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Long-Term effects of Thinning in Natural Pine Forests Undergrowth

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Abstract*— Ground cover vegetation is crucial for biodiversity in northern conifer forests, providing habitat, food, and ecosystem functions like seedling regeneration and nutrient cycling. Their composition is shaped by tree species, canopy structure, and environmental factors like temperature, light, water, and soil nutrients. Forest management can modify these processes by increasing light availability, fostering conditions more typical of a natural pine forest biotope, and promoting plant growth. This study aimed to assess whether natural pine forest management influenced ground cover vegetation over 20 years. Six plots across three locations were analyzed. In the studied managed plots, first-story pine trees were thinned by removing second-story spruces between 2004 and 2005. Some plots were thinned (managed), while others remained untouched (control). Initial vegetation assessments recorded species in 10×10m plots before thinning. In 2024, vegetation was reassessed using transects with three 1×1m plots placed along cardinal directions. Vegetation was categorized into trees and shrubs, herbs, mosses, and lichens. The 2024 assessment of managed plots revealed a decline in moss and lichen species, a slight increase in herbaceous species, and a more pronounced increase in tree and shrub species. The opposite trend was observed in control plots. Shannon index values showed significant differences between years (p=0.03) across all vegetation layers but not between management types or factor interactions. Similarly, the total species count varied significantly between years (p=0.02) but not between management types. However, within small 1×1m plots (2024), species count differed significantly between management types (p=0.004). These findings suggest that thinning influences ground cover vegetation composition over time, promoting tree and shrub growth while reducing moss and lichen cover. Species diversity shifts appear more pronounced at finer spatial scales, highlighting the importance of localized conditions in shaping ground cover vegetation dynamics.

***Keywords*— pine, thinning, undergrowth.**

I. INTRODUCTION

The composition of tree species is a fundamental characteristic of forest ecosystems, yet is frequently shaped by silvicultural practices [1]. Various stand attributes, including forest age, tree density, and sub-canopy retention, influence ground cover vegetation by affecting key environmental factors such as light availability, temperature, moisture, and soil nutrients [2], [3], [4], [5], [6], [7]. Overstory tree species richness has been positively linked to ground cover vegetation diversity and biomass [8], [9], though this relationship can be moderated by forest density, which regulates sub-canopy climate conditions [10], [11]. The structure and density of the canopy and shrub layers play a crucial role in shaping understory vegetation by influencing light penetration, moisture retention, and litter quality, which

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in turn impact soil properties such as temperature, pH, and nutrient availability [1], [12]. Light is often the primary limiting factor for understory plant diversity and cover [13], greater canopy openness can enhance resource availability and promote understory growth [14]. The presence or absence of a sub-canopy layer also significantly affects understory vegetation [15]. Forest density, defined by tree abundance in terms of basal area, stem density, or volume per unit area, can override the effects of species composition by limiting light availability on the forest floor and intensifying below-ground competition for resources [16]. In boreal forests, where understory vegetation is essential to ecosystem functioning, it contributes to overstory succession, nutrient cycling, and long-term stand productivity [17], [18]. As the dominant component of floristic diversity in northern conifer forests [19], understory vegetation supports biodiversity by providing habitat and food for wildlife, facilitating tree seedling regeneration, and enhancing soil nutrient cycling [20], [21]. While the overstory largely determines overall forest productivity through biomass accumulation, understory vegetation plays a critical role in nutrient cycling and soil carbon storage due to its significantly higher turnover rate [18], [22]. Identifying the factors that shape ground cover diversity, abundance, and composition is vital for sustainable forest management, particularly for ensuring successful overstory regeneration and the conservation of biodiversity.

II. Materials and Methods

For the purpose of this study, three locations of natural pine forests were selected (Fig. 1). The stands represented *Myrtillosa* and *Vacciniosa* types, and their age was between 183 and 258 years. In 2004 – 2005, in each of them, two plots were established (10 x 10m): one managed and one left unmanaged as a control. Large overstory pines were thinned in managed plots with the complete removal of Norway spruce growing in the understory. Before thinning, vegetation assessments were conducted in each 10 x 10 m plot. Three layers were distinguished: moss and lichen, herbs, and trees and shrubs. For each plot, the percentage cover and species present were recorded. In the tree and shrub layer, trees with a diameter $\leqslant$ 6 cm and height $\leqslant$ 2 m were included. In 2024, a re-evaluation of the overstory vegetation was carried out in the same plots, with transects established along four cardinal directions and 1 x 1 m sampling plots (Fig. 2). Likewise, the percentage coverage occupied by litter, exposed soil, fallen deadwood and tree root necks in the sample area was assessed, which together with the moss and lichen layer made 100% coverage. The percentage coverage of these categories was assessed only during the 2024 survey. For data analysis, linear mixed-effects models were used to compare Shannon indices. Poisson generalized linear mixed-effects models were applied to compare species numbers, while Tweedie generalized linear mixed-effects models were used to compare species cover.

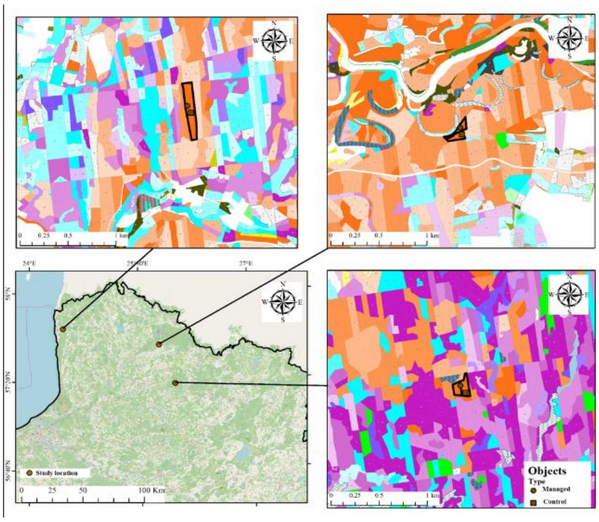

Fig. 1. Location of the studied forest areas and the sample plots.

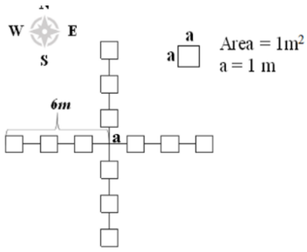

Fig. 2. Vegetation data collection transect scheme.

III. Results and Discussion

The composition and abundance of understory plant communities in forest ecosystems are largely shaped by competitive interactions among understory species, constrained by soil resources and light availability regulated by the overstory [23]. Light transmission is lower under spruce, resulting in reduced resource availability [24]. Before pine thinning in 2004, the species composition in both managed and control stands was similar, with only slight differences (Fig. 3). While tree and shrub proportions were comparable, herbaceous plants were more abundant in the control stands, whereas mosses and lichens were more prevalent in the managed stands. By the second vegetation assessment in 2024, notable shifts had occurred. In the managed stands, moss and lichen species declined, herbaceous species had a slight increase, and tree and shrub species became more dominant. The herb layer is relatively less affected by canopy closure than the shrub layer [14]. In contrast, the control plots followed the opposite trend: tree and shrub species declined, moss and lichen species increased, and herbaceous plants experienced a slight increase. Vascular and nonvascular species tend to replace one another in proportion to varying site conditions, leading to relatively consistent total understory cover and species richness across different overstory types and stand ages [3]. Carpet-forming bryophytes [25] and *Vaccinium* species may inhibit the establishment of additional plant species [7], [26]

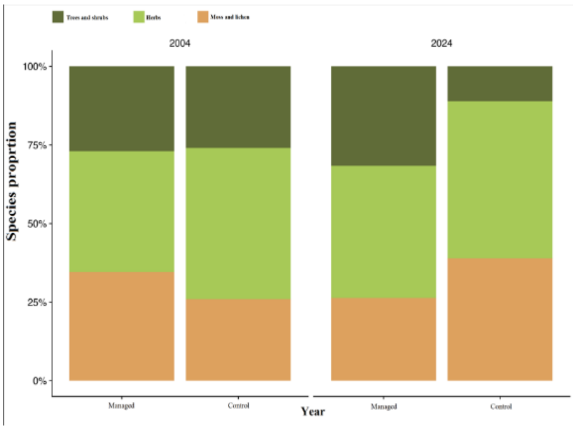

Fig. 3. Proportion of species in different vegetation layers by management type in the 2004 and 2024 surveys.

Old-growth boreal forests generally sustain understory communities characterized by low species diversity and limited productivity [27]. As the overstory matures, shifts in understory plant diversity can be expected, driven by changes in light availability, litter accumulation, nutrient cycling [28], and disturbance patterns [29]. In the first assessment (2004), a total of 36 species were identified, whereas in the 2024 assessment, this number decreased to 25. This may be partially attributed to stand age, as a decline in species richness has been observed in ageing Scots pine forests [26], [29], [30]. To compare species numbers across years (Table 1), data were analyzed at the plot level. The total number of species differed significantly between years ($p = 0.02$), but no significant differences were found between management types or factor interactions.

TABLE 1 MEAN SPECIES NUMBER IN SAMPLING PLOTS UNDER DIFFERENT MANAGEMENT TYPES ACROSS TWO ASSESSMENT YEARS

Type	Total	Herbs	Moss and lichen	Trees and shrubs
		2004		
Managed	14.67±2.50	5.67±1.53	5.33±1.15	3.67±2.08
Control	14.00±3.61	6.0±3.61	4.33±1.15	3.67±1.53
		2024		
Managed	5.75±1.40	4.33±1.15	3.67±1.15	3.00±2.65
Control	4.03±1.44	4.33±3.21	3.67±1.15	0.67±0.58

A higher number of unique species—those recorded only in a specific year—was observed in 2004, with 11 unique species compared to just 5 in 2024 (Table 2). Notably, the unique species in 2024 were primarily mosses, while in 2004, unique species were found across all vegetation layers. This may be due to more favourable growth conditions for mosses, as the tree layer was also composed of Norway spruce, which supports bryophyte growth better than Scots pine [1], [7], yet Scots pine supports higher coverage of vascular plants [26].

TABLE 2 LIST OF UNIQUE SPECIES DOCUMENTED FOR THE OBSERVATION YEAR

2004		**2005**	
Species	***Vegetation layer***	***Species***	***Vegetation layer***
Coryllus avellana L.	Trees and shrubs	*Populous tremula* L.	Trees and shrubs
Salix caprea L.	Trees and shrubs	*Aulacomnium palustre* (Hedw.) Schwägr.	Moss and lichen
Rubus idaeus L.	Herbs	*Plagiomnium affine* (Blandow ex Funck) T.J.Kop.	Moss and lichen
Rubus saxatilis L.	Herbs	*Plagiomnium ellipticum* (Brid.) T.J.Kop.	Moss and lichen
Vaccinium uliginosum L.	Herbs	*Rhytidiadelphus triquetrus* (Hedw.) Warnst.	Moss and lichen
Brachythecium oedipodium (Mitt.) A.Jaeger	Moss and lichen		
Dicranum montanum Hedw.	Moss and lichen		
Dicranum scoparium Hedw.	Moss and lichen		
Polytrichum juniperinum Hedw.	Moss and lichen		
Sphagnum capillifolium Hedw.	Moss and lichen		

The Shannon index values varied significantly between years ($p = 0.03$) when all vegetation layers were analyzed as a single dataset. However, no significant differences were found between management types or their interactions. Species diversity might increase following a disturbance [29], [31], [32], however, low-intensity disturbances, such as canopy gap formation, provide less of an increase in understory resource availability compared to stand-replacing disturbances. As a result, they lead to smaller, more transient increases in diversity and cover, with only minor shifts in composition driven mainly by changes in the relative abundance of pre-existing species [30], [33]. Or even 17 years after density reduction treatments, there may be no impact on understory succession [34]. In 2024, Shannon index values remained similar across different management types, with an average of 1.66 ± 0.35 in the managed stand and 1.63 ± 0.12 in the control stand. Over time, the index declined, reaching 1.55 ± 0.25 in the managed stand and 1.10 ± 0.24 in the control stand by 2024. When considering only the 2024 data, a significant difference ($p = 0.03$) emerged between stand types, with the managed stand maintaining a notably higher Shannon index (1.28 ± 0.22) than the control stand (0.79 ± 0.29).

No distinct grouping of the analyzed plots was observed during the DCA analysis (Fig. 4). Mature pine forests are distinguished by the presence of Ericaceae species [29]. It appears that the coverage and frequency of dwarf shrubs, such as *Vaccinium myrtillus* L. and *Vaccinium vitis-idaea* L., remained stable over time and across different forest management types. The frequency of these species was consistently around 80% between years. For *Vaccinium myrtillus*, the percentage cover slightly decreased from an average of 24% to 16%, while *Vaccinium vitis-idaea* increased from 2% to 8%. Excessive increases in light conditions may have a negative effect on *Vaccinium myrtillus* [29], and data from Scandinavian boreal forests have shown a decrease in the dominance of Ericaceous species following cutting [35]. However, it is important to consider the differences in sampling plots between the two observation years, so the interpretation should be made with caution. The reduced light levels in the control plots might promote the growth of shade-tolerant plants in the understory [36]. However, no clear connection was found between the control plots and shade-tolerant species (Fig. 4). Late-successional bryophyte species (*Dicranum polysetum* Sw., *Hylocomium splendens* (Hedw.) Schimp., *Pleurozium schreberi* (Brid.) Mitt.) showed an increase in both frequency and percentage cover during the second observation [37], indicating the maturity of the studied stands.

This can affect bryophyte cover that often respond to these changes differently than herbaceous plants [1].

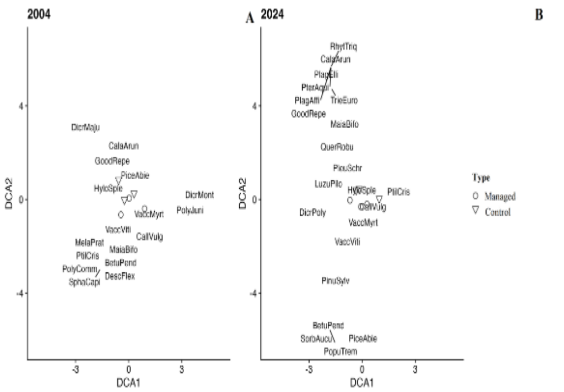

Fig. 4. DCA ordination of ground cover vegetation species and sample plots based on their projective cover. The management approach is indicated by type.

In 2024, the percentage cover of perennials, mosses, and lichens was significantly higher in managed stands compared to control stands ($p < 0.001$ and $p = 0.001$, respectively). A decline in bryophyte cover with increasing forest density, along with a more pronounced reduction in vascular plants in spruce-dominated forests, has been observed in other studies [7]. However, no significant differences were observed in tree cover between management types ($p = 0.104$). Litter cover was significantly lower in managed stands than in control plots. The average litter cover within a 1×1 m sample plot was 5.06 ± 5.49% in managed stands, compared to 9.53 ± 10.86% in control stands. This can affect bryophyte cover that often responds to these changes differently than herbaceous plants [1]. A comparison with 2004 was not possible, as litter cover was not assessed in that year.

Understory plant species play a crucial role in maintaining forest ecosystem stability and supporting key ecological functions. Determining appropriate forest management is essential for promoting their growth and development. Research indicates that stand density and canopy structure influence both the understory environment and vegetation growth [38]. In this study, it remains unclear whether the changes in species diversity and coverage were driven by management practices improving light conditions or by the removal of Norway spruce, as tree species is a key limiting factor for vascular plant diversity [1]. Our study, along with others, suggests that lower-density management strategies better support species conservation and ecosystem function [39].

IV. CONCLUSIONS

In managed plots, mosses and lichens decreased, while trees, shrubs, and herbaceous species increased. In control plots, the opposite trend occurred, with a slight rise in perennials. Species numbers varied significantly between assessment years but not between management types, with higher numbers in the first year. In 2024, species count differed significantly both within the year and across management types, with managed plots having more species. Managed stands in 2024 had significantly higher herbaceous, moss, and lichen cover than control plots. The litter layer was significantly lower in managed forests.

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