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# State of young stands regenerated with oak, alder or larch in Finland

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**ABSTRACT**
Climate change and the appreciation of biodiversity have sparked an increasing interest to widen the traditionally limited tree species composition of Nordic silviculture. It has been recognized that Black alder, Siberian larch, and English oak might have enough economic potential to be a viable alternative to commonly utilized conifers on some sites. The aim of this study is to examine the current state of young stands regenerated with these selected tree species in Finland and to pinpoint current silvicultural shortcomings, which hinder the forestry of these species. Inventories of 46 sapling stands were carried out and their silvicultural state was assessed. We discovered that even though stands rarely met the standards of silvicultural recommendations, intended main tree species were rarely suppressed by naturally emerged saplings, and serious damage was not common. Sites regenerated with these less utilized tree species were generally suitable for the chosen species. Increasing the proportion of oak, alder and larch seems to be a viable option for diversifying the tree species composition. More precise silvicultural recommendations are needed, and they need to be adopted in practice, as most issues found were related to the quality of forest management.

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## Introduction

Finnish forests are dominated by conifers: 63% of productive forests are dominated by Scots pine (*Pinus sylvestris* L.) and 25% by Norway spruce (*Picea abies* (L.) Karst.) (Korhonen et al. 2021). Conifers are naturally abundant in boreal forests (European Environment Agency 2006). However, commercial forestry further amplifies this, since conifers' high timber prices, quality, demand and relatively simple management make them an appealing option to forest owners (Pukkala 2018; Huuskonen et al. 2021; Ruotsalainen et al. 2022). However, this has created forest ecosystems with reduced vegetation complexity and lowered biodiversity (Kuuluvainen 2002; Mönkkönen et al. 2022). Low tree species diversity under the changing climate increases the risk of damage caused by pests and pathogens (Parviainen et al. 2010; Felton et al. 2016; Jonsson et al. 2024). Widening the range of tree species even as pure stands increases diversity at a landscape level (Peterson et al. 1998; Sebald et al. 2021). Globally, tree species composition will shift due to climate change (Sittaro et al. 2017). In Southern Finland, the changing climate will impair the growth conditions of conifers, especially Norway spruce (Peltola et al. 2010; Kellomäki et al. 2018; Chakraborty et al. 2024). However, conditions for broadleaved trees may improve (Parviainen et al. 2010). Therefore, increasing tree species diversity has been suggested as a tool to mitigate risks related to climate change and to increase biodiversity (Ruotsalainen 2017; Ruotsalainen et al. 2022). In addition, it is possible to promote tree species which are currently abundant in warmer areas and thus more likely to thrive under the changing climate (Williams and Dumroese 2013). Widening the range of tree species also spreads the risks related to fluctuations of markets and climate (Ruotsalainen et al. 2022).

The small diversity of tree species in Finnish forests can only partly be explained by the small number of native tree species. Even though the number of tree species found in Finland is smaller compared to more southern parts of Europe or North America, there are over 20 native tree species, although not all of them are feasible for silviculture (Tertti 1949; Valkonen 1997; Vankat 2002). Finnish forest law § 8 permits regeneration

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with any reasonable tree species and would thus allow a more versatile usage of tree species (Laki Metsälain Muuttamisesta, 1085/2013). Forest certifications, such as FSC and PEFC, limit the use of exotic trees, but there are some exceptions that are treated as native species, such as Siberian larch (FSC 2023; PEFC Finland 2024). However, major sawmills in Finland tend to be specialized in spruce, pine or both (Brunila and Hämäläinen 2015). The plywood industry utilizes birch along with conifers (Viitanen and Mutanen 2017). The low demand for less common tree species does not encourage forest owners to establish stands with them, and thus the supply remains so small that it is not feasible for sawmills to specialize in them either (Ruotsalainen et al. 2022). For less common tree species, silvicultural recommendations are less precise and less empirically based than those for the main tree species (Äijälä et al. 2019). Yet, plenty of hardwood lumber, for example alder, is imported to Finland (Louna and Valkonen 1995). Therefore, less utilized trees clearly are feasible as raw material.

Throughout history, the silviculture of several domestic and exotic tree species has been experimented with in Finland, with varying results (Ruotsalainen 2017). Ruotsalainen et al. (2022) suggested eight different tree species with the greatest potential to diversify the range of tree species, including English oak (*Quercus robur* L.), black alder (*Alnus glutinosa* (L.) Gaertn.*)*, and Siberian larch, sometimes referred to as Russian larch (*Larix archangelica* (Ledeb), previously *Larix sibrica*) (from here on oak, alder and larch). These three species were selected for this study due to their economic potential (Louna and Valkonen 1995; Verkasalo 1998; Verkasalo and Viitanen 2001), non-exotic status (Ruotsalainen et al. 2022), and popularity among the rare broadleaved trees (Korhonen et al. 2021).

The tree species compositions of other forested Nordic countries do not greatly differ from Finland. Norway spruce and Scots pine are dominant tree species in Sweden, even though the proportion of broad-leaved trees is significant in its southern parts (Roberge et al. 2024). Thus, the forest industry of Sweden emphasizes processing conifers (Björklund et al. 2024). The history of Swedish silviculture is similar to that of Finland, and therefore similar aspects have contributed to the domination of conifers (Jönsson 2024). Similarly, the forests of Norway are dominated by conifers (Trollstøl et al. 2020). Therefore, the need to increase the tree species variation in forests has been recognized in Nordic countries (Felton et al. 2016; Forzieri et al. 2024). In Nordic countries, the proportion of sites regenerated with Norway spruce has already declined due to its sensitivity to disturbances (Larsen et al. 2010; SOS 2024; SVT 2024b). Similar trends can be seen in Central Europe, where a shift from Norway spruce forests to more broadleaf-dominated forests is needed to mitigate the risks related to climate change, such as pest outbreaks and drought (Bosela et al. 2021; Kozhoridze et al. 2024). As Finland will most likely face similar issues in the future, it is vital to have alternative tree species available for silviculture.

English Oak is a widely spread tree species as it can be natively found in Europe all the way from the Mediterranean coast to southern parts of the Nordic countries (Eaton et al. 2016). Only the southernmost part of Finland is within the native range of oak (Väre and Kiuru 2016). Despite that, oak stands can be established even in central Finland in suitable habitats (Valkonen et al. 1995). Oak is a long-lived tree species, which starts to produce seed at a fairly old age compared to other broadleaved trees (Jalas 1965). High density is required in young oak stands to improve timber quality, which can be further improved by pruning (Antikainen 1992; Kiuru 1996). As oak stands mature, the need for light increases; therefore, frequent but moderate thinnings are required to ensure suitable conditions while promoting natural de-branching and preventing the emergence of water sprouts (Antikainen 1992). High-quality oak is a valuable raw material mostly used in carpentry (Valkonen et al. 1995). In addition, oak can greatly improve biodiversity as it functions as a host species for a great number of living organisms (Ruotsalainen et al. 2022). Finnish silvicultural recommendations for oak by Äijälä et al. (2019) are fairly brief, focusing mostly on the establishment of stands and the aspects affecting timber quality. The silviculture of oak is more established in Sweden compared to Finland. The Swedish recommendations are similar, although perhaps more detailed compared to the Finnish ones (Drößler et al. 2012; Äijälä et al. 2019; Rytter 2019). However, a major difference is that in Sweden, to establish a pure oak stand, planting up to 13,000 trees per hectare or sowing up to 70 kg of acorns is considered a valid method (Drößler et al. 2012). Such numbers are far higher compared to Finnish literature, where the recommended way to establish an oak stand is to plant oaks in groups totaling only 500 to 600 trees per hectare and to plant another tree species between these groups to promote shading (Äijälä et al. 2019). Mixing spruce and oak is not unheard of in Sweden, even though these mixtures are usually established by regenerating both species naturally on suitable sites (Drößler et al. 2012). In Norway, oaks are rare; hence, literature is sparse and Norwegian silviculture tends to generally follow practices from other Scandinavian countries (Madsen et al. 2013).

The natural habitat of black alder extends all the way from southern Spain to near the Arctic Circle (Tracy et al. 2016). Alder thrives in areas where flowing water can be found (Väre and Kiuru 2016). Alder is a fast-growing pioneer species, which may reach a height of up to 30 meters (Salmi 1978b; Mäkinen 2018). In suitable conditions, alder can produce straight and slowly tapering stems (Yli-Vakkuri 1978; Salmi 1978b). The rotation period of alder might be as short as 30–50 years while still producing valuable logs (Napola 2004; Kiuru 2008). To ensure good quality, alder stands should be established as fairly dense (Napola 2017). The first thinning of alder stands is recommended to be fairly intensive, even up to 50% of the stem count, but later thinnings ought to be more moderate in order to prevent branching (Äijälä et al. 2019). Alder is mostly used in decorative interior pieces, such as panels and sauna interiors (Väre and Kiuru 2016; Ruotsalainen et al. 2022). In Finland, the natural habitats where alder naturally occurs are often conserved, which hinders loggings, thus reducing the availability of alder (Napola 2004).

The Finnish silvicultural recommendations by Äijälä et al. (2019) consider 1600 to 2000 saplings per hectare sufficient. In Sweden, although the planting of alder is described as unusual, recommendations do exist; they suggest a planting density of 2500 saplings per hectare (Rytter et al. 2014). Both recommendations emphasize the importance of adequate lighting conditions and the need for regular thinnings (Rytter et al. 2014; Äijälä et al. 2019; Rytter 2019). Norwegian literature emphasizes alder's ability to thrive in flooded areas and their unappealing characteristics to herbivores, making it a low-risk alternative (Kohmann 2005).

The western population of Siberian larch (*Larix archangelica*) is native to western Eastern Europe; while it shares its name with a larger population of larch trees found in Siberia (*Larix sibirica*), it is a separate species (Kozhin and Sennikov 2016). Nowadays, there are no naturally emerging larch stands in Finland, but they have been a part of the native flora prior to the latest glacial period and even during the Early Holocene period (Bergstedt and Lyck 2007; Väre and Kiuru 2016; Salonen et al. 2024). Yet, larch is considered equal to native species in legislation and forest certifications (Ruotsalainen et al. 2022). A fast growth rate and high log yield are characteristic of larch (Lähde et al. 1984; Verkasalo 1993). Larch thrives on sites with fertile soils (Ruotsalainen et al. 2022). Larch requires plenty of light (Rantala and Anttila 2004). Therefore, in Finland, it is recommended to establish larch stands with low density of only 1300 stems per hectare, and to carry out frequent thinnings (Äijälä et al. 2019). Swedish recommendations for the planting density of larch follow the recommendations for spruce (Arvidsson 2006), which results in a higher stem count, especially in fertile sites (Skogsstyrelsen 2018). The recommendations from both Finland and Sweden emphasize the need of proper lighting conditions (Äijälä et al. 2019; Nilsson 2024). However, while there is plenty of Finnish literature about Siberian larch (Lepistö and Napola 2005; Lukkarinen 2013), Swedish research seems to have focused more on hybrid larch (*Larix* × *eurolepis* Henry) (Larsson-Stern 2003; Ekö et al. 2004; Johansson 2012). Several larch species have been introduced in Norway, but even with all species combined, their proportion remains small (Øyen 2006). Between 2010 and 2019, an average of nearly 160 million saplings were delivered annually from nurseries (SVT 2024a). Despite economic uncertainties, more than half a million of those saplings were of less utilized tree species (SVT 2024a). While the proportion is small, this implies that there are forest owners who have chosen to cultivate stands with species other than spruce, pine, or birch. They have chosen to do so out of pure interest in unusual species, for the sake of trial or due to the conditions that prevail at the site, but in some cases also to mitigate damage or to prepare for climate change (Otsamo et al. 2025). However, we do not know how these stands have developed or how they have been managed.

Valkonen et al. (1995) described young stands of rare hardwoods in the 1990s. However, that study was conducted mainly on sites established on former agricultural land and silvicultural practices, such as soil preparation, have changed since then. Thus, the current situation might differ. This study provides insight on how well the forest establishment with selected less utilized tree species has succeeded, and whether there are pitfalls related to the early management of these tree species. Such information is a prerequisite for promoting widespread use of less utilized tree species. Recommendations and practices cannot be improved if there is no up-to-date knowledge about how current practices work. Such information is sparse and potentially outdated. At the same time, diversifying tree species is increasingly discussed as a practical climate-adaptation and biodiversity measure, creating an urgent need to understand how these stands perform under current management. An inventory of less utilized tree species was needed, as, for example, NFI (national forest inventory) is not a sufficient tool for gathering information about these species. The aim of this study is to investigate the current state of recently established stands that have been regenerated with less utilized tree species: Siberian larch, black alder or English oak. The research questions are:

1. Has the regeneration been successful in terms of crop tree density?
2. Has the early management been adequate?
3. What kinds of damage have these stands faced?
4. How well have the planted trees grown compared to naturally emerged saplings?
5. Do these stand meet the silvicultural recommendations?

Interest in oak, alder, and larch is increasing among forest owners, yet the evidence base for practical regeneration and early-management methods is notably scarcer than for pine and spruce. Because these stands are still relatively uncommon, there is limited contemporary research and little cumulative operational experience to verify which practices produce well-stocked, high-quality young stands. This study, therefore, serves as a necessary baseline and a first step toward improved guidance. It aims to document current outcomes in young stands, to identify recurrent management bottlenecks and knowledge gaps, and to provide a foundation for targeted follow-up studies, which refine silvicultural recommendations for these less utilized tree species under Finnish conditions.

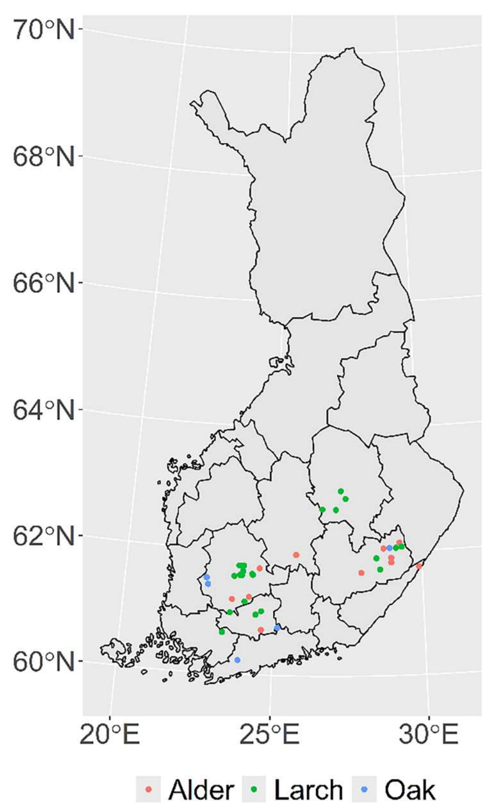


**Figure 1.** Locations of the stands that were regenerated with oak, alder or larch and measured for this study. Measured plots varied from 60.23°N to 62.97°N and from 22.74°E to 29.90°E.

## Materials and methods

### Field measurements

Sites, which had been regenerated to oak, alder or larch were recognized by utilizing notifications of forest use and notifications of stand establishment submitted to the Finnish Forest Centre. Sites with an area smaller than 0.1 ha were excluded. Only recently established sites were considered: the notifications of forest use were from years between 2006 and 2019 and the notifications of stand establishment were from 2006 to 2014. After an amendment in 2014, the latter have not been submitted since. Notifications of forest use could be submitted up to three years prior to logging, and therefore the period under which the stands could have been established was between 2006 and 2022. To simplify the logistics of fieldwork, measurements were focused around certain areas where multiple sites were in clusters. Geographical variation was maintained by selecting multiple clusters around southern and central Finland; the measurements were conducted adjacent to Savonlinna, Tampere and Kuopio. Originally, 88 stands were selected as suitable to be measured. However, the notifications of forest use and stand establishment were not binding. Thus, several sites had been regenerated with some other tree species, or no cuttings had been conducted; therefore, these sites had to be discarded from the study. In some cases, the characteristics of the stand prevented measurements; e.g., the stand was too narrow to fit plots within it, or there were obstacles such as large boulders dominating the landscape. Eventually, a total of 46 sites were measured (Figure 1). Field measurements were conducted during the summer of 2023.

In every stand, at least five circular plots with a radius of 3.99 meters were measured. The plots were established along the longest line, which could be fitted inside the stand. The distance between the plots within the stand was fixed but varied between stands from 20 to 50 meters depending on the size of the stand. A minimum of 5 plots was measured on each stand, but if there was much variation within the stand, the number of plots was increased. If all plots could not be fitted along the longest possible line, another line perpendicular to the original line was established and similar circular plots were placed along the new line. The height and diameter at breast height (DBH) of every tree of the intended main tree species (i.e. the main tree species forest owner has reported in the notification of forest use) within each plot was measured. In addition, tree species and possible visible damage, its cause and severity were recorded. The cause of damage was classified by a predetermined coding system, which included 16 different common factors to cause damage. These causes included different abiotic damage agents, different pests, herbivores, pathogens and different forms of man-made damage. It was also possible to record damage without a known cause. Severity of the damage was estimated with a four-step scale, where the least severe one was already healed damage, and the most severe one was mortal damage.

The stem count of naturally emerged conifers and broadleaved trees was calculated. The height and DBH of one average-sized conifer and one broadleaved tree were measured on each plot. The average-sized tree was estimated at each plot by the field crew. Only naturally regenerated trees that were competing with planted trees were recorded: tree height had to be over 50 cm or at least 50% of the dominant height of the stand.

In each stand, the quality of previous forest management and the current need for forest management were assessed by a four-step classification system: "properly done", "poorly done", "not done", and "no need". The operation was considered properly done if conditions after the operation were within the recommendations of Äijälä et al. (2019). In cases where the operation had been carried out, but not following the recommendations, the classification "poorly done" was assigned. If there was an obvious need for management, classification "not done" was used. If there was no urgent need for management or it was impossible to assess whether any silvicultural operation was carried out in the past, it was classified as "no need". The need for management was assessed by a trained field crew. The success of regeneration was divided into two classes based on the number of crop trees: "properly done" and "poorly done". Suggested densities from silvicultural recommendations by Äijälä et al. (2019) were used as a baseline to compare whether the regeneration had been successful. Overall stand quality was estimated on a three-step scale based on whether the silviculture was economically viable with the current tree population: good, developable, or undevelopable. A stand was classified as "good" if there were no obvious issues that would affect the silviculture. The classification "developable" was used if there were issues with the stand, such as a stand structure that was too dense or sparse, or serious damage. A stand was classified as "undevelopable" if it would not be feasible to continue silviculture using the current tree population, for reasons such as insufficient stem count, severely neglected forest management, unsuitable tree species for the site, or poor quality due to severe damage. In addition to crop trees, naturally emerging trees were also taken into account. Thus, stands with a sparse population of intended main tree species could be classified as developable if there were sufficiently naturally emerging saplings suitable to be used in silviculture. Silviculture and stand quality were assessed by the field crew based on the measurements and overview of the site, and how they compared to the recommendations.

On every site, forest type, intended main tree species and stand age were recorded. Forest type describes site fertility by assessing local flora present at the forest floor. Each forest type has certain indicator species that are not present in less fertile sites. Cajander's (1925) classification was used. The most common forest types from the most to the least fertile are: *Oxalis-Myrtillus*-type (OMT, herb-rich heath forests), *Myrtillus*-type (MT, Mesic hearth forests), *Vaccinium*-type (VT, sub-xeric hearth forests) and *Calluna*-type (CT, xeric heath forests) (Tonteri 1994). The fertility of peatlands was determined and classified using a similar system to that for mineral soils (Laine et al. 2012). The intended main tree species refers to the tree species that had been used during regeneration. Stand age was estimated by visual inspection of planted trees and by the submission year of the notifications of stand establishment or forest use. Especially on sites regenerated with broadleaved trees, estimating stand age was difficult and the date of notification submission became more important.

## Analysis

Additional environmental data was added to explain the site characteristics. Topographic wetness index (TWI) (Salmivaara et al. 2017) was combined with measurement data to explain the hydrological characteristics of the sites. TWI raster data (16 m x 16 m) was extracted by the extent of measured stands, and mean value of raster values within each stand was calculated to determine the average wetness of each stand. The average effective temperature sums (TS) were based on the measurements of meteorological stations during the years 1990–2020 interpolated onto a 10 km x 10 km grid by the Finnish Meteorological Institute (Venäläinen et al. 2005). The TS of the grid where the stand was located was used as the climatic data.

Stand characteristics were calculated using the software R (R Core Team 2024). Data were split into 3 groups by the intended main tree species. The datasets were further separated into three groups by the recorded tree species (intended main species, other conifers, other broadleaved trees). Arithmetic mean diameter, height and stem count per hectare were calculated for each stand and separately for each group within each stand. Differences in mean height, stem count and mean diameter between groups (intended main tree species, other conifers and other broadleaved) were examined by using analyses of variance, in which the interaction of tree species and stand age was used as the independent variable. Variances were homogenized by performing a square root transformation on the dependent variable. Tukey's HSD post-hoc test was used to perform pairwise comparisons. Frequencies of different types of damage and their causes were calculated by the intended main tree species for each stand and for the whole dataset. To study whether there were statistically significant differences in the frequency of damage between the intended main tree species, a pairwise chi-squared test was carried out with each combination of intended main tree species. In addition, the quality of silvicultural operations was summarized by counting the number of occurrences of each class by intended main tree species. To assess whether there were differences in the quality of forest management between intended main tree species, statistical analyses were performed. The classes "properly done" and "no current need" were combined into one group, and the classes "poorly done" and "not done but needed" were combined into another group. Using this data, a pairwise Fisher's test was conducted to each intended tree species combination separately. This analysis was carried out for all silvicultural operations that were assessed: soil preparation, cleaning of regeneration site, weeding, early cleaning and precommercial thinning.

## Results

### Stand characteristics

The age of the measured stands varied between 3 and 16 years. On average, larch stands were the oldest, but they also had the greatest difference between the youngest and the oldest stand. On average, larches were taller than other tree species on stands where larch was the intended main tree species. Similar characteristics could be seen on stands that were regenerated with alder. However, oaks were on average shorter than other species. DBH followed the same pattern: on average, oak was smaller than other tree species while larch and alder had a higher diameter compared to other tree species. The proportion of larches and alders, which had not yet reached breast height, was small: 4% of all measured trees on both species. The proportion of short oaks was higher as 24% of measured trees were less than 1.3 meters high. Stem count varied greatly among all tree species.

Although there were differences in the mean values, they were rarely statistically significant with a confidence interval of 95%. Larches and alders were significantly taller than trees in "other conifers" class, and larches had a higher diameter at breast height than broadleaved trees. The stem count of naturally regenerated broadleaved trees was significantly higher than the stem count of any intended main tree species (Table 1). The average annual height increments were 75, 47 and 30 cm for alder, larch and oak respectively. Stem count varied greatly especially among alder and larch (Figures 2 and 3). Oak had a considerably lower maximum stem count than alder or larch.

### Damage

The total proportion of damaged trees was quite low. 90% of larches did not show any signs of damage. The proportion of damaged alders was even lower: 97% were undamaged. Oak suffered damage slightly more frequently as only 75% of trees were undamaged. The frequency of damage was statistically different between all intended main tree species. In most cases, the cause of damage was unknown. The most frequent known cause of damage was browsing by cervids in alder (0.5% of all trees) (Figure 4). For oak, damage caused by competition within the vegetation and browsing by cervids was equally common. For larch, the most common known cause of damage was browsing by cervids. Most of the damage recorded was classified as permanent among larches (4% of all trees) and alders (2% of all trees). Among oaks, most of the damage was classified as temporary (14% of all trees), while permanent damage was recorded in only 1% of all oaks. The proportion of dead or dying trees was 7% for oaks, 3% for larch and less than 1% for alder. Even though the number of damaged trees was low, there were no completely damage-free stands.

### Silvicultural quality

Stand quality was assessed using a 3-step classification: good, developable, or undevelopable. The highest quality was found in larch stands: 78% of the stands were classified as good and the remaining 22% as developable. No larch stands were classified as undevelopable. The quality of alder was slightly poorer, as the most common classification was developable, with a proportion of 46%. 30% of the alder stands were good and the remaining 23% were classified as undevelopable. 67% of the oak stands were classified as developable, and the rest, 33%, were classified as good. No oak stands were classified as undevelopable.

**Table 1.** Arithmetic mean, standard deviation and range of mean height, mean diameter, stem count and estimated age of measured stands by the planted tree species.

| | Larch | | | Other conifers | | | Other broadleaved | | |
|---|---|---|---|---|---|---|---|---|---|
| $n = 27$ | Mean | SD | Min–Max | Mean | SD | Min–Max | Mean | SD | Min–Max |
| Diameter (cm) | 6.3[a] | 3.3 | 0.3–12.4 | 4.7[ab] | 2.8 | 0.0–10.0 | 3.1[b] | 1.7 | 0.2–6.4 |
| Height (m) | 5.5[a] | 2.1 | 0.9–9.4 | 3.9[b] | 1.7 | 0.9–7.1 | 4.6[ab] | 1.8 | 0.9–7.5 |
| Stem count (n ha$^{-1}$) | 953[a] | 397 | 143–1759 | 497[a] | 783 | 50–3559 | 1935[b] | 2194 | 89–8717 |
| Age (years) | 12 | 3.5 | 3–16 | | | | | | |
| | Alder | | | Other conifers | | | Other broadleaved | | |
| $n = 13$ | Mean | SD | Min–Max | Mean | SD | Min–Max | Mean | SD | Min–Max |
| Diameter (cm) | 4.3[a] | 2.6 | 1.2–8.4 | 3.5[a] | 3.7 | 0.2–12.6 | 2.5[a] | 1.5 | 0.8–5.2 |
| Height (m) | 5.6[a] | 2 | 2.9–9.9 | 3.5[b] | 1.8 | 1.8–6.7 | 4.1[ab] | 1.9 | 1.8–7.7 |
| Stem count (n ha$^{-1}$) | 980[a] | 633 | 80–1919 | 799[a] | 738 | 57–2099 | 3103[b] | 2914 | 160–9077 |
| Age (years) | 8 | 2.2 | 5–12 | | | | | | |
| | Oak | | | Other conifers | | | Other broadleaved | | |
| $n = 6$ | Mean | SD | Min–Max | Mean | SD | Min–Max | Mean | SD | Min–Max |
| Diameter (cm) | 1.8[a] | 2.1 | 0.3–5.7 | 5.2[a] | 5.7 | 0.0–16.0 | 2.3[a] | 1.3 | 0.2–3.7 |
| Height (m) | 2.4[a] | 1.6 | 0.9–4.9 | 4.6[a] | 3.7 | 1.0–11.6 | 3.9[a] | 1.7 | 1.5–6.0 |
| Stem count (n ha$^{-1}$) | 424[a] | 283 | 67–760 | 724[a] | 750 | 40–1700 | 2342[b] | 1790 | 320–4932 |
| Age (years) | 10 | 2.3 | 8–13 | | | | | | |

Notes: Different letters mark statistically significant differences in mean values within the same variable and intended main tree species (i.e., values on the same row) with a 95% confidence level. Due to the site differences, comparisons should be made only within the same intended tree species.

In most stands, some level of silviculture-related neglect could be found: either one or more management practices were needed but had not been done, or they had been done poorly. Generally, forest management operations had been carried out when needed, excluding precommercial thinning (PCT). Over 50% of alder stands needed PCT. The conditions of oak stands were similar: 50% of stands needed PCT. Pre-commercial thinning had rarely been neglected on larch stands, but on some stands the operation had been carried out poorly. There were also many cases in which there was no need for PCT (Figure 5). No tree species was better managed than the other, as there were no statistically significant differences between the intended tree species in the proportion of neglect of any individual silvicultural operation.

### *Site characteristics*

***Wetness index.*** Mean wetness index within stand varied between tree species. On average, it was highest on alder stands. The greatest variation was found on larch stands. The smallest average, maximum and minimum were found on oak stands (Table 2).

The average of the wetness index was higher on alder stands compared to larch and oak stands ($p = 0.001$ between alder and larch and $p = 0.008$ between alder and oak). Alder stands also had a higher wetness index compared to their surrounding areas with a radius of 100 km within Finnish borders. Paired t-test suggests a significant difference with a $p$-value of 0.003. Oak and larch stands did not differ significantly from surrounding areas. All oak stands had been established in areas where the average temperature sum was greater than 1350 d.d. Alder and larch stands had been established in areas with slightly lower temperature sums (Table 2). However, there were no statistically significant differences between tree species.

Most of the sites were relatively fertile; they were mostly *Myrtillus* type (MT, mesic heath forest) or *Oxalis-Myrtillus* type (OMT, herb-rich heath forest) following Cajanders (1925) forest type classification. One site was a less fertile *Vaccinium* type (VT, sub-xeric heath forest), and one site was a more fertile *Oxalis-Maianthemum* type (OMaT, herb-rich forest). Only three sites had been established on dried peatlands, while the rest were on mineral soils. Two of the peatland stands had been planted with alder and one with oak. All larch sites were on mineral soils.

## Discussion

Generally, the stand densities of planted tree species were low. Average densities were 953 stems per hectare for larch, 980 stems per hectare for alder and 424 stems per hectare for oak. Recommended planting densities in Finland are 1300 stems per hectare for larch, 1600–2000 stems per hectare for alder, and 500–600 stems per hectare for oak if the oaks are planted in groups with another tree species (Äijälä et al. 2019). On most stands, silvicultural recommendations were not met. The recommended density was reached only on 22% of the larch stands and on 15% of the alder stands. On oak stands, the proportion was slightly higher: a stem count of 500 stems per hectare was achieved on 33% of the stands. The lowest total stem count was found on a larch-dominated stand with 1000 trees per hectare, out of which 53% were larch while the rest were naturally emerged saplings. Since

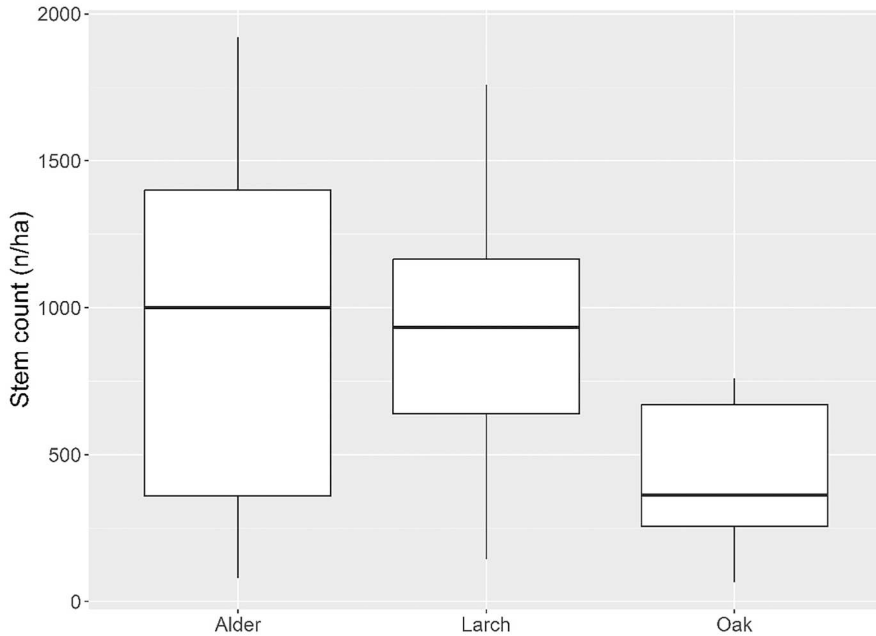


**Figure 2.** Stem count distribution of intended main tree species grouped by tree species.

most stands had a lower than recommended density – in some cases drastically so – the importance of naturally emerged saplings increases as supplementary sapling material. To utilize naturally emerged saplings, their growth dynamics need to match those of the main tree species to ensure a single-storied structure (Huuskonen et al. 2021). It is worth noting that a lower than recommended density might be caused by mortality, but it is also possible that the initial planting density had been lower than recommended to begin with. Such a structure might be caused by budget constraints, as forest regeneration with less utilized tree species is often more expensive compared to more traditional species (Otsamo et al. 2025). Too sparse a stand structure

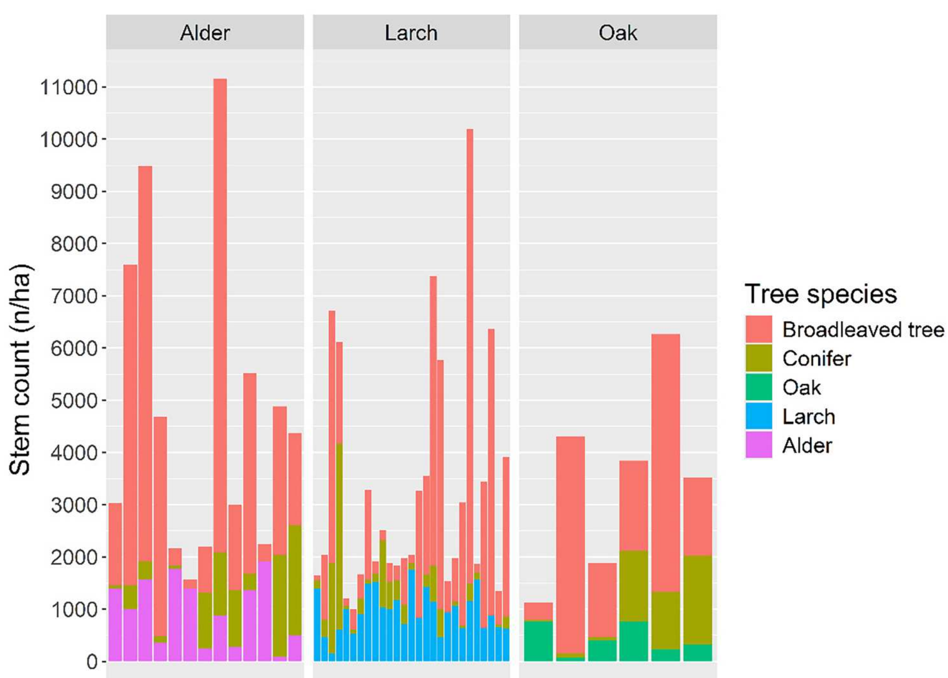


**Figure 3.** Tree species and stem count distribution by intended main tree species on different sites (x-axis) by tree species. The lowest total stem count could be found on larch sites, and the highest on alder sites. The lowest variation could be found in oak stands.

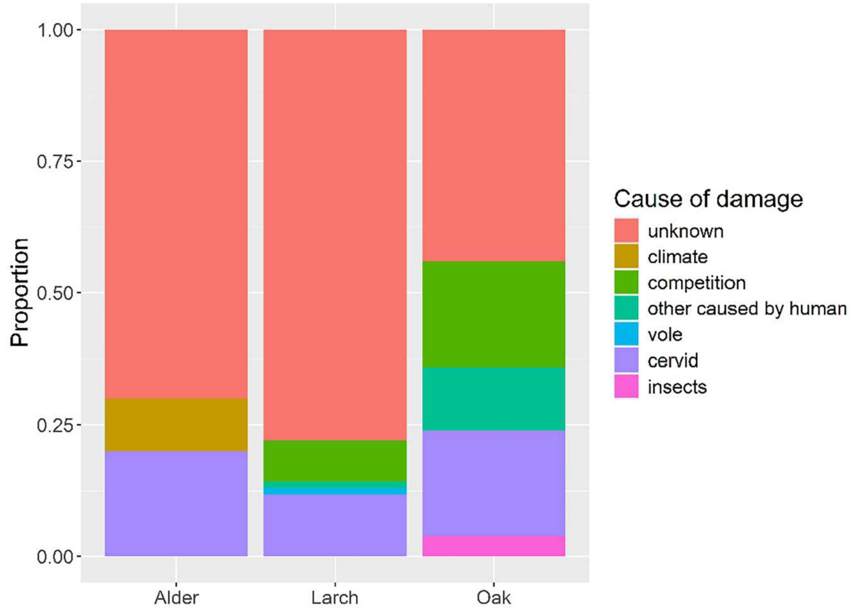


**Figure 4.** Proportions of causes of recorded damage by tree species. Unknown = the cause of damage cannot be recognized; Climate = damage has been caused by climatic factors such as frost, wind, etc. Competition = damage has been caused by competition within the vegetation. Other caused by humans = damage has been caused by humans but not while harvesting. Vole = the damage has been caused by voles. Cervid = damage has been caused by browsing cervids. Insects = damage has been caused by insects. It should be noted that the proportion of damaged trees was low.

reduces the profitability of silviculture and yield. The quality of timber in sparse oak and alder stands declines since both species require shading to prevent forking and large branches (Antikainen 1992; Claessens et al. 2010). Too low a density also reduces profitability since the full yield potential of the stand is not utilized (Coordes 2013). It is worth noting that even though some larch stands were remarkably sparse, field crew still did not consider them as undevelopable. This was most likely because an abundance of light and space does not affect larches negatively.

Signs of neglect of silvicultural operations were common. Often, the operations were either poorly executed or not executed at all. This could also be seen in the tree species composition: the number of naturally emerged broadleaved trees was high in all examined tree species. If precommercial thinning had been carried out successfully, such a tree species composition should not have existed (Fahlvik 2005). It is worth noting that even if a silvicultural operation was needed but had not been carried out, it does not necessarily mean it will not be carried out in the future.

The lack of early forest management does not only overshadow the silviculture of less utilized trees. Precommercial thinnings have generally been carried out increasingly late since the 1980s (Korhonen et al. 2017). However, the latest NFI shows that for the first time, the proportion of forests whose early management has been neglected has decreased (Korhonen et al. 2024).

One possible factor causing poor management is the lack of know-how: since these species are less utilized, forest owners might not have such well-established practices compared to more traditional tree species. Since regenerating stands with rarer tree species is more expensive than using traditional conifers (Ruotsalainen et al. 2022), poor management seems more likely to result from a lack of knowledge than carelessness.

Another possible reason for deviating from silvicultural recommendations might be the personal goals of forest owners. These may include, e.g., biodiversity, resilience or recreational values (Kronholm et al. 2020). Otsamo et al. (2025) found that forest owners were generally happy with the state of their forests established with less-utilized tree species. Since economic interests are rarely the motive for establishing these forests (Otsamo et al. 2025), managing them according to the silvicultural recommendations might not be a priority.

Despite the neglect of forest management, trees appeared to be healthy, and damage was rare. Planted tree species were not suppressed by naturally emerged saplings as the stand mean heights did not differ between planted species and naturally emerged broadleaved trees. Larch and alder are notorious for growing fast (Salmi 1978a; Vuokila et al. 1983) and,

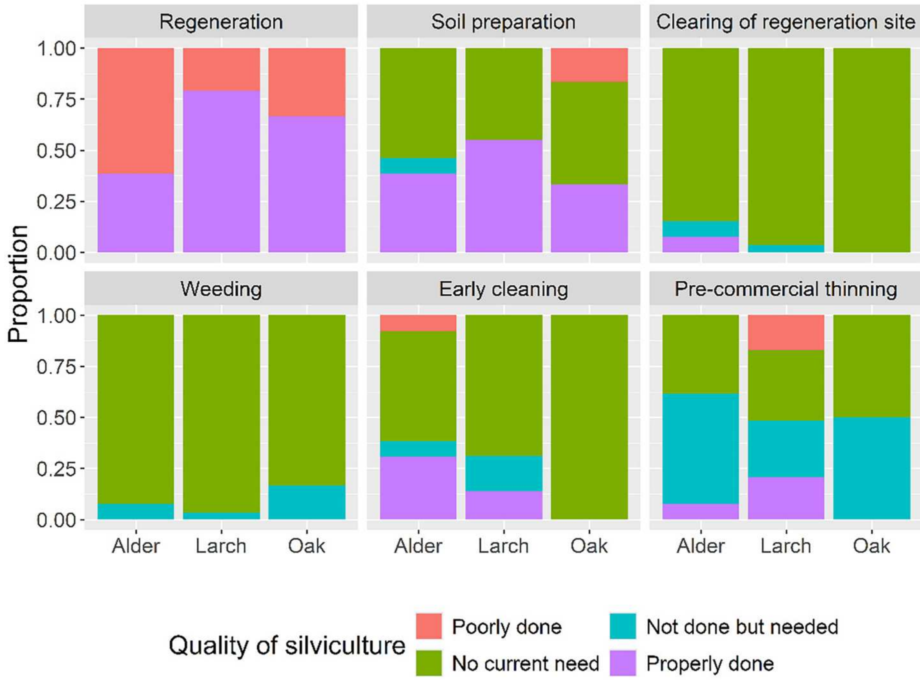


**Figure 5.** Quality of silviculture by silvicultural operations determined at the time of measurement by intended tree species. If the measuring group was unable to determine the quality, the class "no current need" was used. The longer a time has passed since the silvicultural operation, the more difficult assessing the quality becomes and thus the probability of being classified as "no current need" increases.

therefore, they are able to avoid being suppressed by naturally emerged saplings. Due to their fast early growth, larch and alder rarely require early cleaning (Rantala 2018; Äijälä et al. 2019), as the main motive for early cleaning is to reduce competition caused by naturally emerged saplings (Uotila 2017). While rapid early growth prevents crop trees from being suppressed, it is vital to ensure adequate growth space to promote diameter growth. Neglecting PCT will result in a high stem count, which will eventually cause overstocking and high competition for resources (Chase et al. 2016). Abundance of light is especially important for larch as it cannot sustain a normal crown in shady conditions, which results in growth losses (Rantala and Anttila 2004; Bergstedt and Lyck 2007). Oak can tolerate more shading at a young age, and the use of faster-growing trees as shelter trees is even recommended (Antikainen 1992; Kiuru 2008).

While the "no current need" class was a common one for soil preparation, it does not necessarily mean that no soil preparation was carried out, but rather that the field crew was unable to determine how well it was done. As a stand ages, the prepared soil gets covered by vegetation, making it difficult to assess the quality of soil preparation.

The special requirements of the desired tree species had generally been considered in forest management. Alders thrive in moist areas such as river banks, shores or near springs (Väre and Kiuru 2016). This most likely explains why alder stands had generally been established in unusually wet areas. In Finland, oak grows naturally only in the hemiboreal zone whereas larch and alder are also abundant in the boreal zone (Väre et al. 2021). Hence, the minimum temperature sums were slightly higher on oak stands than on larch or alder stands. All examined tree species require fairly fertile sites to be economically viable options (Ruotsalainen et al. 2022). Almost all measured stands had been established on sites with vegetation typical for areas with high fertility.

**Table 2.** Characteristics of stand mean wetness index values and temperature sums (d.d. threshold +5°C) by tree species.

| | Alder | | | Larch | | | Oak | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Min–Max | Mean | SD | Min–Max | Mean | SD | Min–Max |
| Wetness index | 9224[a] | 1406 | 7042–12,013 | 7350[b] | 1194 | 5186–10,297 | 7121[b] | 954 | 6271–8830 |
| temperature sum (d.d) | 1362[a] | 46.4 | 1272–1431 | 1359[a] | 44.3 | 1269–1432 | 1399[a] | 57.1 | 1339–1494 |

Note: Different letters mark statistical difference within the same variable at a 95% confidence level.

In Finland, there has been a growing interest in the silviculture of less utilized trees, but recent information on this topic is scarce. This study provided an overview of the current condition of less utilized tree species stands and insight into what should be studied in the future. As none of the Nordic countries have thorough instructions on how to manage these forests, there is potential for multinational cooperation. The main aspect hindering the composition of silvicultural recommendations for these species is the lack of recent studies on growth and yield. In addition, further studies on why early management is often neglected should be conducted to find ways to improve the quality of stands. The structure and characteristics of the data limited the possible analyses: variation in stand age, site conditions and management history made it impossible to accurately describe the growth patterns or compare differences between intended main tree species.

## Conclusions

The sapling stands regenerated with oak, alder or larch rarely met all standards of silvicultural recommendations, but most stands still had the potential to develop as intended. The issues lay mostly in the stand density or quality of forest management. Some stands had been well managed, and regeneration and early development had been successful. Generally, crop trees were not suppressed by naturally emerged trees, and damage was not common. These findings suggest that with good management, it is possible to establish high-quality stands. A higher standard of forest management could likely be achieved by developing more thorough silvicultural recommendations, promoting forest owners' know-how, and emphasizing the importance of timely management. The structure of the data limited some of the analysis, and therefore, further studies with more intensive measurements with multiple time points are required to describe the development of stands and the effects of management on the development. This would also provide a basis to build or update growth models separately for alder, larch and oak. However, we were able to provide an overview of the aspects that have been successful when managing these stands, and pinpoint which factors require more attention. Our results show that with proper forest management and selection of suitable sites, it is possible to increase the tree species diversity in forests by cultivating oak, alder or larch even on a small scale, thereby enhancing forest biodiversity and resilience in the changing climate.

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## Author contributions

CRediT: **Lauri Männistö:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Visualization, Writing – original draft, Writing – review & editing; **Janne Miettinen:** Data curation, Formal analysis, Writing – review & editing; **Jari Miina:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing; **Saija Huuskonen:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing; **Raito Paananen:** Conceptualization, Data curation, Methodology, Project administration, Supervision, Writing – review & editing; **Minna Luoto:** Conceptualization, Data curation, Project administration, Supervision, Writing – review & editing; **Katri Himanen:** Conceptualization, Funding acquisition, Project administration, Writing – review & editing.

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