., Servant, G., Hamilton, A., 2010. Using cattle for conservation objectives in a Scots pine *Pinus sylvestris* forest: results of two trials. *Eur. J. For. Res.* 129 (3), 299–312.
- Hartig, F., 2022. DHARMA: Residual Diagnostics For Hierarchical (Multi-Level /Mixed) Regression Models (version 0.4.5) [Programvare]. <https://CRAN.R-project.org/package=DHARMA>.
- Hester, A.J., Edenius, L., Buttenschön, R.M., Kuiters, A.T., 2000. Interactions between forests and herbivores: the role of controlled grazing experiments. *Forestry* 73 (4), 381–391.
- Hjeljord, O., Histøl, T., Wam, H.K., 2014. Forest pasturing of livestock in Norway: effects on spruce regeneration. *J. For. Res. (Harbin)* 25 (4), 941–945.
- Hylen, G., Fernández, C.A., Granhus, A., 2022. Skogressurser i Norge: Status og Framtidsscenarier. NIBIO. <https://nibio.brage.unit.no/nibio-xmlui/handle/11250/2996908>.
- Janis, C., 2008. An Evolutionary History of Browsing and Grazing ungulates. I *The Ecology of Browsing and Grazing* (s. 21–45). Springer.
- Jensen, W.F., Rea, R.V., Penner, C.E., Smith, J.R., Bragina, E.V., Razenkova, E., Balciauskas, L., Bao, H., Bystiansky, S., Csányi, S., Chovanova, Z., Done, G., Hackländer, K., Heurich, M., Jiang, G., Kazarez, A., Pusenius, J., Solberg, E.J., Veeroja, R., Widemo, F., 2020. A review of circumpolar moose populations with emphasis on Eurasian moose distributions and densities. *Alces* 56, 63–78.
- Kolstad, A.L., Austrheim, G., Solberg, E.J., De Vriendt, L., Speed, J.D., 2018. Pervasive moose browsing in boreal forests alters successional trajectories by severely suppressing keystone species. *Ecosphere* 9 (10), e02458.
- Kuuluvainen, T., Tahvonen, O., Aakala, T., 2012. Even-aged and uneven-aged forest management in boreal Fennoscandia: a review. *Ambio* 41 (7), 720–737.
- Lüdecke, D., 2018. ggeffects: tidy data frames of marginal effects from regression models. *J. Open. Source Softw.* 3, 772. <https://doi.org/10.21105/joss.00772>.
- Makowski, D., Ben-Shachar, M.S., Patil, I., Lüdecke, D., 2020. Estimation of Model-Based Predictions, Contrasts and Means. CRAN. <https://github.com/easystats/modelbased>.
- Mysterud, A., 2000. Diet overlap among ruminants in Fennoscandia. *Oecologia* 124 (1), 130–137.
- NIBIO, 2023. Kilden—Arealinformasjon. [https://kilden.nibio.no/?topic=arealinformasjon&x=6790064.33&y=308057.54&zoom=5.4&bgLayer=graatone&layers=ar50\\_skogbonitet&layers.opacity=0.75&layers.visibility=true](https://kilden.nibio.no/?topic=arealinformasjon&x=6790064.33&y=308057.54&zoom=5.4&bgLayer=graatone&layers=ar50_skogbonitet&layers.opacity=0.75&layers.visibility=true).
- Nofence (2022). Available at: <https://www.nofence.no/en/what-is-nofence> (Accessed June 4, 2024).
- Noordermeer, L., Korpunen, H., Berg, S., Gobakken, T., Astrup, R., 2023. Economic losses caused by butt rot in Norway spruce trees in Norway. *Scand. J. For. Res.* 38 (7–8), 497–505. <https://doi.org/10.1080/02827581.2023.2273252>.
- Popay, I., Field, R., 1996. Grazing animals as weed control agents. *Weed Technol.* 217–231.
- R Core Team, 2022. R: A Language and Environment for Statistical Computing [Programvare]. R Foundation for Statistical Computing. <https://www.R-project.org/>.
- Rekdal, Y., 2006. Storfbeite i Utmark For Eiendommene Løset, Deset og Rød. \AAmot kommune. Oppdragsrapport fra Skog og Landskap.
- Rekdal, Y., Angeloff, M., Haugen, F.-A., 2018. Kjøttfe På utmarksbeite. I 94. NIBIO. <https://nibio.brage.unit.no/nibio-xmlui/handle/11250/2579819>.
- RStudio Team, 2022. RStudio: Integrated Development Environment for R [Programvare]. RStudio, PBC. <http://www.rstudio.com/>.
- Sjögren, K.G., Austrheim, G., Stene, K., Hjelle Loe, K., Rosvold, J., Tretvik, A.M., 2015. Fjelllets kulturlandskapshistorie. I *Fjelllets kulturlandskap: Arealbruk og Landskap Gjennom Flere Tusen år* (s. 159–179). [https://www.ntnu.no/documents/10476/1264108740/Fjelllets%C2%B1kulturlandskap\\_5korr.pdf/d03c841e-9b8a-4529-9d87-4506978b0cfd](https://www.ntnu.no/documents/10476/1264108740/Fjelllets%C2%B1kulturlandskap_5korr.pdf/d03c841e-9b8a-4529-9d87-4506978b0cfd).
- Spedener, M., Tofastrud, M., Austrheim, G., Zimmermann, B., 2024a. A grazer in a browser's habitat: resource selection of foraging cattle in productive boreal forest. *Rangel. Ecol. Manage.* 93, 15–23. <https://doi.org/10.1016/j.rama.2023.12.004>.
- Spedener, M., Mathisen, K.M., Tofastrud, M., Austrheim, G., Zimmermann, B., 2024b. Data and code used to study the effects of summer grazing cattle in boreal production forest on young spruce. Mendeley Data V1. <https://doi.org/10.17632/8hb9d9cdxs.1>.
- Speed, J.D.M., Austrheim, G., Kolstad, A.L., Solberg, E.J., 2019. Long-term changes in northern large-herbivore communities reveal differential rewinding rates in space and time. *PLoS ONE* 14 (5), e0217166. <https://doi.org/10.1371/journal.pone.0217166>.
- SSB, 2023a. 06286: Productive Forest area, By Development Class 1957-1964 - 2018-2022. Statbank Norway. SSB. <https://www.ssb.no/en/statbank/table/06286/tableViewLayout1/>.
- SSB, 2023b. 12660: Livestock Grazing On Outfield Pastures (M) 1995 - 2022. Statbank Norway. SSB. <https://www.ssb.no/en/statbank/table/12660>.
- SSB, 2023c. Arealbruk Og Arealressurser. SSB. <https://www.ssb.no/natur-og-miljo/areal/statistikk/arealbruk-og-arealressurser>.
- SSB, 2024. Commercial Roundwood Removals. SSB. <https://www.ssb.no/en/jord-skog-jakt-og-fiskeri/skogbruk/statistikk/skogavirkning-for-salg>.
- Tofastrud, M., Devineau, O., Zimmermann, B., 2019. Habitat selection of free-ranging cattle in productive coniferous forests of south-eastern Norway. *For. Ecol. Manage.* 437, 1–9. <https://doi.org/10.1016/j.foreco.2019.01.014>.
- Tofastrud, M., Hesse, A., Rekdal, Y., Zimmermann, B., 2020. Weight gain of free-ranging beef cattle grazing in the boreal forest of south-eastern Norway. *Livest. Sci.* 233, 103955. <https://doi.org/10.1016/j.livsci.2020.103955>.
- Tohiran, K.A., Nobilly, F., Zulkifli, R., Ashton-Butt, A., Azhar, B., 2019. Cattle-grazing in oil palm plantations sustainably controls understory vegetation. *Agric. Ecosyst. Environ.* 278, 54–60. <https://doi.org/10.1016/j.agee.2019.03.021>.
- Varga, A., Demeter, L., Ulicsni, V., Öllerer, K., Biró, M., Babai, D., Molnár, Z., 2020. Prohibited, but still present: local and traditional knowledge about the practice and impact of forest grazing by domestic livestock in Hungary. *J. Ethnobiol. Ethnomed.* 16 (1), 51. <https://doi.org/10.1186/s13002-020-00397-x>.
- Wam, H.K., Hjeljord, O., 2010. Moose summer and winter diets along a large scale gradient of forage availability in southern Norway. *Eur. J. Wildl. Res.* 56 (5), 745–755. <https://doi.org/10.1007/s10344-010-0370-4>.
- Wickham, H., 2016. ggplot2: Elegant Graphics For Data Analysis. Springer-Verlag. <https://ggplot2.tidyverse.org>.
- Zweifel-Schilly, B., Leuenberger, Y., Kreuzer, M., Suter, W., 2012. A herbivore's food landscape: seasonal dynamics and nutritional implications of diet selection by a red deer population in contrasting Alpine habitats. *J. Zool.* 286 (1), 68–80. <https://doi.org/10.1111/j.1469-7998.2011.00853.x>.