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Diverging national methods used to survey moose browsing damage in Scandinavia

Master thesis

Master’s in applied ecology

2022

26.5.2022 Dokka

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Abstract

Wildlife management rarely takes the distribution range of populations into account, but instead follows administrative borders. Population ranges and individual home ranges often cross administrative borders where different legislations and management goals will make cooperation difficult. The moose (*Alces alces)* population in the GRENSEVILT study area, nordre Finnskogen, is trans-boundary and migrates between the summer area in Norway and winter area in Sweden. During winter, moose can impact and damage the commercially valuable tree species, Scots pine *(Pinus sylvestris)* through top and lateral shoot browsing, bark browsing and stem breakage. When the top shoot or the stem is browsed or broken, the quality and value of the timber will be reduced. This creates a conflict between silviculture and hunting. In Norway and Sweden, two different methods for surveying browsing damage by moose on pine are used. Both methods target single pine trees on sample plots within young pine stands with the height of 0.5-4 meters. The Norwegian Solbraa method looks at food availability and the degree of browsing, quantified as the proportion of browsed shoots, as well as measuring any stem damage in the stands. The Swedish method, called Äbin, looks at the proportion of damaged trees in a moose management area (MMA) quantified as the number of damaged trees out of the total amount of trees. A fundamental difference between the methods is that the Solbraa method gives detailed information of the browsing pressure in stands, whereas Äbin gives information about the proportion of damaged trees in the MMA's. The Solbraa and Äbin methods have two different thresholds for browsing damage based on the degree of browsing and the proportion of damaged trees. I found that there was a significant positive relationship between fresh stem damage and browsing pressure at different spatial levels, from individual trees to a regional level. However, the management thresholds based on either Solbraa or Äbin were not comparable at all. I also found that it is possible to convert the results from the Solbraa method to Äbin, but not the other way around. I would suggest agreeing on a joint method of surveying browsing damage by moose and a common threshold consisting of the density of undamaged trees for different site indexes. I also suggest regular and systematic surveys on both sides of the border. Combining the two methods gives more valuable information on both the forestry and the moose population.

Key words: *Alces alces,* Browsing damage, Browsing pressure, *Pinus sylvestris* Scots pine, Solbraa, Äbin

Sammendrag

Viltforvaltning begrenses ofte av administrative grenser istedenfor å forholde seg til hele leveområdet til viltpopulasjoner. Populasjoners leveområder og individuelle hjemmeområder krysser ofte de administrative grensene, hvor forskjellige lovverk og forvaltningsmål gjør et samarbeid vanskelig. Elgstammen *(Alces Alces)* i GRENSEVILT sitt studieområde, nordre Finnskogen, er grenseoverskridende og trekker mellom sommerområdet i Norge, og vinterområdet i Sverige. Om vinteren kan elg beite og skade den kommersielt verdifulle trearten furu *(Pinus sylvestris)* gjennom toppskudd- og sideskuddbeiting, barkgnaging og stammebrekk. Når toppskuddet eller treet er beitet eller brekt, vil kvaliteten og verdien av tømmeret bli redusert. Dette skaper en konflikt mellom skogbruk og jegere. I Norge og Sverige brukes to forskjellige metoder for elgbeitetaksering. Begge metodene sikter på enkelte furutrær på testflater i ungfurubestander med høyde mellom 0.5-4 meter. Den norske Solbraa-metoden, sikter på mattilgang og beitetrykk av elg, beskrevet som beitegrad som er registrert som beitede skudd av tilgjengelige skudd, samtidig som den ser på stammeskader. Den svenske metoden for elgbeitetaksering, kalt Äbin, sikter på andel skadde trær i et älgforvaltningsområde (MMA), beskrevet som antall skadde trær av det totale antallet trær. En fundamental forskjell på metodene er at Solbraa-metoden gir detaljert informasjon om beitesituasjonen i en bestand, noe Äbin ikke gjør. Äbin gir istedenfor informasjon om andel skadde trær i älgforvaltningsområdene. Solbraa- og Äbin-metoden bruker to forskjellige terskler for beiteskade basert på beitegrad og andel skadde trær. Jeg fant ut at det var en signifikant positiv sammenheng mellom ferske stammeskader og beitegrad på forskjellige nivåer, fra enkelttrær til regionalt nivå. Forvaltnings-tersklene basert på Solbraa og Äbin var ikke sammenlignbare. Jeg fant også ut at man kan konvertere resultatene fra Solbraa-metoden til Äbin, men ikke omvendt. Jeg foreslår å samarbeide om en ny metode for elgbeitetaksering og en felles terskel for beiteskade basert på tetthet av uskadde trær i forskjellige boniteter. Jeg vil også foreslå regelmessig og systematisk elgbeitetaksering på begge sider av grensa. En kombinasjon av metodene gir mer verdifull informasjon om skogen og elgstammen.

Nøkkelord: *Alces alces*, Beiteskade, Beitetrykk, Furu, *Pinus sylvestris*, Solbraa, Äbin

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1. Introduction

Wildlife management rarely takes the natural geographical distribution range of subpopulations into consideration, but often follows administrative borders such as municipality, county, or country borders (Bischof et al., 2016). Different legislations, traditions and cultures makes it difficult to cooperate on managing trans-boundary populations, which can cause large conflicts. The home-range and area use of large herbivores is often larger than the administrative borders (Fattorini et al., 2020). Therefore, large herbivores and trans-boundary populations often tend to inflict damage unequal in areas with different landowners. Whereas some landowners experience a higher income from the existence of a high population in the form of hunting, landowners of another part of the home range experience a higher cost in form of forest damage. This will increase the conflict between landowners, silviculture, and hunters (Zimmermann et al., 2022; Bhat & Huffaker, 2007) An important prerequisite of successful management is a joint monitoring system of transboundary wildlife populations and their interferences with human interests. In this study, I compare national methods used to survey browsing impacts on forestry for the joint Scandinavian moose population.

Moose is the largest wild herbivore in Scandinavia with an adult live weight of between 300-500 kg. The species is adapted to the conditions of the boreal forest biome, with a strong, large body with long legs and thick fur to handle long, snow-rich winters. The short neck and long legs make the moose a specialized browser (Schwarz et al., 2007; Schwartz et al., 1988). Because of the large body size, moose need a lot of food. During the winter, an adult moose can browse 8-16 kg of twigs daily, depending on the area and the available browse (Sæther et al., 1992). During the summer, moose eat mainly leaves from deciduous trees, herbs, shrubs, and bilberry (*Vaccinium myrtillus)* (Wam & Hjeljord, 2010). In winter, snow and frost is a limiting factor for food availability for moose, and they often migrate between a summer area at higher altitudes and a winter area at lower altitudes (Ball et al., 2001; Sand et al., 2022).

Areas with little snow and good availability of the preferred deciduous tree species rowan (*Sorbus aucuparia*), aspen (*Populus tremula*) and willows (*Salix spp.*), which are the moose's preferred food (Heikkilä & Mikkonen, 1992; Månsson et al., 2007), are good winter areas for moose. They can also browse on pine and birch (*Betula pubescens, Betula pendula)*. These species are less preferred by moose but often much more abundant in production forests than the other tree species (Heikkilä & Mikkonen, 1992; Månsson et al., 2007). For calf-bearing cows, to live through the winter with a good enough fitness to keep the calf, they need to maximize their energy consumption gain by browsing as much as possible while moving as little as possible (Wam & Hjeljord, 2010). During winter, moose can concentrate in certain areas and thereby locally reach very high population densities that by far exceed the average moose density during summer (Sweanor & Sandegren, 1986) This can lead to a locally high browsing pressure on young pine trees in the winter areas (Nikula et al., 2004).

Pine is one of the most important and valuable tree species for forest industry in Norway and Sweden (Øyen et al., 2006) while it is also the quantitatively most important winter food species for moose during winter (Cederlund et al., 1980). Extensive moose browsing is therefore a big problem in forestry since it may reduce the timber quality and volume growth of future trees (Wallgren et al., 2014), which lowers the profitability of production forests for landowners (Øyen et al., 2006). The trees can handle some browsing, but intensive browsing over time will ruin the tree (Bergqvist et al., 2001). Previously browsed trees have a higher chance of being browsed again the next year, which will affect quality and growth of the trees even more (Bergqvist et al., 2001). One of the reasons for repeated browsing is that the re-growing shoots have a higher nutrient value with increased nitrogen and phosphorus content and less deterrents, i.e., lower monoterpene levels (Löyttyniemi, 1985).

Moose can select individual Scots pine trees with higher nitrogen contents (Niemelä & Danell, 1988; Gill, 1992). Niemelä & Danell (1988) found that the consumption of biomass by moose was greater on Scots pine on fertile soil, compared to Scots pine in areas with poor soil fertility (Niemelä & Danell, 1988). Even though field layer quality can increase browsing pressure (Gill, 1992; Heikkilä & Härkönen, 1993), it can also have the opposite effect (Danell et al., 1991; Lavsund, 1987). Abundance of pine and mixture and composition of tree species are also important factors for browsing levels on pine (Bergqvist et al., 2014; Herfindal et al., 2015). In a study from Finland, pure pine stands had less damage than mixed pine stands (Nevalainen et al., 2016). Other studies show that in stands where the deciduous trees, e.g., birch and aspen were taller than the pine trees, the probability of pine browsing was higher (Nikula et al., 2008; Bergqvist et al., 2014). A common practice for improving the young pine stands has therefore been to remove the broadleaf trees 5-10 years after regeneration. This silvicultural practice was done to make stands less attractive for moose and avoid large aggregations of moose on young forest stands that can lead to browsing damage on pine (Heikkilä et al., 2003). However, high abundance of high-quality browse has also been shown to be negatively related to pine damage by moose, so timing and intensity of cleaning out deciduous trees on pine stands must be planned carefully, depending on the pine abundance in the stand (Herfindal et al., 2015).

In Norway, moose management is planned on municipality-level, but in some instances multiple municipalities can work together. Multiple hunting areas can also cooperate and make a «moose region» (Forskrift om forvaltning av hjortevilt, 2016, §3-4). The Norwegian law says that the municipality should suggest a goal for the development of the moose population which should consider available browse, the development of the moose population, damages on forestry and agriculture and moose collisions (Forskrift om forvaltning av hjortevilt, 2016, §3). From this goal the landowners need to make multi-year plans for the management of the moose population (Forskrift om forvaltning av hjortevilt, 2016, §2h).

Moose browsing surveys in Norway follow mostly the Solbraa method (Solbraa, 2008). The goal of the Solbraa method is to measure food availability and how large proportion of the food capacity is used by moose. It quantifies the degree of browsing, i.e., how many of the available shoots are browsed (Solbraa, 2008). More than 30% of the shoots browsed is considered a significant browsing pressure that urges a reduction of the moose population and stands with more than 40 % of shoots browsed are considered overbrowsed. This information can then be used to change the goal of the new multi-year plan to manage local moose populations (Skogkurs, 2017).

Sweden is divided into multiple moose management areas (MMA), and the management authority is on county level (Länsstyrelsen). There are approximately 130 MMAs in Sweden. MMAs are surveyed with a method for browsing damage called Äbin (älgbetningsinventering). This browsing survey is carried out in the moose management areas, MMAs (Skogsstyrelsen, 2021, Landsstyrelsen, n.d.), and aims at quantifying browsing damage on the forest caused by moose. Instead of looking at the degree of browsing, they count damaged trees and look at what type of damage it is (Landsstyrelsen, 2021). They then count the number of damaged trees within a MMA and divide it with the total number of trees of each species within the MMA. According to national objectives, the proportion of pines within young forest stand with annual browsing damage should not exceed 5 % in a MMA, although it can be higher some years as long as it stays below 5% on average. When the proportion of damaged pines exceeds 20 % in a MMA, the area is referred to as strongly overbrowsed (Landsstyrelsen, 2021).

This study is a part of the EU-funded GRENSEVILT project and is aimed to compare the Norwegian (Solbraa) and the Swedish (Äbin) method for moose browsing surveys. My thesis consists of two parts; the first is a review of the two methods, and the second is the application of a hybrid protocol between Solbraa and Äbin in a joint, trans-boundary study area to see if the two main national measurements, browsing pressure in Solbraa and stem damage in Äbin, and the management thresholds are comparable. A comparison of these two methods is necessary to enhance management collaboration between countries when sharing a joint moose population. I aimed at answering the following questions:

1. What are the differences and similarities of the Norwegian and the Swedish browsing survey methods?
2. Are the results from the two methods comparable, and can they be used for cross border management?

   (i) To what degree is stem damage from Äbin comparable to browsing pressure from the Solbraa method?

   (ii) Are the thresholds of Degree of browsing and Degree of damage comparable at the regional level?

   (iii) Is it possible to convert the results from one method to the other?

3. How can we improve the methods?

2. Comparison of the Norwegian and the Swedish methods for surveying browsing damage

There are multiple similarities of the two methods especially in the way stands are selected and how tree species are surveyed. It is obvious that both methods were informed by the extensive literature about moose behavior and diet (e.g., Shipley et al., 1998; Bergqvist et al., 2018; Cederlund et al., 1980). However, the two methods have some differences, especially on the variables measured in the plots.

Both the Solbraa- and the Äbin method have similar criterias for the stand selection. The stand area should be at least 0.5 ha, where the average stand height is for the Solbraa method; 0.5-3.5 meters but varying up to 4 meters depending on where the survey is done, and for the Äbin method the criteria is that the average stand height is 1-4 meters (Table 1). The Solbraa method uses a random stand selection within the survey area, whereas the Äbin method randomly places 1 km^2 square grids in the moose management area where maximum five stands per grid square are surveyed. Within these stands, both methods use a transect grid. In Solbraa the grid cell size is adjusted to the size of the stand so approximately 30 plots of 12.5 m^2 fit in the stand, whereas in Äbin it is fixed. The transect grid in Äbin is 80 meters between each plot, and maximum 15 plots of 38.5 m^2 in each stand. In Solbraa, more but smaller plots are sampled per stand, as compared to Äbin. The reason for these differences is that the Solbraa method estimates an average degree of browsing for each stand irrespective of stand size (>= 0.5 ha). Äbin is not used to estimate stand averages, but rather regional (square) averages. Thus, a stand with very few pines will contribute very little to the results in the Äbin method, while it will contribute equally to the result as other stands with more pines in the Solbraa method.

Other information about the stand that is noted in both methods is average height of the stand and the future trees. The Äbin method also notes the average age of the stand, and on plot level, Äbin includes the vegetation layer and if there has been pre-commercial thinning in the stand (Table 1). While the Äbin method measures the proportion of the tree species in percentage, they measure up to 20 trees of each species to calculate the density in the Solbraa method (Table 1).

After measuring the stand, the variables in the plots are measured. There are some similarities in both methods. First, the tree species measured and counted are the same with Scots pine, Norway spruce *(Picea abies)*, birch, and RASO (rowan, aspen, salix and oak *(Quercus spp.*), although other species like lodgepole pine *(Pinus contorta)* are surveyed if occurring (Table 1). The tree measure of height, and how it is used, is different. The Solbraa method measures the height of the eligible tree to the nearest decimeter, and for pine and spruce the height is measured to the highest living shoot on undamaged and damaged plants, not destroyed. The Äbin method measures the average height of the two highest conifers in the plot before browsing damage and divides it by two to get the average half height.

When there are more than 70 % deciduous trees in the plot, these are used to determine average half height. Measuring trees above half average height is done to approximate trees that are left after precommercial thinning. Furthermore, it decreases the risk of including trees that have naturally regenerated after the landowner regenerated the stand. For pine specifically these lower trees are often outcompeted anyway due to insufficient light conditions.

The tree registration in the two methods is different. In the Äbin method they count the number of trees of each species above the half average height only. For pine they count each individual tree over the average half height, for spruce they count both damaged and undamaged trees above average half height, and for birch, RASO, and other tree species they count if they are taller than the average half height. For the RASO trees, the tallest individual tree of each species is measured if the stem is taller than 3 dm. In the Solbraa method they count up to 20 trees of each species except for juniper (*Juniperus spp.)* between 0.5-3 meters. They also count small trees of pine and spruce which are between 0.1-0.5 meters to collect information of the rejuvenation to the landowners (Skogkurs, 2017). Spruce and pine below 0.5 meters with browsing damage are also counted as normal (Table 1). This difference might also be a cause of the time spent in each plot. The number of pine trees in an area of 12.5m^2 could be high so limiting the number could be very time saving, considering counting shoots on 20 pine trees in 30 plots per stand with potentially hundreds of shoots each takes a long time.

The definition of stem damage is similar for the two methods but have one difference. Both methods count the tree as damaged if the top shoot is browsed, the stem is broken, or wood is exposed by bark browsing or antler rubbing. The Solbraa method counts bark browsing if more than 25% of the wood is exposed, and unlike the Äbin method, they count it as damage if more than 60% of needle mass is browsed (Solbraa, 2008). Then the damaged trees are categorized. In the Solbraa method they categorize each tree of each species into three categories: undamaged, damaged, and destroyed plants (Table 1). In the Äbin method they categorize damage in 5 categories; Number of stems above half-average height with damage, number of stems above half-average height undamaged by deer/game, number of stems above half-average height with only old deer damage, number of stems above half-average height where the top shoot is damaged, and undamaged by ungulates (Table 1). Both methods measure the age of browse, but differently. The Solbraa method measures it in two categories: browsing recently and browsing earlier (Table 1). They do this to show the development in the browsing pressure in the stand over the last years (Skogkurs, 2017). Whereas the Äbin method looks at the browsing of the top shoot. If the top shoot is browsed it has either; only winter damage, both winter and summer, only summer or has old damage only (Table 1).

In the Äbin method the main measurement of the survey is if the tree has stem damage or not. The reason behind this is that these kinds of damages affect the timber quality negatively and reduces the value of the future timber (Wallgren et al., 2014). In comparison to the Äbin method, the degree of browsing, or the browsing pressure is the main measurement of the Solbraa method. The degree of browsing is measured as percent browsed shoots out of the total available browsable yearly shoots within a stand, which means that the moose could have eaten them during the winter. Only the shoots over 5 cm are counted, because small and brown shoots are not really moose food. Then they calculate the degree of browsing in 10% classes as 0,1,2…10. Browsing 1 tells us that moose have browsed between 5-15% of the available shoots (Table 1).

The two methods have slightly different goals. The Solbraa method includes not only forest damage, it is also used for measuring how much of the available food for moose is eaten and uses this information as a tool to help control the moose population so the moose population stays healthy (Solbraa, 2014). The Äbin method looks at how large percentage of the trees that are damaged and will not reach 5 meters without damage, and if the percentage of damaged trees is too high, the moose population needs to be regulated (Skogsstyrelsen, 2022). This indicates that the Äbin method is more interested in the forest and the forest damage (Skogsstyrelsen, 2021), and the Solbraa method is also interested in how much available food there is for moose, so that the moose population stays healthy with high weights and condition (Solbraa, 2014).

Table 1. Comparison of the Solbraa method and the Äbin method used to survey moose browsing impacts on forest resources in Norway and Sweden, respectively.

	SOLBRAA (Norway)	ÄBIN (Sweden)
Survey area	Municipality	Moose management area (MMA's)
Survey frequency	Regularity varies. Often varies with management plan	Once every two years
Stand selection		
Selection process	Randomly picked	1 km^2 square grids randomly placed in area; max five stands per grid square.
Stand type	Young forest stands	Young forest stands
Average height	0.5-3 meters tall	1-4 meters stand average height
Stand area	Preferred: 1-2 ha.Min/Max: 0.5-5 ha.	Minimum 0.5 ha.
Plot selection		
Grid	Transect grid Adjusted after area of the stand (the distance between the survey lines multiplied by the distance between the plots within the line)	Transect grid Distance between plots in meters intended as a square grid 80m.
Plots per stand	30 plots per stand, min 26, max 34	Max 15 plots per stand
Plot area	Radius ~ 2m, area ~12.5m^2	Radius ~ 3.5m, area ~ 38.5m^2
Stand variable measurement		
Stand height	Average height of the future trees. The height is rounded to the closest half meter.	Average height of a number of representative production stems.
Average age	Not specified, but potentially known from landowner and logging history.	Measured by counting branch turns for number of representative production trees in the stand. Branch turns + 2 = age of the tree.
Tree species	Defined by the tree species that will dominate in the future.	Proportion of pine, spruce, birch etc. given as a percentage without decimals adding up to 100. Register which tree species is intended to rejuvenate.
Elevation	Height above sea level: noted in whole 50 meters from the center of the stand.	Not specified.
Site productivity	Site index (H40).	Site index (H100), understory vegetation. 1) lingonberry type (poor soil quality=dry=pine), 2) bilberry type (intermediate soil quality), 3) grass type (rich quality=moist=spruce).
Plot variable measurement		
Pre-commercial thinning	Not specified	Indicate if there has been pre commercial thinning or not.
Pellet piles	Count winter pellet groups	Count winter pellet groups
Tree species counted	Pine, spruce, birch, juniper, rowan, aspen, willows, oak.	Pine, spruce, birch, juniper, rowan, aspen, willows, oak, lodgepole pine, larch.
Average height	<u>For each tree species,</u> average height on eligible trees (see tree registration) is noted to the nearest decimeter. For pine and spruce, calculate average height on undamaged and damaged plants, not destroyed. The height is counted to the top of the highest living shoot or branch. Juniper height not recorded.	Average height of the two tallest conifers within the sampling plot before any fresh game damage. Calculate half-height by dividing average height by 2. In predominantly deciduous stands (more than 7/10 trees), the deciduous trees are used to determine average plot height, not conifers. Also count the number of spruce (+ damage) and birch stems above the half average height, and the number of other production tree species (e.g., larch, lodgepole pine) rowan, aspen, salix, oak, above the half average height
Tree registration	Count pine and spruce trees with a height of 0.5-3m, with or without browsing damage. Count pine and spruce trees with a height of 0.1-0.5 meters is counted and registered as "small plants". Maximum number of small plants of each species is [20of pine and spruce between 0.5-3 meters] (Spruce and pine that are below 0.5 meters because of browsing, are also counted in this group)	Count only trees taller than the half height. Trees that might later be thinned are included. Go through the trees within the plot to register trees with browsing damages on the central axel of the tree including top shoot. Browsing damages on lateral shoots is not registered. PINE: Each individual pine that is taller than the half average height is registered. OTHER SPECIES: (1) Number of spruce stems above the half average height with annual damage

	The Maximum number of plants that can be registered of each species are 20. Juniper or willow which might cover the whole ground is measured in the grade of coverage on the area, where 20 is full coverage	(2) Number of spruce stems above the half average height without annual damage (3) Number of birch stems above half average height (4) Number of other stems above half average height (5) Number of RASO stems above half average height RASO SPECIES: Measure the tallest individual within each of the four RASO tree species which occurs in the sample plot. The stem must be taller than 3 dm to be included. If the tree has been browsed during the winter, the height must be estimated at what it was before the browsing. Register the number of RASO trees with beneficial competitive status (i.e., taller than 2x half-average-height)
Determining individuals	Skewed stems with the root within the circle are counted. Stems on the same root but are separated at ground level are different plants. Multiple stem shoots from the same stump are counted as multiple plants.	If stems appear separate at ground level, count as separate trees
Definition of damage	Browsing damage is defined as trees with a browsed top shoot, bark browsing of more than 25 % of the stem circumference, or a stem breakage or if more than 60% of the needle mass is browsed	Browsing damage includes top shoot browsing, stem breakage, and bark damage caused by gnawing or antler rubbing where wood is exposed Counts as stem damage when the tree has top shoot browse, stem breakage or bark browsing.
Damaged vs Undamaged categories	ALL SPECIES: The plants are divided into the following categories based on how severe browsing damage is: (1) undamaged: Plants with no or minimal damages (2) damaged plants (3) destroyed plants: Standing plants, but dead or dying. Not developable. Ruined plants will fall and disappear.	FOR PINE: 1) Number of stems above half-average height with damage (divided into summer, winter and re-damaged; see below) 2) Number of stems above half-average height undamaged by deer/game (can have other damage) 3) Number of stems above half-average height with only old deer damage 4) Number of stems above half-average height where shooting top shoot (not yet lignified) is damaged.
Degree of browsing (Browsing pressure)	Percent browsed shoots out of the total available amount browsable yearly shoots. With available and browsable shoots, if the moose could have eaten them when it was there during the winter. The length of the shoot must be minimum 5 cm. Shoots under the snow and tiny, pinched shoots does not count. An average of the counted plants is calculated. The browsing is registered in 10%- classes as 0, 1, 2 etc. Browsing 1 says that the moose have browsed 5-15% of the available shoots.	Not specified
Age of browse	Two categories: 'Browsing recently' means the current winter. 'Browsing earlier' describes the browsing the two last years (before the last year). The relation between browsing last and browsing before shows the development in the browsing pressure in the area over the last years.	Determined in the classes: winter, summer, and old. Browsing on the current year's top shoot is noted. If the tree has more than one top, only the dominant one is determined as the top shoot. If any of the other tops than the dominant one is browsed, it is considered undamaged. PINE: Each individual pine is classified in one of the five categories: (1) has winter damage but not summer (fresh) (2) is re-browsed in winter after summer damage (both winter and summer damage or without old damage) (3) has summer damage but lacks winter damage (may also have old damage) (4) has old damage only, (neither winter nor summer damage) i.e., older than previous years' vegetation season. do not have deer damage but have other damage (e.g. hare) (5) undamaged by ungulates

The Solbraa method and the Äbin method have two different thresholds for browsing (Table 2). The main goal of Swedish forestry and wildlife management is to keep the degree of damage on less than 5 % to keep at least 85 % of pine trees undamaged by cervids so that 7/10 pine trees reach 5 meter (Skogsstyrelsen, 2021), so that they are outside the reach for moose damage (Lindmark et al., 2020). When the degree of damage is less than 5 % over a period of time, this means that the balance of moose and forest is tolerable (Skogsstyrelsen, 2022). That also means that the degree of damage can be higher some years, as long as the long-term percentage averages at 5 % or below. When the percentage of stem damage reaches 10-20%, chances are the long-term average will not reach 5 % and something needs to be done. If the percentage of stem damage is more than 20 %, it is very difficult to do forestry, and the moose population needs to be reduced (Skogsstyrelsen, 2022). In comparison to the Äbin method, Solbraa (2014) says that pine trees can handle an average browsing pressure of 30-35 % over time without ruining the timber production negatively (Solbraa, 2014).

Table 2. The thresholds of degree of moose browsing and damage. Solbraa - percent browsed shoots of available shoots; Äbin - percent damaged trees in MMA, (Skogkurs, 2017; Skogsstyrelsen, 2022).

Solbraa		**Äbin**	
≤ 15 %	Little browsing	≤ 5 %	Tolerable damage
16-30 %	Moderate browsing	5-10 %	Acceptable damage
31-40 %	Significant browsing	10-20 %	Serious damage
41-55 %	Overbrowsing	≥ 20 %	Strong overbrowsing
≥ 56%	Strong overbrowsing		

3. Case study in a cross-bordering area

3.1 Study area

The study area is nordre Finnskogen on the border of Innlandet county, formerly old Hedmark county in Norway to the west and Värmland in Sweden to the east. Finnskogen ranges across multiple Norwegian counties; Elverum (60°53´00N, 11°34´00Ø), Trysil (61°18´36N, 12°18´54Ø), Åsnes (60°39´13N, 12°09´11Ø), Grue (60°27´02N, 12°12´20Ø) and Våler (60°45′12″N 11°53′51″Ø), and one Swedish municipality; Torsby (60°08´00N, 13°00´00Ø). The study area is approximately 3530 km^2 and is dominated by coniferous forests. The area consists of 81.1% forest, 13.3% mire, 3.1% lakes, 1.7% agricultural land and 0.8% other landscapes. Of the forested land, 471km^2 are young forest stands (Zimmermann et al., 2022). The area is dominated by coniferous forest where the dominant tree species are Norway spruce and Scots pine intermixed with silver birch (*Betula pubecens*), downey birch (*Betula pendula*), rowan, willows, and aspen, and most of the area is managed for forestry. The understory vegetation is dominated by lichen and moss, heather (*Calluna vulgaris*), common grass (*Poaceae spp.*), bilberry and lingon (*Vaccinium vitis-idaea*). The average temperature in old Hedmark county is 4.5 degrees Celsius (Norsk klimaservicesenter, 2021), and the snow depth is higher north in the study area than in the south (Meteorologisk institutt, 2022).

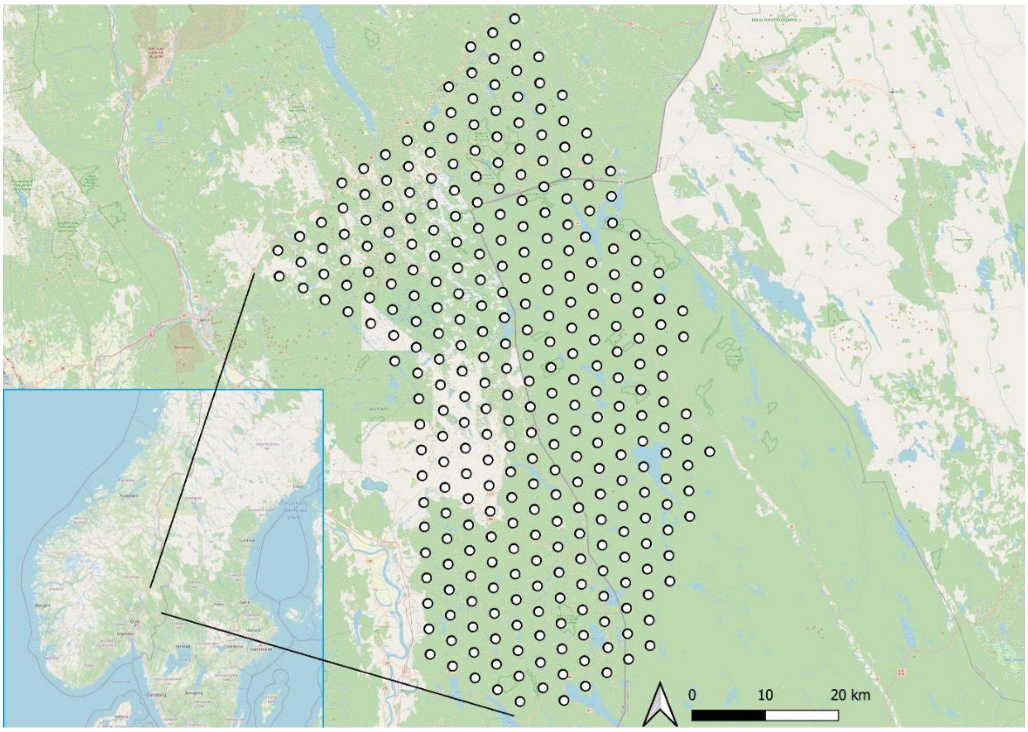

Figure 1. Map of the GRENSEVILT study area of nordre Finnskogen with all squares. Made in QGIS 3.16.3. using OSM (Open Street map).

3.2 Sampling design

The study area was determined by the migration route and winter and summer areas of GPS-collared moose, in order to ensure that it covered a natural, all-year population range of moose (Sand et al., 2022). We placed a hexagonal grid of 2 km side length (3.5 km between centre points) in the study area, resulting in 308 grid hexagons. Each centre point was buffered with a square of 1 km^2. The square itself was divided into a grid of 80 m cell size, and the centre of each grid cell was a potential sample plot for the browsing survey. If the plot was falling into a young pine stand, it was sampled. We sampled maximum 15 plots per square (Zimmermann et al., 2022), (Figure 1). If there were more than 15 eligible plots in a square, 15 plots were randomly picked in R (R core team, 2020). For this study we focused on young forest stands since we were looking for browsing damage on pine, and it is in young forest moose have the highest consumption of browse (Bergqvist et al., 2018) and damage (Nevalainen et al., 2016). We took the plot size, plot selection and the square grid from Äbin (Table 1). By using the structure form Äbin, we limited the number of plots surveyed, otherwise it would have taken too long to survey the area. We had a criterion that we only surveyed the stand if there was more than 10 % pine between 0.5-4 m which is the combination of the lowest and the tallest height of Äbin and the Solbraa method. Field layer and pre-commercial thinning from Äbin was also of interest, so we used the same categories and measured them in the plots.

For this study, we were only interested in browsing damage on Scots pine, so the only measurements for the other species was height and number, which was later used to calculate density like they do in Äbin and the Solbraa method.

We started the fieldwork in the start of May and finished in the end of June 2021. For browsing survey, it is easier to count the fresh browsing damage and the available shoots before the pine tree starts growing new shoots. Therefore, it is necessary to do it early in the spring (Skogkurs, 2017). The snow season in the study area is longer in the north than in the south, so we started the fieldwork in the southern part of the study area and successively moved northwards. This way we started working where the snow was gone, and by the time we were done in the south, the snow had melted in the north. To navigate to the sample plots, we used field tablets including digital maps and GPS. The criteria for the hybrid method are young Scots pine forest where at least 10% of the production trees are pine with an average height of 0.5-4 meters (Table 3), since we focus only on browsing damage on pine within the height range of the two methods. We had maximum 15 browsing plots in each Square, and the distance between the plots was at least 80 meters. We went as close to the plot as possible, and then we walked three steps in the direction of the plot to cope for the GPS-error. In the center, we placed a screwdriver with a rope of 3.5 meters and started counting. For the height measures of the trees, we used a measuring stick up to 2 meters, and a measuring pole of 3.5 meters with decimeter units. To collect the data, we used the app KoBoCollect (KoboToolbox, 2021) and filled in a form that ended up in an excel sheet.

We started counting the number of Scots pine, Norway spruce, downey birch, silver birch, rowan, aspen and willow, and measured the height of up to 10 trees of each species, counted from the center of the plot so we could not select the trees we subjectively wanted to measure (Table 3). The height was measured to the highest living shoot or branch of the tree. For the pine trees we measured top shoot browsing, stem break and bark browsing, accumulated browsing, with the categories undamaged, light, moderate, intense, destroyed, or other and we counted the freshly browsed shoots and the unbrowsed available shoots. If the top shoot had been browsed, we looked at if it was browsed in winter only, summer only, both summer and winter or had old browsing damage. We also looked at the dominant understory vegetation class, categorized into; grass, blueberry, lingonberry, heather, lichen/moss, bog (Table 3).

Table 3. The protocol for the hybrid method used in the large-scale browsing survey on pine in the GRENSEVILT study area in northern Finnskogen

In the stand	**Survey only if eligible**	
	Average stand height 0.5-4m	Yes/no
	Are there 10% young pine in the stand?	Yes/no
In the plot	**Go to the center of the plot, and take location with GPS**	**Use a screwdriver and a 3.5 m rope to define the plot**
	Take photo of plot towards north	
	Pre-commercial Thinning	Yes/no
	Field Layer	Lichen/moss, Heather, Bog, Lingonberry, Blueberry, Grass
	Count number of trees within each species	Scots pine, Norway spruce, Rowan, Downey birch, Silver birch, Aspen, Willow.
	Measure tree height	Up to 10 trees per species, between 0.5-3 m.
For Scots pine Up to 10 trees per plot	**Top shoot browsing**	Yes/no If yes: Only winter damage Only summer damage Both winter and summer damage Only old damage Other
	Fresh stem breakage	Yes/no
	Old stem breakage	Yes/no
	Fresh bark browsing / antler rubbing	Yes/no
	Old bark browsing / antler rubbing	Yes/no
	Accumulated browsing	**Undamaged** – no browsing **Light damage** – lateral browsing only **Moderate damage** – top shoot browsing and moderate lateral browsing. **Intense damage** – Strongly altered growth from due to browsing. **Destroyed** – Tree is standing but dead or dying. **Other** – disease, rodent or hare browsing.
	Count unbrowsed shoots	All unbrowsed shoots more than 5 cm long between 0.5-3 meters..
	Count browsed shoots	Fresh browsed shoots between 0.5-3 meters.

3.3 Data analysis

For the data cleaning, exploration, and analyses, I used R (R core team, 2020) with R-studio (R-studio Team, 2022). I defined browsing pressure (Degree of browsing) as browsed shoots of total available shoots, and fresh stem damage was defined as damage to the tree in the form of fresh top shoot browsing, fresh stem breakage or fresh bark browsing, just like the Solbraa and Äbin methods. Old stem damage was counted, but not used in the analyses. For the analysis, I combined the field layer (Table 3) into three different categories, poor, medium, and rich, because there were few samples of some of the categories.

For my first analysis, I wanted to see if stem damage and browsing pressure are comparable. I used a Generalized linear mixed effect model (GLMM) from the package lme4 (Bates, 2015) with a binomial distribution and the BOBYQA optimizer. Because we counted trees in multiple plots in multiple squares, which could be in the same stand, I added SquareID and Plot as a random effect to correct for spatial autocorrelation. My response variable was fresh stem damage, and the main predictor variable was browsing pressure. I then added biologically meaningful fixed effects, which I scaled by z-value, one by one and selected the best model based on the Akaike's information criterion (AIC) (Table 6). I added squared height as a fixed effect because I wanted to see if there was a quadratic effect, since I thought there would be more stem damages on shorter trees than on taller trees. Then I used the DHARMa package in R (Hartig, 2022) to first check for dispersion problems. Then I looked at the qq-plot to examine if there were any deviations or outliers from the expected distribution. Then I used the prediction model from ggeffects (Lüdcke, 2018) to visualize the models.

For my second analysis I wanted to see if degree of damage and degree of browsing was comparable on square level and use that to see if the thresholds of the two methods are comparable. To find the degree of damage I grouped the individual trees by SquareID. For degree of browsing, I pooled all shoots counted per tree and plot and calculated the proportion of browsed shoots. For stem damage, I pooled all pine trees surveyed per plot and calculated the proportion of damaged trees. I then made a linear regression model in R with degree of damage as the response variable and degree of browsing as the predictor. I visualized the comparison of the threshold using the ggplot2 package in R (Wickham, 2016).

4. Results

4.1 Samples

The study area contained 308 squares where 121 squares had eligible browsing plots. In total, 1161 plots were surveyed, whereas 697 were eligible and 549 had Scots pine with shoots. In total, we surveyed 3120 Scots pine trees, and 3027 trees had available shoots. Of those 3120 trees, 592 (19%) had fresh damages. We counted in total 108585 shoots, and 9376 (8.6%) were browsed. The degree of damage on square level was on average 20% ± 0.039 (2SE), and the degree of browsing was on average 12 % ±0.035 (2SE).

4.2 Is stem damage from Äbin comparable to browsing pressure from the Solbraa method?

The best model used to relate stem damage to browsing pressure included squared height, pine density and field layer (Table 6, model P6). There was a strong significant positive relationship between stem damage and browsing pressure ($p<0.001$, Table 4, Figure 2). I also found that squared height, and Field layer richness had a significant positive effect on stem damage ($p<0.05$, Table 4). The probability of stem damage on pine, increased up to a height of 2 meters, and then decreased with increasing tree height (Figure 3). Pine density showed a tendency to be positively related to stem damage ($p=0.07$, Table 4).

Table 4. Output from GLMM (generalized mixed effects model). Response variable is Fresh stem damage, and family is binomial.

	Estimate	Std.Error	Z value	Pr(>|z|)
Intercept	-2.61512	0.15359	-17.026	<0.001 ***
sBrowsing pressure	5.02774	0.25051	20.070	<0.001 ***
sHeight	0.03386	0.11615	0.292	0.7706
sHeight^2	0.03386	0.06014	-2.128	0.0333 *
sPinedensity	-0.16567	0.09389	-1.764	0.0777 .
FieldLayerpoor	-0.22205	0.17882	-1.242	0.2143
FieldLayerRich	0.38685	0.18745	2.064	0.0390 *
Random effects				
Groups	Name	Variance	Std.Dev.	
Plot:SquareID	Intercept	0.56584	0.7522	
SquareID	Intercept	0.09641	0.3105	
Number of obs:	Intercept: 3027,	Groups: Plot:SquareID, 549; SquareID, 121		

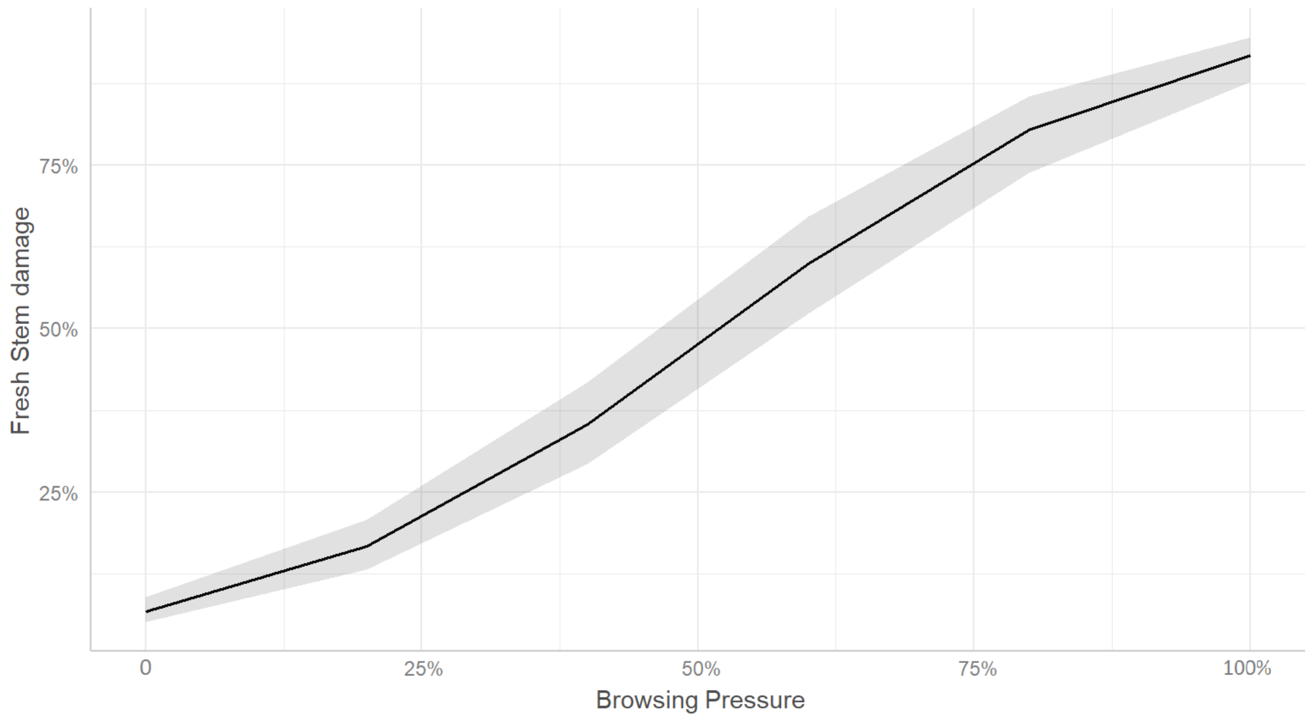

Figure 2. Predicted relationship between the probability of stem damage and browsing pressure on average-sized, young pine trees in the GRENSEVILT study area in spring 2021 (95% confidence interval in grey). Figure from unscaled model.

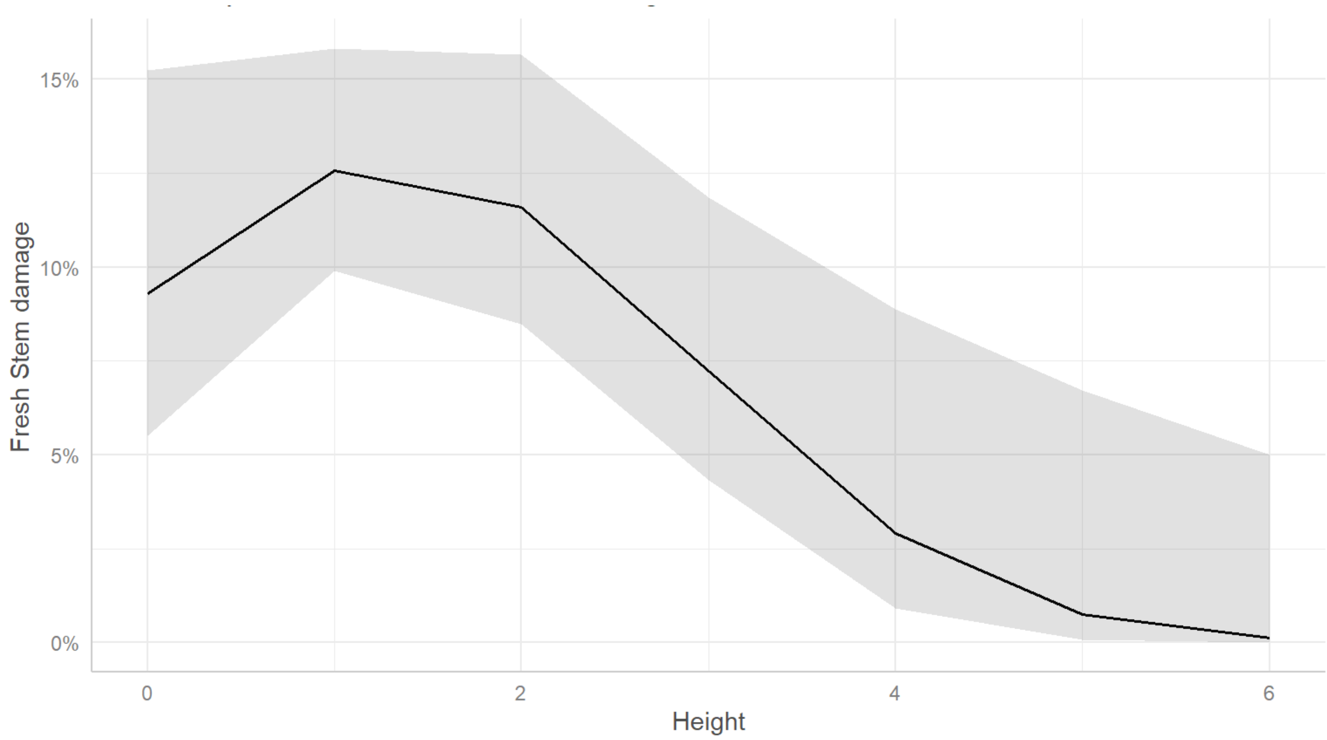

Figure 3. Predicted relationship between the probability of stem damage and tree height (m) of young pine trees in the GRENSEVILT study area in spring 2021. (95% confidence interval in grey). Prediction based on the unscaled model.

4.3 Are the thresholds for degree of damage and degree of browsing comparable on square level?

There is a strong significant positive relationship between degree of damage and degree of browsing also on square level ($p < 0.001$, Table 5, Figure 4), and the degree of browsing explains 49% of the degree of damage ($r^2=0.49$, Table 5). I compared the degree of damage and degree of browsing on square level with the threshold from both methods and found that they are not comparable at all (Figure 4). Most of the squares had little to moderate browsing when using the threshold from Solbraa, while they were overbrowsed when using the threshold from Äbin (Figure 4).

Table 5. Output from the linear model of Degree of damage as the response variable and degree of browsing as the explanatory variable.

	Estimate	Std. Error	t value	Pr(>|t|)	
Intercept	0.10528	0.01617	6.509	<0.001	***
Degree of browsing	0.78003	0.07161	10.893	< 0.001	***

Residual standard error: 0.1506 on 119 degrees of freedom
Multiple R-squared: 0.4993, Adjusted R-squared: 0.4951
F-statistic: 118.7 on 1 and 119 DF, p-value: < 2.2e-16

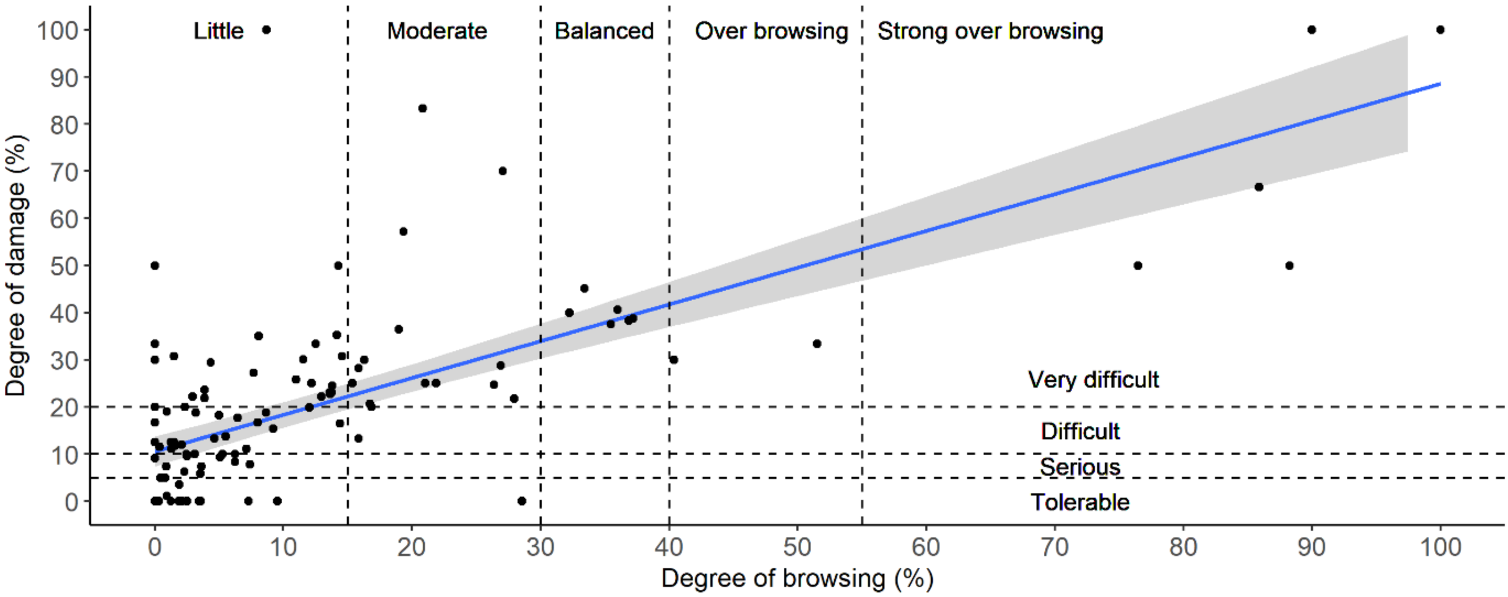

Figure 2. Degree of damage and browsing for each Square in nordre Finnskogen to compare the thresholds of the Solbraa method and Äbin, with a linear model method with standard deviation in grey. The y-axis shows the threshold in Äbin, while the x-axis shows the threshold in the Solbraa method.

5. Discussion

5.1 What are the advantages and disadvantages of the two methods?

The size and structure of the grids used to locate sample plots differ between the two methods. Whereas the Solbraa method use more and smaller plots with a grid adjusted to each stand, Äbin uses larger and fewer plots in each stand with a predetermined grid. This might be because the browsing pressure on pine trees might have a high variation within the stand, and since Äbin only measures stem damage, fewer large plots might give sufficient information. One of the advantages of the Äbin method is that it is faster, and the sample gives sufficient information about browsing damage in the square. The Solbraa method needs to survey a larger area of each stand to get a better picture of the browsing pressure and the availability of browse, so more but smaller plots will give a more detailed representation of each stand. The size of plots often depends on what is surveyed and how much time it takes (Henttonen & Kangas, 2015). The main advantage of the Solbraa method is that it gives more information within each stand about both the stem damage and the browsing pressure, although the disadvantage is that it is slower because of the counting of shoots. Another big difference of the two methods is that Äbin measures half average height of trees, and the Solbraa method does not. The advantage of this is that the trees that are not supposed to rejuvenate or occur in the stand in the future, will not be counted, e.g., 50 cm trees in a stand with a half average height of 2 m, because these small trees will be gone after the pre-commercial thinning. These trees and the "small trees" category in the Solbraa method are important to understand the total available browse but are not necessary to measure in Äbin. The Solbraa method counts the shoots as "browsed recently" and "browsed earlier" which tells us if the shoots are browsed this winter or a couple of years ago. This is done to show the development of browsing over the last year. This is not done in Äbin, because they do not count shoots, but also because they survey the MMA's every other year, instead of every 4 years or so in Norway. By surveying more often, you get a better picture of the development in the stand, or area. This way, management actions can be applied more quickly, allowing for more adaptive management (Bottan et al., 2002; Suzuki et al., 2022).

Another difference between the methods is the way they categorize the damage on Scots pine. In Äbin they categorize them by what kind of top shoot damage it has e.g., fresh winter, fresh summer, old or undamaged, while in the Solbraa method they categorize them as undamaged, damaged, or destroyed. This is an advantage for the Äbin method because what kind of category the damaged tree fits in is objective, while in the Solbraa method, it is subjective. The Solbraa method does not specify if trees with top shoot damage can be fit in the "undamaged" category, because if only the top shoot is browsed out of 100 lateral shoots, it is minimal damage, even though it might reduce the timber quality (Wallgren et al., 2014). A fundamental difference between the methods is that the Solbraa method produces relevant results for individual stands because of the browsing pressure and available browse, whereas Äbin does not, but instead gives relevant results for the timber production in the MMA's.

5.2 Is stem damage comparable to browsing pressure?

There is a significant positive relationship between stem damage and browsing pressure. That means stem damage and browsing pressure might be used interchangeably. The top shoot has a higher nutritious value than the lateral shoots (Cline et al., 2009; Gill & Beardall, 2001). That would indicate that moose would select the top shoot rather than the lateral shoots or start browsing the top shoot of a tree and then keep browsing the lateral shoots on the same tree. By browsing more shoots from the same tree, the moose also saves energy by not moving for every bite (Wam, & Hjeljord, 2010; Sæther & Andersen, 2011). Another reason for this might be if the top shoot of a short pine tree with few shoots above 0.5 meters is browsed, this one browsed shoot counts as stem damage and will also indicate a high browsing pressure. For example, a tree of 0.5 m with one browsed top shoot above 0.5 m, will indicate stem damage and 100% browsing pressure. Though, intermediate-sized trees at approximately 2 m had the highest chance to be damaged by moose, as compared to smaller and larger trees. For moose to reach the top shoot of the taller trees, it needs to break the stem (Telfer & Cairns, 1978). Trees within the reach of moose during winter, when moose walk on top of the snow, would be easier to browse.

I found that the cconsumption of available browse and stem damage is higher in rich vegetation than in poor vegetation. This matches the results of other studies (Heikkilä & Härkönen, 1993; Heikkilä, 1990), although others have the opposite result (Lääperi & Löytyniemi, 1988). The higher probability of stem damage in richer vegetation, might be caused by a higher nutritious value of the shoots or a different morphology (Nikula et al., 2008). Moose also selects shoots with a larger diameter and larger size on Scots pine over smaller shoots (Niemel & Danell, 1988; Shipley et al., 1998), which can also be a reason for a higher probability of damage in richer vegetation.

5.3 Are the thresholds of the two methods comparable?

There is a significant relationship between the degree of damage from Äbin and the degree of browsing from the Solbraa method. Most of the squares have less than 30 % degree of browsing, which is acceptable in Norway, but the same squares have above 5% degree of damage, and a quite a lot of them are above 20 % degree of damage as well, which tells us that forestry is very difficult. This means that the two thresholds do not correlate at all.

Although pine trees might handle a 30-35 % browsing pressure, a high degree of browsing increases the probability that the top shoot are browsed, which might reduce the timber quality (Wallgren et al., 2014). Solbraa (2014) says that the landowners income from moose in comparison to the timber is approximately 10-15 %. Because of that, the cost of browsing pressure should not be higher than the income the landowners make from the moose which of course varies depending on if they sell the hunting rights or hunt on their own land amongst other things. Solbraa (2014) then says that this translates into 30-35 % browsing pressure on average, and the lower the pine density, the lower accepted browsing pressure (Solbraa, 2014). Although, this might not be the case since the distribution of browsing is not the same in different areas, which means that some landowners will profit more from hunting sales, whereas other landowners will have more cost in the form of browsing damage from moose (Zimmermann et al., 2022).

Since they have so different thresholds, this causes the two countries to manage the same trans-boundary moose population vastly different. The threshold is much lower in Sweden than in Norway, which cause the management on the Swedish side of the border to reduce the moose population, whereas the management on the Norwegian side wants to increase the moose population because the area seemingly can hold more moose, which gives higher income to the landowners from hunting. This again, will increase the conflict between hunters and the silviculture even more. The management of moose today is very counterproductive and because of this, it is important to improve the methods and find a common way of surveying browsing damage and agree on a common threshold for browsing damage so it is possible for Norway and Sweden to cooperate on a cross border management of the migrating trans-boundary moose population.

5.4 Can the results from one method be converted to the other method?

Most of the variables from the Solbraa method can be converted to the Äbin method, and since stem damage is defined approximately the same, the main results can be converted this way by counting the proportion of trees for the entire area like in Äbin, instead of the average of the stands like in Solbraa. Converting the results from Äbin to Solbraa will be more difficult, because even though stem damage and browsing pressure are comparable, the food availability, which is a big part of the Solbraa method, is not registered in Äbin. Another problem when converting the results from Äbin to Solbraa is that most of the available browse falls below the half-average height, which is not registered in Äbin.

5.5 How can we improve the two methods?

There are many similarities of the Solbraa method and Äbin, and it seems that the two methods complement each other with measurements that is important for a browsing survey (Shipley, 1998; Bergqvist et al., 2016; Cederlund et al., 1980; Parker & Morton, 1978). Solbraa could for instance measure the field layer or under story vegetation like Äbin, because there is strong evidence that the quality of the field layer impacts browsing both positive and negative because of pine density, the nutritious value of the shoots and the effect other tree species have on browsing (Heikkilä & Härkönen, 1993; Heikkilä, 1990; Lääperi & Löytyniemi, 1988; Nikula et al., 2008; Nevalainen et al., 2016). For example, it is shown that there is more damage on Scots pine in stands with mixed tree species than in pure Scots pine stands (Nevalainen et al., 2016). In the Solbraa method, they do note what kind of stands are adjacent to the surveyed stand though (Skogkurs, 2017). The neighbor stands and the mosaic of older forests and seedling forests have shown to have an effect on the browsing pressure (Heikkilä, 1990; Nikula et al., 2021). Another important measurement that is only measured in the Solbraa method is browsing pressure. Counting shoots takes a lot of time, but gives interesting information, and by counting shoots one can include a new parameter to look at, accumulated damage. Both methods give poor information of how damaged the tree is and how the shape of it is. Take accumulated damage from the hybrid method for example. This parameter gives us valuable information on how the situation of the stand is, not only by counting pressure and stem damage, but by looking at the trees. If the accumulated damage in the stand is close to light damage on average, that means the trees have lateral shoot browsing, but little top shoot browsing.

Though for instance, if the accumulated damage in the stand is closer to intense damage, the stand is highly over browsed. Understanding how a tree is damaged is more interesting than knowing only that it is.

For a possible joint method for surveying browsing damage, one should think about combining the best of both. I would suggest dividing the survey in two main parts, by using the browsing pressure from the Solbraa method to look at the available food and use the Äbin method for counting stem damage on the future trees by using average half height. Even though the trees below average half height might be thinned, it is still available food for moose, and should be counted as available browse. I would suggest that the new method for surveying browsing damage by moose should focus on the density of undamaged stems for different site indexes by counting the trees above half average height. A lower site index would tolerate lower browsing damage than stands of higher site index because the production will be lower. I would also suggest that the threshold should focus on this, because what really matters for forestry is how many trees in the stand that reach maturity without any damage. By using the site index, it is also possible to know how many trees per ha you can expect.

Lastly, I would suggest that Norway and Sweden agree on a common method for surveying browsing damage of moose and agreeing on a common threshold, to better compare and cooperate on the management of moose. Also, surveying browsing damage should be done regularly by both countries and a cooperation of the sampling across the border is needed. When sharing a joint moose population, it is needed to manage it in its entire distribution range, not just winter or summer. This way, different landowners, and countries do not need to work against each other, but instead cooperate towards a unified goal.

6. Acknowledgements

This thesis is a part of the EU-funded GRENSEVILT project and marks the end of my Master program in applied ecology at the Inland Norway University of Applied Sciences. The planning process, the field work and the group meetings have been very exciting and educational, and I really appreciate the opportunity to be a part of this project.

I would like to thank Karen Marie Mathisen for including me in the project, and Håkan Sand & Christer Kalén for interesting inputs in the group meetings, Erik Versluijs for a great time during field work, and my peer, Paige Hellbaum for interesting and educational discussions during meetings and field work.

I would especially express my gratitude to my supervisor Barbara Zimmerman, for the guidance both during the writing process and statistics, and by taking the time to explain all of my questions. Your supervision has been very valuable.

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8. Appendix

Table 6. Model selection by AIC. All the models include the random effect SquareID/Plot.

Model	Formula	df	AIC
P1	FreshStemdamage ~ sBrowsingPressure	4	2039.679
P2	FreshStemdamage ~ sBrowsingPressure + sHeight	5	2037.029
P3	FreshStemdamage ~ sBrowsingPressure + sHeight + sPsyDensity	6	2033.493
P4	FreshStemdamage ~ sBrowsingPressure + sHeight + sPsyDensity + FieldLayer3	8	2028.0.45
P5	FreshStemdamage ~ sBrowsingPressure + sHeight + I(sHeight^2) +sPsyDensity + FieldLayer3	9	2024.719