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Current state of mixed forests available for wood supply in Finland and Sweden

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ABSTRACT

This study's objectives were to suggest harmonised criteria for the definition of mixed forests for two Nordic countries, describe their principal mixture types, and provide an overview of their current extent. We used national forest inventory data compiled in Finland and Sweden, considering the forest available for wood supply (FAWS), excluding seedling and sapling plots before canopy closure. The definition of the mixed forest was based on the threshold criteria, which indicate the basal area proportion of the dominant tree species of the total in a stand. The proportion of mixed forests increased with higher threshold criteria: 21% to 42% in Finland and 24% to 49% in Sweden, as the threshold criterion was changed from 65% to 85%. With a threshold criterion of 75%, the area of mixed FAWS was 5.6 million ha (31% of FAWS) in Finland and 6.5 million ha (36%) in Sweden. The dominant mixture type was the pine-spruce-birches mixture (31%) in Finland and the pine-spruce mixture (29%) in Sweden. The proportion of peatland forest of mixed forests was similar in the countries: 9–10%. The mixed forests proportion increased from north boreal to hemiboreal, increasing with more mature development classes.

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National Forest Inventory (NFI); forest available for wood supply (FAWS); scots pine; Norway spruce; birch spp.; conifer mixed forests

Introduction

In Finland and Sweden, the growing bioeconomy is increasing demand for renewable raw material from forests. Both countries committed decades ago to applying Multi-Functional and Sustainable Forest Management (Resolution H1 MCPFE in Helsinki (MCPFE 1993)), which includes the maintenance of the balance between society's increasing demands for forest products and benefits and the preservation of forest health and diversity. Moreover, a characteristic feature of forest and ecosystem management is the concept of integration (Beland Lindahl and Westholm 2011; Simonsson et al. 2015), and the ecological, economic, and social functions of forests must therefore be considered simultaneously. In recent decades, the management of coniferous forests mixed with broadleaves instead of monocultures has been a debated and suggested method for integration (Keskitalo et al. 2016; Felton et al. 2016; Lodin et al. 2017; Hallberg-Sramek et al. 2023).

In Finland and Sweden, the prevailing silviculture in production forests has favoured the coniferous tree species, Scots pine (*Pinus sylvestris* L., hereafter pine) and Norway spruce (*Picea abies* (L.) Karst., hereafter spruce). The forest industry has regarded them as more productive and valuable than broadleaved tree species. As a result, most production forests are established as either pure coniferous stands or are strongly dominated by conifers (Nilsson et al. 2012; Korhonen et al. 2021). However, mixed-species forests, including both broadleaves and conifers, can commonly provide a wider range of ecosystem services than monocultures (Felton et al. 2016; Huuskonen et al. 2021) due to increased biodiversity, strengthened vitality, and improved resilience, and are therefore more adaptive to environmental changes (Messier et al. 2022).

According to Forest Europe (2020), less than a fifth of the forest area in Finland (14%) and in Sweden (17%) is covered by mixed forests, which are defined as forests where no single tree species accounts for more than 75% of the tree crown cover. In the boreal forests of Finland and Sweden, the number of tree species in mixed forests is usually low, and mixed forests have been studied less than monocultures. One of the challenges especially is the lack of general and explicit definitions of a mixed forest. Bravo-Oviedo et al. (2014) offered a generally consistent definition, but without thresholds for species proportions in terms of basal area. The definition of mixed forests therefore varies between countries. National forest inventories (NFI) apply 75% and 65% of the basal area in Finland and Sweden respectively as thresholds for the most dominant species to distinguish between monoculture and mixed forest. Typically, the NFI reports describe forest area and resources by main tree species, development class, soil type, and subregion, but the species mixtures are described in less detail.

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In this study, we developed harmonised criteria for mixed forests to compare Finnish and Swedish forests. The targeted area in this study was the forests available for wood supply to analyse the mixed forest state in productive forests. The specific research aims were: (1) to explore how the threshold criteria and definition of a mixed forest affected the estimate of the area proportion of mixed forests; (2) to identify the area and sites where mixed forests were most frequent; (3) to examine what the most common tree species mixtures are; and (4) to explore how the mixtures varied among the development classes.

Material and methods

Description of NFI data

We used the sample plot data of the Finnish 12th NFI, measured in 2014–2018. The sampling design in the Finnish NFI was systematic cluster sampling (Korhonen et al. 2021), except for the application of balanced sampling in the Åland region (Räty et al. 2019). The maximum plot radius in Finnish NFI12 was nine metres. For Sweden, we used both temporary (7 m radius) and permanent (10 m radius) sample plots from the Swedish NFI between 2012 and 2016 (Fridman et al. 2014). In both NFIs, only plots classified as forest available for wood supply (FAWS) were included in this study, based on land cover classifications according to the national and FAO classifications. Measurements and assessments were made at three different levels: tree; sample plot; and forest stand level.

Calculation of plot-level variables from tree measurements

For both countries, a NFI field plot can be divided into two or more forest stands if the plot falls at the border of stands. In this study, we used only the part of the plot that was inside the stand where the plot-centre was located (plot-centre stand). We calculated the tree basal area by tree species groups using the measured tree diameters. The tree species groups we used were as follows: pine (P); spruce (S); birches (B) (silver and downy, respectively *Betula pendula* Roth and *Betula pubescens* Enrh.) and other tree species (O). After calculating the tree basal areas by species groups, we converted the results into stand basal area (BA) based on hectare. Using the sample plots from the NFI implies a small-scale definition with tree-by-tree species mixed forest, as the sample plot is a maximum of 254 m^2 in Finland or 314 m^2 in Sweden. However, we have carefully assessed the mixture within each subplot of the data in accordance with the stand delineation assessed by NFI. Our definition of a mixed forest therefore means the mixture of tree species at subplot level.

Criteria for selecting plots and data harmonisation for both countries

The following criteria were used to select the sample plots in our study.

(1) Land use/land cover class: forest land, i.e. we excluded poorly productive forests (maximum mean annual increment <1 m^3 ha^{-1} $year^{-1}$) and land uses other than forest land.
(2) Forest available for wood supply: we excluded protected forests and other forests where harvesting was not allowed to determine the distribution of mixture types in productive forests.
(3) Development class: Young thinning stand (mean diameter at breast height (DBH) 10–16 cm), Advanced thinning stand (mean DBH >16 cm but not mature for final felling), and Mature forest (mature for final felling, minimum mean DBH criteria vary from 22 cm to 27 cm according to site productivity) were included from the Finnish NFI. Unthinned forest (most trees under 20 cm in DBH), Thinned forest (younger than allowable age for final felling, mean DBH can vary), and Final felling forest (older than the allowable age for final harvest recommended by the tables in Section 6.4 of the field instruction (SLU 2022), mean DBH can vary) were included from the Swedish NFI. (Note: the minimum criterion for the mean DBH of young thinning stands in Finland is around 8 cm. To harmonise with the Swedish data, we applied a minimum DBH of 10 cm in this study.) Seedling sites and sapling stands before the canopy closure, where trees were less than 10 cm in stem diameter at breast height (1.3 m above the ground), were not considered in the analysis.

In the analysis, the data were classified based on soil type, vegetation zone, and development class and were harmonised between countries. The original national soil type classifications were simplified to separate mineral soils and peatlands. In using the harmonised definition, the plots were classified as peatland if the organic layer was peat and at least 30 cm thick and as thin peat if the organic layer was peat and less than 30 cm thick.

The forest growth condition varies by biogeographical zone. Most of Finland and Sweden belongs to the boreal biogeographical zone; the southern parts belong to the hemiboreal subzone of the temperate zone (Ahti et al. 1968). Four vegetation zones were used in the analysis: northern, middle, southern, and hemi-boreal. To classify the climatic zones, we applied the country-wise vegetation zone maps provided by SYKE in Finland (SYKE 2015) and SNFI in Sweden (Nilsson et al. 2014). The boundary of the vegetation zone between countries was therefore somewhat dislocated in the northern and middle boreal zones. Table 1 shows the number of plots by different class used in this analysis.

Definitions of mixed forest type

The definition of mixed forest was based on the BA proportion by tree species (Figure 1). If none of the species-groups had a larger proportion than a designated threshold, the plot was regarded as a mixed forest plot. Otherwise, the plot was categorised as a monoculture. To examine how much the area proportion of mixed forest changed by

Table 1. The number of plots in National Forest Inventory (NFI) data from Finland (FI) and Sweden (SE). Only the plots classified as forest available for wood supply (FAWS) were analysed for this study.

Criteria	Class	Finnish NFI12 No. of plots for mixed forest [(a)]	No. of plots in total	% of mixed forest	Swedish NFI No. of plots for mixed forest [(a)]	No. of plots in total	% of mixed forest
Site type	Mineral soil	9779	31606	30.9	7135	20421	34.9
	Thin peat	2303	7917	29.1	–	–	–
	Peatland	1147	3000	38.2	851	1868	45.6
Vegetation zone	Northern boreal	1240	4488	27.6	707	2566	27.6
	Middle boreal	4885	16558	29.5	2929	7948	36.9
	Southern boreal	6544	19958	32.8	1203	3112	38.7
	Hemiboreal	560	1519	36.9	3147	8663	36.3
Development class [(b)]	Young thinning stand (FI)/ Unthinned forest (SE)	4766	14205	33.6	2896	8781	33.0
	Advanced thinning stand (FI)/ Thinned forest (SE)	5574	15363	36.3	1527	4473	34.1
	Mature stand (FI)/ Final felling forest (SE)	2131	4993	42.7	3563	9035	39.4
	Other classes	758	7962	9.5	–	–	–
	Total	13229	42523	31.1	7986	22289	35.8

[(a)]The number of plots for mixed forests was provided based on the threshold criterion for a basal area proportion of 75% of the most dominant species in a stand.
[(b)]The development class refers to the terminology of the Finnish and Swedish NFIs respectively and is not directly comparable between countries.

country, the threshold criteria for the BA ratio of single species were tested in a range from 65% to 85% by 5%, as this was considered sufficient to examine the trend. The 75% threshold criterion was applied in the analyses to define mixed forest types by conforming with the recent reports where the same criterion was applied (Forest Europe 2020; Korhonen et al. 2021).

Next, we checked the BA proportion of the top dominant species group in terms of BA. If it was more than 50% of total BA, the mixed forest type was named after the most dominant tree species group, e.g. pine, spruce, birches, or other mixed forest. Furthermore, we checked the second most dominant species. If it was more than 25% of the total, the species name was added to the nomenclature, as it could denote a proportion more than half the rest of the total BA (or more than a quarter). For example, a pine-spruce forest (P-S in Figure 1) was defined as one in which pine was more than 50% and spruce more than 25% of the basal area proportion (Figure 1).

In addition to the definitions above such as P-S, S-B, B-S, and etc., pine, spruce, and birches (P-S-B) mixtures are of great interest, as these species are the most common and important in Finland and Sweden. Classifying the P-S-B mixture as special cases by checking the three species rather than the most dominant two species was therefore considered. We used the category of case 1 for the pine-spruce-birches forest type (P-S-B c1 in Figure 1) for those plots where the most dominant species had a BA proportion of more than 50%, and all the pine, spruce, and birches each had a BA proportion of more than 10%. If the most dominant species was pine, spruce, or birch, any of the top species had a BA proportion of more than 25%, and all the pine, spruce, and birches each had a BA proportion of more than 10%, the plots were also categorised as case 2 for the pine-spruce-birches forest type (e.g. P-S-B c2 in Figure 1). For example, a plot with a BA proportion of spruce of 60%, birches of 30%, and pine of 10% or a plot with spruce of 60%, birches of 20%, and pine of 20% was classified as P-S-B c1. A plot with 40–30–30% or 45–40–15% was classified as P-S-B c2.

We also defined additional categories such as case 2 for pine-other, spruce-other, and birches-other, where 50% ≤BA <75% for the most dominant species, and the BA <25% for the second most dominant species (e.g. P-O c2, S-O c2, and B-O c2 in Figure 1). Otherwise, the plots were categorised as case 1 or 2 for other mixed forest (e.g. OM c1 and OM c2). This mixed forest type can be defined as a plot where other species rather than pine, spruce, or birches were dominant (OM c1 in Figure 1) or a plot where pine, spruce, or birches had a minor proportion (OM c2 in Figure 1). Cases 1 and 2 were designed to identify the mixture types and helped describe the majority or minority of the species' BA proportions.

Results

Area of mixed forests depending on different basal area thresholds

The total area of FAWS used for the analysis of mixed species proportions in this study was 18.2 million ha in Finland and 18.0 million ha in Sweden. The proportion of mixed forest increased with a similarly spaced interval between the threshold criteria of 65% to 85% for monoculture vs mixture. In Finland, the increase ranged from 21% (3.8 million ha) to 42% (7.6 million ha) and in Sweden from 24% (4.3 million ha) to 49% (8.8 million ha) (Figure 2). The increase of mixed forest was 5–7% in both countries for each increased step of the 5% threshold criteria for the plot considered a monoculture.

Hereafter, all further analyses were based on the 75% threshold criteria, in which the mixed forest corresponded to 31% (5.6 million ha) vs monoculture 69% (12.6 million ha) in Finland and 36% (6.5 million ha) vs 64% (11.5 million ha) in Sweden (Figure 3 (a1,b1)). While the total area was about 0.2 million ha larger in Finland, the area of mixed forest in FAWS was 0.9 million ha (5%) larger in Sweden.

The area and proportion by defined mixed forest type

Using the 75% basal area threshold criterion for monoculture, the pine-spruce-birches forest was the most common mixture

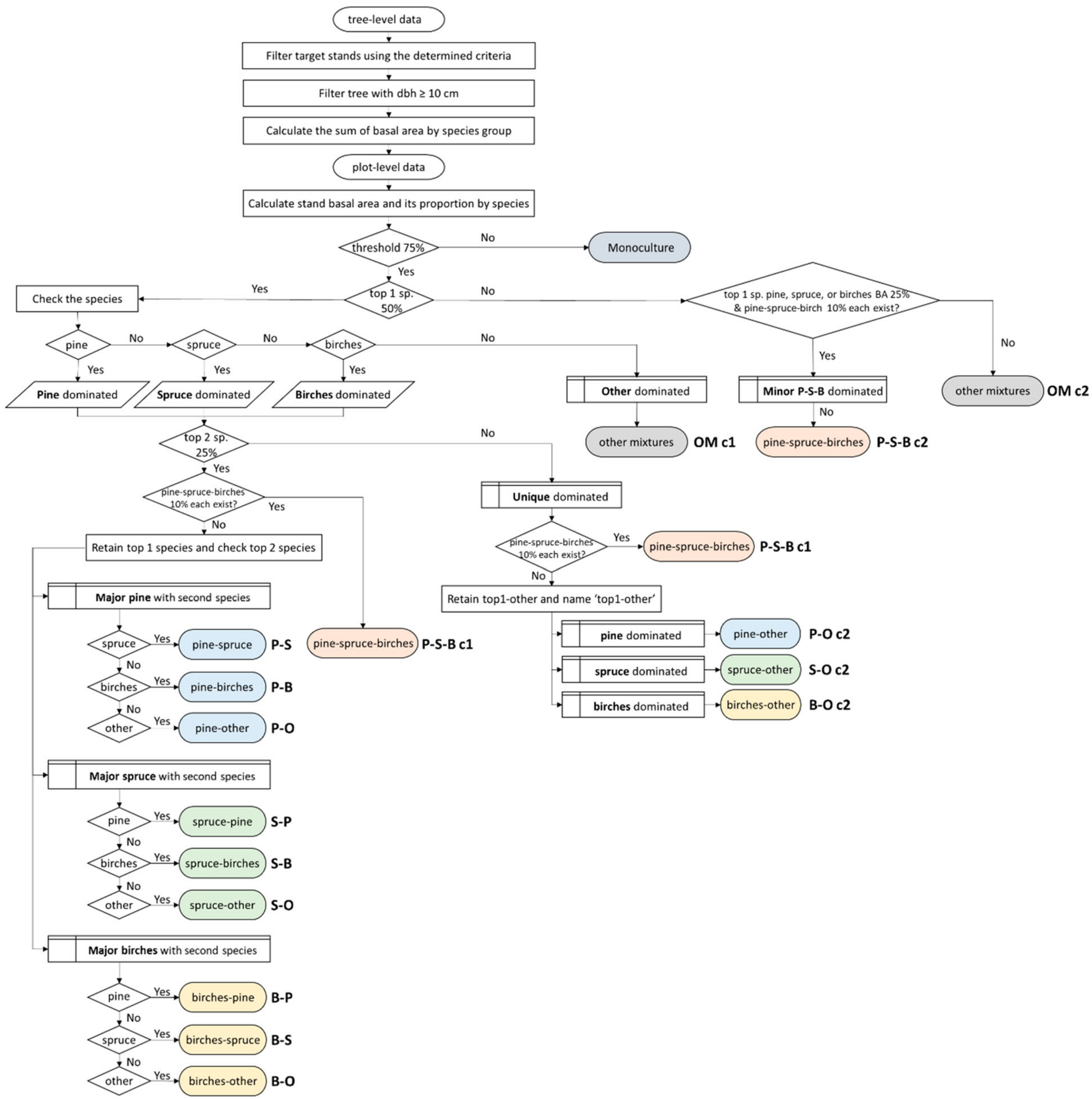

Figure 1. Definition of the mixed forest based on the stand basal area (BA) with the same criteria for both countries. In the example, the threshold criterion for the BA proportion of the most dominant species is 75%. Mixed forests are classified into groups coloured by tree species mixtures. The symbols in bold are referenced in Material and Methods for readability.

in Finland, covering 30.5% (1.7 million ha) of the total area of mixed forests, followed by the pine-spruce forest (20.2%). In Sweden, the area of pine-spruce forest was largest, with a proportion of 28.8% (1.9 million ha), followed by spruce-birches forest (19.1%) (Figure 3 (a2,b2)).

In both countries, pine was more dominant than the other species in each mixed forest type (e.g. pine-spruce, pine-birches, pine-spruce-birches). Additionally, the forest area with the class of minor p-s-b dom type (P-S-B c2), where the basal area proportion of a top dominating species is more than 25% but less than 50%, was 12.8% (0.7 million ha) of the area of mixed forests in Finland and 6.6% (0.4 million ha) in Sweden.

A relatively small proportion of the mixed forest was dominated by either pine, spruce or birches and in mixture with other species, e.g. alder (*Alnus incana* and *A. glutinosa*) or aspen (*Populus tremula*). The area proportion of pine-other, spruce-other, and birches-other stands was 4.7%, 4.0%, and 2.7% in Finland and 9.1%, 9.1%, and 3.6% in Sweden respectively. The proportion of mixed forests not dominated by pine, spruce, or birches was 8.7% of mixed forests in Finland and 6.5% in Sweden.

The area and proportion of mixed forests by soil type

On mineral soils, pine-spruce-birches mixtures were the most common mixtures in Finland, whereas in Sweden, the pine-spruce mixtures were the most common (Figure 4). Mineral soils represented 73% of mixed forests in Finland and 90% in Sweden. On peatlands pine-spruce-birches was the most

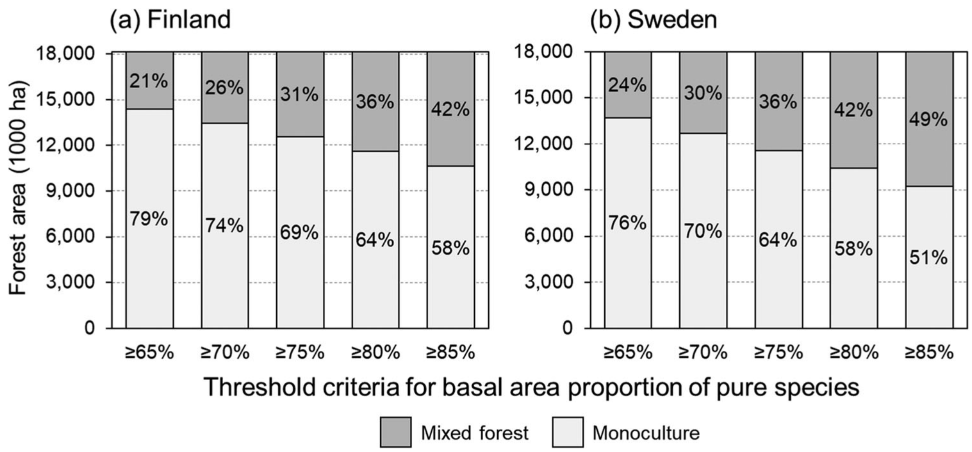

Figure 2. Area comparison of mixed forest vs monoculture in line with different basal area thresholds for the forest available for wood supply in Finland (a) and Sweden (b). The x-axis defines the minimum percentage of the stand occupied by a single species in each class, e.g. the forest area is categorised as a monoculture if a species of basal area proportion occupies more than or is equal to 75% in the ≥75% class.

common mixture in both Finland (3.2% of mixed forests) and Sweden (2.4%). Similarly, the pine-spruce-birches forest was the most common mixture on thin peat sites (6.0%) in Finland; the thin peat category (18% of forest area in Finland) is not defined in the Swedish NFI.

The area and proportion of mixed forests by vegetation zone

The largest mixed forest area by vegetation zone was in the southern boreal (2.3 million ha) in Finland and in the middle boreal (2.9 million ha) in Sweden (Figure 5 (b1–b4)). Although the total mixed forest area differed between countries by vegetation zone, the area proportion in Finland and Sweden was similar: 27% vs 28% in the northern boreal, 30% vs 37% in the middle boreal, 33% vs 40% in the southern boreal, and 37% vs 37% in the hemiboreal (Figure 5 (b1–b4)). The proportion of mixed forests increased in both countries towards the south.

In the southern, middle, and northern boreal zones, the pine-spruce-birches mixtures were the most common in Finland (Figure 5 (c1–c4)). On the other hand, in Sweden, the spruce-birches mixture was the most common in the northern boreal, and the pine-spruce mixture was the most common in the middle boreal and southern boreal zones. Unlike the other mixture types, the proportion of the birches-other mixture and other mixtures tended to be greater from the northern boreal to the southern boreal. In particular, the trend of other mixtures along the vegetation zone was found to noticeably increase towards the south in both countries.

The area and proportion of mixed forests by development class

The proportion of mixed forests increased towards older development classes in both countries, e.g. 33%, 36%, to 43% in Finland and 33%, 35%, to 39% in Sweden (Figure 6 (a1,b1)). In *Young thinning* stands, pine-spruce, pine-birches, and spruce-birches forests were evenly represented (17–18%) in Finland (Figure 6 (a2)). In Sweden, in the *Unthinned* forests class spruce-birches (23%), pine-spruce (22%), and pine-spruce-birches (18%) mixtures were the most common mixed forests (Figure 6 (b2)). In *Advanced thinning* stands, the pine-spruce-birches mixture (34%) represented the largest area of mixed forests in Finland, while in the *Thinned* forests class, the pine-spruce mixture was clearly the largest area of mixed forests (34%) in Sweden. In *Mature* stands, the pine-spruce-birches mixture was most common (31%) in Finland, whereas in the *Final Felling* forests class, the pine-spruce mixture was the most common in Sweden.

Discussion

Characteristics in accordance with mixed forest definitions

The definition of what constitutes a mono- or multi-specific forest varies between countries and organisations (Bruchwald 1984; Bravo-Oviedo et al. 2014). We focused on forests with development stages starting from young thinning stands after canopy closure. The BA proportion of the most dominant species was applied as classification criteria for mixed stand or monoculture. The BA is often used to describe the stand density after canopy closure instead of the stem number because it explains the density-driven competition more significantly and allows the avoidance of any bias caused by a decreasing reverse J-shaped and right-skewed diameter distribution in mixed forests (Aldea et al. 2023). By using the definition via the basal area instead of the stem number, the different tree size and the tree species could be taken into account in classifying the mixtures. The stem number would otherwise strongly take up the mixture type in spite of the small occupancy rate of the BA. For example, if the stem number criterion is applied, a mature stand in which large birches are dominant with a large number of small spruce saplings would be classified as a spruce monoculture or heavily spruce-dominated mixtures. This would give rise to an obvious misinterpretation. The mixed forests

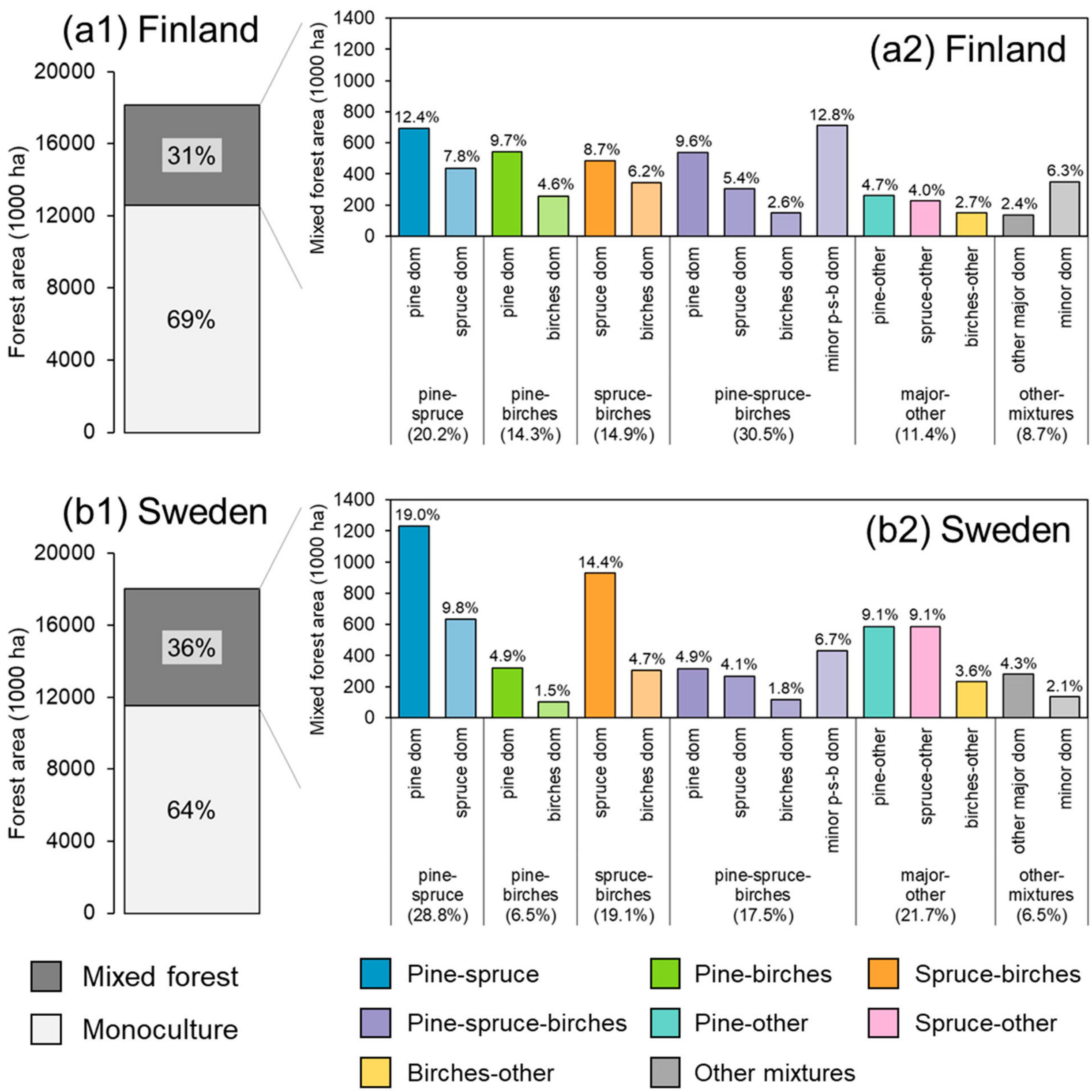

Figure 3. Proportion of mixed forest in the forest available for wood supply (FAWS) and the proportions by mixed forest type in Finland (a) and Sweden (b). Each of the mixed forest types (e.g. pine-spruce) is further divided into dominant tree species (e.g. pine-dom and spruce-dom).

therefore appeared more adequately with the BA criteria than the stem number criteria, regardless of a variety of tree sizes in the diameter distribution.

Our analysis revealed that the applied BA threshold notably affected the overall mixed forest area in both Finland and Sweden. Within the range of the threshold from 65% to 85%, the mixed forests area increased by 21% and 25% for Finland and Sweden respectively (Figure 2), i.e. almost doubling the mixed forest area: 21–42% in Finland and 24–49% in Sweden. These results showed the similar change of the mixed forest proportion in both countries, highlighting the need for the well-justified common threshold to make it comparable internationally. In other studies, the 75% threshold criteria have been applied for the definition of mixed forest based on the BA in Finnish NFI reporting (Korhonen et al. 2021) and on tree crown cover criterion in Forest Europe reporting (Forest Europe 2020). Except for the results for the threshold comparisons discussed above, we therefore used the 75% threshold criteria in our study. By doing so, 31% of the forest area in Finland and 36% in Sweden were classified as mixed forest (Figure 2).

Area estimates based on NFI data contain a sampling variance. The area estimates for mixed forests with the 75% threshold value are 5.6 million ha in Finland and 6.5 million ha in Sweden (Figure 2). The area estimate for a domain of this size is expected to have a standard error of about 1% in the Finnish NFI12 (cf. Appendix Table 1 of Korhonen et al. 2021) and 2.5% in the Swedish NFI (cf. Table 5 of Toet et al. 2007).

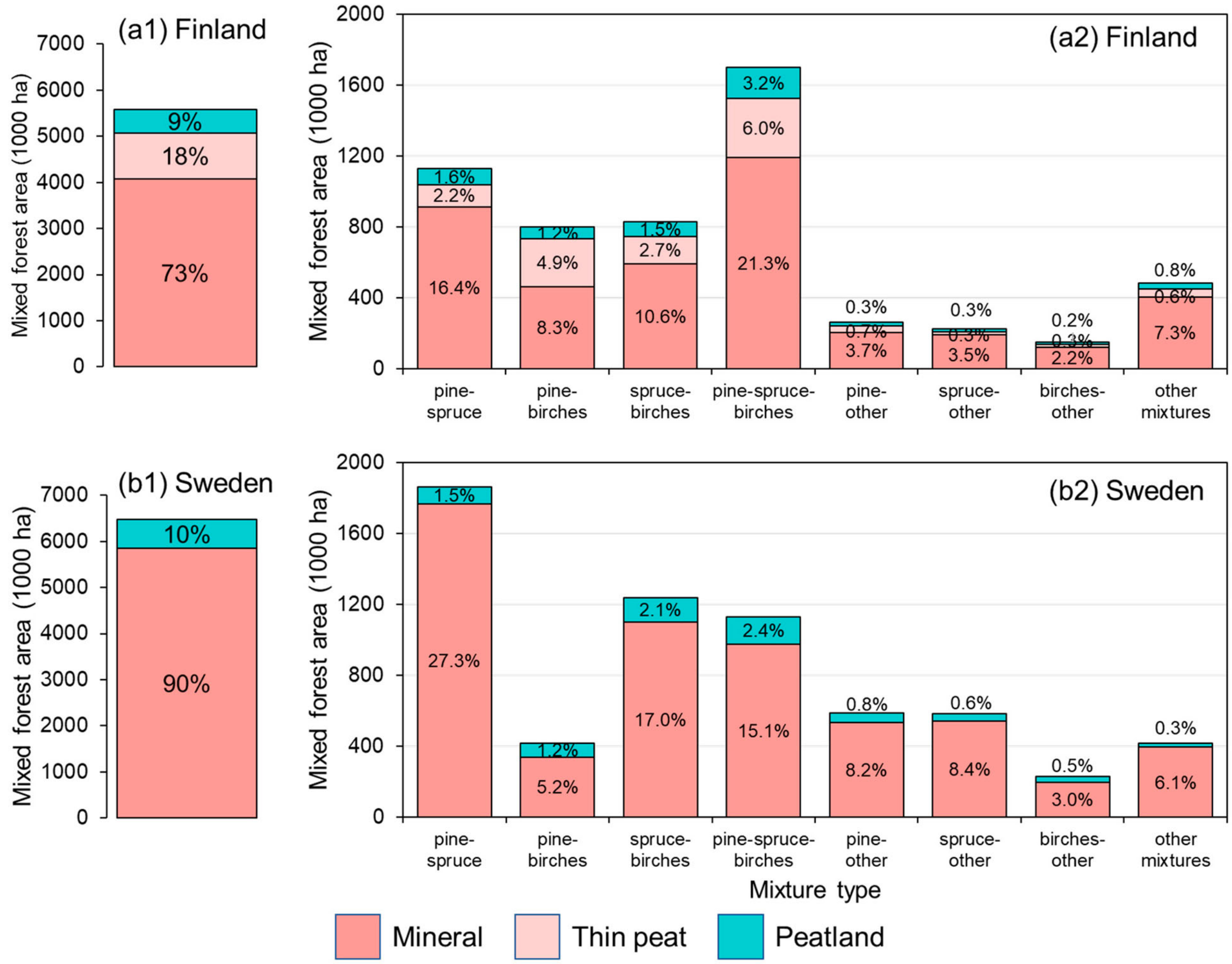

Figure 4. Mixed forest area by soil type (a1 and b1) and the area proportion by mixture and soil types (a2 and b2) in Finland and Sweden.

Differences and similarities of mixed forest composition between Finland and Sweden

We evaluated the mixtures by tree species, finding that a majority was comprised of pine, spruce, or birches mixtures, whereas other broadleaved trees were only sparsely found in both countries (Figure 3). However, this result was not entirely consistent with the previous literature (Forest Europe 2020), which is probably because of differences between the definitions of our study and the reports by the Finnish and Swedish NFIs.

The definition of mixed forest significantly affects the estimate of mixed forest. For example, the Finnish NFI uses a 75% criterion, while the Swedish NFI uses 65% (Nilsson et al. 2013; Korhonen et al. 2017). In the report about the state of Europe's Forest, the mixed forest is defined by the 75% threshold criterion based on tree crown cover, and as a result, an average of less than a fifth of the forest land area (14% in Finland and 17% in Sweden) was covered by mixed forests (Forest Europe 2020). Moreover, the Finnish NFI and Forest Europe define mixed forests as only coniferous-broadleaved mixtures, which implies that two dominant coniferous species were not classified as mixed forests, i.e. pine-spruce mixtures (Korhonen et al. 2017). The distinct definition may greatly influence the number of mixed forest area differences by publications, e.g. reports by the Finnish NFI, Swedish NFI, and Forest Europe.

In our study, by using the same mixed forest criteria, we compared the current state of mixed forests between two countries. Our results substantiated that the methodologies and experimental design used for the NFIs were elaborate and compatible between Finland and Sweden. It will therefore provide more opportunities to study forest structures in a different way by consolidating the NFI data.

Distribution characteristics and management strategy by vegetation zone

The proportion of mixed forests in both countries was larger in the southern region than in the northern region, e.g. northern boreal vs southern or hemiboreal (Figure 5). Southern regions would be the most suitable by their nature to further increase the proportion of mixed stands, especially by increasing broadleaved mixtures. Broadleaved mixtures are known to be beneficial for increased biodiversity, strengthened vitality, and improved resilience, thus making forests more resilient to environmental changes (Messier et al. 2022). However, coniferous mixtures can place the emphasis on more promotion in the northern boreal zone.

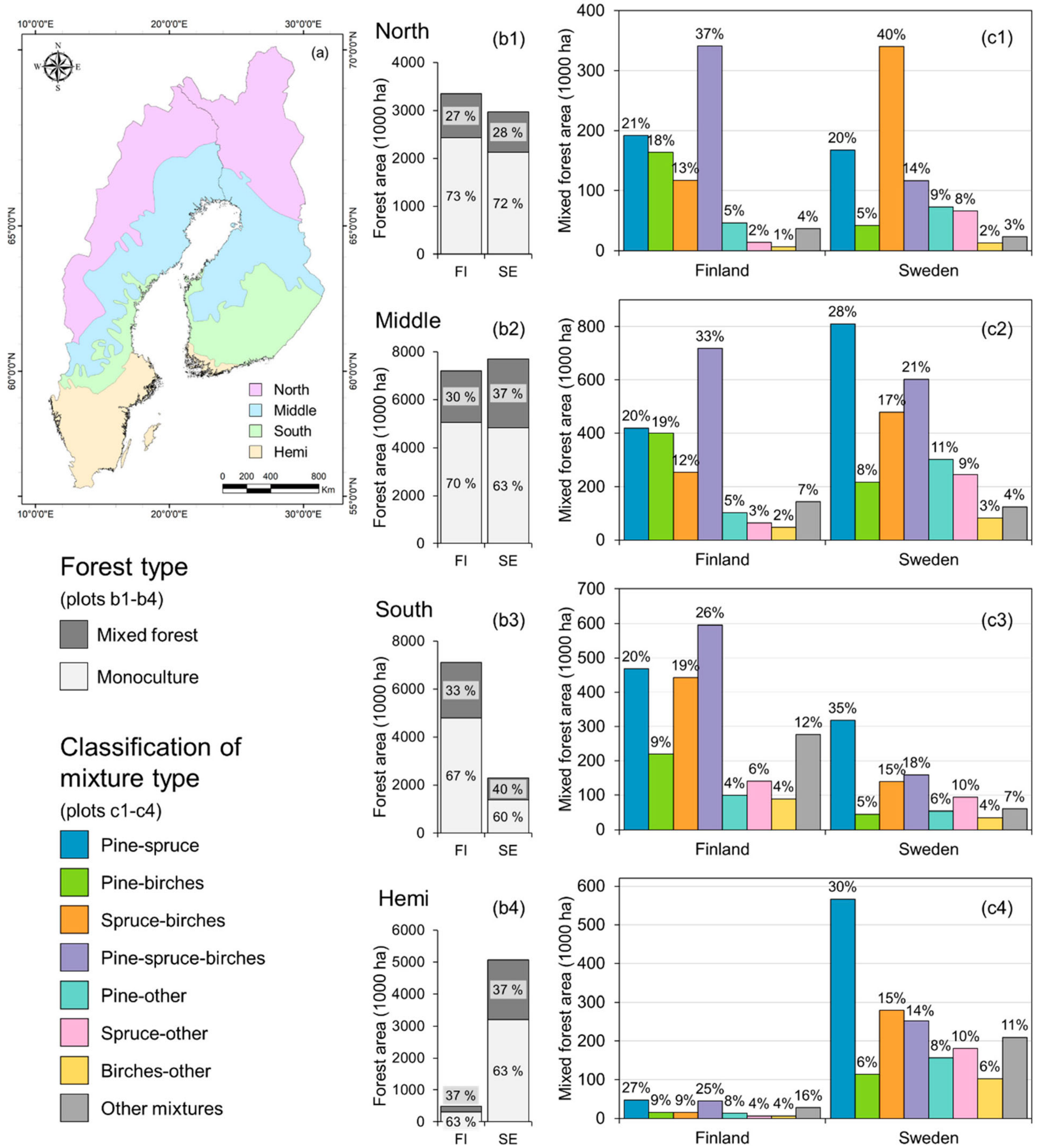

Figure 5. The area and proportion of mixed forests by vegetation zone in each country. The proportion of mixtures was calculated by country (b1–b4 and c1–c4). The c1–c4 plots target only the mixed forest area as a total. The map sources (a) are available from SYKE (SYKE 2015) for Finland (FI) and the Swedish NFI (Nilsson et al. 2014) for Sweden (SE).

The pine-spruce mixture is a viable option on suitable sites, particularly with high browsing risk areas (Bianchi et al. 2021).

Differences by development class in mixed-forest distribution

Most of the forests in the study data probably originated more than 30 years ago and were therefore regenerated and managed in accordance with silvicultural practices, which do not currently prevail in production forests. Both countries have since adopted forest policies and legislation aiming for more multifunctional and sustainable forestry. However, the shift in forest policy and changed silviculture is yet to be seen in mature forests. We compared the mixtures by development class starting from advanced young but not yet thinned stands to mature stands. In both countries, the proportion of mixed forests was higher in the older development stages (Figure 6).

The results indicate that forest management recommendations for precommercial thinning and commercial thinning have highlighted pure conifer stands in recent decades. They may also indicate that previous thinnings did not remove the

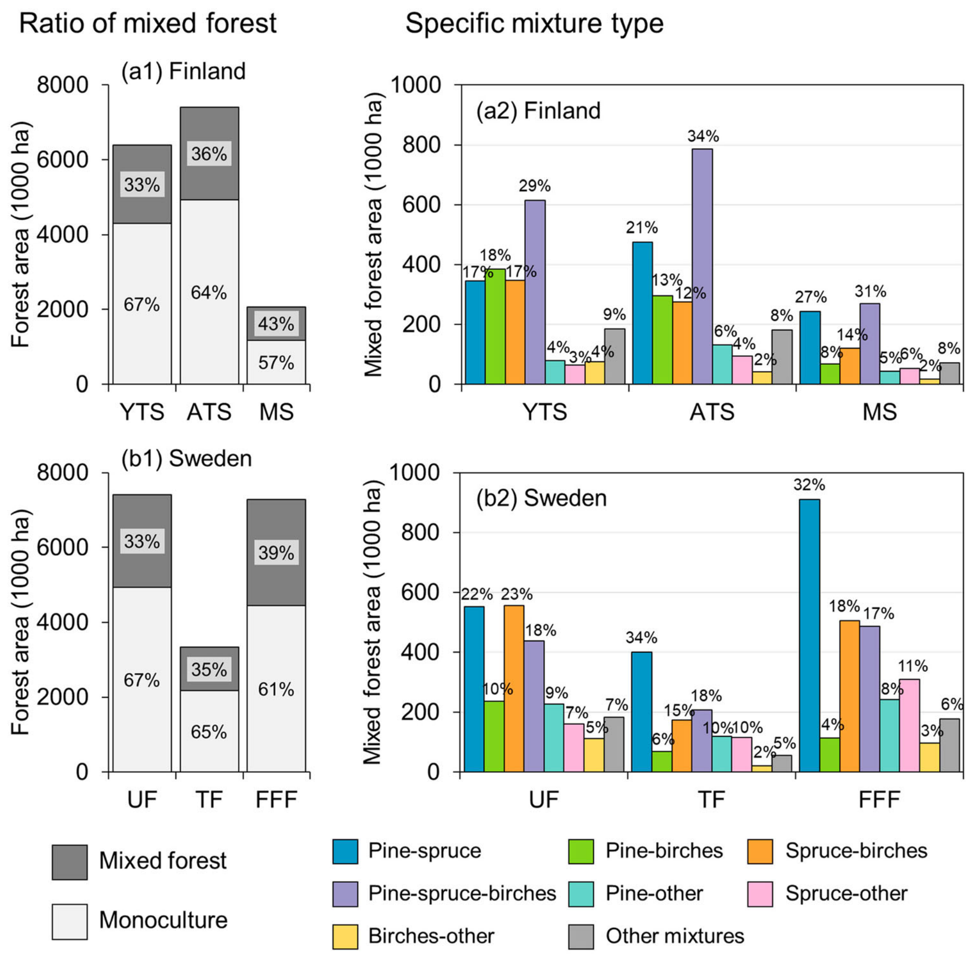

Figure 6. Ratio of mixed forest (a1 and b1) and the mixed forest area with its proportion (a2 and b2) by development class. The proportion was calculated by each class in both counties. The classes are not directly comparable across the countries, and the detailed definition of classification is explained in Material and methods. YTS: young thinning stand, ATS: advanced thinning stand, MS: mature stand, UF: unthinned forest, TF: thinned forest, FFF: final felling forest.

early ingrowth of secondary species in older stands. Similar indications have been found in a previous study, where pine mixtures were biased to a high proportion of pine basal area and a low proportion of pine stems, indicating mixtures with few large pine trees and many small spruce (Appiah Mensah et al. 2020). In contrast, the spruce-dominated mixtures in the same study showed a high correlation of mixture proportion in stems and the basal area, indicating these mixtures were probably mostly stem-by-stem mixtures from the regeneration phase. This was further strengthened by the analysis of the spruce-birches mixtures in southern Sweden (Holmström et al. 2021). The higher proportion of mixed forest in older stands could also imply a long-term historical shift in forest management, with regenerations less mixed than 60–100 years ago.

Conclusion

Mixed forests in Finland and Sweden were analysed using the NFI data targeting forests available for wood supply. We compared the threshold criteria for the BA proportion of the most dominant species, finding that the proportion of mixed forest by criteria changed similarly in both countries. Similarly, the mixed forest area accounted for 31% in Finland and 36% in Sweden in accordance with our most targeted criterion: a threshold criterion of 75% for the BA proportion of a single species. The major mixture types and main tree species were consistent between countries, such as pine-spruce, pine-birches, spruce-birches, and pine-spruce-birches. Moreover, the proportion of mixed forest in the same vegetation zone was similar in the two countries. It was remarkable that the proportion of mixed forest generally tended to be larger as the vegetation zone moved from the northern boreal to the southern boreal zones. Yet it will be necessary to further study how to manage forests by vegetation zone considering the pros and cons of monoculture and mixed forest in terms of wood supply and environmental issues.

The direct comparison of development class across the country was not feasible due to the different data characteristics, but there was also a noticeable trend in both countries for the proportion of mixed forest to increase with a more mature development class. As our results could imply a long-term shift in forest management, we need to prepare our strategy to deal with mixed forest issues in the current situation. It was also found that species mixture should be promoted in the early stage of stand development to maintain or increase the proportion of mixtures. Overall, this study offered results to determine the current state of mixed forests in Finland and Sweden and provided necessary information and ideas to prepare strategies for forest management planning from a practical perspective in silvicultural treatment. Furthermore, it was considered to clearly demonstrate that the NFIs' methods in both countries were similar and thus compatible, meaning various issues such as other forest structures could be further examined together.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Authors' contributions

Conceptualisation: SH, EH, JH, UN; Data curation: KTK, BW; Formal analysis: DL, EH; Funding acquisition: SH, JA, JH; Investigation: KTK, BW; Methodology: DL, EH, SH; Project administration: SH, EH; Software: DL, EH; Supervision: SH; Validation: KTK, BW; Visualisation: DL; Writing – original draft preparation: DL, EH, SH; Writing – review and editing: DL, EH, JH, UN, KTK, SB, JA, SH. All authors read and approved the final manuscript.

Data availability

The research data and materials are generally confidential and available for scientific research on request from the authors, Kari T Korhonen and Bertil Westerlund, for the Finnish and Swedish National Forest Inventory data respectively.

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References

Ahti T, Hämet-Ahti L, Jalas J. 1968. Vegetation zones and their sections in northwestern Europe. Ann Bot Fenn. 5(3):169–211.

Aldea J, Bianchi S, Nilsson U, Hynynen J, Lee D, Holmström E, Huuskonen S. 2023. Evaluation of growth models for mixed forests used in Swedish and Finnish decision support systems. For Ecol Manag. 529:120721. doi:10.1016/j.foreco.2022.120721.

Appiah Mensah A, Petersson H, Saarela S, Goude M, Holmström E. 2020. Using heterogeneity indices to adjust basal area – Leaf area index relationship in managed coniferous stands. For Ecol Manag. 458:117699. doi:10.1016/j.foreco.2019.117699.

Beland Lindahl K, Westholm E. 2011. Food, paper, wood, or energy? Global trends and future Swedish forest use. Forests. 2(1):51–65. doi:10.3390/f2010051.

Bianchi S, Huuskonen S, Hynynen J, Oijala T, Siipilehto J, Saksa T. 2021. Development of young mixed Norway spruce and Scots pine stands with juvenile stand management in Finland. Scand J For Res. 36 (5):374–388. doi:10.1080/02827581.2021.1936155.

Bravo-Oviedo A, Pretzsch H, Ammer C, Andenmatten E, Barbati A, Barreiro S, Brang P, Bravo F, Coll L, Corona P, et al. 2014. European Mixed Forests: definition and research perspectives. For Syst. 23(3):518–533. doi:10.5424/fs/2014233-06256.

Bruchwald A. 1984. Estimation of attacking spruce trees by root rot (Fomes annosus Fr.) in spruce-pine stands of Puszcza Romincka. Ann Wars Agric Univ SGGW-AR For Wood Technol Pol. 32:7–11.

Felton A, Gustafsson L, Roberge J-M, Ranius T, Hjältén J, Rudolphi J, Lindbladh M, Weslien J, Rist L, Brunet J, Felton AM. 2016. How climate change adaptation and mitigation strategies can threaten or enhance the biodiversity of production forests: Insights from Sweden. Biol Conserv. 194:11–20. doi:10.1016/j.biocon.2015.11.030.

Forest Europe. 2020. State of Europe's Forest 2020 [Internet]. Ministerial Conference on the Protection of Forests in Europe: Forest Europe Liaison Unit Bratislava; [accessed 2023 Jun 17]. https://foresteurope.org/state-europes-forests-2020/.

Fridman J, Holm S, Nilsson M, Nilsson P, Ringvall AH, Ståhl G. 2014. Adapting National Forest Inventories to changing requirements – the case of the Swedish National Forest Inventory at the turn of the 20th century. Silva Fenn. 48(3). doi:10.14214/sf.1095.

Hallberg-Sramek I, Nordström E-M, Priebe J, Reimerson E, Mårald E, Nordin A. 2023. Combining scientific and local knowledge improves evaluating future scenarios of forest ecosystem services. Ecosyst Serv. 60:101512. doi:10.1016/j.ecoser.2023.101512.

Holmström E, Carlström T, Goude M, Lidman FD, Felton A. 2021. Keeping mixtures of Norway spruce and birch in production forests: insights from survey data. Scand J For Res. 36(2–3):155–163. doi:10.1080/02827581.2021.1883729.

Huuskonen S, Domisch T, Finér L, Hantula J, Hynynen J, Matala J, Miina J, Neuvonen S, Nevalainen S, Niemistö P, et al. 2021. What is the potential for replacing monocultures with mixed-species stands to enhance ecosystem services in boreal forests in Fennoscandia? For Ecol Manag. 479:118558. doi:10.1016/j.foreco.2020.118558.

Keskitalo ECH, Bergh J, Felton A, Björkman C, Berlin M, Axelsson P, Ring E, Ågren A, Roberge J-M, Klapwijk MJ, Boberg J. 2016. Adaptation to climate change in Swedish forestry. Forests. 7(2):28. doi:10.3390/f7020028.

Korhonen KT, Ahola A, Heikkinen J, Henttonen HM, Hotanen J-P, Ihalainen A, Melin M, Pitkänen J, Räty M, Sirviö M, Strandström M. 2021. Forests of Finland 2014–2018 and their development 1921–2018. Silva Fenn. 55(5). doi:10.14214/sf.10662.

Korhonen KT, Ihalainen A, Ahola A, Heikkinen J, Henttonen HM, Hotanen J-P, Nevalainen S, Pitkänen J, Strandström M, Viiri H. 2017. Suomen metsät 2009–2013 ja niiden kehitys 1921–2013 [Internet]. Helsinki: Luonnonvarakeskus (Luke). https://www.silvafennica.fi/article/10662.

Lodin I, Brukas V, Wallin I. 2017. Spruce or not? Contextual and attitudinal drivers behind the choice of tree species in southern Sweden. For Policy Econ. 83:191–198. doi:10.1016/j.forpol.2016.11.010.

MCPFE. 1993. Resolution H1 General Guidelines for the Sustainable Management of Forests in Europe [Internet]. Helsinki: Ministerial Conference on the Protection of Forests in Europe. https://

foresteurope.org/wp-content/uploads/2022/01/MC_helsinki_resolutionH1.pdf.

Messier C, Bauhus J, Sousa-Silva R, Auge H, Baeten L, Barsoum N, Bruelheide H, Caldwell B, Cavender-Bares J, Dhiedt E, et al. 2022. For the sake of resilience and multifunctionality, let's diversify planted forests!. Conserv Lett. 15(1):e12829. doi:10.1111/conl.12829.

Nilsson P, Cory N, Fridman J, Kempe G. 2012. Skogsdata: aktuella uppgifter om de svenska skogarna från Riksskogstaxeringen. 2012, Tema: Skogsodling, skogsvård och avverkning [Internet]. Umeå: Institutionen för skoglig resurshushållning, Sveriges lantbruksuniversitet. https://pub.epsilon.slu.se/9266/1/SkogsData2012_webb.pdf.

Nilsson P, Cory N, Fridman J, Kempe G. 2013. Skogsdata: aktuella uppgifter om de svenska skogarna från Riksskogstaxeringen. 2013, Tema: Olika mått på skogens ålder och trädslagssammansättning [Internet]. Umeå: Institutionen för skoglig resurshushållning, Sveriges lantbruksuniversitet. https://pub.epsilon.slu.se/9266/1/SkogsData2012_webb.pdf.

Nilsson P, Cory N, Wulff S. 2014. Skogsdata: aktuella uppgifter om de svenska skogarna från Riksskogstaxeringen. 2014, Tema: Biologisk mångfald [Internet]. Umeå: Institutionen för skoglig resurshushållning, Sveriges lantbruksuniversitet. https://www.slu.se/globalassets/ew/org/centrb/rt/dokument/skogsdata/skogsdata2014_webb.pdf.

Räty M, Heikkinen J, Korhonen KT, Peräsaari J, Ihalainen A, Pitkänen J, Susanna Kangas A. 2019. Effect of cluster configuration and auxiliary variables on the efficiency of local pivotal method for national forest inventory. Scand J For Res. 34(7):607–616. doi:10.1080/02827581.2019.1662938.

Simonsson P, Gustafsson L, Östlund L. 2015. Retention forestry in Sweden: driving forces, debate and implementation 1968–2003. Scand J For Res. 30(2):154–173. doi:10.1080/02827581.2014.968201.

SLU. 2022. Fältinstruktion 2022 RIS Riksinventeringen av skog [Internet]. Umeå: SLU, institutionen för skoglig resurshushållning Umeå och Institutionen för mark och miljö Uppsala. [accessed 2023 Aug 14]. https://www.slu.se/globalassets/ew/org/centrb/mi/22_ris_fin.pdf.

SYKE. 2015. Metsäkasvillisuusvyöhykkeet. Suom Ymp [Internet]. [accessed 2022 Mar 22]. https://ckan.ymparisto.fi/en/dataset/metsakasvillisuusvyohykkeet.

Toet H, Fridman J, Holm S. 2007. Precisionen i Riksskogstaxeringens skattningar 1998-2002 [Internet]. Umeå: SLU, institutionen för skoglig resurshushållning. [accessed 2023 Aug 14]. https://urn.kb.se/resolve?urn=urn:nbn:se:naturvardsverket:diva-310.