Scandinavian Journal of Forest Research

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/sfor20

Exploring the diversity of non-industrial private forest properties in Southern Sweden

Tristan R.M. Bakx, Cecilia Akselsson & Renats Trubins

To cite this article: Tristan R.M. Bakx, Cecilia Akselsson & Renats Trubins (2024) Exploring the diversity of non-industrial private forest properties in Southern Sweden, Scandinavian Journal of Forest Research, 39:6, 298-309, DOI: 10.1080/02827581.2024.2398235

To link to this article: https://doi.org/10.1080/02827581.2024.2398235

SCANDINAVIAN JOURNAL OF FOREST RESEARCH
2024, VOL. 39, NO. 6, 298–309
https://doi.org/10.1080/02827581.2024.2398235

Exploring the diversity of non-industrial private forest properties in Southern Sweden

Tristan R.M. Bakx[a,b], Cecilia Akselsson[b,c] and Renats Trubins[d]

[a]CREAF, Cerdanyola del Vallès, Spain; [b]Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden; [c]Centre for Environmental and Climate Science, Lund University, Lund, Sweden; [d]Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, Alnarp, Sweden

ABSTRACT
Diverse forest landscapes contribute to reaching various forest policy goals. Understanding how the diversity of forests in a landscape is distributed among forest properties and how it is related to biogeographical and ownership factors can be helpful for effective policy implementation. We created a forest characteristics-based typology of non-industrial private forest properties aiming to capture the between-property forest diversity in a municipality in southern Sweden, and studied how it was related to owner age and gender, landscape position, and storm damage. Using public data of forests and latent profile analysis, we detected five clusters of properties. Four clusters differed mainly by age structure and species composition. One of them was clearly marked by a high proportion of young mixed forest following severe storm damage >15 years prior. The fifth cluster was marked by a greater occurrence of nature conservation agreements and conservation value forests. Conifer-dominated properties were larger than broadleaf-dominated properties. Owner age only slightly differed between clusters, being higher for properties characterized by a prevalence of older coniferous or by noble broadleaved forests and nature conservation. Properties in the latter cluster were more often owned by women and located close to lakes.

ARTICLE HISTORY
Received 12 November 2023
Accepted 25 August 2024

KEYWORDS
Forestry; non-industrial private forest owners; typology; landscapes; storm damage

Introduction

What forests look like is influenced by multiple factors that operate at different spatial and temporal scales. From large to small scale these include, respectively, climate, biogeographical features, natural disturbances, and management. Forest management can strongly influence the ecosystem services (ES) that are delivered (Pukkala 2016; Sing et al. 2018; Baskent et al. 2020). An estimated 60% of European forests are in privately owned properties[1] of varying sizes (Živojinović et al. 2015; Weiss et al. 2019). In many countries, non-industrial private forest (NIPF) owners constitute a large share of the privately owned forest, making it so that many people are involved in the decision-making that leads to ES production (UNECE 2010; Nilsson et al. 2021).

Currently, the demand for ES from forests is diversifying due to the introduction of new international policy targets and strategies such as the Kunming-Montreal Global Biodiversity Framework, the EU Forest Strategy, and the EU Biodiversity Strategy. To meet the diversifying demands, landscape-scale diversification of management has been proposed, and its effects on ecosystem service production have been investigated (e.g. Duncker et al. 2012; Schwaiger et al. 2019; Eyvindson et al. 2021). This scientific evidence is followed in Sweden by a policy strategy to achieve more diverse forest landscapes through diverse forest management (Swedish: Variationsrikt Skogsbruk; Swedish Forest Agency 2023a). Adapting new management diversification policies to the existing diversity of forest estates could make the policy implementation more effective. For this, it is necessary to know what between-property diversity currently exists in forest landscapes, and little is known about that as previous NIPF-oriented studies have mainly focused on the values or preferences of NIPF owners rather than the forests on their properties. This way, policy implementation could be made more effective by not only targeting suitable owners with matching objectives but also suitable properties with matching possibilities.

The management decisions of forest owners are influenced by forest composition and are one of the defining factors influencing forest composition. A European review found that NIPF owners have diverse views of forest management and, using typologies, can be classified into multi-objective owners, recreationists, investors, farmers, and indifferent owners (Ficko et al. 2019). Also in Sweden, forest owners have been classified by their level of interest in forest management and their objectives from timber production to conservation (Ingemarson et al. 2006; Eggers et al. 2014). The preferences of NIPF owners are often related to owner and

CONTACT Tristan R.M. Bakx t.bakx@creaf.uab.cat CREAF, Cerdanyola del Vallès 08193, Spain; Department of Physical Geography and Ecosystem Science, Lund University, Lund SE-223 62, Sweden

Supplemental data for this article can be accessed online at https://doi.org/10.1080/02827581.2024.2398235.

property characteristics. For example, owners' silvicultural activity level has been related to ownership size (Joshi and Arano 2009), female owners have been found to be more conservation-oriented (Umaerus et al. 2019; Tiebel et al. 2022), and owner age has been generally found to be negatively related to management activity (Kuuluvainen and Salo 1991; Tornqvist 1995; Joshi and Arano 2009). Owner preferences are one of the factors influencing their decisions, in addition to norms, regulations and economic factors, which then partially shape the forest. However, the relationship between the current owner preferences and forest characteristics is dependent on the duration of ownership and the consistency in the pattern of management behavior limiting the possibility to relate owner preferences to forest characteristics.

Other factors also affect what forest properties look like and can thus limit the conversion of preferences into successful management or shape forests otherwise. Multiple species of broadleaves in temperate and boreal forests are associated with riparian zones, especially on lakesides, and provide unique biodiversity in the landscape (Barker et al. 2002; Komonen et al. 2008). This biogeographical pattern affects management and has been reinforced by generally lower harvesting intensity in riparian and lakeshore zones (Richardson et al. 2012). Natural disturbances, such as storms, wildfires, and pest outbreaks, also play a large role in shaping forest landscapes. They disturb the age and species structures that were intended by managers and therefore limit the near to medium term future possibilities for forest management (Jõgiste et al. 2017). The largest natural disturbance in recent decades in Southern Sweden was the storm Gudrun in January 2005, felling the equivalent of three annual harvests in Southern Sweden in a single night (Swedish Forest Agency 2006a). Natural disturbances are expected to increase in the near and farther future and their legacy effects could thus become a larger contributor to forest structure of many properties (Seidl et al. 2017).

In this study, we studied how landscape-level forest diversity is distributed among NIPF forest properties. To that end, we investigated how we could divide forest properties into different clusters based on the characteristics of the forest. We further studied if the clusters were related to the owner's gender and age and property size, and if they were related to the distance to lakes or storm damage from Gudrun. We expected that forest properties show diversity in age, species composition, and indicators of management practices, and that larger properties would be comprised of more coniferous forest. Further, we expected properties with a focus on nature conservation to be more often owned by women and to be closer to lakes and properties with older forests to be owned by older owners. Finally, we expected the damage caused by Gudrun to be unevenly distributed between the forest properties.

Methods

Overview

We studied forest properties owned by NIPF owners in the municipality of Alvesta, Sweden. Based on a cadastral map, we identified those properties and summarized data from national data sources as metrics that describe the forest in each property. Then clusters of similar forest properties were detected in the data with a latent profile analysis (Weller et al. 2020). We described those clusters and related each to descriptors of the owner, the proximity to lakes, and to an indicator of storm damage, to see if those factors could explain some of the patterns we found. We did all data processing, analysis, and visualization in R (R Core Team 2022).

Study location

The study includes forests owned by NIPF owners within the municipality of Alvesta in southern Sweden (56° 50′ N, 14° 29′ E, Figure 1). The municipality has an area of 1080 km^2 mostly covered by forest (721 km^2, 67%) which is mostly owned by NIPF owners (∼510 km^2, 71% of the total forest area). The study area has a temperate climate (Köppen class Cfb, Kottek et al. 2006), and the most common soil types are till, fluvioglacial sediments, and peat soils. The region (Småland) in which Alvesta is situated is situated is characterized by high production forest with a species mix of Norway Spruce, Scots Pine, Birch, and to a lesser extent European Oak and European Beech. The region is characterized by a strong timber industry and intensive management.

Forest properties map

We used the Swedish cadastral map from the Swedish Land Survey (Swedish: Lantmäteriet) with an anonymized owner

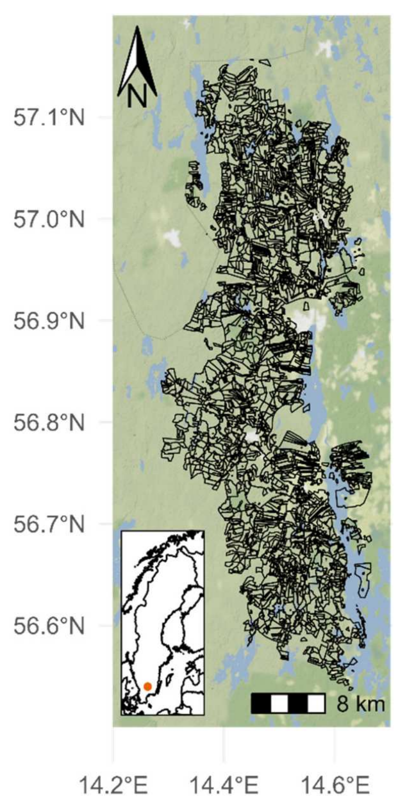

Figure 1. Forest property map of Alvesta. NIPF properties with >2 ha of forest are included. The inset shows the location of the study area in Sweden.

identifier, owner age, and gender (Lantmäteriet 2023; Figure 1). First, we extracted all NIPF-owned properties within Alvesta municipality. Then we calculated the total area of the properties of those owners in Kronoberg County (the county where Alvesta is located). Finally, we calculated the area of the properties within Alvesta municipality and the area and proportion of forest within each property, using the forest categories from the national landcover data (10 × 10 m resolution, Ahlkrona et al. 2018). We kept only the properties with more than 2 ha of forest to exclude properties such as houses with gardens and forests too small to be economically relevant to the owner. This resulted in 1255 properties owned by 1092 owners and a total of 49862 ha of forest in the selected properties. We continued the analysis at the property level, so $n = 1255$ for this study.

Forest metrics

For each property, we calculated a set of 15 metrics describing the characteristics of the forest (Table 1). We used data from the SLU Forest Map 2015 (SLU 2005), the National LiDAR data (Swedish Forest Agency 2023b), the NFI (Fridman et al. 2014), and a map of executed fellings (Swedish Forest Agency 2018). The SLU Forest Map 2015 and the National LiDAR data provide wall-to-wall raster data on volume by species, height, diameter at breast height, and basal area. The SLU Forest Map 2015 dataset estimates species volumes per raster cell based on spectral data from the Sentinel-2 satellite, stereoscopic aerial photographs, and the NFI. The NFI provides additional forest characteristics for sample plots across Sweden. We calculated the Pearson correlation coefficient r for the combinations of all variables so that in the interpretation of the results we can take the multicollinearity of variables into account (Appendix S1).

Age and volume

The age and volume structure are indicative of past management actions and important for the identification of forest properties for policy implementation (e.g. conservation value, potential for continuous cover forestry conversion, carbon storage). There is no up-to-date wall-to-wall raster data of forest age available in Sweden. We used the volume by species, height, and basal area from SLU Forest Map 2015 to find the most similar NFI plot (by multivariate Euclidean distance) for each pixel where the height was >1.3 m. Then we took the age from that NFI plot as an estimate of the age of the forest there. For the pixels with height <1.3 m, we used 0 years as the age. Then we calculated the mean age of the forest in each property. We also calculated the proportion of forest older than the legally lowest allowable final felling age (LAFFA; according to the 1993 revision of the Forestry Act 1979:429). A low proportion of forest older than LAFFA is an indication of high harvesting activity. We calculated the proportion of the property that was harvested between 2001 and 2010 and between 2011 and 2021, using the executed fellings map to indicate the harvesting practices in the last two decades.

Table 1. Overview of property-level forest metrics.

	Name	Unit	Description	Source
Age and volume	Proportion forest cover	–	Proportion of each property that is covered by forest	Cadastral map and NMD
	Average age	years	Average age of the forest in the property	NFI data
	Proportion older than LAFFA	–	Proportion of the property by area older than the lowest allowable final felling age (LAFFA)	NFI data SLU Forest Map
	Proportion clearcut 2001–2010	–	Proportion of the property that was clear cut between 2001 and 2010	Swedish Forest Agency
	Proportion clearcut 2011–2021	–	Proportion of the property that was clear cut between 2010 and 2021	Swedish Forest Agency
	Standing volume, 40–60 years old	m^3sk/ha[a]	Mean standing volume in the forest that is 40–60 years old	National LiDAR data and NFI data
	Prop. broadleaved volume, 40–60 years old	–	Proportion of forest by volume that is broadleaved in the forest that is 40–60 years old	National LiDAR data and NFI data
Forest composition	Proportion noble broadleaved forest	–	Proportion of forest in property with >70% Oak and Beech by volume	SLU Forest Map
	Proportion other broadleaved forest	–	Proportion of forest in property with >70% other broadleaved species by volume	SLU Forest Map
	Proportion coniferous forest	–	Proportion of forest in property with >70% Spruce and Pine by volume	SLU Forest Map
	Proportion mixed forest	–	Proportion of forest in property where no species group is >70% by volume	SLU Forest Map
	Proportion mixed young forest		Proportion by area of mixed forest in the forest under 20 years old	SLU Forest Map
Nature conservation	Nature Conservation Agreement	–	Proportion of forest that is under a nature conservation agreement	Swedish Forest Agency
	Biotope Protection Area	–	Proportion of forest that is under a Biotope Protection Area	Swedish Forest Agency
	Woodland Key Habitat	–	Proportion of forest that is a Woodland Key Habitat	Swedish Forest Agency

[a] m^3sk/ha refers to the Swedish measure of standing timber stock in cubic meters per hectare including the top and bark but excluding the branches, stumps and roots.

Forest species composition

We took the percentage forest area of the property from the national landcover data. We extracted information about the species composition from the SLU Forest Map 2015 (12.5 ×

12.5 m resolution). The species-level product that is available comes with uncertainties, so we decided to group species to limit uncertainty as species within a group are less distinct from another than between groups. We defined three species groups: noble broadleaves (Oak, *Quercus spp.*, and Beech, *Fagus Sylvatica*), other broadleaves (all other broadleaved species, in Southern Sweden largely Birch, *Betula spp.*), conifers (Norway Spruce, *Picea abies*, and Scots Pine, *Pinus sylvestris*). The noble broadleaved forest was defined as when a pixel had at least 70% noble broadleaves, as coniferous forest when a pixel had at least 70% conifers, and as other broadleaved forest when a pixel had at least 70% other broadleaves. In all other cases, the forest was classified as mixed. We calculated the proportion by forest area of noble broadleaved, coniferous, other broadleaves, and mixed forest. We also calculated the proportion by area of mixed forest in the forest under 20 years old as an indication of the treatment of admixture of broadleaves in young plantations.

We also calculated the mean standing volume in the forest that was between 40 and 60 years old, where a high value might indicate a low degree of thinning. Finally, we calculated the proportion of broadleaved volume in forest between 40 and 60 years old to indicate the tendency of forest owners to clean out or leave broadleaves in their properties.

Nature conservation

The management and history of a forest can lead to valuable forests from the perspective of biodiversity conservation. The proportion of forest that is protected or considered valuable can thus inform us about the management history of a property as well as about a forest owner's preference to protect their forest. We calculated the proportion of forest area that was protected under a Nature Conservation Agreement or Biotope Protection Area and the proportion of forest area that was identified as Woodland Key Habitat (according to Swedish Government Decision N2018/03141/SK). The Nature Conservation Agreement areas are areas where forest owners sign voluntary agreements with the Swedish Government to not harvest their forest and conserve biodiversity. The Biotope Protection Areas are small pieces of land that are protected due to their specific characteristics that are of conservation value often decided upon by the municipality, the county, or the forest agency. The Woodland Key Habitats are unprotected but considered valuable for nature conservation as a result of inventories by the Swedish Government that was done between the early 1990s and 2021.

Additional descriptors of forest properties

We additionally recorded some descriptors of the forest properties that we did not use in the latent profile analysis but rather used to further explore differences between the clusters that were found in the analysis (Table 2). We calculated several metrics related to property size to estimate how much forest a property consists of and how much forest an owner has in total. From the cadastral map and the national landcover data, we calculated the property forest area and the total forest area owned in Kronoberg County by the given owner. To investigate if clustering patterns could be related to the distance of properties to lakes we quantified the distance of each property to the nearest lake and if properties were on a lakeside or not (<5 m to the nearest lake to take potential mapping inaccuracies into account). We also consider the age and the gender (male or female) of the forest owners of each property as it was available from the cadastral map.

Table 2. Additional information about the property and owner.

Name	Unit	Description
Property area	ha	The total forest area of the property
Total area in Kronoberg by owner	ha	The total forest area owned by a landowner in all of Kronoberg
Distance to lake	m	Distance of the edge of the property to the nearest lake
Lakeside	Binary	If a property was less than 5 meters from the nearest lake
Owner age	Years	The age of the forest owner
Gender	Female/Male	The gender of the registered forest owner

All information was sourced from the Swedish cadastral map.

Analysis

Forest property typology

To study how forest properties can be divided into clusters by their characteristics, we executed a latent profile analysis (LPA) using the *mclust* package in R (Scrucca et al. 2016). LPA assumes that each observation belongs to a latent subpopulation and uses a Gaussian mixture model with an expectation maximization algorithm to find these latent subpopulations. This clustering method has multiple benefits over traditional clustering methods such as k-means or hierarchical clustering. First, the LPA approach allows for a wide variety of combinations of shapes and sizes of the clusters in multidimensional data space, improving model fit. Second, it allowed us to estimate the probability of properties belonging to each of the clusters and thus quantify the uncertainty of cluster assignment. Because of this we will be able to use the individual cluster assignment probabilities in future studies, e.g. forest owner interviews, and select those properties that had a low uncertainty of belonging to their cluster. We could quantify the mean and 95% confidence interval of each of the metrics to use them to describe the profile of each cluster.

We fitted models for multiple cluster shapes, sizes, and orientations and calculated BIC (Bayesian Information Criterion) and ICL (Integrated Complete-data Likelihood) for models with 3–5 clusters. We selected the model with the best shape, size, orientation, and number of clusters based on the BIC and ICL. To confirm that the number of clusters was the best for that type of model we performed a bootstrapped Likelihood Ratio Test with 999 replications comparing the model fit for models with 3–5 clusters again.

Then, we fitted the final LPA model and calculated the predicted probability that a forest property belongs to any of the clusters. Then we assigned each property to the cluster to which it had the highest probability to belong. We calculated the uncertainty as 1 minus the probability for the assigned cluster. We used this uncertainty to visualize the distribution of uncertainty for each of the clusters.

After the clustering, we calculated the mean value of each variable per cluster to visualize the latent profile for each of the clusters. We also estimated the 95% confidence intervals for the metric means for each cluster and for the percentage of properties that was assigned to a cluster by doing a bootstrap resampling of the clustering with 999 bootstrap replications.

Post hoc tests of significant difference for LPA and additional variables

We tested for the significance of between-cluster differences for all variables in the LPA with the Games-Howell non-parametric posthoc test, suitable for clusters with unequal variances and sample sizes. We chose $p = 0.05$ as the threshold for significant differences.

We did the same for property size, the area owned in Kronoberg, owner age, and the distance to the nearest lake to see if the clusters aligned with certain characteristics. For owner gender, we tested if the gender ratio of each cluster differed significantly from the overall ratio (i.e. for all properties together) of 68% men and 32% women with a goodness of fit chi-squared test. Similarly, we assessed whether the proportion of lakeside properties compared to non-lakeside properties in each cluster differed significantly from the overall ratio of 22% and 78%, respectively.

Storm damage

To study if part of the typology could be explained by the effects of the storm Gudrun we related the clusters to the proportion of the forest area that was felled by the storm. We used the "executed fellings" data from the Swedish Forest Agency. It is based on an automated change detection analysis for satellite data from 2003 onwards to identify forest harvests, so not only registered harvests are included but all deforestation events are. Since the storm Gudrun happened at the start of 2005, and virtually no normal harvests were done in the affected region for the rest of the year and for some time after, we can assume that all identified harvests in 2005 were windfalls from Gudrun (Swedish Forest Agency 2006a; Lodin and Brukas 2021). Therefore, we took the percentage area harvested in 2005 as the Gudrun storm damage. We also calculated the percentage area harvested in 2004 to compare harvest levels with a normal year pre-storm.

Results

Clusters

The best model had five clusters (Table 3). This model was significantly better than models with fewer clusters according to the bootstrap likelihood ratio test (Appendix S2). The uncertainty of cluster assignment was generally low (mean probability of not belonging to the assigned cluster = 3-5%), indicating that the clusters were well-defined (Appendix S2). Based on the salient characteristics of the clusters we named them "average coniferous", "average broadleaved", "young mixed", "old coniferous", and "noble broadleaved, protected".

Average coniferous

The first cluster contained 33.2% of the forest properties and 45.0% of the total forest area (Table 3, Figures 2 and 3). For most of the metrics, the forest inside these properties was around the mean of all forest properties in Alvesta municipality. The age and the % of broadleaved forest were a little bit below and the % of coniferous forest was above the mean (Table 4).

Average broadleaved

The second cluster contained 21.7% of the forest properties and 10.8% of the total forest area (Figures 2 and 3). Compared to the overall average, forests on these properties are older, have more broadleaved area and less forest that is above the LAFFA, which can be explained by the higher percentage of noble broadleaves which have a higher LAFFA than conifers. Overall, these forest properties have the lowest percentage of forest cover, indicating that these properties possibly are or have historically been farms with a mixed forestry and agriculture land-use.

Young mixed

The third cluster contained 14.8% of the forest properties and 10.8% of the total forest area (Figures 2 and 3). The forests in these properties were the youngest and had been harvested intensively between 2001 and 2010. The mean total volume in forests between 40 and 60 years was the lowest indicating relatively sparse forests in that age category. The forest properties in this cluster also had a high proportion of mixed forest, especially below 20 years old. At the same time, the percentage of coniferous forest was lowest in these properties. We hypothesize that these forest properties were significantly affected by the storm Gudrun in 2005 and test this later with a post-hoc test.

Old coniferous

The fourth cluster contained 26.8% of the forest properties and 31.7% of the total forest area (Figures 2 and 3). The defining characteristics are the combination of a high

Table 3. Overview of the clusters.

Cluster	% of properties (n properties)	95% CI of the % of properties	% of total forest area
Average coniferous	33.2% (417)	29.2–36.8%	45.0%
Average broadleaved	21.7% (272)	17.1–24.8%	10.8%
Young mixed	14.8% (186)	11.9–18.2%	10.8%
Old coniferous	26.8% (337)	22.7–30.3%	31.7%
Noble broadleaved, protected	3.4% (43)	1.9–8.7%	1.7%

The percentage and number of properties in each cluster, and the % of the total forest area in all the NIPF properties in each cluster.

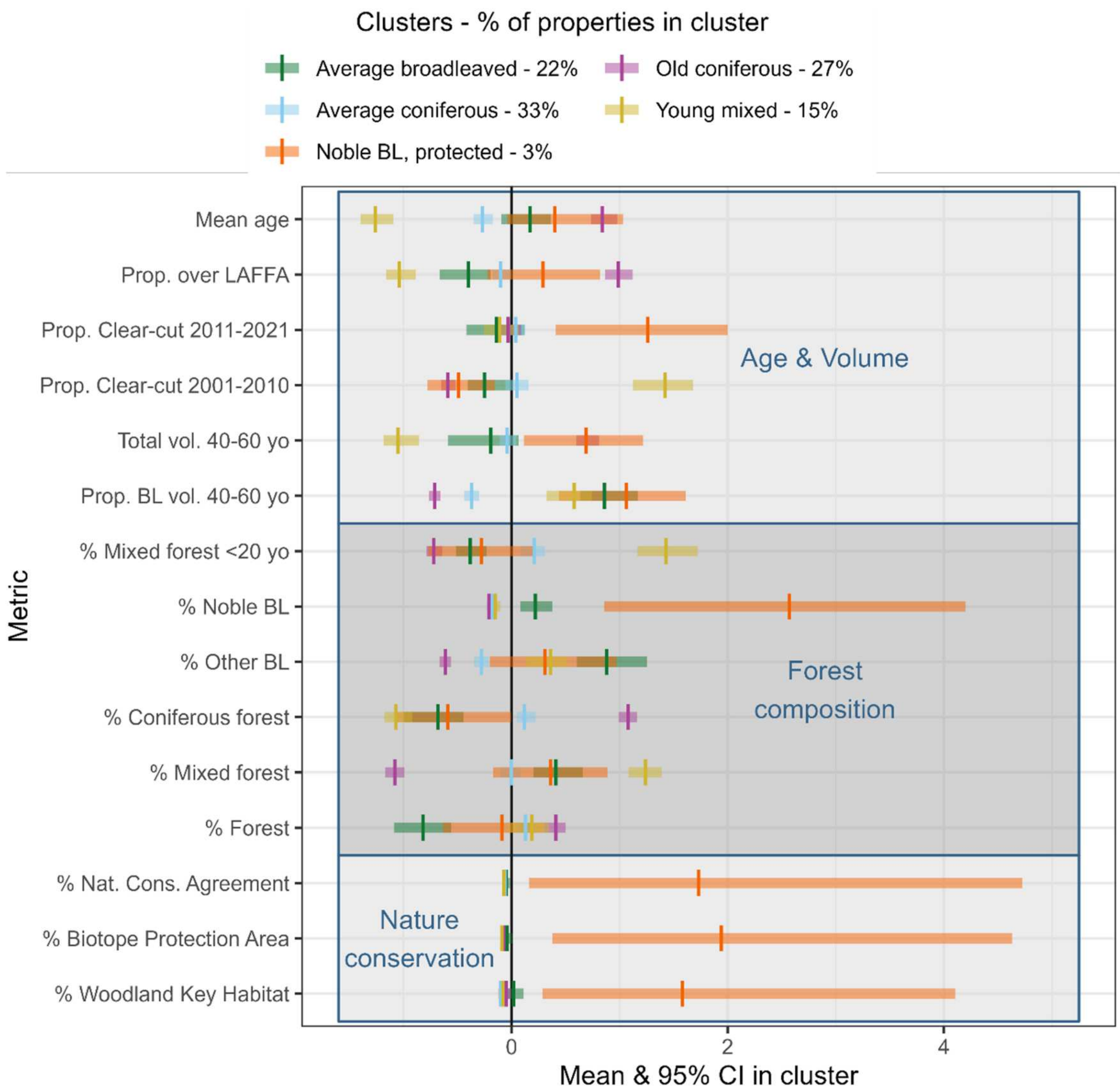

Figure 2. Forest property metric values for the five clusters according to the LPA. Metrics are listed on the y-axis. The x-axis scale is standardized against the overall mean for each metric i.e. "zero" is the mean of all clusters. Vertical bars indicate the standardized mean and horizontal bars indicate 95% confidence interval for each cluster.

amount of coniferous forest, highest mean age, and consequently, a large fraction of the property being over the LAFFA. The area of mixed forest in these properties was lowest. These properties have the highest forest cover fraction.

Noble broadleaved, protected

Finally, the fifth cluster contained only 3.4% of the properties and 1.7% of the total forest area (Figures 2 and 3). Despite the number of properties in the cluster being so small we decided to keep the model with 5 clusters since it did add distinct information to the typology. The cluster contained almost all the properties with nature conservation areas and had the highest percentage of noble broadleaved forest. This was also reflected in the high broadleaved proportion in forest 40–60 years old. The forest was also older than average which can be expected with the high amount of noble broadleaved forest and conservation areas. Interestingly, the properties in this cluster had the highest proportion of clear-cuts in the last decade.

Spatial distribution of the clusters

The clusters were clearly not homogeneously distributed in space (Figure 3). The average broadleaved cluster was concentrated in the east where also the biggest lakes are located. The average coniferous cluster occurred everywhere in the study area and the noble broadleaved cluster as well, although it only consisted of a few properties. The majority of the properties in the young mixed cluster were found in a limited area in the southern part of the municipality and the old coniferous cluster could be found everywhere but rarely in the general area of the young mixed cluster.

Comparisons of additional descriptors of forest properties and owner characteristics

The properties belonging to the average coniferous (54 ha; mean forest area) and old coniferous (47 ha) clusters in the average were significantly larger than broadleaved (20 ha), noble broadleaved (20 ha), and young mixed (29 ha) clusters (Figure 4(a); statistical details in Appendix S3). There were no

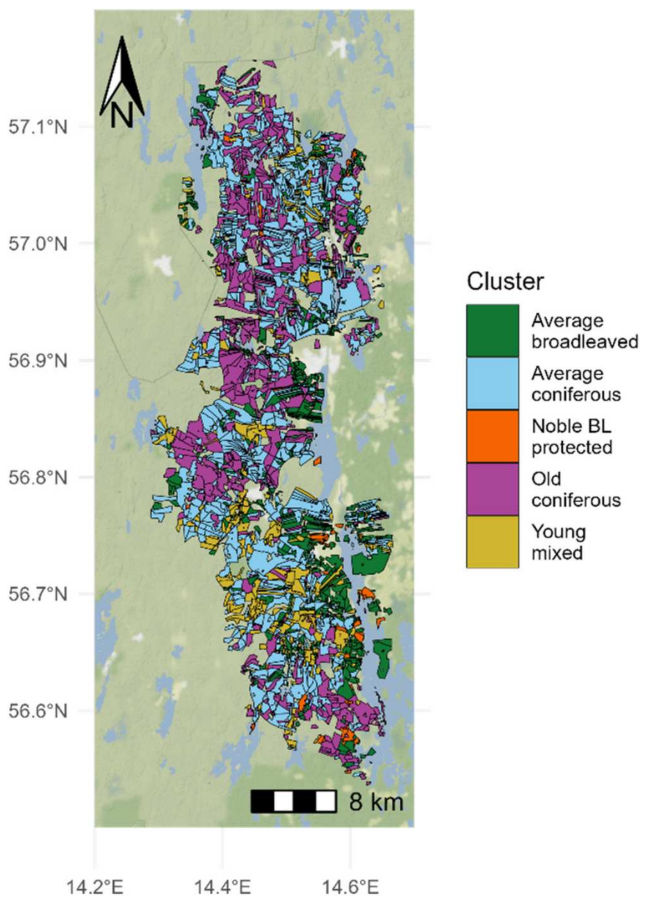

Figure 3. Map of the distribution of cluster assignment among NIPF properties.

meaningful differences in the total forest area owned in Kronoberg County (recall that one owner can possess multiple properties) other than that the owners of noble broadleaved properties owned less forest than the owners of average coniferous and old coniferous properties ($p < 0.01$ and $p = 0.01$, respectively; Figure 4(b)). The differences in owner age were only small, and generally not statistically significant, except that owners of average broadleaved properties were 3.7 years younger than those of old coniferous properties ($p = 0.01$; Figure 4(c); statistical details in Appendix S3). Interestingly, the noble broadleaved cluster was the only one for which the gender ratio differed significantly from the total population average (Figure 4(d); statistical details in Appendix S3). The properties in the noble broadleaved cluster were closest to lakes and most often situated on a lakeside whereas properties from the young mixed cluster were farthest from lakes and least often on a lakeside (Figure 4(e,f); statistical details in Appendix S3).

Gudrun storm damage

In 2005, 14% of the forest area in the studied properties was felled due to Gudrun. Spruce forests were most affected by the storm and broadleaved forests least (Swedish Forest Agency 2006b). In our results, we see that in 2005, on properties in the young mixed cluster 35% of forest area was felled, while in the average broadleaved and average coniferous the corresponding figure was 12% and 14%, respectively (Figure 5(A)). On properties that are in the noble broadleaved and those in the old coniferous clusters about 5% of the forest area was felled. In 2004, there were some significant but small differences between the groups, showing that harvesting levels in a normal year were well below the levels of 2005 and roughly equal between the clusters (Figure 5(B)).

Discussion

Understanding patterns within the clusters

Average coniferous

The first cluster included properties with forests that were conifer dominated and the age of the forests was around the overall average. The position in the landscape relative to lakes was at the overall average, which indicates that this biogeographical driver likely was not very important in shaping the species and age structure. These properties mostly resemble Swedish production ideals in terms of species and age structure, with the only exception being that 42% of forest was older than the LAFFA, indicating longer than optimal (from production point of view) rotations, but this was no different from most of the other clusters (Beland Lindahl et al. 2017). The properties were also large, which has been reported to be positively corelated

Table 4. The mean of each metric in each cluster and the significant differences between the clusters in the LPA.

	Overall mean	Average coniferous	Average broadleaved	Young mixed	Old coniferous	Noble BL protected
Mean age (years)	49.3	46.6^{d}	51.2^{a}	37^{b}	57.5^{c}	52.5^{acd}
% older than LAFFA	44.3	42.8^{d}	38.3^{a}	28.3^{b}	59.3^{c}	48.5^{d}
% Clearcut 2001–2010	15.3	16.1^{d}	11.8^{a}	35^{b}	7.1^{c}	9^{ac}
% Clearcut 2011–2021	4.8	5.1^{b}	3.8^{a}	4.1^{ab}	4.7^{ab}	13.2^{c}
Tot. vol., 40–60 yo (m^3sk/ha)	164.6	163.1^{a}	158.4^{a}	126.9^{b}	189.1^{c}	187.4^{c}
% BL volume 40–60 yo	24.4	18.9^{d}	37.7^{a}	33.5^{b}	13.5^{c}	41.3^{a}
% Mixed forest <20 yo	14.2	16.4^{db}	10.2^{a}	28.8^{b}	6.9^{c}	11.6^{acd}
% Noble BL forest	0.4	0.2^{b}	0.8^{a}	0.2^{b}	0.1^{b}	4.4^{c}
% Other BL forest	9	6.7^{d}	16.3^{a}	12^{b}	4^{c}	12^{abd}
% Coniferous forest	49.1	51.5^{d}	35.5^{a}	27.3^{b}	70.9^{c}	36.4^{ab}
% Mixed forest	41.4	41.6^{d}	47.5^{a}	60.5^{b}	25^{c}	47.3^{ad}
% Forest cover	73.2	75.3^{b}	60.3^{a}	76.1^{b}	79.4^{c}	72.4^{bc}
% Nat. Cons. Agreement	0.1	0^{a}	0^{a}	0^{a}	0^{a}	3.3^{a}
% Biotope Protection Area	0.3	0^{a}	0.1^{a}	0^{a}	0.1^{a}	6.1^{a}
% Woodland Key Habitat	0.4	0.1^{b}	0.4^{a}	0.2^{ab}	0.3^{ab}	4.5^{ab}

The Games-Howell non-parametric post hoc test was used for testing differences between clusters. The method is suitable for groups with unequal variances and sample sizes. The significance level was $p = 0.05$. Different letters indicate significant between-group differences (compact letter display).

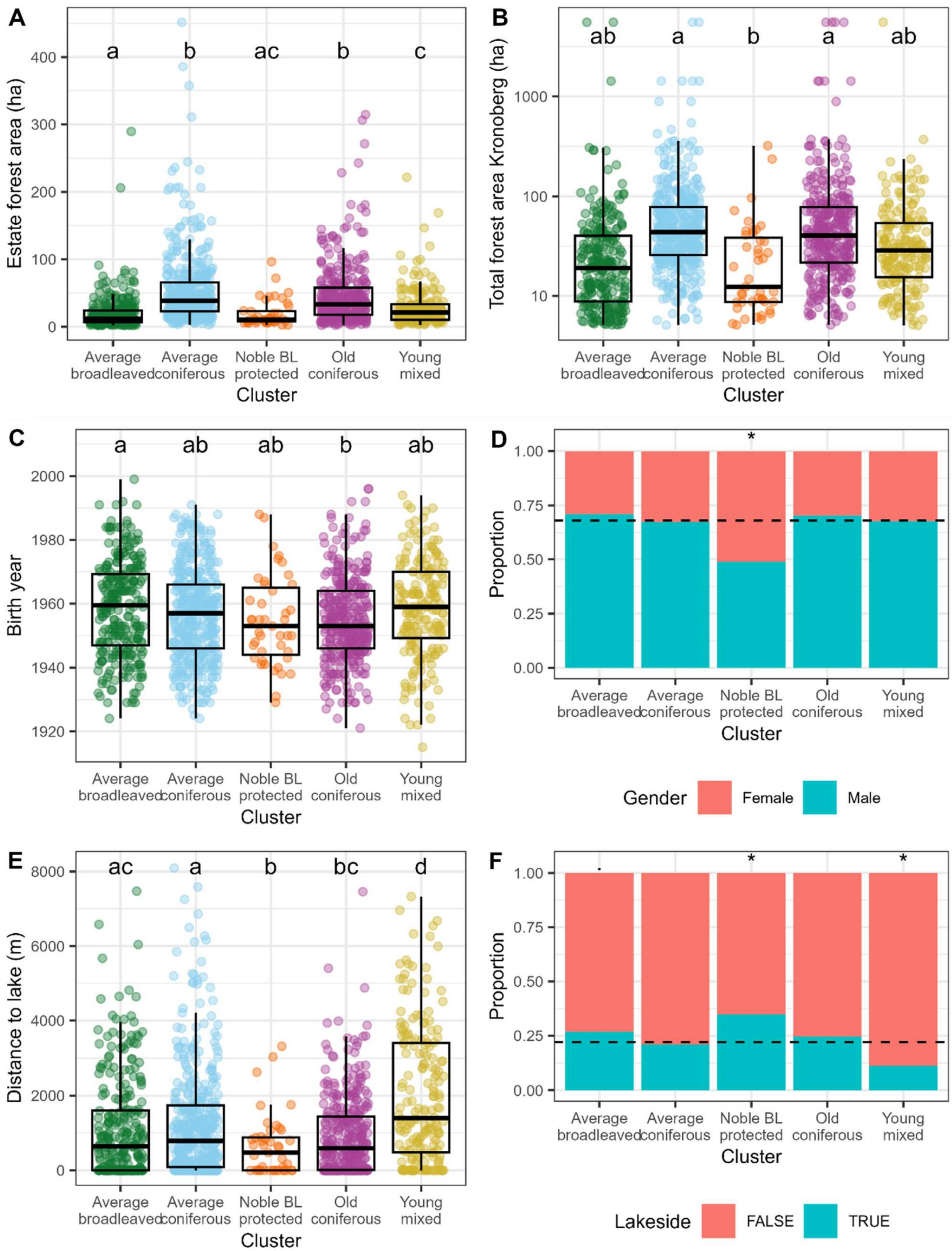

Figure 4. Ownership characteristics of the clustered forest properties. A. Boxplot of forest area in the properties. B. Boxplot of the total area owned by the forest owner. Y-axis is log10 transformed. C. Boxplot of the birth year of the forest owner. D. Proportions of male/female gender in each of the clusters. E. Boxplot of distance to the nearest lake. F. Proportions of lakeside and non-lakeside properties. A, B, C, E: Different letters denote significant differences ($p < 0.05$; compact letter display). D, F: Dotted lines indicate the population ratio and asterisks (*) indicate a significant difference ($p < 0.05$) from the total population ratio from a Chi-squared test.

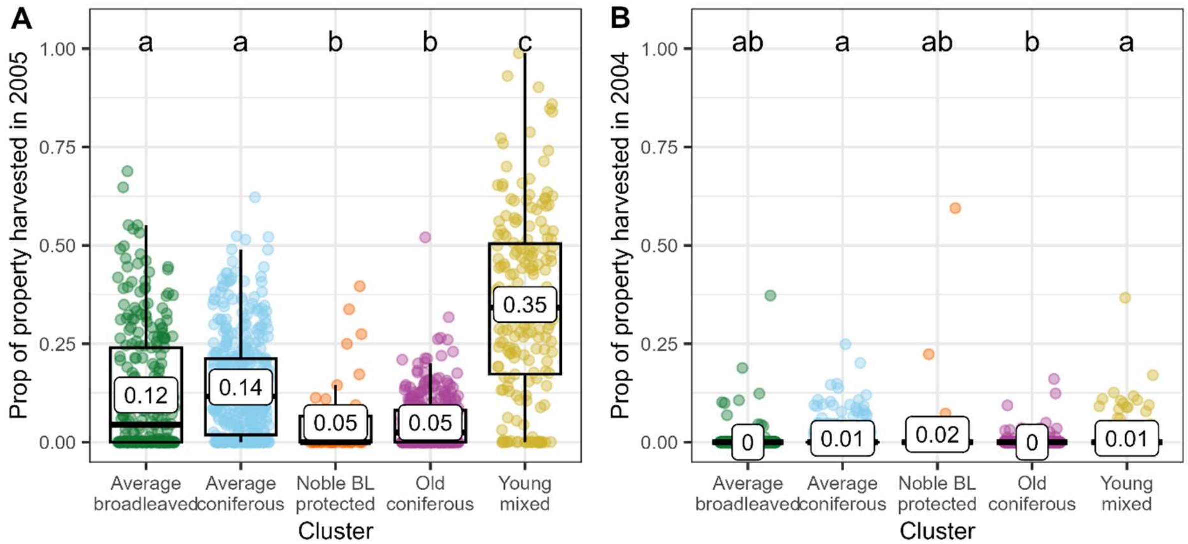

Figure 5. The proportion of property harvested in 2005 and 2004 per cluster. The proportion harvested is calculated as the area harvested in a given year according to the executed clear fellings (of any nature) map from the Swedish Forest Agency divided by the total forest area according to the national landcover data. Different letters denote significant differences ($p < 0.05$). Group means are given on the label. A. Harvests in 2005, when Gudrun caused major windfall in the area and no other forest was harvested for the rest of the year. B. Harvests in 2004, when no significant storm damage was reported in the area, representing normal harvesting.

with forest owners' tendency to prioritize production and economic gain (Eggers et al. 2014).

Average broadleaved

The second cluster was characterized by high broadleaved occurrence. High broadleaf occurrence is known to be related to the position in the landscape close to water and we found this to be true in our study as well (Barker et al. 2002; Macdonald et al. 2006). The lower proportion of forest area on these properties also indicates a higher proportion of agricultural land which can also be expected from the position in the landscape as soils close to lakes are often better soils for agriculture. Thus, the properties belonging to this cluster could be expected to have a history of being combined agriculture-forestry farms driven by self-employed farmers living on the properties. Such ownership, at least in the past, implied a reliance on the forest as a supportive activity for agriculture: timber and firewood extraction for own use, forest grazing of animals, additional fodder, and other non-wood products of agricultural use in the more remote past (Tornqvist 1995). This type of forest use might have contributed to the higher proportion of broadleaved trees (not necessarily noble) that we see on these properties, in addition to the direct influence of better soils.

Old coniferous

Properties in this cluster had the oldest forest as well as the largest proportion of coniferous forest area. Like the average coniferous properties, their position in the landscape relative to lakes was on average not different from the overall mean and the properties were large. The properties in this cluster had the lowest damage due to Gudrun, meaning that these properties did not see widespread forest rejuvenation due to the storm like some other properties. We did not find large differences in owner age between any of the clusters as on average the owners were roughly 60–70 years old. Still, the oldest and most conifer-dominated properties in our study were owned by somewhat older people than other forest properties. This result that owners of properties in this cluster were oldest showed weak support to previous studies that show how owners that are preparing their property for leaving it to the next generation are accumulating standing stock to increase the value of the inheritance (Kuuluvainen and Salo 1991; Joshi and Arano 2009).

Young mixed

In Kronoberg County, 18% of the standing volume was felled by the storm Gudrun (Swedish Forest Agency 2005). We show here that, in our study area, this loss was especially concentrated in a group of properties, leaving a lasting impact. Many studies have investigated the risk of forests to storm damage in relation to the position in the landscapes (Mitchell 2013; Gardiner 2021). The properties in this cluster were farthest away from lakes and upland forests can be particularly vulnerable to storm damage. The forestry sector in the region was occupied with clearing felled trees and preventing further natural disasters such as fire and pest outbreaks which was an initial reason why normal forestry operations could not ensue (Swedish Forest Agency 2006b). Furthermore, the financial burden caused by lost revenue from the storm has resulted in a reduced rate of pre-commercial thinnings (i.e. when usually broadleaves are removed from coniferous plantations; Valinger et al. 2014; Lodin and Brukas 2021). Besides the fact that some owners might intentionally create mixed species stands, the storm disturbance can explain why on average the forests in this cluster are so young and have such a high degree of mixed species forest, especially in the younger age class.

Noble BL protected

Three factors in our exploration of explanatory factors set the properties in the noble broadleaved, protected cluster apart from the other properties. First, these properties were closest to lakes and most often on a lakeside, which increases the likelihood that management pressures were reduced as well as the likelihood increased occurrence of broadleaved trees of conservation value. Second, these properties were amongst the smallest in the municipality and therefore, are likely to be less actively managed for timber production (Lidestav and Berg Lejon 2013). Third, these properties were more often owned by women than the properties in other clusters, in agreement with previous studies showing that female private forest owners are more conservation-oriented (Umaerus et al. 2019; Tiebel et al. 2022).

Are the clusters compatible with existing owner typologies?

It is interesting to consider compatibility between the property types from this analysis and owner types from owner typologies, as both typologies matter from policy implementation point of view. While any property type can be owned by any owner type, especially if the ownership period has not been long, some property types might point stronger in the direction of some owner type(s). Such associations could potentially be inferred by juxtaposing the management history, to the extent it can be inferred from forest characteristics, with the management preferences of different owner types. Thus, the average coniferous properties well align with the investor (traditionalist, timber producer, production-oriented, economist) owner type, of the types reviewed by Ficko et al. (2019), due to the existing age and species structure suitable for and, under a longer ownership period, resulting from economic timber-production oriented forest management. The average broadleaved properties align well with farmers, multi-objective owners, recreationists, or environmentally oriented owners due their species composition combined with a not very high forest age, mixed landcover, and the position in the landscape. The old coniferous properties could be associated with indifferent (passive, uninterested) owners or recreationists due to the high forests age. However, combined with a very low occurrence of broadleaves, the cluster could also point towards traditionalists and investors of a more conservative kind (higher age of the owners also corroborates this possibility). The noble broadleaved, protected properties would be in line with recreationist or environmental owners, although legal restrictions that prevent owners from replacing noble broadleaves with other species, reduce the value of the noble broadleaves occurrence as an indicator of owner preferences. Finally, as we have no information on their forest characteristics prior to the storm, and due to the stochastic nature of disturbances, we are not able to associate the mixed young properties with any particular forest owner type.

Other considerations

Even though we could detect clear differences between the clusters, there were also clear overlaps between them. This was most likely due to similarities in management history and the biophysical conditions for the forest growth. The whole forest landscape has been subject to the same historical transformations such as the felling of old-growth forests, fire suppression, and conversion to rotation forestry since the mid-twentieth century (Östlund et al. 1997). Most forests in the study area are either coniferous or mixed (i.e. no tree species has a coverage of >70%) as a result of planting of coniferous trees and the natural regeneration of broadleaves. An explanation as to why young mixed forests are so common is that naturally regenerated birch has been more commonly retained in new stands since the 2005 storm Gudrun (Lodin and Brukas 2021). Furthermore, 69% of productive forest land in Southern Sweden is under a management certification scheme and coniferous stands are required to be somewhat mixed with broadleaves to be certified (>10% of standing volume in FSC; Brukas et al. 2013; Swedish Forest Agency 2023c). All clusters had on average a large fraction of the forest over the LAFFA, indicating that the minimum legal harvesting age is not restrictive as forest owners decide to harvest most forest later. This is also in line with earlier research that found that forest owners do not harvest their forest as it is recommended by forest industrial actors (Eggers et al. 2015; Lodin and Brukas 2021).

The distribution of storm damage was highly unequal between the clusters. While across the landscape 14% of the area was damaged, the damage to certain forest properties was devastating as up to 100% of the forest area got damaged in Gudrun. Assuming that the forest composition of the two least affected clusters with the oldest forests, *old coniferous* and *noble broadleaved protected*, was similar in 2005 as now, we can see potential explanations for why they were relatively unaffected. The noble broadleaved protected properties had more forest that was without leaves at the time of the storm making it less susceptible to storm damage. The clear spatial separation of young mixed and old coniferous properties in the landscape was possibly related to their exposure and susceptibility to the storm, such as the, topography, the aerodynamic characteristics of the above-ground features (e.g. infrastructure creating large gaps in the vegetation), and soils (Mitchell 2013). Future studies should investigate the factors that influence storm damage risk across spatial scales to enhance the potential for risk mitigation. In the meanwhile, diversification at the scale of the property can reduce the risk of catastrophic damage for individual properties.

Limitations

We kept some of our forest metrics more general than would be possible with the available data to prevent susceptibility to uncertainties. We did not estimate age using the NFI link for stands with the mean height below 1.3 m but set the age to 0 years because the volume estimates are too uncertain for such young forests and the link with the NFI data would be too weak. Overall, the mean age of forest properties was thus slightly underestimated, but we do not expect this to significantly affect our results since only a small portion of the total forest area was lower than 1.3 m. Further, there might be some uncertainty in separating individual species of broadleaves and conifers from each other in the SLU

Forest Map. This uncertainty might lead to a slight overestimation of the amount of mixed forest if some species' presences are in fact false positives. Improved species-level volume maps are needed to further limit this issue.

The data on owners we had access to was limited: e.g. we did not have access to ownership duration, co-ownership, or owners place of residence and therefore, we did not try to make any other inferences than those strictly related to the available data (such as trying to model an owner's likelihood of owning a particular type of property based on demographic variables). We did not include other biogeographical influences than the vicinity of properties to lakes. This was because the mapping of lakes in Sweden is of high quality and lakeshore forest structure is likely to be distinct while most other factors either are not mapped at sufficient resolution (frost damage risk, soils), or are not significantly diverse at the scale of the study area (e.g. topography, accessibility, streams), or both. Concerning disturbances, we did not have data for other, smaller, disturbance events that might have occurred in past decades and thus could not account similarly for them.

Conclusion

We showed that it is possible to create a typology providing new insights into the diversity of private non-industrial forest properties in Southern Sweden. The clusters could be distinguished mainly by age structure and species composition. We were able to, to some degree, distinguish between the influences of management legacy, biogeographical factors, and disturbance history on the formation of the clusters. Previous studies have suggested landscape scale management planning with varying local priorities as a cost-effective approach to increase landscape scale forest multifunctionality. Based on the results from this study, one way to increase the chances of success of diversification policies at the landscape level could be adapting the local priorities to the existing diversity of forest property types, taking management legacy, biogeographical differences, and disturbance history into account.

Note

1. In this paper, "property" always refers to the land that can be considered as possession. "Property" is not used as "feature"/"characteristic" in this paper.

Acknowledgments

This paper is a contribution to the Strategic Research Area Biodiversity and Ecosystem Services in a Changing Climate, BECC, funded by the Swedish Government, and the ForestPath project, funded by FORMAS. We thank Ljusk Ola Eriksson for his contributions to the data collection. We would like to thank Kristina Blennow, Marie Appelstrand, and Hanna Ekström for their valuable insights and constructive discussions on the research.

Disclosure statement

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

Funding

This work was supported by Swedish Government and FORMAS.

References

Ahlkrona E, Cristvall C, Jönsson C, Mattisson A, Olsson B. 2018. Nationella marktäckedata basskikt. Stockholm, Sweden: Naturvårdsverket.

Barker JR, Ringold PL, Bollman M. 2002. Patterns of tree dominance in coniferous riparian forests. For Ecol Manag. 166:311–329. doi:10.1016/S0378-1127(01)00683-1.

Baskent EZ, Borges JG, Kašpar J, Tahri M. 2020. A design for addressing multiple ecosystem services in forest management planning. Forests. 11:1–24.

Beland Lindahl K, Sténs A, Sandström C, Johansson J, Lidskog R, Ranius T, Roberge JM. 2017. The Swedish forestry model: more of everything? Forest Pol Econ. 77:44–55. doi:10.1016/j.forpol.2015.10.012.

Brukas V, Felton A, Lindbladh M, Sallnäs O. 2013. Linking forest management, policy and biodiversity indicators – a comparison of Lithuania and Southern Sweden. For Ecol Manag. 291:181–189. doi:10.1016/j.foreco.2012.11.034.

Duncker PS, Raulund-Rasmussen K, Gundersen P, Katzensteiner K, De Jong J, Ravn HP, Smith M, Eckmüllner O, Spiecker H. 2012. How forest management affects ecosystem services, including timber production and economic return: Synergies and trade-offs. Ecol Soc. 17 (4):50. doi:10.5751/ES-05066-170450.

Eggers J, Holmström H, Lämås T, Lind T, Öhman K. 2015. Accounting for a diverse forest ownership structure in projections of forest sustainability indicators. Forests. 6(11):4001–4033. doi:10.3390/f6114001.

Eggers J, Lämås T, Lind T, Öhman K. 2014. Factors influencing the choice of management strategy among small-scale private forest owners in Sweden. Forests. 5:1695–1716. doi:10.3390/f5071695.

Eyvindson K, Duflot R, Triviño M, Blattert C, Potterf M, Mönkkönen M. 2021. High boreal forest multifunctionality requires continuous cover forestry as a dominant management. Land Use Policy. 100:104918. doi:10.1016/j.landusepol.2020.104918.

Ficko A, Lidestav G, Ní Dhubháin Á, Karppinen H, Zivojinovic I, Westin K. 2019. European private forest owner typologies: a review of methods and use. Forest Pol Econ. 99:21–31. doi:10.1016/j.forpol.2017.09.010.

Fridman J, Holm S, Nilsson M, Nilsson P, Ringvall A, 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. 48:1–29. doi:10.14214/sf.1095.

Gardiner B. 2021. Wind damage to forests and trees: a review with an emphasis on planted and managed forests. J Forest Res. 26:248–266. doi:10.1080/13416979.2021.1940665.

Ingemarson F, Lindhagen A, Eriksson L. 2006. A typology of small-scale private forest owners in Sweden. Scand J Forest Res. 21:249–259. doi:10.1080/02827580600662256.

Jõgiste K, Korjus H, Stanturf JA, Frelich LE, Baders E, Donis J, Jansons A, Kangur A, Köster K, Laarmann D, et al. 2017. Hemiboreal forest: natural disturbances and the importance of ecosystem legacies to management. Ecosphere. 8(2):e01706. doi:10.1002/ecs2.1706.

Joshi S, Arano KG. 2009. Determinants of private forest management decisions: a study on West Virginia NIPF landowners. Forest Pol Econ. 11:118–125. doi:10.1016/j.forpol.2008.10.005.

Komonen A, Niemi ME, Junninen K. 2008. Lakeside riparian forests support diversity of wood fungi in managed boreal forests. Can J For Res. 38:2650–2659. doi:10.1139/X08-105.

Kottek M, Grieser J, Beck C, Rudolf B, Rubel F. 2006. World map of the Köppen-Geiger climate classification updated. Meteorol Z. 15:259–263. doi:10.1127/0941-2948/2006/0130.

Kuuluvainen J, Salo J. 1991. Timber supply and life cycle harvest of non-industrial private forest owners: an empirical analysis of the Finnish case. For Sci. 37:1011–1029. doi:10.1093/forestscience/37.4.1011.

Lantmäteriet. 2023. Fastighetsindelning Nedladdning, vektor. 1–37.

Lidestav G, Berg Lejon S. 2013. Harvesting and silvicultural activities in Swedish family forestry – behavior changes from a gender perspective. Scand J Forest Res. 28:136–142. doi:10.1080/02827581.2012.701324.

Lodin I, Brukas V. 2021. Ideal vs real forest management: challenges in promoting production-oriented silvicultural ideals among small-scale forest owners in southern Sweden. Land Use Policy. 100:104931. doi:10.1016/j.landusepol.2020.104931.

Macdonald SE, Eaton B, Machtans CS, Paszkowski C, Hannon S, Boutin S. 2006. Is forest close to lakes ecologically unique? For Ecol Manag. 223:1–17. doi:10.1016/j.foreco.2005.06.017.

Mitchell SJ. 2013. Wind as a natural disturbance agent in forests: a synthesis. Forestry. 86:147–157. doi:10.1093/forestry/cps058.

Nilsson P, Roberge C, Fridman J. 2021. Forest statistics 2021. Umeå: Swedish University of Agricultural Sciences.

Östlund L, Zackrisson O, Axelsson AL. 1997. The history and transformation of a Scandinavian boreal forest landscape since the 19th century. Can J For Res. 27:1198–1206. doi:10.1139/x97-070.

Pukkala T. 2016. Which type of forest management provides most ecosystem services? Forest Ecosyst. 3:1–16. doi:10.1186/s40663-016-0068-5.

R Core Team. 2022. R (4.2.2, 2022-10-31): a language and environment for statistical computing.

Richardson JS, Naiman RJ, Bisson PA. 2012. How did fixed-width buffers become standard practice for protecting freshwaters and their riparian areas from forest harvest practices? Freshwater Sci. 31:232–238. doi:10.1899/11-031.1.

Schwaiger F, Poschenrieder W, Biber P, Pretzsch H. 2019. Ecosystem service trade-offs for adaptive forest management. Ecosyst Serv. 39:100993. doi:10.1016/j.ecoser.2019.100993.

Scrucca L, Fop M, Murphy TB, Raftery AE. 2016. mclust 5: clustering, classification and density estimation using Gaussian finite mixture models. R Journal. 8:289–317. doi:10.32614/RJ-2016-021.

Seidl R, Thom D, Kautz M, Martin-Benito D, Peltoniemi M, Vacchiano G, Wild J, Ascoli D, Petr M, Honkaniemi J, et al. 2017. Forest disturbances under climate change. Nat Clim Change. 7:395–402. doi:10.1038/nclimate3303.

Sing L, Metzger MJ, Paterson JS, Ray D. 2018. A review of the effects of forest management intensity on ecosystem services for northern European temperate forests with a focus on the UK. Forestry. 91:151–164. doi:10.1093/forestry/cpx042.

SLU. 2005. SLU forest map. Swedish University of Agricultural Sciences. https://www.slu.se/en/Collaborative-Centres-and-Projects/the-swedish-national-forest-inventory/forest-statistics/slu-forest-map/.

Swedish Forest Agency. 2005. Sammanställning av Stormskador på skog i Sverige under de senaste 210 åren. [Summary of Sorm Damages in Sweden during the Last 210 Years]. In Swedish. 1–23 Report 2005:9.

Swedish Forest Agency. 2006a. Stormen 2005 – en skoglig analys. Meddelande 1 – 2006 [Stormen 2005 – a forest analysis. Message 1 – 2006]. 208.

Swedish Forest Agency. 2006b. Efter Gudrun. 1–16.

Swedish Forest Agency. 2018. Executed fellings. http://geodpags.skogsstyrelsen.se/geodataport/feeds/UtfordAvverk.xml.

Swedish Forest Agency. 2023a. Slutrapport för Ett mer variationsrikt skogsbruk (ENG: Final report for more diversity oriented forestry).

Swedish Forest Agency. 2023b. Basic forest data. https://www.skogsstyrelsen.se/skogligagrunddata.

Swedish Forest Agency. 2023c. Voluntary set-asides and forest land under forest management certification schemes. https://www.skogsstyrelsen.se/en/statistics/subject-areas/voluntary-set-aside-and-certified-forest-area/.

Tiebel M, Mölder A, Plieninger T. 2022. Conservation perspectives of small-scale private forest owners in Europe: a systematic review. Ambio. 51:836–848. doi:10.1007/s13280-021-01615-w.

Tornqvist T. 1995. Report 41: Inheritors of the woodlands: A sociological study of private, non-industrial forest ownership - Swedish: Skogsrikets arvingar: En sociologisk studie av skogsägarskap inom privat, enskilt skogsbruk. Uppsala: Swedish University of Agricultural Sciences.

Umaerus P, Högvall Nordin M, Lidestav G. 2019. Do female forest owners think and act "greener"? Forest Pol Econ. 99:52–58. doi:10.1016/j.forpol.2017.12.001.

UNECE. 2010. Geneva timber and forest study paper 26 – private forest ownership in Europe. 1–120.

Valinger E, Kempe G, Fridman J. 2014. Forest management and forest state in southern Sweden before and after the impact of storm Gudrun in the winter of 2005. Scand J Forest Res. 29:466–472. doi:10.1080/02827581.2014.927528.

Weiss G, Lawrence A, Hujala T, Lidestav G, Nichiforel L, Nybakk E, Quiroga S, Sarvašová Z, Suarez C, Živojinović I. 2019. Forest ownership changes in Europe: state of knowledge and conceptual foundations. Forest Pol Econ. 99:9–20. doi:10.1016/j.forpol.2018.03.003.

Weller BE, Bowen NK, Faubert SJ. 2020. Latent class analysis: a guide to best practice. J Black Psychol. 46:287–311. doi:10.1177/0095798420930932.

Živojinović I, Weiss G, Lidestav G, Feliciano D, Hujala T, Dobšinská Z, Lawrence A, Nybakk E, Quiroga S, Schraml U. 2015. Forest land ownership change in Europe. COST action FP1201 FACESMAP country reports, Joint Volume. EFICEEC-EFISEE Research Report. 693. University of Natural Resources and Life Sciences, Vienna (BOKU), Vienna, Austria.