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Experimental thinning of streamside spruce forests

Study design, site descriptions, and pre-thinning conditions at six field sites established in 2022

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Datalogger installations (left) and vegetation quadrats (right) in a study plot at the E314 Svanå site. Photo: E. Ring.

Contents

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Preface

This report was produced as part of two projects on the implementation of functional forest buffers along streams in Sweden. In 2021, Skogforsk was granted funding from Skogssällskapet to study different thinning regimes as a means for improving the functionality of spruce-dominated streamside forests (project 2021-910: ”Hur skapa funktionella kantzoner vid gallring?”). The project runs from 1 April 2021 to 31 August 2025. Two major aims of the project are to 1) increase the knowledge regarding short-term effects of different thinning regimes on ground vegetation and trees in spruce-dominated streamside forest, and 2) design the field experiment in a way that render monitoring possible over the next 20–30 years. Six field sites were established during 2022. These sites are also part of the project “MUST DEFINE: Using a MUltiple STakeholder Dialog and Experiments to reFINE the Swedish Strategic Management Objectives for forest buffers along streams” funded by Formas (grant no. 2021-02426) and led by Lenka Kuglerová at SLU. The MUST DEFINE-project runs from 1 December 2021 to 30 May 2025.

We thank Skogssällskapet, Stora Enso Skog, and Sveaskog for hosting the field sites and adapting their procedures to accommodate the experimental set-up, and Skogssällskapet (project 2021-910) and Formas for funding (grant no. 2021-02426). The ground vegetation inventory was performed by Anders Hedlund (Hedlund Ecology).

In this report, the experimental design, field sites, and pre-treatment conditions are presented. Data on site and stand characteristics, and understory vegetation were compiled by E. Ring, E. Fredriksson, J. Sonesson, L. Djupström, and M. Krook, all at Skogforsk. Data on deadwood and microclimate were compiled by M. Cosovic, E. Maher Hasselquist, and L. Kuglerová, all at SLU.

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The authors

Sammanfattning

Sex fältförsök har lagts ut på skogsmark i Mellansverige för att undersöka hur olika typer av gallring i enskiktad granskog intill vattendrag påverkar vegetationsutveckling, död ved och mikroklimat i den strandnära zonen. Försöken benämns E312 Bredvik, E313 Bredvik, E314 Svanå, E315 Bäckhammar, E316 Munkfors och E317 Lattao. Syftet med försöken är att öka kunskapen om hur man i samband med förstagallring kan skapa funktionella kantzoner intill vattendrag enligt skogsbrukets målbilder för god miljöhänsyn mot sjöar och vattendrag. Den strandnära skogens funktionalitet kommer att bedömas utifrån bland annat andel lövträd, grad av skiktning (enskiktat-flerskiktat), markvegetationens täckningsgrad och sammansättning samt mikroklimat.

De gallringsbehandlingar som studeras är 1) ingen gallring, 2) gallring enligt ”Gallringsmall för barr och löv”, 3) intensiv gallring, det vill säga gallring till halva grundytan jämfört med behandling 2 samt 4) alla barrträd gallras bort.

Varje fältförsök består av fyra provytor utlagda intill ett mindre vattendrag (förutom i E316 Munkfors där endast tre ytor rymdes). Provytorna är ca 30 m långa, 12 m breda och har en 10 m buffertzon på vardera kortsida som gallrats på samma sätt som provytan. De fyra (tre i E316 Munkfors) gallringsbehandlingarna har gjorts i alla försök. Behandlingarna fördelades slumpmässigt mellan provytorna inom varje försök. Gallringarna i E312 och E313 Bredvik samt E314 Svanå gjordes under september till oktober 2022. E317 Lattao gallrades i januari 2023, E316 Munkfors i januari 2024 och E315 Bäckhammar i juli 2024.

Försöken ligger på plan eller lätt sluttande frisk-fuktig eller fuktig mark. Tre försök är på torvmark och tre på fastmark. Karaktären på vattendragssträckorna som gränsar mot provytorna är dike i E312 och E313 Bredvik, rätat vattendrag i E316 Munkfors, fördjupat vattendrag i E314 Svanå och naturligt vattendrag i E315 Bäckhammar och E317 Lattao. Beståndsåldern i försöken varierade mellan 34 och 43 år och ståndortsindex mellan G31 och G35.

Innan gallring inventerades träd, markvegetation och död ved på provytorna. Dessutom mättes temperatur i marken och ovan markytan, markfuktighet, relativ luftfuktighet och ljusstyrka. I denna rapport beskrivs studiens utformning, försöksområdena, förhållandena innan gallring och gallringmetoderna.

Summary

Six study sites have been established on forest land in central Sweden to investigate how different types of thinning of single-layered spruce-dominated streamside forests affect vegetation development, deadwood, and microclimate. The sites are named E312 Bredvik, E313 Bredvik, E314 Svanå, E315 Bäckhammar, E316 Munkfors, and E317 Lattao. The purpose of establishing the study sites is to increase knowledge of how to create functional forest buffers adjacent to watercourses in conjunction with first thinning, in accordance with the strategic environmental objectives for forest buffers near lakes and streams. The functionality of the streamside forest will be assessed based on, for example, the proportion of broadleaved trees, the degree of layering (single-layered to multi-layered), the understory vegetation coverage and composition, and microclimate.

The thinning treatments studied are 1) no thinning, 2) thinning according to the thinning guide 'Gallringsmall för barr och löv', 3) intensive thinning, i.e., thinning to half the basal area of treatment 2, and 4) all conifers harvested.

Each study site consists of four study plots located next to a small watercourse (except E316 Munkfors which only accommodated three plots). The plots are approximately 30 m long, 12 m wide, and have a 10 m buffer zone on each short side that was thinned in the same way as the plot. The four thinning treatments (three in E316 Munkfors) were performed at all sites. The treatments were randomly distributed among the study plots at each site. Thinning in E312 and E313 Bredvik and E314 Svanå was executed during September to October 2022. E317 Lattao was thinned in January 2023, E316 Munkfors in January 2024 and E315 Bäckhammar in July 2024.

The sites are located on flat or gently sloping ground with mesic-moist or moist soil. Three sites are on peat soil and three on mineral soil. The watercourses have somewhat different characteristics: the watercourse is a ditch in E312 and E313 Bredvik, a straightened watercourse in E316 Munkfors, a deepened watercourse in E314 Svanå and a natural watercourse in E315 Bäckhammar and E317 Lattao. Stand age varied between 34 and 43 years and site index between G31 and G35.

Trees, understory vegetation, and deadwood were inventoried on the study plots before thinning. In addition, temperature in the soil and above the soil surface, soil moisture, relative air humidity, and light intensity were recorded. This report describes the experimental design, study sites, pre-thinning conditions, as well as the methods of the thinning operations.

Introduction

Riparian forests and adjacent streams are inter-connected (Tolkkinen et al. 2020). In Sweden, the importance of protecting riparian forests has received increased attention over the last two to three decades (Hasselquist et al. 2020). A common strategy for protection is to leave strips of forest (forest buffers) along watercourses and lakes during clearcutting (Andersson et al. 2013, Kuglerová et al. 2020, Ring et al. 2022). Adequately designed forest buffers help maintain important functions from unwanted impact of forestry (Kuglerová et al. 2014, Hasselquist et al. 2021). However, Hasselquist et al. (2021) suggested that the ecological benefits of mixed-species, multi-layered riparian forests with a high proportion of broadleaved species are higher than what is typically found in many managed forests in Fennoscandia today, referring specifically to the poor ecological functioning of spruce-dominated, single-layered streamside forests.

The strategic environmental objectives for forest buffers near lakes and streams have been defined within a dialogue process where representatives from the Swedish Forest Agency, the Swedish Agency for Marine and Water Management, the Water Authority of the Bothnian Sea Water District, and the forest sector participated (https://www.skogsstyrelsen.se/mer-om-skog/malbilder-for-god-miljohansyn/, Andersson et al. 2013). The purpose of forest buffers near lakes and streams, according to these objectives, is to maintain important chemical processes in the soil, such as nutrient uptake, denitrification, etc.; prevent elevated sediment transport and stabilize streambanks; maintain nutrient and energy supply from litterfall and insects to aquatic organisms; provide shading and regulate temperature; supply deadwood; and maintain biodiversity (Andersson et al. 2013). Forest buffers providing these functions are considered ‘functional’.

The functionality of forest buffers may change over time because of wind felling or targeted forest management (Hasselquist et al. 2021). After clearcutting, the streamside forest is more exposed to wind. This can lead to excessive wind felling in the buffer and impair its functionality with respect to the deadwood supply rate, shading, sediment transport, and streambank stability (Grizzel & Wolff 1998, Mäenpää et al. 2020, Kuglerová et al. 2023, Hasselquist et al. 2024). To improve the functionality of streamside forests or buffers with low functionality, selective felling, continuous cover forestry, and gap formation have been proposed (Andersson et al. 2013, Ring et al. 2018). However, there is limited scientific and empirical evidence from Fennoscandia of how various forest buffer management strategies affect the functionality of streamside forests and buffers. Studies have been performed in spruce-dominated buffers in Finland (Oldén et al. 2019a & b, Mäenpää et al. 2020) and effects on benthic macroinvertebrates have been investigated after selective thinning along streams in young coniferous forest in Sweden (Högbom et al. 2002, Ring et al. 2023). In a modelling study using the Heureka decision-support system, stand development of streamside forests subjected to different management was simulated for three forest landscapes in Sweden (Sonesson et al. 2021). The results suggested trade-offs between the proportion of broadleaved trees and the amount of deadwood, both of which are important for buffer functionality. Leaving the forest buffer for free development reduced the proportion of broadleaved trees but increased the amount of coarse deadwood according to the simulation. Selective thinning to promote broadleaved trees resulted in less deadwood but higher stem volume of broadleaved trees.

To start managing streamside forests with low functionality early during the rotation could improve their function throughout the rotation and after they have been left as forest buffers at the end of the rotation (Hasselquist et al. 2021). Action could be taken already at pre-commercial thinning or thinning. However, more knowledge on how different management strategies affect the development of the streamside forest is needed. Therefore, six field sites were established to study how various thinning regimes, performed in the streamside forest at first thinning, affect biodiversity of understory vegetation, trees, deadwood, and microclimate. In this report, the experimental design, study sites, and pre-thinning conditions are presented.

Material and methods

This study takes a starting point in the functionality concept of the strategic environmental objectives for good environmental consideration regarding forests beside lakes and streams (Andersson et al. 2013). Streamside forest dominated by even-aged spruce and ready for first thinning in a rotation forestry context was at focus. The hypothesis was that the functionality of these forests is likely to increase with an increased proportion of broadleaved trees. The search for field sites was concentrated to south-central Sweden to reduce the variation in climate and weather and shorten the transportation during field work. The main priority was to find sites with suitable characteristics of the streamside forest. Less focus was placed on the characteristics of the watercourse.

Table 1. Description of the thinning treatments applied in the streamside forests.

Abbreviation	Thinning treatment	Comment
Ctrl	No thinning.	The streamside forest is left to develop without interference.
Th	Thinning according to recommended thinning guides (Gallringsmall för barr och löv, https://www.skogskunskap.se/rakna-med-verktyg/skogsvard/gallringsmall/). The stem selection was made from below, i.e., the trees with the smallest diameters at breast height were first extracted. The tree species priority was first to extract pines, second broadleaves and third spruce, all with spatial considerations.	This treatment represents a common procedure for thinning production stands of Norway spruce.
IntTh	Intensive thinning, i.e., harvesting to half the basal area as in Th. The stem selection was made from below. The tree species priority was first to extract pines, second spruce and third broadleaves, all with spatial considerations.	Intensive thinning may promote regeneration and growth of an understory of small trees and shrubs, which increases the variation in the streamside zone.
AllCon	All conifers harvested.	Removal of all conifers opens the streamside zone for natural regeneration of new streamside vegetation dominated by broadleaved trees.

The study includes four thinning treatments representing varying thinning intensities performed in streamside spruce-dominated stands ready for first thinning (Table 1).

Going forward, we plan to assess the level of functionality of these streamside forests, for example, by evaluating 1) the proportion of broadleaf trees, 2) the forest canopy structure (single-layered or multi-layered), 3) the field-layer species composition and cover, and 4) trends in microclimate. The functionality is considered improved if thinning results in a higher proportion of broadleaf trees, a more complex canopy structure, or higher species diversity and/or cover of the field-layer vegetation compared with no thinning, while not significantly affecting the riparian microclimate.

Experimental design

Six field sites were established during 2022 in south-central Sweden: E312 Bredvik, E313 Bredvik, E314 Svanå, E315 Bäckhammar, E316 Munkfors, and E317 Lattao (Fig. 1). Henceforth, the sites are referred to by number and/or name (excluding "E"). At each site, four study plots were established beside a watercourse, except at 316 Munkfors, which had three plots (due to lack of space). The thinning treatments were randomly assigned to the study plots within each site. Hence, all treatments are represented at five sites but not replicated within site. The treatments Ctrl, IntTh, and AllCon are represented at 316 Munkfors, however, not the Th treatment.

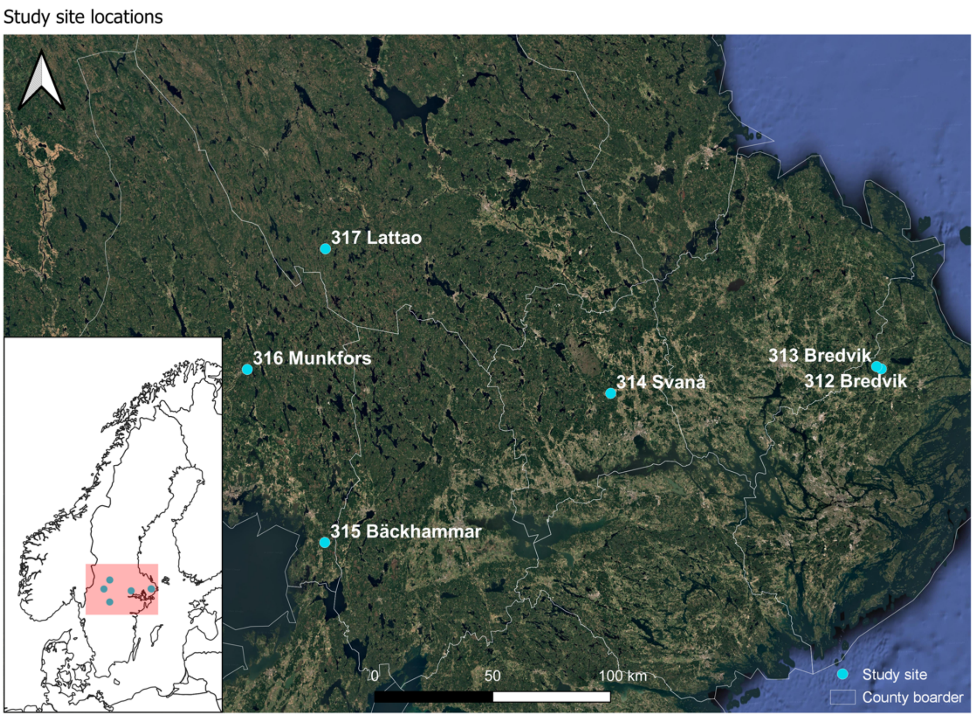


Fig. 1. Map of the locations of the study sites 312 and 313 Bredvik, 314 Svanå, 315 Bäckhammar, 316 Munkfors and 317 Lattao. © Google Satellite map.

The study plots are approximately 30 m long and 12 m wide, bordered by a watercourse on one side and a logging trail on the other (Fig. 2). On each short side, there is a 10 m long buffer subjected to the same thinning regime as the study plot, to reduce edge effects. At each site, the plots were placed on the same side of the watercourse in parts of the stand with similar characteristics. As a result, the plots sometimes lie side by side and sometimes at a distance (Fig. 3).

In each study plot, 16 permanent vegetation quadrats were established along four transects located perpendicular to the watercourse (Fig. 2). Each transect has four vegetation quadrats at fixed positions (positions 1–4), hereafter referred to as position within the plot. Positions 1, 2, and 3 are placed 3, 6, and 9 m, respectively, from the plot border beside the logging trail. Position 4 is placed outside the tree line to reflect the vegetation zone near the watercourse, which sometimes required adjusting to the terrain conditions (Fig. 3). The vegetation quadrats are marked with red metal bars in two opposite corners.

The experimental design comprises the following factors:

1. Study site (n=6)
2. Thinning treatment (n=4)
3. Position within the plot (n=4)
4. Time (repeated measurements)

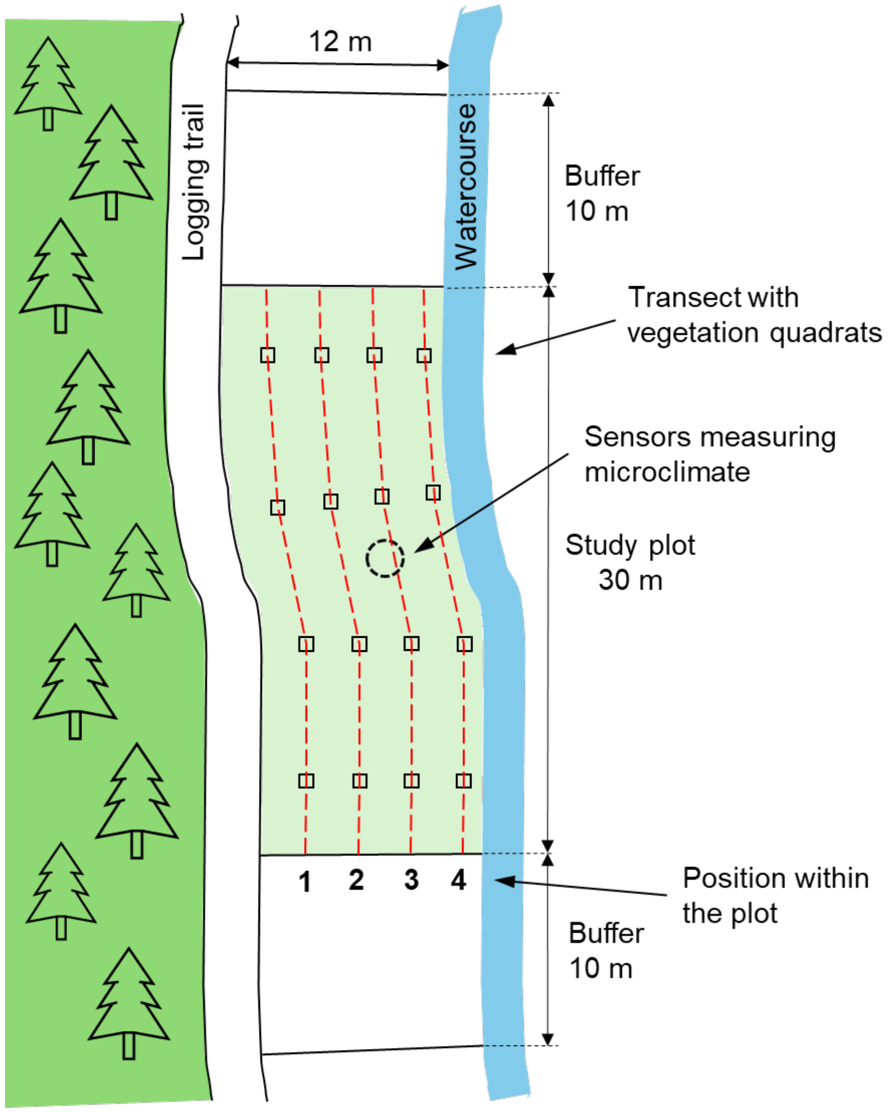
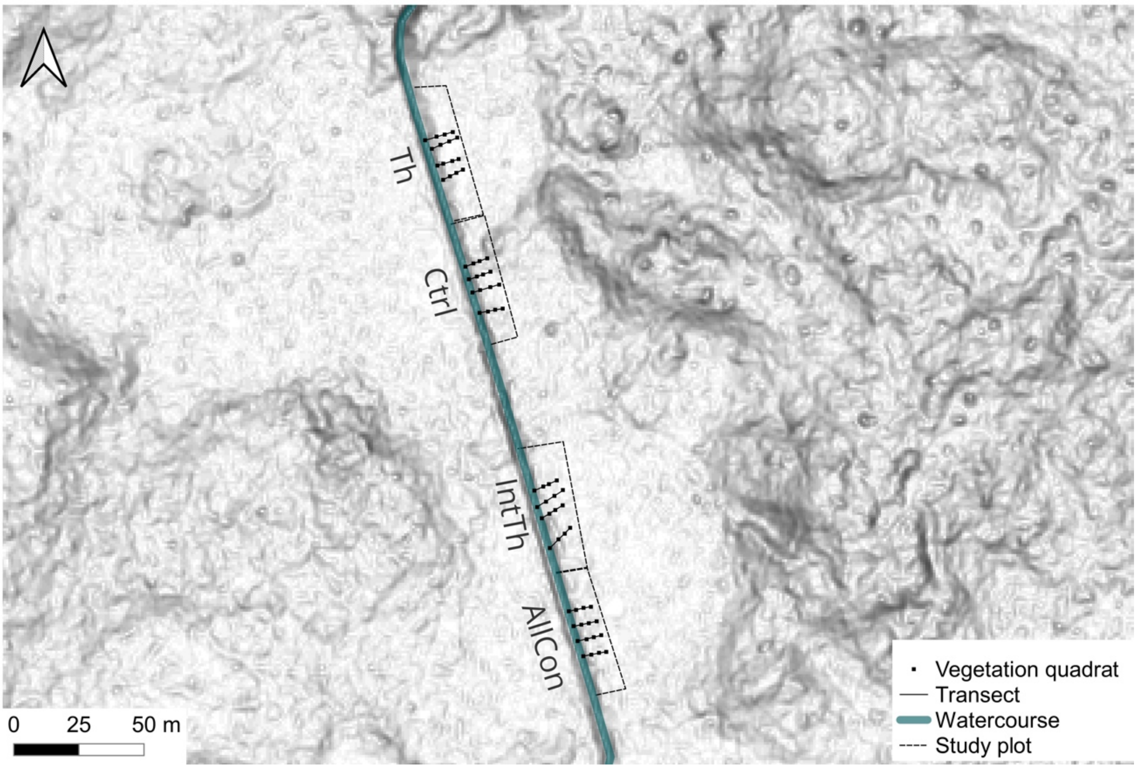


Fig. 2. Schematic design of a study plot. The buffers were thinned in the same way as the study plot. The study plot accommodates 16 permanent vegetation quadrats, sized 0.5 m × 0.5 m, representing four positions within the plot, arranged in four transects located perpendicular to the watercourse.

E312 Bredvik



E313 Bredvik

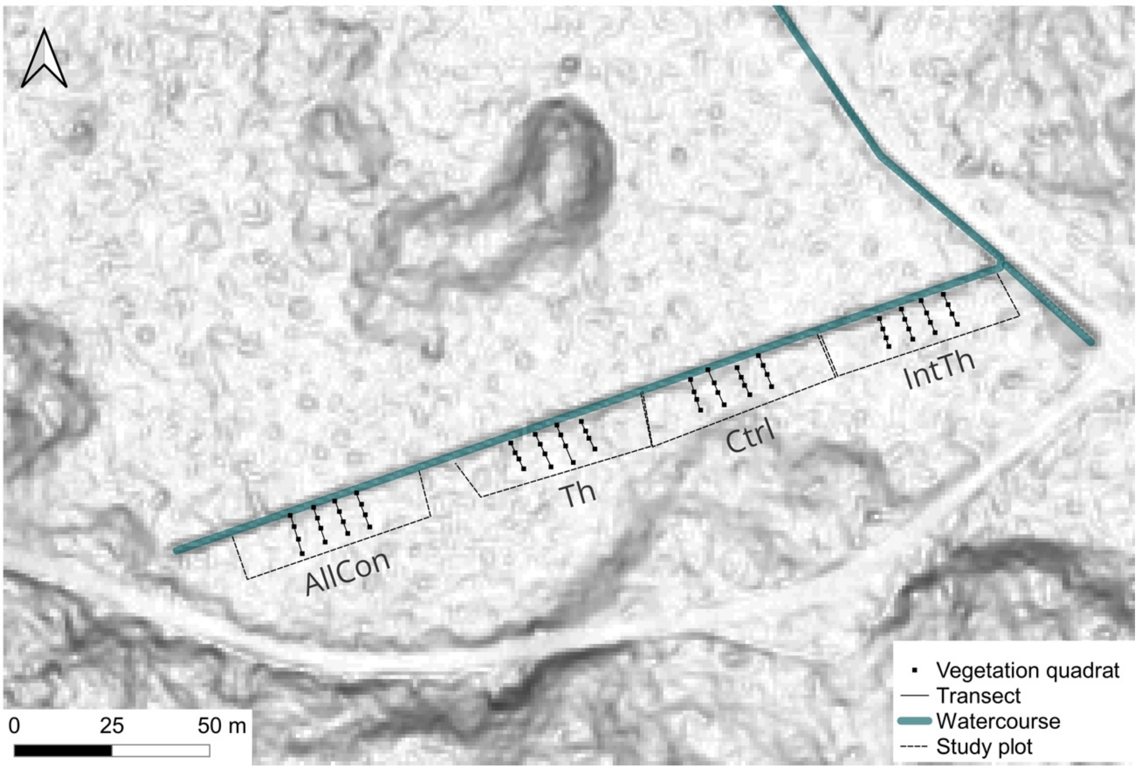


Fig. 3a. Maps of the 312 and 313 Bredvik sites showing the study plots with treatment abbreviations, overlaid on the national elevation model [1 m] © Lantmäteriet.

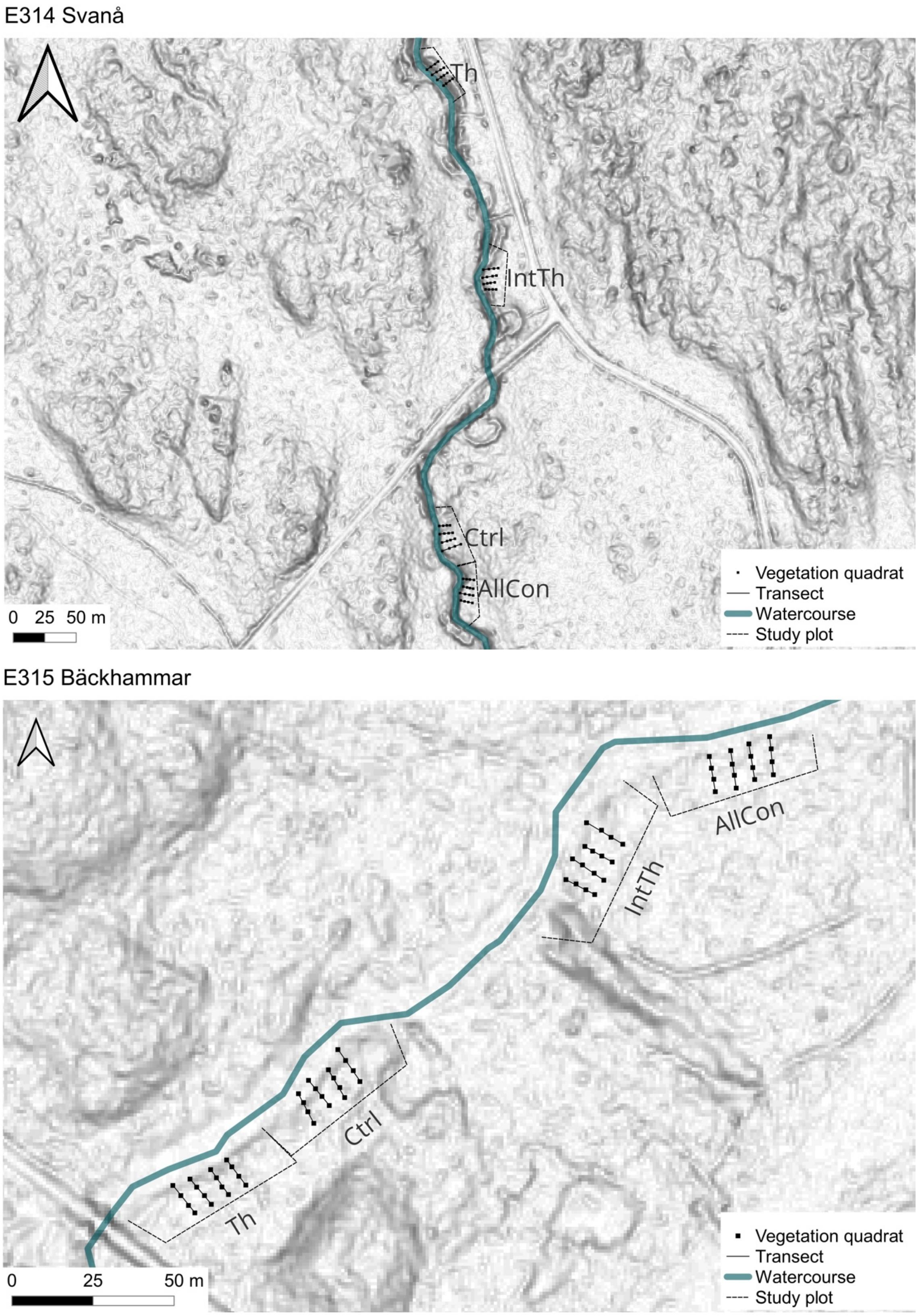
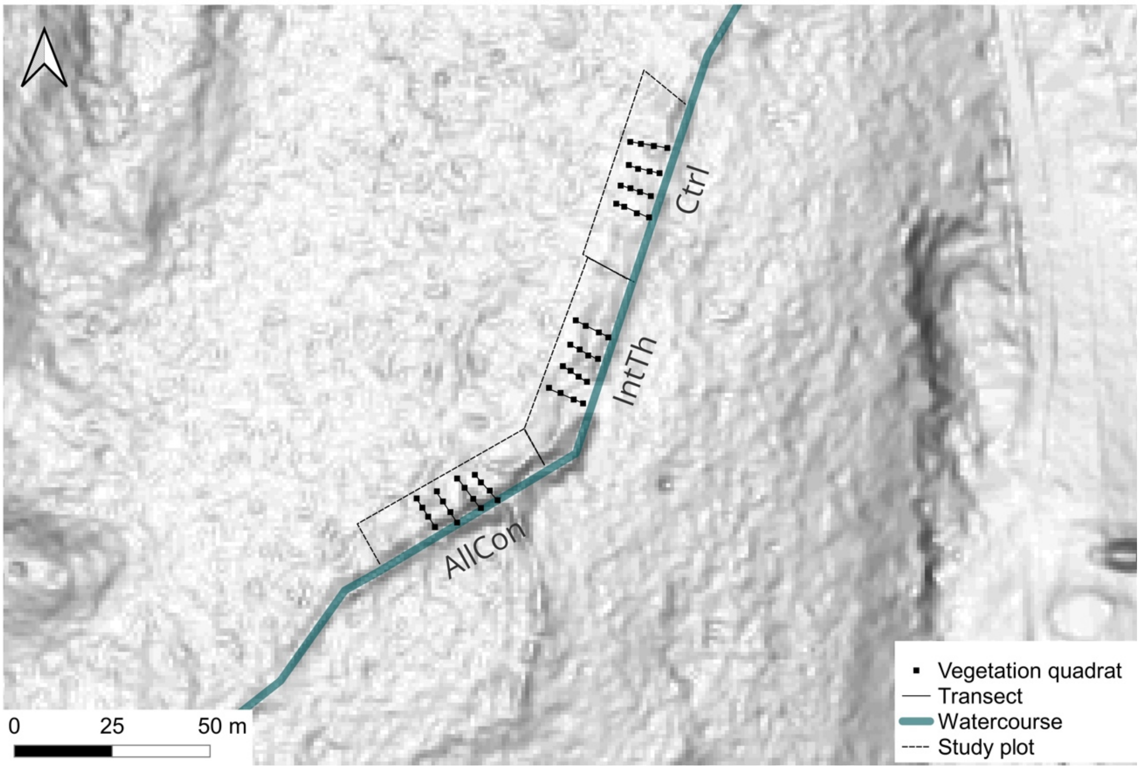


Fig. 3b. Maps of the 314 Svanå and 315 Bäckhammar sites showing the study plots with treatment abbreviations, overlaid on the national elevation model [1 m] © Lantmäteriet.

E316 Munkfors



E317 Lattao

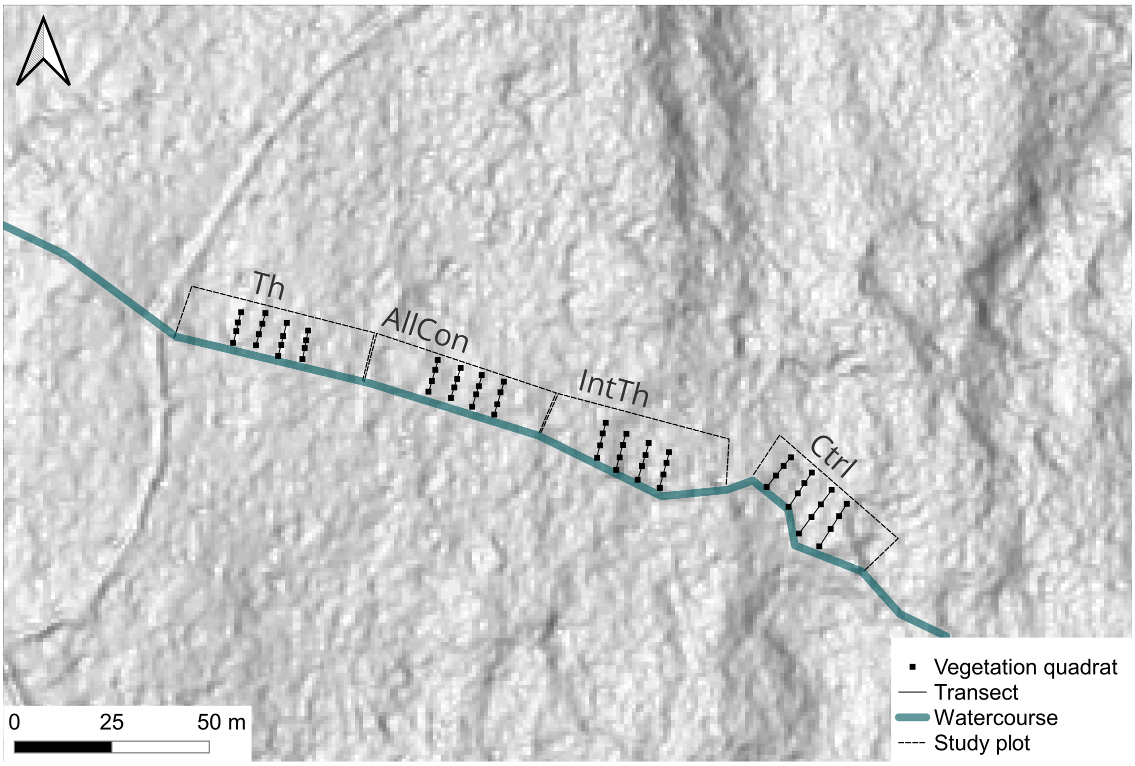


Fig. 3c. Maps of the 316 Munkfors and 317 Lattao sites showing the study plots with treatment abbreviations, overlaid on the national elevation model [1 m] © Lantmäteriet.

Thinning operations

The study plots were thinned using harvesters and forwarders, complemented with some manual felling. Before the operation, the trees to be harvested had been marked out. The harvester began the operation by making a logging trail along the study plots and placing tops, branches, and/or small trees on the trail to reinforce the soil (Fig. 4). Then the harvester felled all marked trees that could be reached from the trail, without entering the plots. Since the harvesters´ cranes were shorter than the width of the study plots, trees located near the watercourses and other trees out of reach were manually felled. The harvester moved all harvested logs close to the trail, and the forwarder collected the logs without entering the plots. No transportation was allowed in the study plots.

A. The harvester started the operation by creating a logging trail beside the study plots and reinforcing it with tops, branches, and/or small trees.

B. The harvester cut the trees in the study plots that could be reached from the logging trail and placed them close to the trail. Any remaining trees were manually felled and moved close to the trail by the harvester.

C. The forwarder used the logging trail when collecting the harvested trees.

Fig. 4. Thinning of the study plots at 313 Bredvik. Photos: E. Ring

The thinning treatments were planned to be performed during autumn 2022 and winter 2022/2023, i.e., after the pre-treatment measurements in 2022 and before the growing season in 2023. This was accomplished at four sites (Table 2). At 315 Bäckhammar and 316 Munkfors, the thinnings were postponed because of low soil bearing capacity (preventing off-road transportation by forestry machinery), and at 315 Bäckhammar, also a period with high fire hazard. This postponed post-treatment monitoring by one or two seasons (Table 2).

Site descriptions

The study sites are situated in flat terrain, except 317 Lattao, which is located on a gentle hillslope. The altitude varies from approximately 25 (Bredvik sites) to 380 (317 Lattao) m above sea level. The soils consist of peat or fine-textured mineral soil and were classed as moist or mesic-moist (Tables 2–3). The annual mean precipitation ranges from 583 to 813 mm, and the annual mean air temperature from 4.6 to 6.9°C (Table 2, Fig. 5). Meta-data of the sites have been published in the Silvaboreal database (www.silvaboreal.com).

The stands were ready for first thinning, except at 317 Lattao, which was not yet in need of thinning. The 317 Lattao site was still found suitable for the study. The 316 Munkfors site accommodated only three plots with similar stand characteristics. Here, the Th treatment was omitted because it was assumed to have the least impact on the vegetation development. The study plots were not cleaned from undergrowth before executing the thinnings. However, at 316 Munkfors, undergrowth cleaning had been performed in 2016.

The watercourse reaches bordering the study plots at 312 and 313 Bredvik consists of ditches. At 316 Munkfors the watercourse reach appears to have been straightened (Figs. 3c, 6 & 7). At 314 Svanå, the watercourse reach has a meandering but deepened channel along the plots, with excavated soil from the channel deposited on the side. Here, the study plots were located in between the deposited soil as much as possible (Fig. 3b). The watercourse reaches at 315 Bäckhammar and 317 Lattao were judged as natural streams.

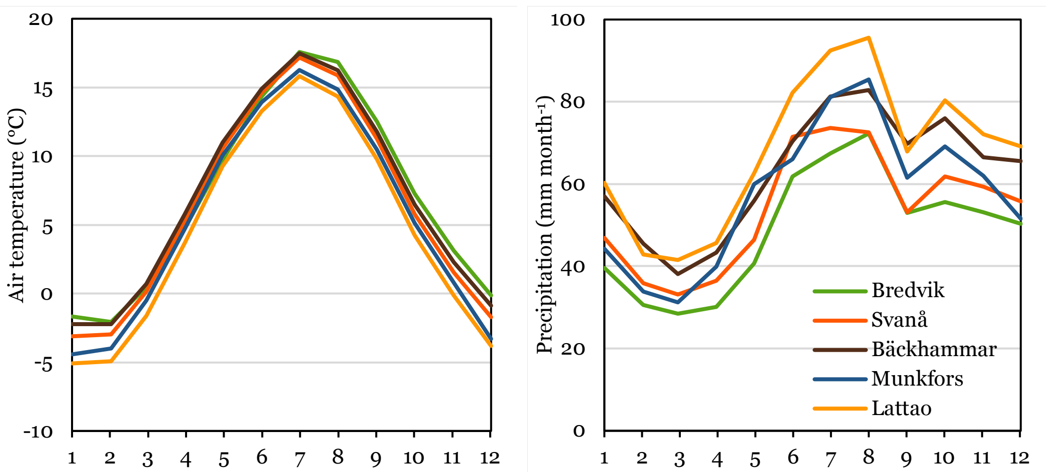


Fig. 5. Monthly mean air temperature and precipitation at the study sites for the 1991-2020 reference period. Data were retrieved from nearby gauging stations operated by the Swedish Hydrological and Meteorological Institute, SMHI (https://www.smhi.se/, accessed on 11 November 2022). The x-axes show month (1 – January to 12 – December).

Table 2. Site descriptions of 312 Bredvik, 313 Bredvik, 314 Svanå, 315 Bäckhammar, 316 Munkfors, and 317 Lattao.

	312 Bredvik	**313 Bredvik**	**314 Svanå**	**315 Bäckhammar**	**316 Munkfors**	**317 Lattao**
Location (SWEREF99 TM)	N6636215 E0691077	N6637358 E0689115	N6626135 E0576238	N6562728 E0455067	N6636158 E0422145	N6687280 E0455330
Altitude (m a.s.l.)[a]	24	25	57	93	163	377
Annual mean precipitation (mm yr^{-1})[b]	583 (Rimbo)	583 (Rimbo)	647 (Skultuna)	752 (Degerfors D)	686 (Munkfors)	813 (Fredriksberg)
Annual mean air temperature (°C)[b]	6.9 (Norrtälje 2)	6.9 (Norrtälje 2)	6.2 (Tomta)	6.8 (Degerfors)	5.5 (Forshult)	4.6 (Fredriksberg)
Character of the watercourse reach bordering the study plots	Ditch	Ditch	Deepened stream	Natural stream	Straightened stream	Natural stream
Character of the watercourse network (watercourse name)	Modified stream (-)	Ditch[c] (-)	Modified stream (Lillån)	Modified stream (Visman)	Modified stream (-)	Headwater natural stream (-)
Channel width (at ground surface) (m)	1.5-2.0	0.9-1.2	2.0-2.8	4-6	0.9-1.6	0.2-0.5
Perennial or temporary water flow	Temporary	Temporary	Perennial	Perennial	Perennial	Unclear
No. of study plots	4	4	4	4	3	4
Year of pre-treatment monitoring	2022	2022	2022	2022	2022	2022
Date of thinning	11 Oct. 2022	12 Oct. 2022	5-6 Sept. 2022	1 July 2024	10 Jan. 2024	17 Jan. 2023
First year of post-treatment monitoring	2023	2023	2023	2025	2024	2023

[a] Median altitude of all GPS-positions measured at each site.

[b] Data for the 1991–2020 reference period at nearby gauging stations (station names in brackets) operated by SMHI (https://www.smhi.se/, accessed on 11 November 2022).

[c] Judging from maps, the greater network is ditch or possibly modified stream.

Table 3. Soil conditions at the study plot centres at 312 Bredvik, 313 Bredvik, 314 Svanå, 315 Bäckhammar, 316 Munkfors, and 317 Lattao. The probe used to determine the soil type reached a maximum depth of 80 cm. Hence, '≥80 cm' indicates a peat depth of at least 80 cm.

Site	Treatment	312 Bredvik	313 Bredvik	314 Svanå	315 Bäckhammar	316 Munkfors	317 Lattao
Soil type (depth of peat/ topsoil organic layer, cm)	Ctrl	peat (≥80/0)	peat (≥80/0)	silt (-/1)	peat (≥80/4)	sand (29/7)	peat (≥80/8)
	Th	peat (≥80/0)	peat (50/0)	silt (-/0)	peat (≥80/5)	-	sandy till (13/5)
	IntTh	peat (≥80/0)	peat (≥80/0)	silt (-/1)	peat (≥80/3)	sand (17/2)	sandy-silty till (10/10)
	AllCon	peat (≥80/0)	peat (50/0)	silt (-/1)	peat (≥80/3)	fine sand (7/10)	sandy till (13/7)
Soil type according to geologic map[a]	All plots	fen peat	fen peat	glacial clay	fen peat	till	till
Soil moisture class[b]	Ctrl	mesic-moist	mesic-moist	moist	mesic-moist	mesic-moist	moist
	Th	mesic-moist	mesic-moist	moist	mesic-moist	-	moist
	IntTh	mesic-moist	mesic-moist	moist	mesic-moist	mesic-moist	mesic-moist
	AllCon	mesic-moist	mesic-moist	moist	mesic-moist	mesic-moist	mesic-moist
Surface structure class[b]	Ctrl	even	even	slightly uneven	even	even	even
	Th	even	even	even	even	-	even
	IntTh	even	even	even	even	even	even
	AllCon	even	even	even	even	slightly uneven	even

[a] Data were from the Geological Survey of Sweden (https://apps.sgu.se/kartvisare/kartvisare-jordarter-25-100.html, accessed on 16 September 2024).

[b] According to the instructions of the Swedish National Forest Inventory (https://www.slu.se/centrumbildningar-och-projekt/riksskogstaxeringen/om-riksskogstaxeringen/om-inventeringen/faltinstruktioner/).

312 Bredvik

313 Bredvik

314 Svanå

315 Bäckhammar

316 Munkfors

317 Lattao

Fig. 6. Photos taken along the watercourse reaches bordering the study sites. All photos were taken during the summer 2022, except for 314 Svanå, which was taken in mid-May 2022 somewhere along the stream (before the establishment of study plots). Photos: A. Hedlund and E. Ring (314 Svanå)

Fig. 7. Photos of the watercourse reaches bordering the study sites, taken in mid-April 2023. At this time, the thinning treatments had been performed at 312 and 313 Bredvik, 314 Svanå, and 317 Lattao, but not at 315 Bäckhammar and 316 Munkfors. Photos: E. Ring

Forest inventory

The trees in each plot were calipered at breast height (1.3 m) and tree species were recorded. The data were used to determine the basal area per plot. Dominant height was assessed as the average height of the three trees with the largest diameter in each plot. The age of these trees was determined by counting tree rings on increment cores. The site index of each site was calculated based on the age and height of the dominant trees using height curves (Johansson et al. 2013).

Basal area (per hectare) and dominant height were used to determine the basal area reduction in each treatment using thinning guides (https://www.skogskunskap.se/rakna-med-verktyg/skogsvard/gallringsmall/). The trees to be harvested were marked on-site following the tree diameter list. Trees with the smallest diameter at breast height were selected for harvest, taking into account their spatial distribution within the plot, until the target basal area was reached.

Soil properties were assessed at the centre of each study plot using a probe. Soil moisture and surface structure classes were determined according to the field instructions from the Swedish National Forest Inventory (https://www.slu.se/centrumbildningar-och-projekt/riksskogstaxeringen/om-riksskogstaxeringen/om-inventeringen/faltinstruktioner/).

Deadwood inventory

In June 2022, all plots were inventoried for large deadwood. Dimensions (diameter and length) were measured on all pieces of deadwood that were over 1 m long and over 5 cm mean diameter, both in the study plots and in the watercourses. The location of each deadwood piece was noted as either lying on the ground, suspended above the ground, standing, forming a bridge across, or lying in the channel of the watercourse. Each piece of deadwood was identified to species and decomposition status using the decay classification from Maser et al. (1979) with 1–5 indicating increasing level of decay for lying deadwood and 6 representing snags. Stumps were also counted.

Decay classes were defined as follows:

- Decay class 1: Fresh deadwood with green parts (needles, leaves)
- Decay class 2: Fresh deadwood without green parts (needles, leaves), branches present, bark intact
- Decay class 3: Most branches absent, bark starting to peel, wood hard
- Decay class 4: No branches, bark peeled, wood softening (knife penetrates couple of cm)
- Decay class 5: No branches, bark peeled, wood soft (knife penetrates completely), bryophytes/fungi present
- Decay class 6: Snags (standing deadwood)

The total volume (m^3) of deadwood in each plot was calculated using functions from Näslund (1947) for spruce, birch, and pine, and from Eriksson (1973) for aspen and alder, for full trees or full tree tops. A cylinder function was used to calculate the volumes for deadwood pieces and deadwood that could not be identified to species.

Inventory of understory vegetation

During the summer of 2022 (4 July–1 September), a total of 368 vegetation quadrats (sized 0.5 m × 0.5 m) were inventoried (64 vegetation quadrats per site, except at 316 Munkfors with 48 quadrats) and photographed. A 50x50 cm metal frame, with a 5x5 grid, placed over the corner bars was used for the inventory. The presence and cover of species were assessed by visual inspection of each of the 25 squares in the grid. Hence, an individual species could get a number from 0–25 depending on how many squares of the grid it was present in. This number was used as an abundance measure, and the cover was approximated as the abundance divided by the total number of squares, i.e., 25. Each species was individually assessed, which can result in a total cover exceeding 100%. Plants leaning into the frame but with the growing spot outside the frame were not included.

Species in the following families were grouped together: *Poaceae spp., Sphagnum spp., Fissidens spp.,* and *Rhytidiadelphus spp.,* while other species were analysed either at genus or species level. Photographs of the vegetation quadrats and a complete list of species are presented in Supplements 1–7.

Differences in species richness and Shannon index between the study sites, thinning treatments, and position within the plot, respectively, were tested using a non-parametric Kruskal Wallis test with a within-group Wilcox comparison, since the data were not normally distributed. Furthermore, non-metric multidimensional scaling plots (NMDS, functions vegdist and metaMDS from the vegan package (Oksanen et al. 2022)) were used to visualize the species composition. Fig. 18 should be interpreted as follows: each point represents a single vegetation quadrat, and the distance between points is a measure of their similarity (short distance–high similarity, long distance–low similarity). Ellipses were added to indicate the 95% confidence interval. Differences in the species composition were tested using PERMANOVA (function adonis2 from the vegan package; Oksanen et al. 2022).

The impact of zero-inflation (large number of zeros in the data) was assessed using NMDS and PERMANOVA after converting the species abundance numbers to presence/absence data. The result did not differ from that of the abundance matrix and are not presented further. All analyses and data visualizations were performed using R Studio version 2023.03.0+386 (R Core Team 2022).

Microclimate

Measurements of air and soil temperature, relative air humidity, soil moisture content, and light intensity were performed in all study plots using dataloggers (in total four loggers per study plot, see photo on cover page). Air and soil temperature were recorded every 15 minutes using a Thermologger and a TMS-4 datalogger, respectively (both loggers from Tomst Ltd., www.tomst.com), while relative air humidity was recorded every 15 minutes using an EL-USB-2 Data Logger (Lascar Electronics Ltd.). All dataloggers were placed approximately 5 m from the edge of the watercourse. The TMS-4 measured air temperature at 2 and 15 cm above ground as well as 6 cm below the surface of the ground. Air temperature and relative humidity were measured at 1.3 m height, with loggers mounted on the north side of a tree trunk to reduce the effect of solar radiation. All air sensors were shielded by removable white plastic shields allowing good ventilation and protecting the sensors from direct sunlight. The TMS-4 was also covered by a metal cage to protect it against disturbance from wild boar.

Additionally, the TMS-4 measured the average soil moisture content every 15 minutes for the top 10 cm of the soil profile based on the soil surface using the time-domain transmission (TDT) method (Wild et al. 2019). In this report, the raw TDT data are presented. Recorded TDT-values typically range from 100 (ambient air) to 3500 (distilled water, Wild et al. 2019). In the future, these raw TDT data will be transformed into volumetric soil moisture content using calibration curves specific to the soil types. In this report, we can compare the relative difference in TDT-values among the plots in a site with similar soil type.

On top of each metal cage, a light logger (HOBO, Onset Computer Corporation, Bourne, MA, USA) was attached with a zip-tie to ensure that the sensor was facing straight upwards. Light intensity (lux) was continuously measured at 1-h intervals beginning on 14 June 2022. The time series presented in this report all end on 5 September 2022 when the first site was thinned.

Results

The streamside forest before and after thinning

The trees in the study plots were between 34 and 43 years old and the site index varied between G31 and G35 (Table 4). Site index, stand age, basal area, dominant height, and tree canopy coverage were lowest for 317 Lattao. This stand had not reached a basal area where thinning is typically applied, but it was still possible to achieve the goals of the treatment (Figs. 9, 12 & 13, Table 4). Broadleaved trees were most prevalent, in terms of basal area, at 314 Svanå and 316 Munkfors (Fig. 10, Table 4). Alder dominated at 314 Svanå and birch at 316 Munkfors (Fig. 8, Table 4). Sites 312 and 313 Bredvik had few or no broadleaved trees.

Fig. 8. Part of the AllCon study plot at 314 Svanå in April 2023, after thinning. This plot had the highest basal area of broadleaved trees among the AllCon plots at the six study sites, consisting exclusively of alder. The alders grow on the streambank to the left in the photo. Photo: E. Ring

In the Th treatment at 312 and 313 Bredvik, 314 Svanå, and 315 Bäckhammar, the basal area was reduced by 32 to 43% compared with before thinning (Fig. 9). Since the stand at 317 Lattao was not yet in need of thinning, the harvested proportion in the Th treatment was only 13% to meet the requirements of the thinning guide.

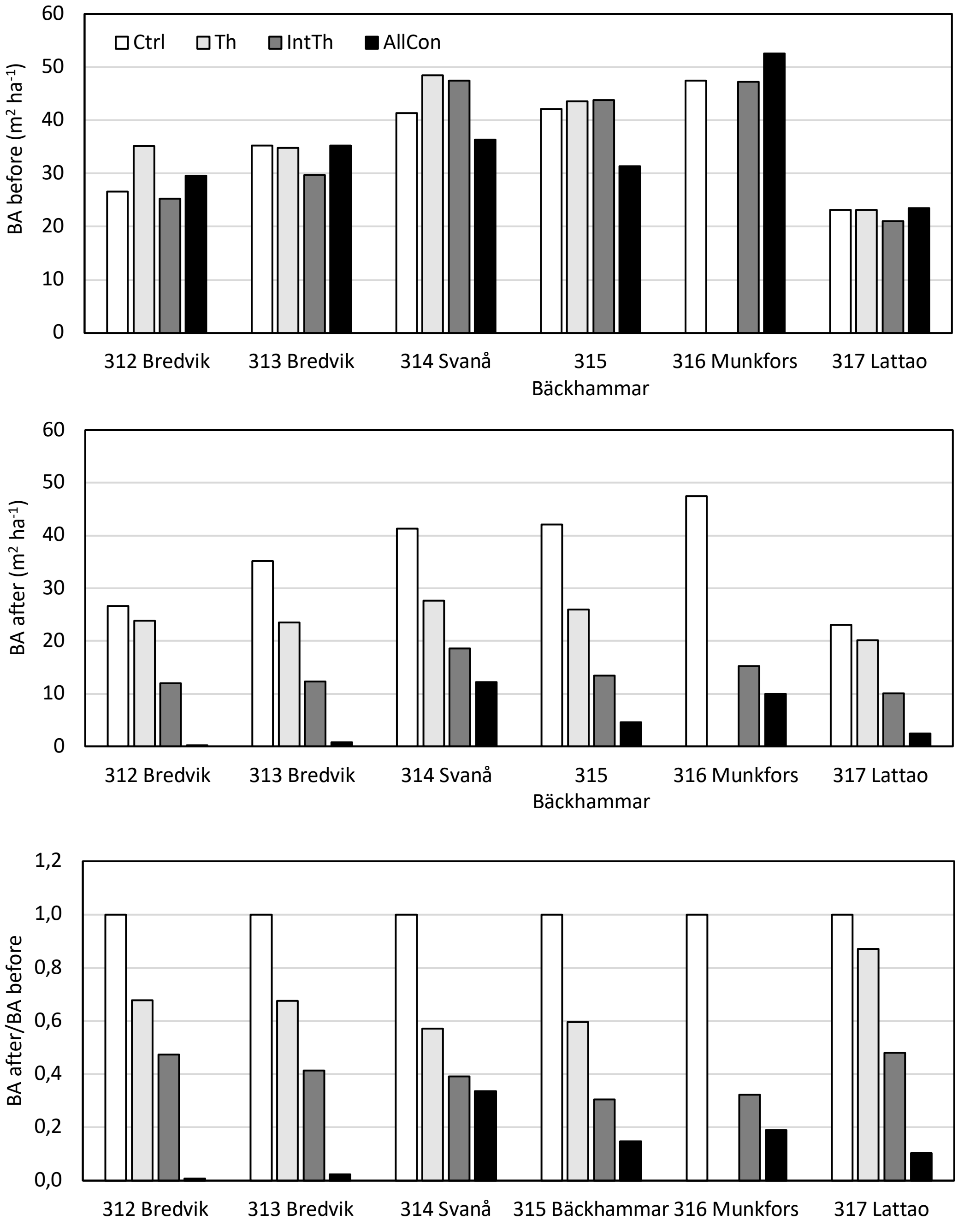


Fig. 9. Total basal area, BA, before (top) and after (middle) thinning, and the BA proportion remaining after thinning (bottom), by treatment at the study sites. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

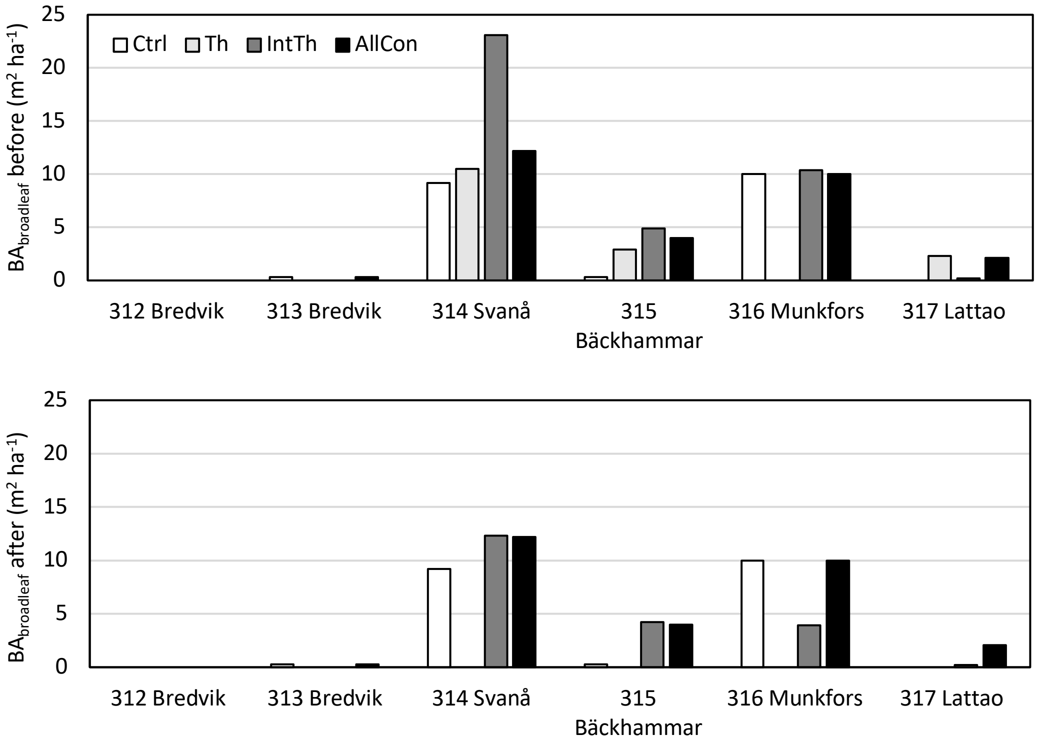


Fig. 10. Basal area, BA, of birch, alder and willow before (top) and after (bottom) thinning by treatment at the study sites. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

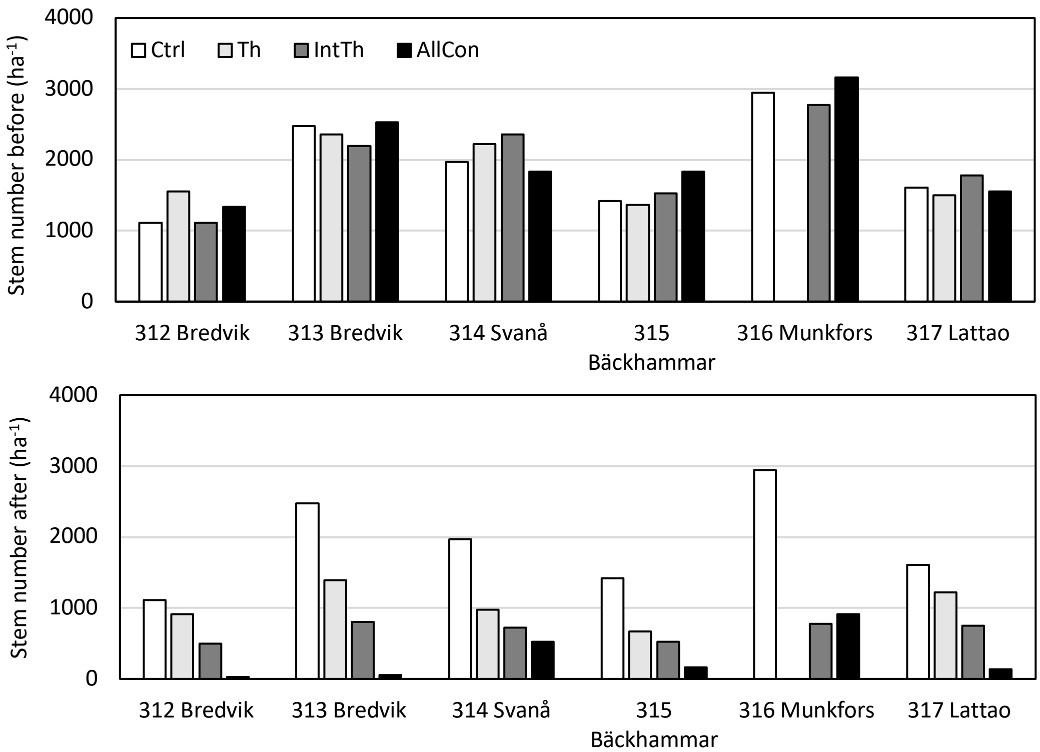


Fig. 11. Stem number before (top) and after (bottom) thinning by treatment at the six study sites. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

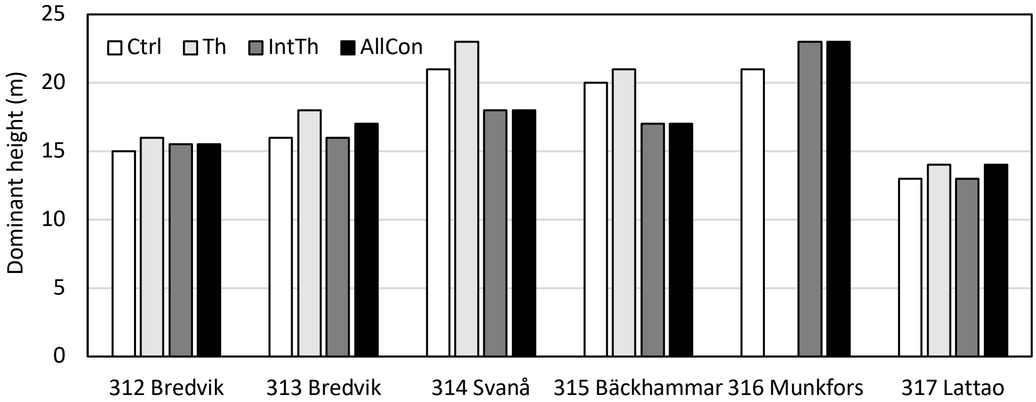


Fig. 12. Dominant tree height (m) before thinning by treatment at the six study sites. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

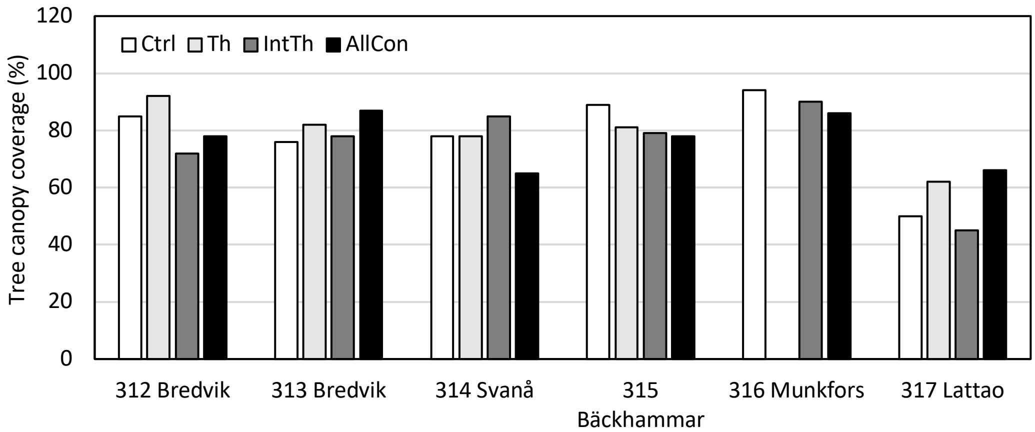


Fig. 13. Tree canopy coverage (%) before thinning by treatment at the six study sites. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

Table 4. Stand characteristics of the streamside forest growing in the study plots before and after thinning at 312 Bredvik, 313 Bredvik, 314 Svanå, 315 Bäckhammar, 316 Munkfors, and 317 Lattao. Basal area after thinning was based on caliper data before thinning and calculated for trees not marked for felling. Tree canopy coverage was assessed by visual inspection of the coverage at the study plot centre. The tree-stand inventories were performed between 20 June and 2 July 2022. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

Site Id Site index (m) Stand age (yrs)	Study plot	Dominant height(m)	Basal area before thinning (m^2 ha^{-1})							Basal area after thinning (m^2 ha^{-1})						Stem number (ha^{-1})		Tree canopy coverage (%)
			Total	Spruce	Pine	Birch	Alder	Willow	Other	Total	Spruce	Pine	Birch	Alder	Willow	Before thinning	After thinning	Before thinning
312 Bredvik	Ctrl	15.0	26.6	26.6						26.6	26.6					1111	1111	85
G33	Th	16.0	35.1	35.1						23.8	23.8					1556	917	92
Age 35	IntTh	15.5	25.3	25.3						12.0	12.0					1111	500	72
	AllCon	15.5	29.6	29.6						0.2	0.2					1333	28	78
313 Bredvik	Ctrl	16.0	35.2	31.2	3.7	0.3				35.2	31.2	3.7	0.3			2472	2472	76
G33	Th	18.0	34.8	34.1	0.7					23.5	23.5					2361	1389	82
Age 36	IntTh	16.0	29.7	28.8	0.9					12.3	12.3					2194	806	78
	AllCon	17.0	35.2	33.2	1.7	0.3				0.8	0.5		0.3			2528	56	87
314 Svanå	Ctrl	21.0	41.3	32.1		1.2	7.5	0.5		41.3	32.1		1.2	7.5	0.5	1972	1972	78
G34	Th	23.0	48.5	38.0		7.8	2.7			27.7	27.7					2222	972	78
Age 40	IntTh	18.0	47.4	24.0		5.0	13.1	5.0	0.3	18.6	6.3		1.2	6.1	5.0	2361	722	85
	AllCon	18.0	36.3	24.1			12.2			12.2				12.2		1833	528	65
315 Bäckhammar	Ctrl	20.0	42.1	36.5	5.3	0.3				42.1	36.2	5.3	0.3			1417	1417	89
G34	Th	21.0	43.6	36.9	3.8	2.9				26.0	26.0					1361	667	81
Age 35	IntTh	17.0	43.8	36.7	2.2	1.4	3.5			13.4	8.7	0.5	1.3	2.9		1528	528	79
	AllCon	17.0	31.4	25.8	1.6	0.1	3.9			4.6	0.6		0.1	3.9		1833	167	78
316 Munkfors	Ctrl	21.0	47.5	32.7	4.8	5.1	4.9			47.5	32.7	4.8	5.1	4.9		2944	2944	94
G35	IntTh	23.0	47.2	16.8	20.0	10.4				15.2	10.6	0.7	3.9			2778	778	90
Age 43	AllCon	23.0	52.6	13.9	28.8	9.8	0.2			10.0			9.8	0.2		3167	917	86
317 Lattao	Ctrl	13.0	23.1	21.7	1.4					23.1	21.7	1.4				1611	1611	50
G31	Th	14.0	23.2	20.9		2.3				20.2	20.2					1500	1222	62
Age 34	IntTh	13.0	21.0	19.7	1.1	0.2				10.1	9.9		0.2			1778	750	45
	AllCon	14.0	23.5	21.4		2.1				2.4	0.3		2.1			1556	139	66

Deadwood before thinning

Total deadwood volume ($m^3\ ha^{-1}$) varied across and within sites. Some plots almost lacked deadwood. The largest volumes were recorded in two plots at 314 Svanå (Fig. 14). The volume of lying deadwood exceeded the volume of standing deadwood at all sites.

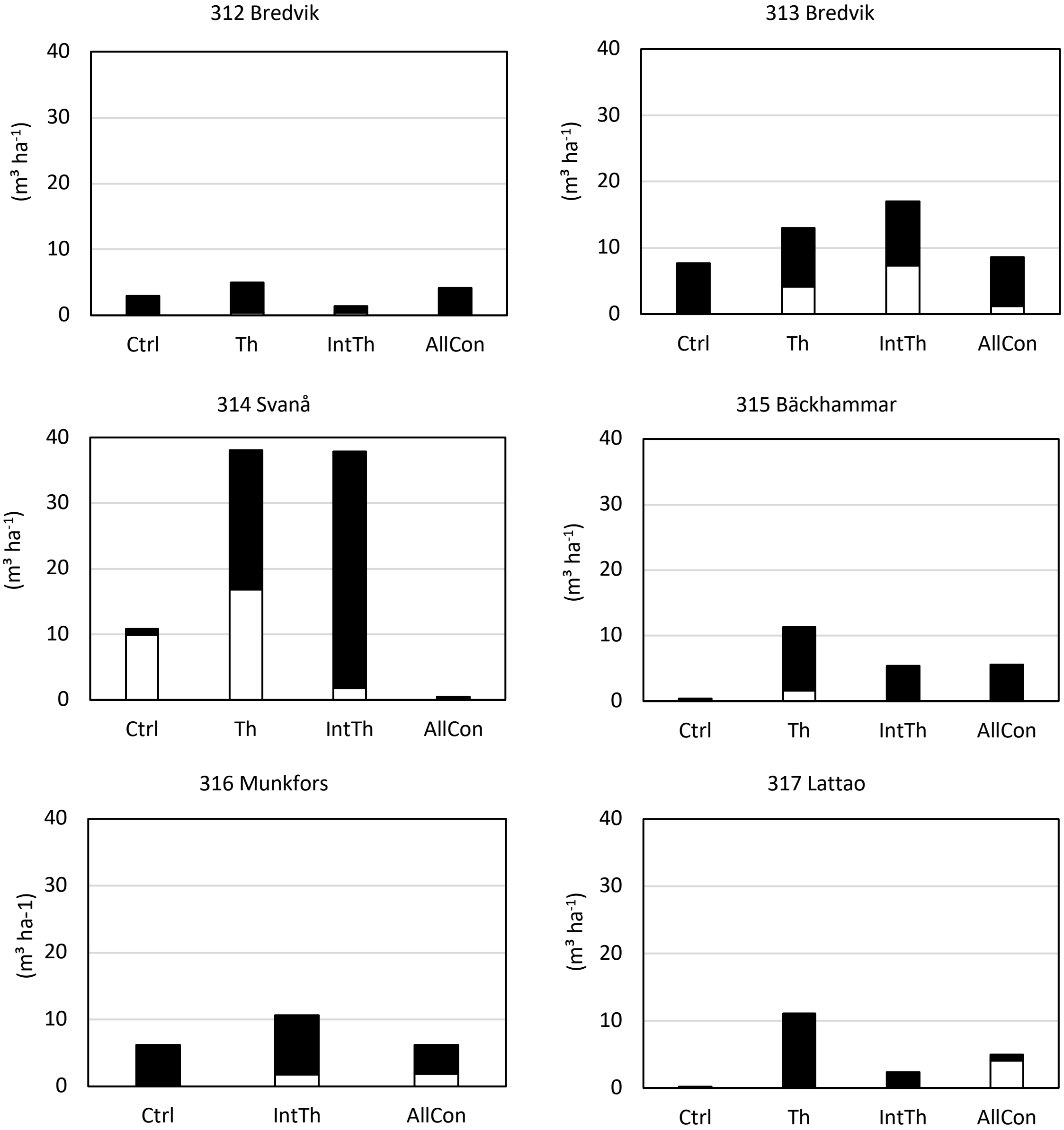


Fig. 14. Total deadwood volume ($m^3\ ha^{-1}$), separated for standing (□) and lying deadwood (■), in the study plots at the six study sites. The plot area was 30 × 12 m^2. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

On four sites (312 and 313 Bredvik, 315 Bäckhammar, and 316 Munkfors) deadwood of decay class 3 was most common (Fig. 15). Decay class 3 represents wood that is not fresh and has visible signs of ongoing decay (peeling bark, broken branches) but is not yet soft (Maser et al. 1979). The lowest number of deadwood pieces was found at 314 Svanå and 317 Lattao. The 317 Lattao site had the highest number of highly decomposed deadwood pieces (decay class 5). The number of standing deadwood pieces (decay class 6) was lower than the total number of lying deadwood pieces at all sites (Fig. 15).

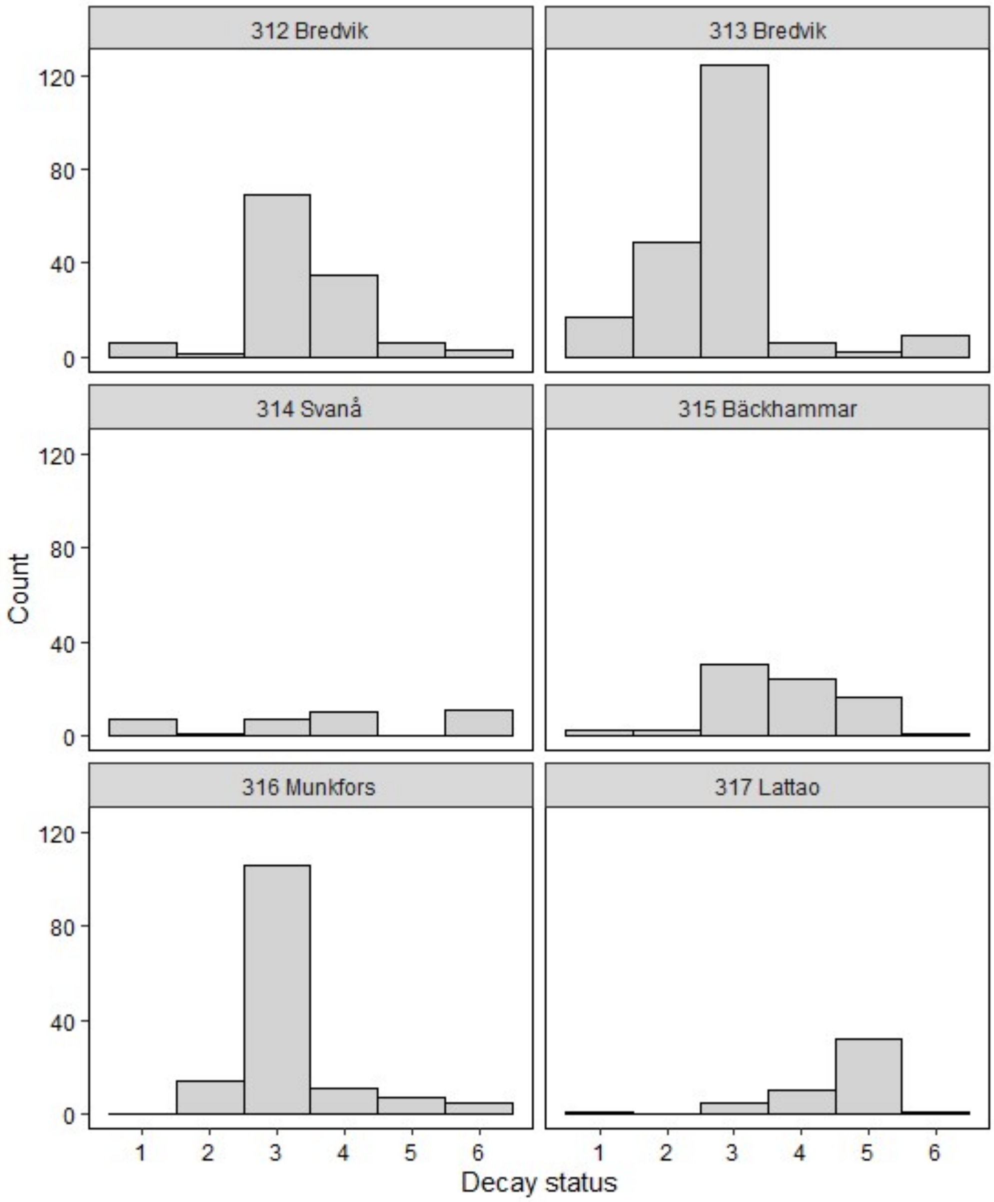


Fig. 15. Number of deadwood pieces within decay classes 1–6 by site (for all plots combined).

Understory vegetation before thinning

The average vegetation cover of all species ranged from 77 ± 53% in 316 Munkfors to 200 ± 55% in 317 Lattao (Fig. 16A). The range was narrower between thinning treatments (117–133%) (Fig. 16B) and positions within the plot (117–133%) (Fig. 16C). It should be noted that only species with an average cover above 5% are included in Fig. 16 for ease of interpretation.

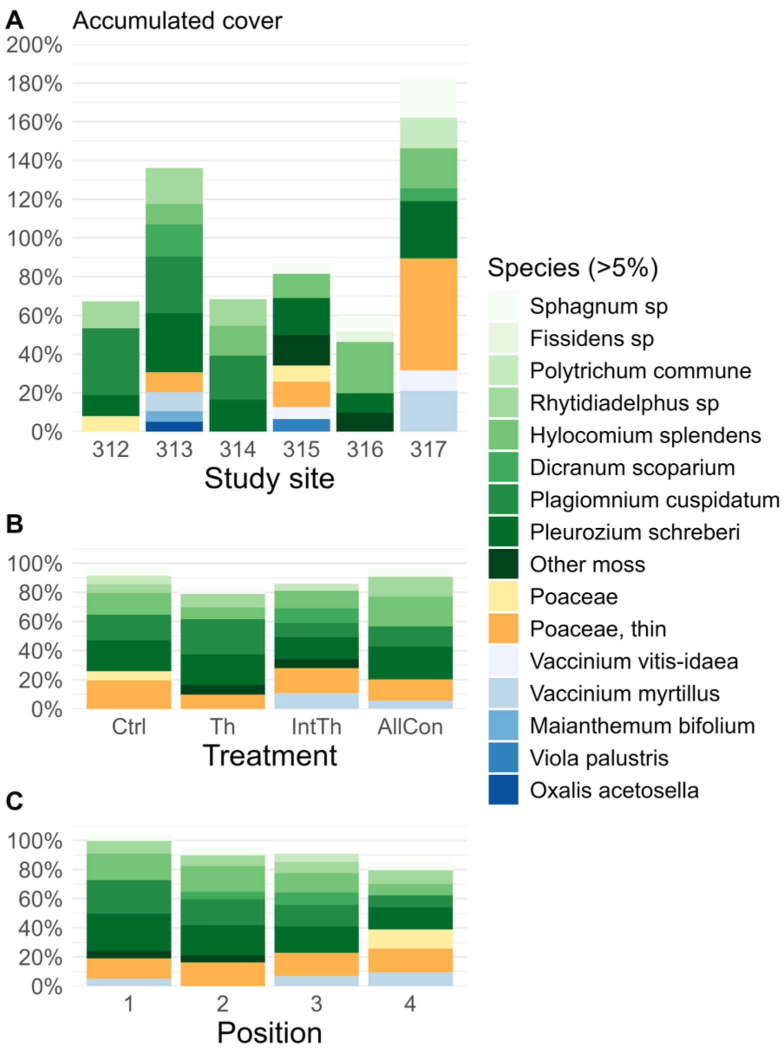


Fig. 16. Average accumulated cover of species with > 5% total cover in 2022, before thinning, by study site (A), thinning treatment (B), and position within the plot (C), where position 4 is closest to the watercourse. Green shades represent mosses, yellow shades grasses and blue shades dwarf scrubs or other vascular plants. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

Species richness (i.e., average species incidence of the vegetation quadrat grid) and diversity (Shannon index) are presented by site, thinning treatment, and vegetation quadrat position in Fig. 17. Among study sites there were differences in both species richness and diversity (see Fig. 17A and 17D), for example when comparing 317 Lattao to 316 Munkfors ($p < 0.05$ for both richness and diversity). There was no statistical difference ($p > 0.05$) between the treatments in either species richness or Shannon index.

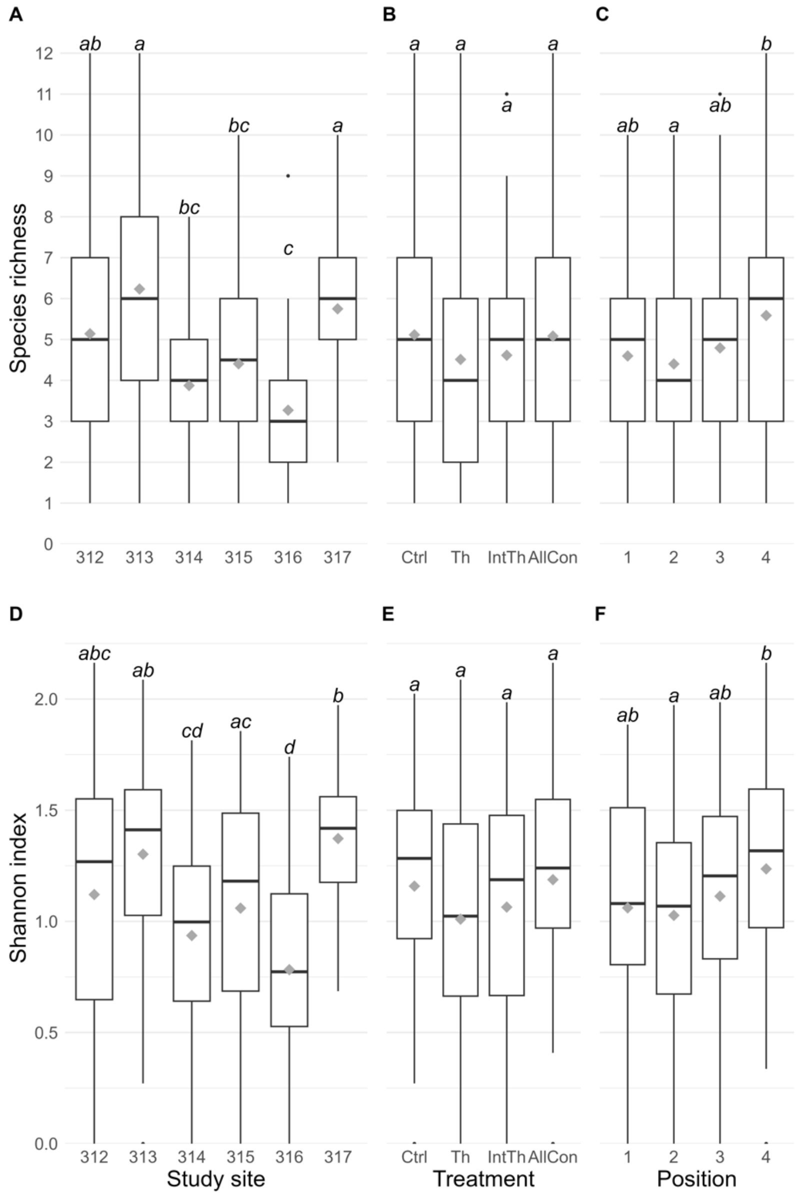


Fig. 17. Boxplots of species richness and Shannon index for 2022 before thinning, by study site (A, D), thinning treatment (B, E) and position within the plot (C, F), where position 4 is closest to the watercourse. Grey diamonds display the average, while black points are outliers. Study site IDs are shown by their site number. Different letters denote differences ($p < 0.05$) based on a Kruskal-Wallis test with Wilcox pairwise comparison. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

Vegetation richness and diversity were similar between positions; however, position 2 was different from position 4 ($\chi^2 = 10.509$, $p = 0.0147$ and $\chi^2 = 10.432$, $p = 0.01523$ respectively).

Significant differences in species composition were detected between study sites ($F = 17.11$, $p < 0.001$, $R^2 = 0.19$), thinning treatments ($F = 2.410$, $p < 0.001$, $R^2 = 0.02$), and position within the plot ($F = 3.754$, $p < 0.001$, $R^2 = 0.03$), respectively. However, the rate at which these comparisons explained the variation in species composition was low ($R^2<0,2$), with study site having the highest R^2. This result is also corroborated by the clearer visual distinction for study sites indicated in Fig. 18A.

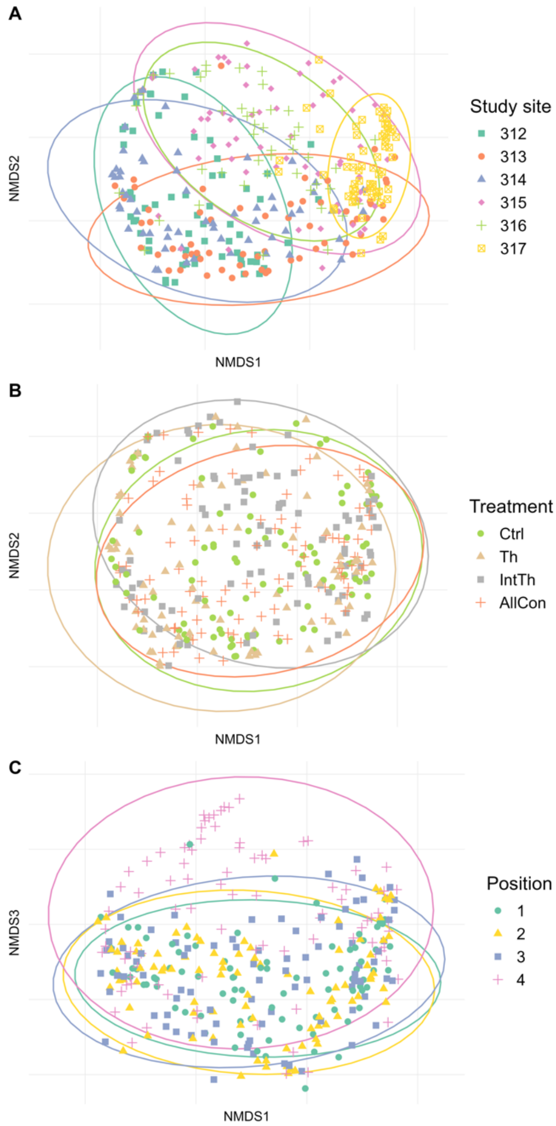


Fig. 18. NMDS plots to visualise the species composition in 2022, before thinning, among study sites (A), thinning treatments (B) and positions within the plot (C) where position 4 is closest to the watercourse. The NMDS stress level was 0.18. A significant difference using a PERMANOVA was found for all three comparisons. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

Microclimate before thinning

Air and soil temperature, soil moisture, relative humidity, and light intensity during the summer of 2022 are presented in Figs. 19–24 and Suppl. 8. The soil temperature at 6 cm depth (T1) was the least variable of all of the temperatures measured, with low standard deviations (SD); in the warmest month (August) the average soil temperature (mean ± SD) ranged from 15.68± 1.67 °C at 312 Bredvik to 11.59 ± 0.85 °C at 317 Lattao (Suppl. 8, Table S1, Fig. 20, top). Temperatures at the soil surface (2 cm, T2; 15cm, T3) were more variable, with higher standard deviations and average temperatures. In the warmest month (August), average soil surface temperatures ranged from 16.55 ± 4.85 °C at 312 Bredvik to 13.98 ± 4.28 °C at 317 Lattao (Suppl. 8, Table S1). The range differences were small, typically within 1 °C, across the experimental plots at each site during the pre-treatment phase (Fig. 20, Suppl. 8).

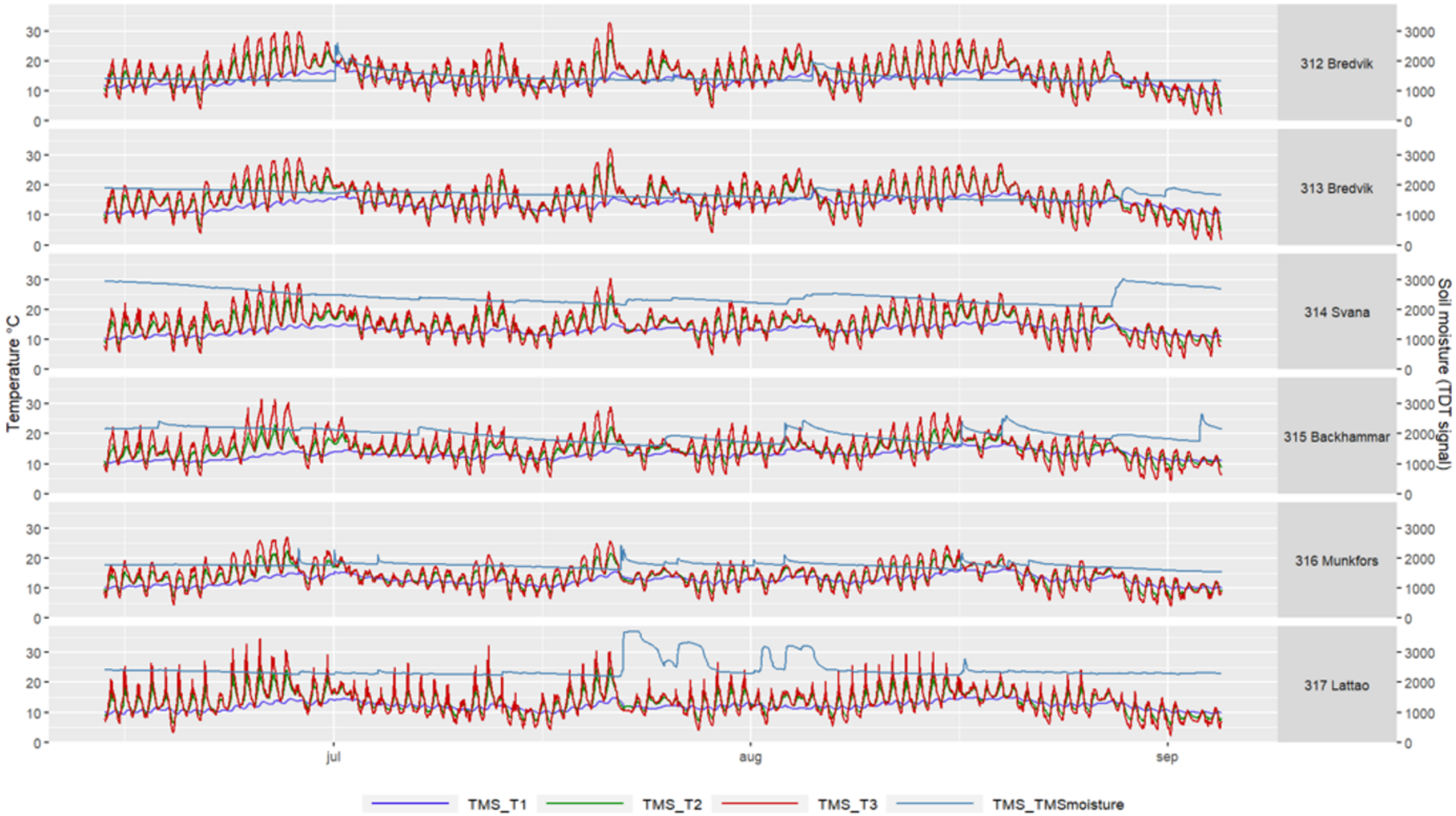


Fig. 19. Soil moisture of the top 10 cm of soil (based on soil surface, regardless of soil type) and temperature at 6 cm soil depth (T1), air temperature 2 cm above the soil surface (T2), and air temperature 15 cm above the soil surface (T3) recorded between 14 June and 5 September 2022 in the control plots at 312 and 313 Bredvik, 314 Svanå, 315 Bäckhammar, 316 Munkfors, and 317 Lattao.

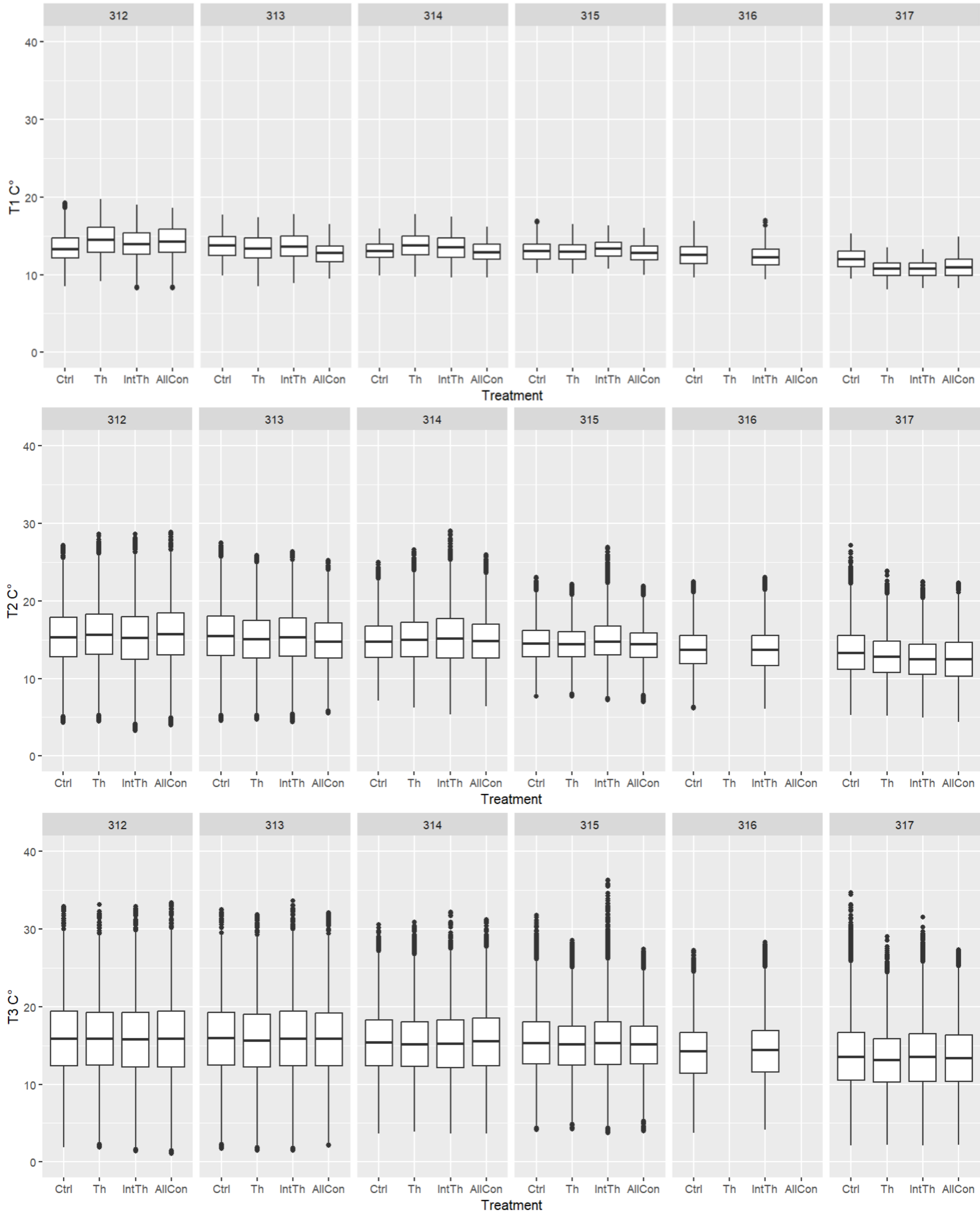


Fig. 20. Boxplots of soil and air temperature (°C) data recorded between 14 June and 5 September 2022 at 312 and 313 Bredvik, 314 Svanå, 315 Bäckhammar, 316 Munkfors, and 317 Lattao. T1 – temperature at 6 cm soil depth (top), T2 – air temperature 2 cm above the soil surface (middle), T3 – air temperature 15 cm above the soil surface (bottom). Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

Soil moisture data have not yet been converted to volumetric soil moisture content, but we can compare the values relative to each other within the sites because plots within sites have similar soil type. Soil moisture did not seem to vary systematically across treatments within sites (Figs. 21, 22G & 22H, Suppl. 8).

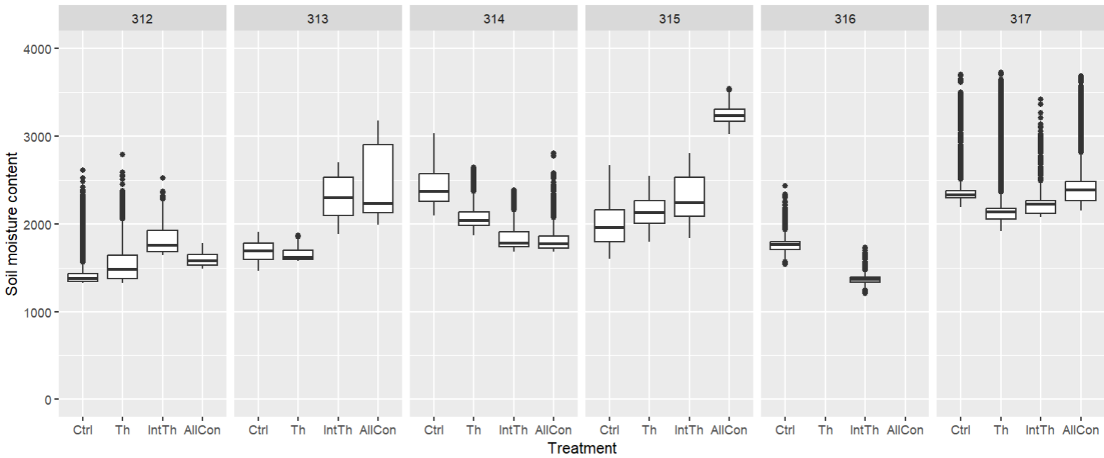


Fig. 21. Boxplots of soil moisture data (raw TDT signal) recorded between 14 June and 5 September 2022 at 312 and 313 Bredvik, 314 Svanå, 315 Bäckhammar, 316 Munkfors, and 317 Lattao. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested. Recorded TDT-values typically range from 100 (ambient air) to 3500 (distilled water, Wild et al. 2019).

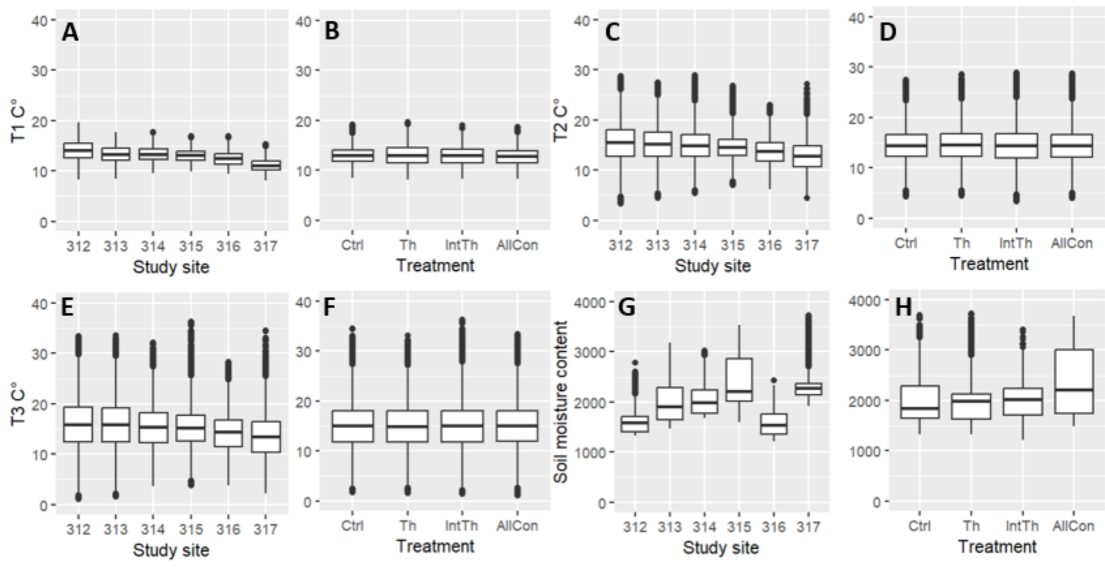


Fig. 22. Boxplots by study site and treatment, respectively, of soil temperature at 6 cm depth (T1) are presented in A and B, air temperature 2 cm above the soil surface (T2) is presented in C and D, air temperature 15 cm above the soil surface (T3) is presented in E and F, and soil moisture (raw TDT signal) of the top 10 cm of the soil is presented in G and H. All data were recorded between 14 June and 5 September 2022 in four study plots at 312 and 313 Bredvik, 314 Svanå, 315 Bäckhammar, 316 Munkfors (three plots), and 317 Lattao, respectively. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

The average relative humidity (%) of the air at 1.3 m height was similar across sites (Fig. 23), with the driest month, June, having 76.93 ± 17.59%, and the wettest month, September, having 88.84 ± 14.51% (Suppl. 8).

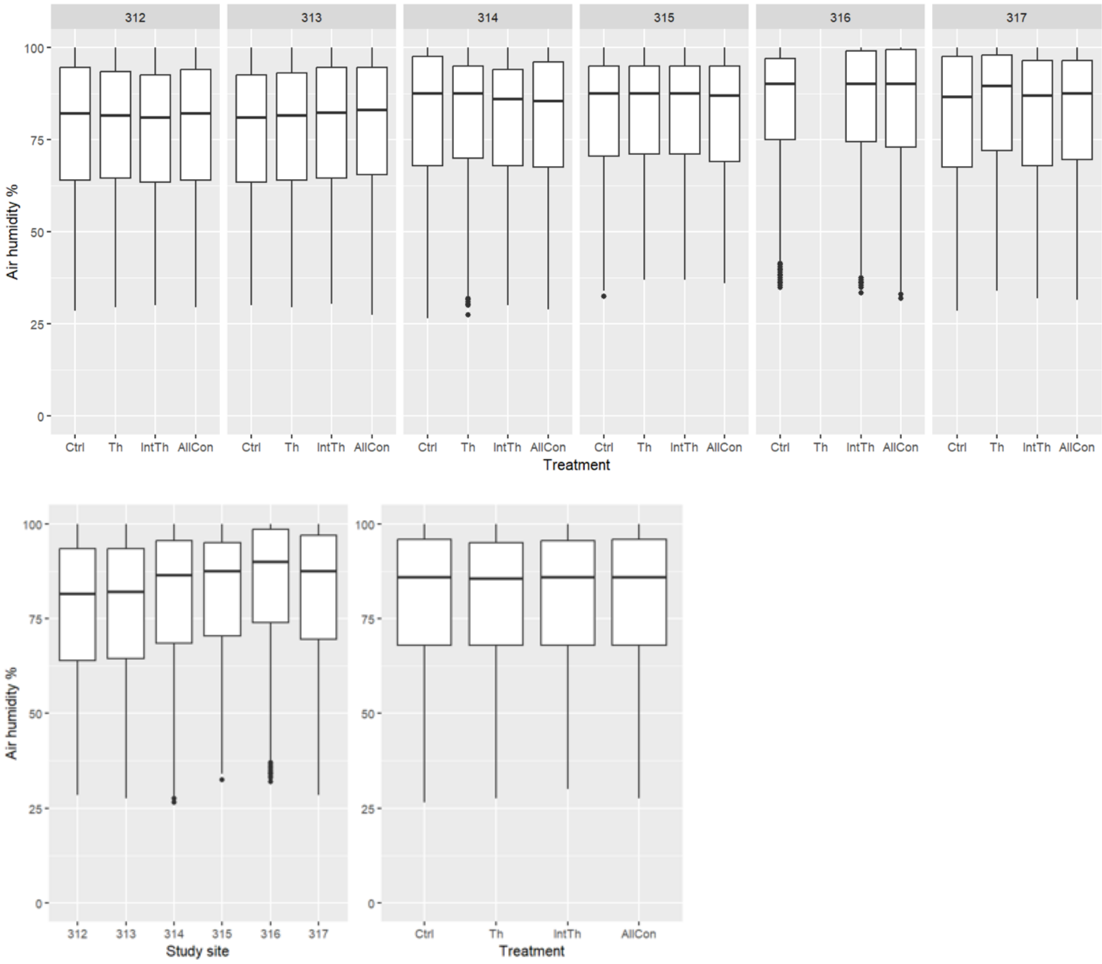


Fig. 23. Boxplots of relative air humidity data recorded between 14 June and 5 September 2022 at 312 and 313 Bredvik, 314 Svanå, 315 Bäckhammar, 316 Munkfors, and 317 Lattao (top). Boxplots by study site and treatment are shown below. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, AllCon – All conifers harvested.

Light intensity showed large variation across sites and plots. The highest intensities (i.e., the highest light) were recorded at 317 Lattao, and the lowest intensities were recorded at 316 Munkfors (Fig. 24).

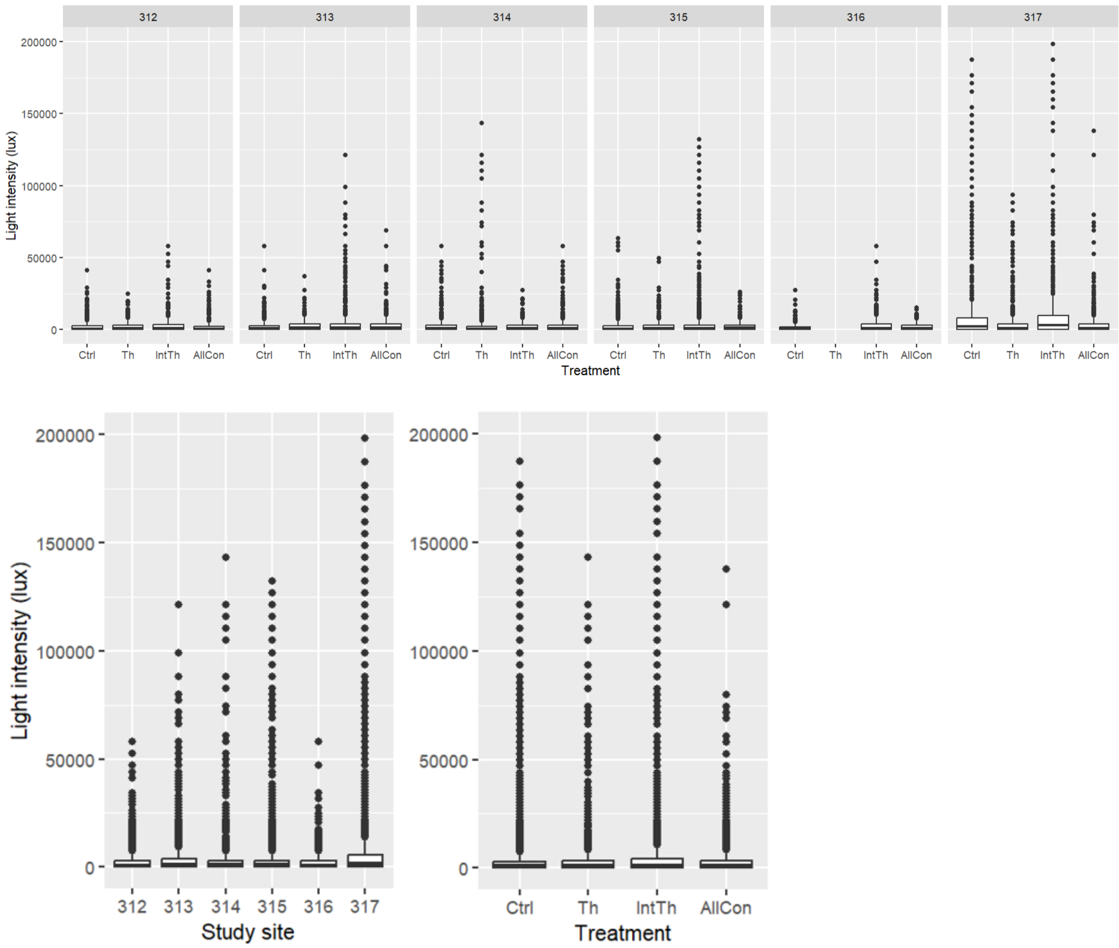


Fig. 24. Boxplots of light intensity (lux) recorded between 14 June and 5 September 2022, at 312 and 313 Bredvik, 314 Svanå, 315 Bäckhammar, 316 Munkfors, and 317 Lattao (top). Boxplots by study site and treatment are shown below. Ctrl – No thinning, Th – Thinning, IntTh – Intensive thinning, and AllCon – All conifers harvested.

Discussion

The main purpose of this report is to provide a detailed description of six recently established study sites, their experimental design, and pre-treatment conditions. The studied thinning treatments are replicated among, but not within, sites. Data on the pre-treatment conditions will make it easier to detect effects of the thinning treatments in future analyses.

The pre-treatment inventories indicated that the stands showed some variation mainly among sites (Figs. 9–13, Table 4). The greatest variation both among and within sites appeared to be related to the amounts of broadleaved trees and deadwood (Figs. 10 & 14). The thinning treatments created strong gradients in the total basal area (Figs. 8–9).

As could be expected, the understory vegetation displayed differences in species composition among sites. Minor differences in species composition could also be detected among treatments and positions within plots. However, the amount of variation that could be explained was low (R^2 between 0.02 and 0.19). In addition, no differences in species richness and diversity among treatments were found, suggesting that the study plots within the sites are suitable for investigating effects of the thinning treatments on the understory vegetation.

The temperature in the soil and above the soil surface showed relatively little variation among and within sites, while the variation in light intensity and soil moisture was high among sites and even across plots within site. The highest light intensities were recorded at 317 Lattao and the lowest at 316 Munkfors. This was probably due to different tree canopy coverage, the mean coverage being 56% at 317 Lattao and 90% at 316 Munkfors (Fig. 13, Table 4). These differences in canopy and consequently light are likely contributing to the high variation in soil moisture, together with microtopographic differences and differences in soil type.

In this study, we focus on the qualities of the streamside forest. Nonetheless, the watercourses deserve mention. The width of the watercourse reaches and their streambanks varied among sites (Table 2). This probably affects the sun exposure and consequently the microclimate of the study plots. For example, at 315 Bäckhammar, the plot borders were well exposed compared with the plot borders at 316 Munkfors (Fig. 7). In addition, sun exposure may vary among sites because the watercourses run in different directions (Fig. 3). Furthermore, the thinning treatments are bound to affect the sun exposure of the ground, given the created gradients in the basal area (Figs. 8–9). Thus, during the initial phase, increased sun exposure of the ground can be expected at increasing thinning intensity.

The postponed thinning at 315 Bäckhammar and 316 Munkfors corresponds to two and one post-treatment monitoring seasons, respectively. The influence of the delays is likely to decrease as vegetation development progresses. Nevertheless, the delays must be considered in future analyses, particularly when evaluating data from the early period after thinning. Overall, however, we believe that the strong treatment gradients in the basal area, the similar harvested basal area proportions across sites (by treatment), and the composition of the understory vegetation provide a good basis for detecting and evaluating effects of the thinning treatments in the future.

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Supplementary information

Supplementary information is presented in Supplements_Skogforsk_Arbetsrapport_1221-2024.pdf which contains Supplements 1–8.

Supplement no.	Content
1	E312 Bredvik: Understory vegetation before thinning – photographs
2	E313 Bredvik: Understory vegetation before thinning – photographs
3	E314 Svanå: Understory vegetation before thinning – photographs
4	E315 Bäckhammar: Understory vegetation before thinning – photographs
5	E316 Munkfors: Understory vegetation before thinning – photographs
6	E317 Lattao: Understory vegetation before thinning – photographs
7	Understory vegetation before thinning – complete species lists and cover
8	Microclimate before thinning – relative air humidity, and soil and air temperature