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Owners of Biodiversity: Linking Forest Ownership and Biodiversity Indicators

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Preface

I am torn between delight and sadness seeing this project coming to an end after two years of work. The idea for this project occurred to me after several times being lectured about “the tragedy of the commons”, but very few times hearing about the opponents of this theory regarding ownership and sustainable nature management. Furthermore, I was disgruntled about the lack of research into how different ownership categories potentially impact biodiversity in Norway. This inspired me to gather ownership data with the goal of making a thesis project, which was made possible with Ulrika Jansson (NINA Oslo) helping me to find supervisors. Writing my thesis has been a fun, challenging, and enriching experience, which has led me to acquire new skills and knowledges.

My thesis project has used a range of different data developed by different actors. I would like to give my thanks to Hans Ole Ørka (NMBU) and colleagues, for giving me access to the Forest Ecological Basemap of Norway, and senior engineer Gunnar Tenge (NMBU), for providing me with the AR5 land resource maps. I would also like to thank the Norwegian Agricultural Agency for granting me access to the biodiversity habitats from environmental inventories in forestry, and email-addresses to forest owners for distributing my questionnaire. I also want to thank the local agricultural offices within my study area, for helpful feedback regarding my questionnaire and help with its distribution. I will forever be grateful to the forest owners that answered my questionnaire and expanded my knowledge about forest management. Finally, I would like to thank my fellow students, Gaute Eiterjord and Therese Moe Øye, for peer-reviewing my thesis and providing me with feedback.

This project would not have been possible to complete without the guidance from my supervisors. I would therefore also like to thank Hans Ole Ørka (NMBU), Ulrika Jansson (NINA Oslo), Vegard Gundersen (NINA Lillehammer), and Terje Gobakken (NMBU). I would also like to express my gratitude to the late Ketil Skogen (NINA Oslo), who guided me through the social science research methods in the early stages of this thesis.

The thesis process and research environments I’ve been introduced to have made me want to pursue research further. I am confident that the experiences I’ve acquired during my time at NMBU will help me in my future endeavours, and I am looking forward to unravelling more questions about nature and society.

Ås, 14th May 2024

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Abstract

Biodiversity indicators and forest management have been shown to differ between different ownership categories in Europe. However, no such comparison has previously been made in Norwegian forests. In this project I aimed to explore the links between biodiversity indicators and forest ownership in Norway. In addition, I sought to see whether forest property size, municipalities, distance to roads, or forest productivity explained the distribution of biodiversity indicators better than ownership categories as explanatory variables. Finally, I wanted to see if there were any differences in forest management between ownership categories, forest property sizes, or municipalities.

The study area consisted of forest properties within ten municipalities in south-eastern Norway, where I applied both natural and social science research methods. The natural science section included biodiversity indicators at: (1) the species level, using delimited observations of red-listed species from the Norwegian Biodiversity Information Centre; (2) the habitat level, using biodiversity habitats from environmental inventories in forestry; and (3) the landscape level, using maps produced from lidar data on forest structure. Shannon indices were calculated to estimate differences in diversity of red-listed species, within the different explanatory variables. The landscape and habitat indicators, on the other hand, were analysed statistically for deviation from the grand mean, and correlation with forest property sizes. The social scientific section contained questionnaire data about the forest management goals and practises of the owners. The management goals were analysed descriptively, and the management practises were analysed both descriptively and with deviation coding.

I found differences between ownership categories, but in contrast to previous research public forest owners did not have higher values of biodiversity indicators than private owners. However, an underlying influence from forest property size was observed, where owners with larger forest properties had lower values of biodiversity indicators. This trend correlated with more large-scale, private individual forest owners having economic profit as their primary goal, and using more clear-cutting in their forestry, compared to small-scale owners. Differences between municipalities seemed to explain the distribution of biodiversity indicators better than ownership, whilst distance to roads overall seemed to explain little to none of the distribution. Higher forest productivity, however, had in general a strong positive correlation with the biodiversity indicator values.

To conclude, overall differences in biodiversity indicators were observed within all the explanatory variables. However, differences in forest productivity and correlations with forest property sizes seemed to explain the distribution of indicators better than ownership categories, distance to roads, or municipalities. Furthermore, forest property sizes seemed to also have influenced the primary management goal and practises of the forest owners. Further research is needed to see how forest property sizes influence forest owners, and whether there are any other interactions influencing the explanatory variables looked at in this thesis.

Sammendrag

Det har blitt påvist forskjeller i skogforvaltning og indikatorer for biomangfold mellom ulike eierformer i Europa. Dette har imidlertid ikke blitt undersøkt i norske skoger. I dette prosjektet hadde jeg som mål å utforske sammenhengene mellom indikatorer for biologisk mangfold og skogeierskap i Norge. I tillegg ønsket jeg å se om skogeiendomsstørrelse, kommuner, avstand til vei, eller skogbonitet forklarte fordelingen av biomangfoldindikatorer bedre enn eierformer som forklaringsvariabel. Jeg ville også undersøke om det var forskjeller i skogforvaltningen mellom eierformer, skogeiendomsstørrelser, og kommuner.

Studieområdet bestod av skogeiendommer innenfor ti kommuner i Sørøst-Norge, hvor jeg anvendte både natur- og samfunnsvitenskapelige forskningsmetoder. Den naturvitenskapelige seksjonen brukte indikatorer for biomangfold på: (1) artsnivået, ved hjelp av avgrensede observasjoner av rødlistede arter fra Artsdatabanken; (2) habitatnivået, ved bruk av livsmiljøer fra miljøregistreringer i skogbruket (MiS); og (3) landskapsnivået, ved bruk av kartdata om skogstrukturer basert på lidar. Shannon-indekser ble beregnet for å estimere forskjeller i mangfoldet av rødlistede arter innenfor de ulike forklaringsvariablene. Landskaps- og habitatsindikatorene ble analysert statistisk ved å analysere avvik fra det totale gjennomsnittet av indikatorene, og korrelasjon med skogeiendomsstørrelser. Den samfunnsvitenskapelige delen inneholdt spørreskjemadata om eiernes skogforvaltningsmål og -praksiser. Skogeiernes mål ble analysert deskriptivt, og forvaltningspraksisene ble analysert både deskriptivt og med avviksanalyser.

Jeg fant forskjeller mellom eierformene, men i motsetning til tidligere forskning hadde offentlige skogeiere ikke større verdier av biomangfoldindikatorer enn private eiere. Imidlertid ble det observert en underliggende påvirkning fra skogeiendomsstørrelser, hvor eiere med større skogeiendommer hadde lavere verdier av indikatorer for biomangfold. Denne trenden korrelerte med at flere privatpersoner med store skogeiendommer hadde økonomisk avkastning som hovedmål, og brukte mer flatehogst i skogforvaltningen sin, sammenlignet med privatpersoner med små skogeiendommer. Forskjeller mellom kommuner så ut til å ha større effekt på indikatorene for biomangfold enn eierform, mens avstand til vei totalt sett så ut til å ha liten til ingen effekt. Økende bonitet, derimot, hadde generelt sett en sterk positiv sammenheng med indikatorverdiene for biomangfold.

Forskjeller i biomangfoldindikatorer ble observert med alle forklaringsvariablene, men forskjeller i skogbonitet og korrelasjoner med skogeiendomsstørrelser syntes å påvirke biologisk mangfold mer enn eierformer, avstand til vei, eller hvilken kommune skogen lå i. I tillegg viste skogeiendomsstørrelse også tegn til å ha påvirket skogeiernes primære forvaltningsmål og -praksiser. Videre forskning er nødvendig for å se hvordan skogeiendomsstørrelser påvirker skogeiere, og om det er noen andre interaksjoner som påvirker forklaringsvariablene som har blitt sett på i denne studien.

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Introduction

Forest ecosystems world-wide are deteriorating due to over-exploitation (IPBES, 2019). Over-exploitation entails harvesting natural resources at an unsustainable rate, such as intense forestry with short rotations (Balvanera et al., 2019). This is the case globally (IPBES, 2019), but over-exploitation is also one of the major threats to biodiversity in Norway (Artsdatabanken, 2021b). Almost half of the 2752 threatened species in Norway live permanently or partially in forests, according to the Norwegian Red List for Species (Artsdatabanken, 2021a). Furthermore, 1132 of the threatened species are assumed to be affected negatively by previous or ongoing forestry activities (Artsdatabanken, 2021b). Most of these species are affected negatively by clear-cutting, but a substantial number is also affected by continuous-cover forestry (Artsdatabanken, 2021b). Thus, forestry can have negative effects on different species, but measures have been put in place to conserve forest habitats important for red-listed species.(Gjerde et al., 2007)

Habitats important for red-listed species (hereafter "biodiversity habitats") are registered in environmental inventories in forestry, called "Miljøregistreringer i Skog (MiS)" in Norwegian (Gjerde et al., 2007). The principles behind the inventories have been described by Baumann et al. (2002a), who have also described the characteristics of the biodiversity habitats (Baumann et al., 2002b), registration methodology (Baumann et al., 2001), and the selection methodology (Baumann et al., 2002c). In addition, the guidelines for environmental inventories were revised in 2017 to comply with Nature in Norway (NiN) (Landbruksdirektoratet, 2020), which is a system of classifying and describing nature types in Norway (Halvorsen et al., 2023). This has resulted in a detailed system for mapping important habitats for red-listed species in the Norwegian forestry sector. However, this system focuses on conserving habitat patches, and not on maintaining continuous and biodiverse forest landscapes.

Forest landscapes can have different characteristics, depending on natural disturbances like forest fires, or human-caused disturbances like forestry activities. Such disturbances can create uniform or multi-layered forest structures, but it can be difficult to see how several small disturbances affect the overall landscape. However, remote sensing techniques have made it possible to acquire detailed information about the state of forest structure at the landscape level (Kangas et al., 2018). One technique used in Norway is lidar (Kangas et al., 2018), which creates a detailed spatial point cloud of x, y and z coordinates of the forest. These data can be used to create high accuracy estimates of tree volume, height, and basal area (Vauhkonen et al., 2014). Such estimates can be used to analyse structural diversity of forests (Müller & Vierling, 2014), forest naturalness (Sverdrup-Thygeson et al., 2016), and inform forest management decisions. These decisions are largely left to forest owners themselves to make, within the frameworks set by public legislation and private agreements.

Norway has enacted legislation[1] supposed to stop the deterioration of biodiversity, through conservation measures and sustainable practises. Some notable examples are the Act on Management of Biological, Geological and Landscape Diversity (Nature Diversity Act, 2009) and the Act relating to forestry (Forestry Act, 2005). The Nature Diversity Act is applicable in most cases of land use change and forestry activities. This is because it contains principles regarding sustainable use of nature (Nature Diversity Act, Chapter II), and general rules about preserving and taking special consideration of prioritised, rare species (Nature Diversity Act, Chapter III, Sections 23-25) and selected habitat types (Nature Diversity Act, Chapter VI). The Forestry Act and its regulations, on the other hand, contain the sector-specific rules about forestry. The purpose of this Act is to ensure that forestry practises are sustainable (Forestry Act, Chapter 1, Section 1). It also demands that forest owners pay regard to environmental values detected in forest inventories (Forestry Act, Chapter 1, Section 4).

In addition to public legislation, most forest owners in Norway also follow the Norwegian PEFC forest standard (PEFC Norway, 2023). This standard contains 30 requirements, which includes requirements to conserve and give due consideration to biodiversity habitats (PEFC Norway, 2023). Thus, public legislation and private agreements form a legal framework for forest owners. Forest owners are, however, as stated in the Forestry Act, Chapter 1, Section 4, left with the freedom to choose how to manage their forests within the legal frameworks. Thus, forest owners are important actors in the management of forests. Different categories of forest ownership have also been linked to differences in biodiversity indicators, in a literature review of 22 studies (Mölder et al., 2021).

Public forests have, overall, had more biodiversity than privately owned forests (Mölder et al., 2021). However, small-scale private forest owners have had high levels of forest heterogeneity, and biodiversity indicators related to traditional forestry practises like pollarding and coppicing (Mölder et al., 2021). On the other hand, some studies have found no significant overall differences between ownership categories, across multiple study areas (Holmgren et al., 2010). It can be presumed that the different owners are subjected to some common rules in every nation. For example, in Norway every forest owner is subjected to the Nature Diversity Act and Forestry Act. However, some specific ownership categories may be subjected to rules unique to their own type of ownership. Such rules may be directly related to forest management, which is the case for Norwegian parish commons (Wille et al., 2011), also referred to as “bygd commons”.

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[1] Throughout this paper all legislation referred to are English translations, to make them readable for non-Norwegian speakers. The English translations have been found in the University of Oslo’s online database**: University of Oslo. (n.d.). *Translated Norwegian Legislation*. Retrieved 8 February 2024 from https://app.uio.no/ub/ujur/oversatte-lover/cgi-bin/sok.cgi?type=LOV**, and on the Norwegian government’s website: **Government.no. (n.d.). *Acts and regulations*. Retrieved 8 February 2024 from https://www.regjeringen.no/en/find-document/acts-and-regulations/id438754/**.

Parish commons are in general obliged to have a manager with an education in forestry, as stated in Section 3-5 of the Act relating to parish commons (Wille et al., 2011). In contrast, other ownership categories may not be obliged by law to have managers with a forestry education. For instance, the Act relating to limited liability companies (Ferguson & Den Norske revisorforening, 2013) does not state any education requirement for managers, although the company may be involved in forestry to the same degree as a parish common.

Thus, there are institutional differences between some ownership categories, that may or may not impose different legal obligations on forest owners that can influence practises. To research this topic to its full extent would require in-depth qualitative research and legal analyses, which are outside the scope of my thesis. However, a question that has been researched in relation to forestry practises in other European countries, is whether there are any differences in biodiversity indicators in forests between ownership categories. This is the main research theme of my thesis, within the context of Norwegian forests.

Different indicators have been created for estimating biodiversity, at both the species, habitat, and landscape level. At the species level it is common to use Shannon indices, to get an estimate of the current species diversity, or Simpson indices to get a better view of which direction the current species composition is heading (Fedor & Zvaríková, 2019). Area proportions of habitats important for certain species, for example red-listed species, can also be used as an indicator of biodiversity at the habitat level (Gjerde et al., 2007; Hekkala et al., 2023). Finally, area proportions of forest structure characteristics can be used as indicators of biodiversity, for example using lidar data to estimate the naturalness of forests (Mienna et al., 2019; Sverdrup-Thygeson et al., 2016; Ørka et al., 2022).

I have included biodiversity indicators at all the mentioned levels in my thesis, using Shannon indices, area proportion of biodiversity habitats, and area proportions of forest structure data based on lidar. Furthermore, I combined natural and social science research methods, to analyse both the spatial distribution of biodiversity indicators between ownership categories, as well as how different owners managed their forests in south-eastern Norway. In addition to ownership categories, both forest property size, municipalities, distance to roads, and forest productivity were included as explanatory variables, to see if they explained the distribution of biodiversity indicators better than ownership.

I sought to answer the following research questions:

1. Are there any overall differences in biodiversity indicators between ownership categories in forests in south-eastern Norway?
2. Is there a correlation between the area proportion of landscape or habitat indicators and the size of forest properties?
3. Are there any overall differences in biodiversity indicators between municipalities, distance to roads, or forest productivity in forests in south-eastern Norway?

4. Do forest property size, distance to roads, municipalities, or forest productivity explain the distribution of biodiversity indicators better than ownership categories?
5. Are there any differences in forest management goals or practises between ownership categories, forest property sizes, or municipalities, and do they explain any of the results regarding biodiversity indicators?

I stated six hypotheses relating to the research questions:

I. Publicly owned and common forests would, overall, have higher biodiversity than privately owned forests, based on the findings of Mölder et al. (2021) for public forests and tendencies observed by Holmgren et al. (2010) for common forests in some study areas.

II. Smaller forest properties would have higher area proportions of habitat indicators, based on the review by (Mölder et al., 2021), and higher area proportions of landscape indicators. Forest property size would also explain the distribution of these biodiversity indicators better than ownership.

III. There would be overall differences in biodiversity indicators between municipalities, but they would not explain the distribution of indicators better than ownership.

IV. There would be lower values of biodiversity indicators closer to roads, due to easier access for forestry activities, and this variable would explain the distribution better than ownership.

V. There would be higher values of biodiversity indicators in high productive forests, due to higher temperature, better soil qualities, and water access, improving the growing conditions for plants. Furthermore, this variable would explain the distribution better than ownership.

VI. Differences in forest management goals and practises would contribute to explaining the results of biodiversity indicator values between ownership categories, forest property sizes, and municipalities.

Materials and methods

Study area

The study area consisted of forests in ten municipalities in south-eastern Norway, within the counties Akershus, Innlandet, and Oslo. A forest mask layer, retrieved from the Forest Ecological Basemap (FEB) developed by Ørka et al. (2022), and AR5 land cover maps (Geonorge, n.d.-a) were used to locate the forests within the study area. The elevation in the study area ranged from 0 to 800 meters above sea level (m.a.s.l.), and much of the forests were located at higher elevations (Figure 1).

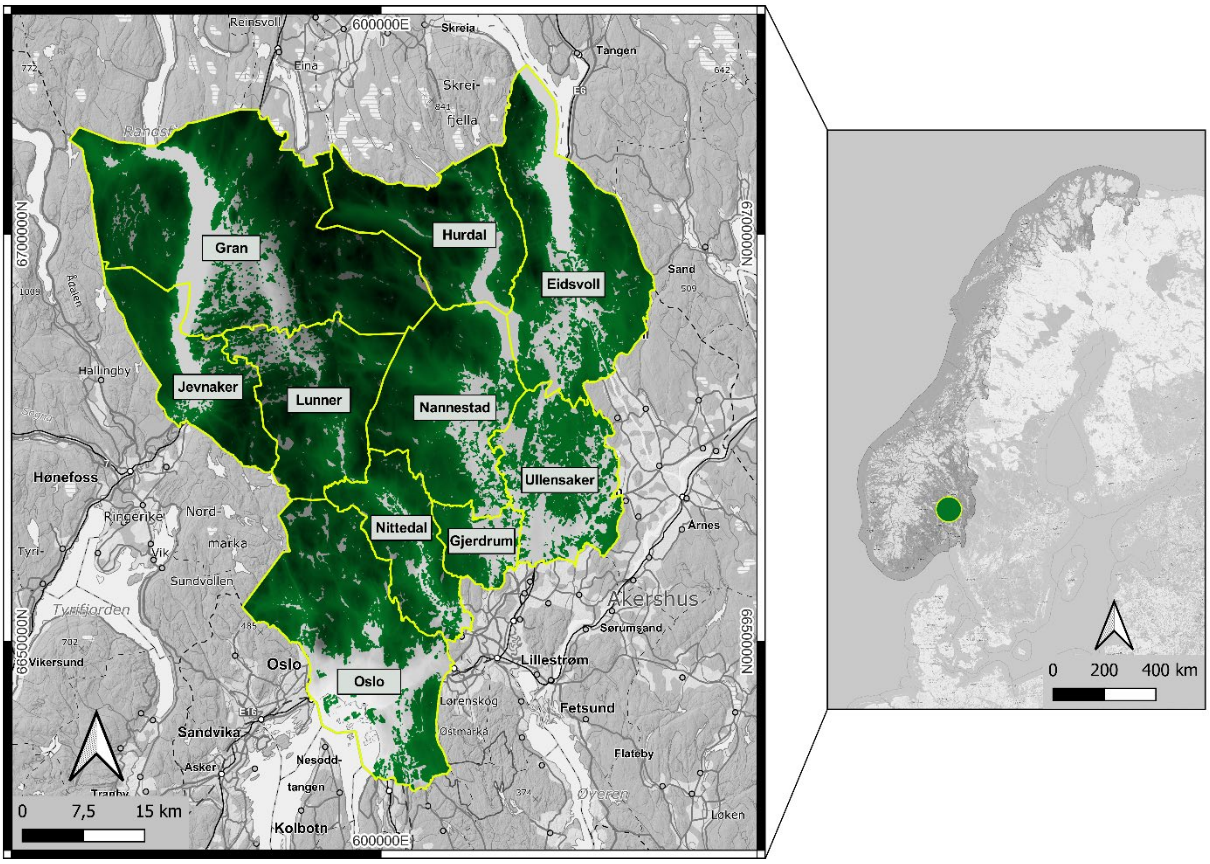


Figure 1: *Digital terrain model of the study area (left) showing municipalities and separated into forests (green) and non-forest land cover (grey) according to FEB. Elevation visualised for forested areas in light green (low elevation) to dark green (high elevation), and for non-forested areas in light grey (low elevation) to dark grey (high elevation). Map of northern Europe with Norway in dark grey (right), and study area marked with a green circle.*

The study area was within a bioclimatic gradient, going from boreonemoral forests in the south to a mix of southern and middle boreal forests dominating north of Oslo (Moen, 1998). The area was dominated by spruce, but it also had a large amount of pine and scattered patches of broadleaved tree species, according to the national forest inventory (Statistics Norway, 2023b). Approximately 20% of the forests in the region were near-natural forests established before 1940, which had not been clear-cut or affected by other registered harvests in the last decades (Storaunet & Rolstad, 2020).

Research design

This study was divided into a natural science and a social science section (Figure 2). In the natural science section, the aim was to relate response variables, in the form of forest biodiversity indicators at three hierarchical levels, to five potential explanatory variables: ownership categories, forest property sizes, municipalities, distance to roads, and forest productivity.

Ownership categories and forest property sizes were the main focus, but the other variables were included to see if they explained the distribution of biodiversity indicators better, and to identify potential confounding effects. Forest productivity was chosen as a variable to see how different levels of productivity affected the distribution of the different biodiversity indicators. Municipalities were included to see if there were indications of differences in forestry policies, management practices, or biodiversity mapping between the municipalities. Finally, distance to roads was selected because road infrastructure is important for logging and other forestry activities that can impact biodiversity.

The biodiversity indicators used in the natural science section were sorted into three hierarchical levels: the species level, using delimited observations of red-listed species; the habitat level, using data from environmental inventories in forestry; and the landscape level, using data on forest structures from the FEB.

The social science section analysed ownership categories, forest property sizes, and municipalities for differences in forest management goals and practises.

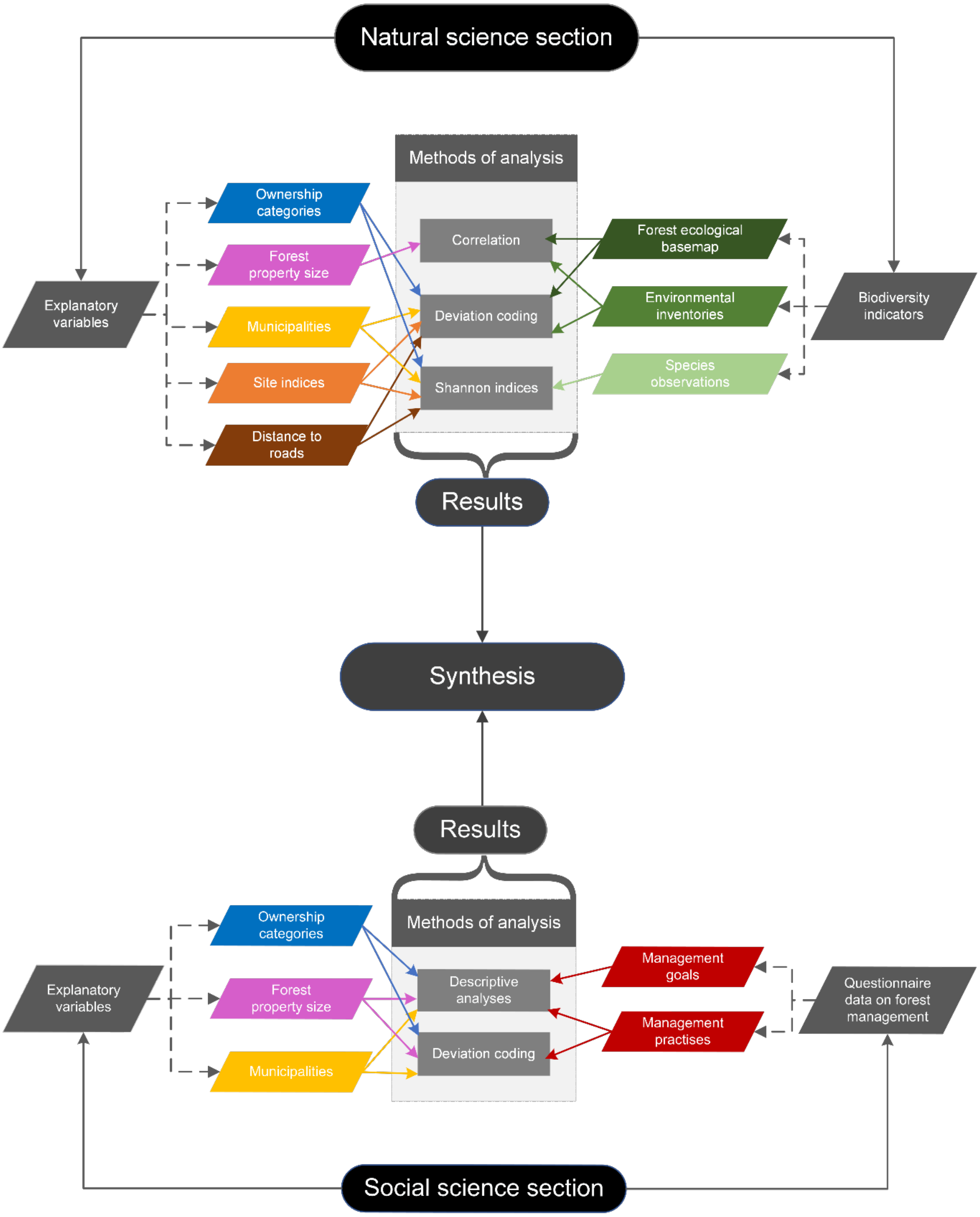


Figure 2*: Research design with data and methods of analysis used in the natural science section (top) and social science section (bottom).*

Natural science section

Species data

The data on observations of red-listed species were retrieved from the Norwegian Biodiversity Information Centre (Artsdatabanken, 2019). The red list categories included in this thesis were: near threatened (NT), vulnerable (VU), threatened (EN), and critically threatened (CR). The data were merged and further delimited by three criteria: (1) the observation had to have been made in the year 2000 or later; (2) the coordinate precision had to be 50 meters or better; and (3) only fungi and lichen, vascular plants, insects, and mosses were included, thus excluding vertebrates and freshwater species. The first criterion was chosen to exclude old observations, which were less certain to still be in the area. The second criterion was chosen to limit the precision error of the observation. Finally, vertebrates were excluded because of their high mobility, which made them a less good indicator for estimating biodiversity in this project. Freshwater species were excluded because I interpreted their occurrence on land as a geometric error.

The counts of both observations and species were highest in fungi and lichen (Table 4), whilst both counts decreased with increasing threatened levels in the red list categories (Table 5). The delimited species data were thereafter intersected with the different explanatory variables, which were used to calculate Shannon indices.

***Table 4**: Count of species and observations within each taxonomic group in the study area.*

	Groups	**Species count**	**Observation count**
Taxonomic	Fungi and lichen	270	3920
	Vascular plants	118	3904
	Insects	72	288
	Mosses	14	222

***Table 5**: Count of species and observations within each red list category in the study area.*

	Groups	**Species count**	**Observation count**
Red list	Near threatened	281	5197
	Vulnerable	136	1698
	Threatened	51	1419
	Critically threatened	6	20

Habitat data

The biodiversity habitat data were provided by the Norwegian Agriculture Agency. The data included all biodiversity habitats within the study area, which had registrations of eleven out of twelve habitat types in the methodology (Baumann et al., 2002b). Six of the eleven habitat types were designated as structural biodiversity habitat types in my thesis (Table 6). This was because they were seen as more linked to forest biodiversity influenced by the forest structure and forest management, rather than site specific factors like type of bedrock, slope, climate, and natural disturbances.

Table 6: Description of the different habitats within the study area, based on the descriptions by Baumann et al. (2002b).

Biodiversity habitats	Structural	Description
Snags	Yes	Standing deadwood.
Logs	Yes	Lying deadwood.
Trees with nutrient-rich bark	Yes	Trees with a pH of more than 5 in the bark.
Trees with pendant lichens	Yes	Trees who have branches and/or trunks with large amounts of filamentous lichens hanging from them.
Late successions of deciduous trees	Yes	Patches of forests with large deciduous trees in the late successional stage
Old trees	Yes	Trees that have been subjectively assessed according to a set of criteria about trees older than 150-200 years.
Burned forest	No	Patches of forests that have burned less than ten years ago.
Rich ground vegetation	No	Forest areas with a large amount of ground vegetation and containing certain indicator species.
Rock walls	No	Rock walls that are above three meters in height.
Clay ravines	No	Elongated depressions in the landscape due to water erosion through clay or other fine-grained marine deposits.
Stream gorges	No	Gorges that have formed in the bedrock due to erosion from streams, causing an environment with a consistently high humidity.

The biodiversity habitats used in this study included areas that had been selected for conservation measures, and areas who had not been selected. In addition, the biodiversity habitats were divided into three groups. The first group contained all habitats, the second group contained all structural habitats, and the third group contained the six individual habitats within the structural category. The biodiversity habitats covered in total almost 2% of the study area, and had their overall highest area proportion in very low productive forests (Table 7).

Table 7: Biodiversity habitats as proportions (%) of total area and area for each AR5 forest productivity class (Ahlstrøm et al., 2019), ranging from very low to high productivity. High productivity in this table also includes very high productive forests, due to little area of very high productive forests in my study area (Table A1 in Appendix A). The "not relevant" productivity class was excluded here, since it supposedly did not include forest land cover (Ahlstrøm et al., 2019).

Level		Biodiversity habitats	Total area proportion (%)	Forest productivity				
				Very low	Low	Medium	High	
Habitat	Merged	**All habitats**	**1.80**	2.96	2.24	1.43	2.03	Area proportion (%)
		Structural habitats	**1.40**	2.37	1.97	1.11	1.27	
	Individual	**Snags**	**0.13**	0.11	0.19	0.11	0.13	
		Logs	**0.55**	0.47	0.59	0.46	0.62	
		Trees with pendant lichens	**0.22**	0.42	0.42	0.21	0.08	
		Late successional deciduous trees	**0.31**	0.18	0.08	0.13	0.64	
		Trees with nutrient-rich bark	**0.01**	0.02	0.01	0.01	0.02	
		Old trees	**0.60**	1.44	1.23	0.45	0.32	

The standard minimum size for all biodiversity habitats is 0.2 hectares, except for rich ground vegetation, which has a minimum size of 0.05 hectares (Landbruksdirektoratet, 2020). All registered biodiversity habitats were therefore assumed to have been registered in line with these minimum standards. However, due to intersection and aggregation processes with the explanatory variables used in my thesis, some habitat areas ended up under the standard minimum sizes. This was seemingly due to geometric errors in the final aggregation of geometries, or because of biodiversity habitats stretching across the geometric borders of different partitioned spatial elements. For example, a biodiversity habitat that was above the standard minimum size might have been split into two spatial objects when intersected with an explanatory variable, and therefore end up below the standard minimum size. This does not make the habitat information invalid, but it does make the minimum size standards not fully applicable in my study. A minimum area threshold was therefore created for the biodiversity habitats, where 0.02 hectares was chosen as the minimum. This threshold was chosen because it was slightly under the lowest of the standard minimum sizes for habitats, and thus included some margin of error, but was still large enough to discard plausible sources of geometric error.

Thus, the biodiversity habitats were delimited to only those at or above 0.02 hectares, after having been aggregated around unique values of forest owners and the relevant explanatory variables. Afterwards the area of the biodiversity habitats was divided by the total forest property area of each forest owner, to calculate the area proportions. Thus, forest properties were used as sample units, to calculate the area proportions of the biodiversity habitats used in the statistical analyses.

Landscape data

The landscape biodiversity indicators were based on three map layers from FEB (Ørka et al., 2022). These map layers were in turn based on lidar data from a national data acquisition campaign (Ørka et al., 2022). Lidar sensors calculate the distance between the sensor and the object an emitted laser pulse hits. The calculation is based on the return time of an emitted laser pulse, information regarding the sensor's position from a Global Positioning System (GPS), and the direction of the emitted pulse from an Inertial Navigation System (INS) (Vauhkonen et al., 2014). The resulting point locations collectively create a high-resolution, three-dimensional point cloud of the forest. This point cloud can be used to describe the forest structure with high accuracy (Vauhkonen et al., 2014). The FEB was provided as a raster with pixel sizes of 0.025 hectares, and the map layers retrieved from it described the naturalness, tree size diversity, and tree height diversity of the forests (Table 8).

Table 8*: Description of the different FEB data used in this project.*

FEB data	Description
Near-natural forests	Forests that were in the mature age class when they were visited between 1994 and 1998, and still was mature when the plot was last visited. Originally referred to as the naturalness definition 7 (NATD7) by Ørka et al. (2022).
Tree size diverse forests	Gradient for forests with a GINI coefficient larger than the 25th percentile of the region's overall GINI coefficient, describing the diversity in tree diameters. Originally referred to as the naturalness definition 4 (NATD4) by Ørka et al. (2022).
Tree height diverse forests	A three-dimensional index consisting of measures on forest height, density and complexity, originally referred to as the forest structure index (FSI) by Ørka et al. (2021). I delimited the FSI to just the complexity dimension in my thesis. This was because the complexity dimension described the diversity of tree heights, through their standard deviations, and was therefore considered as the best measure for structural diversity.

All FEB data were subjected to a sieving process, inspired by Framstad et al. (2020), in QGIS version 3.22 (QGIS Deveopment Team, 2022). QGIS was used for all spatial data manipulation and analyses in my thesis. It was decided to create a threshold in the data, to only extract the highest index values and percent estimates from the FEB data for the analyses. The threshold decided upon was two thirds, on the different value scales. This entailed that the percent estimates for near-natural and tree size diverse forests would be over 66%, and the values for tree height diverse forests would be in the most structurally complex third. All values above the threshold were separated from values at or below the threshold. This separation resulted in binary raster layers, with pixel values of 1 and 0, where 0 represented values at or below the threshold and 1 represented values above the threshold.

The binary FEB data were thereafter processed using the GDAL sieve function. The role of the sieve function was to smooth out pixel values and fill in holes below a certain threshold. The binary data were used as input in the function, using 8-connectedness and four pixels as the threshold. This threshold meant that if less than four 1-value pixels were encapsuled by 0-value pixels, then the 1-value pixels would be changed into 0-value pixels, and vice versa. Also, since 8-connectedness was chosen, pixels next to each other diagonally were also considered as connected, in addition to pixels that were next to each other horizontally or vertically. The threshold of four pixels was chosen based on the work of Framstad et al. (2020), and the 8-connectedness was chosen to retain a more detailed map of the values. This sieving process was run twice, where the first run was to smooth out pixel values and the second run was to fill in holes below the threshold. The 0-value pixels were thereafter discarded, and the 1-value pixels were vectorised into polygon areas. The areas of near-natural and tree size diverse forests covered approximately 23% each of the study area, whilst tree height diverse forests covered approximately 33% (Table 9). Near-natural forests had their highest proportions in high productive forests, whilst both tree size and tree height diverse forests had their highest proportions in low productive forests (Table 9).

Table 9: Area of FEB indicators as proportions (%) of the total forest area and the area of each AR5 forest productivity class (Ahlstrøm et al., 2019), ranging from low to high productivity. High productivity in this table also includes very high productive forests, due to little area of very high productive forests in my study area (Table A1 in Appendix A). The "not relevant" productivity class was excluded here, since it supposedly did not include forest land cover (Ahlstrøm et al., 2019).

Level	FEB indicator	Total area proportion (%)	Forest productivity				
			Very low	Low	Medium	High	
Landscape	**Near-natural forests**	**23.21**	10.82	22.00	22.37	26.34	Area proportion (%)
	Tree size diverse forests	**23.16**	16.02	24.99	22.97	23.10	
	Tree height diverse forests	**32.79**	39.76	41.69	33.68	25.67	

The data were thereafter intersected with each explanatory variable, and areas with the same forest owners and explanatory values were aggregated. This aggregation resulted in some geometric errors, due to minor overlaps and self-intersections in the geometries. One error was that several polygons were at or close to 0 square meters in area. To address this, all polygons below 0.02 hectares were excluded. The 0.02 hectare threshold was chosen to have a slight buffer compared to the original pixel size of 0.025 hectares.

The intersected data was thereafter linked with the total forest property area of each forest owner. This made it possible to calculate what the area proportions of FEB data were out of each owner's total forest property, for each explanatory variable. Thus, forest properties were also used as sample units to calculate the area proportions of the landscape indicators used in the statistical analyses.

Explanatory variables

Ownership categories and forest property size

Ownership categories were categorised based on information from the Norwegian Land Registry (Kartverket, n.d.). The information was retrieved by submitting the cadastral number of the properties and the name of the municipality they were located in, based on spatial data from the Norwegian Mapping Agency (Geonorge, n.d.-b).

The minimum property size was set to ten hectares, to manage the workload. In addition, the land cover types were initially delimited to forests, freshwater and wetlands, according to the AR5 land resource map (Geonorge, n.d.-a), to just include natural habitats. This reduced the number of properties from 12235 to 2196. All properties with a cadastral number were looked up in the Norwegian Land Registry, from 2022 until 2023, and the registered names of the forest owners were encoded in a spatial data table. Ownership category was also encoded in the spatial data table, based on the characteristics of the owners recorded in the land registry (Table 10). Joint stock companies, general partnerships, funds, associations, churches, cooperatives, and foundations were referred to jointly as "private actors" in the visualization of some figures, because the number of groups had to be reduced. Parish-state commons, state commons, and parish commons were also sometimes referred to jointly as "commons" for the same reason.

***Table 10**: Ownership categories and descriptions of why an owner was put in that specific category. The ownership categories are stated both in English and in Norwegian in brackets.*

Ownership category	Description
Joint stock company (Aksjeselskap)	The registered owner was a joint stock company
General partnership (Ansvarlig selskap)	The registered owner was a general partnership
Parish-state commons (Bygde-/statsalmenning)	The property was a common owned both by the state and villagers
Parish commons (Bygdealmenning)	The property was a common owned by villagers
Fund (Fond)	The registered owner was a fund
Association (Forening)	The registered owner was a form of association
Church (Kirke)	The registered owner was a church
Municipality (Kommune)	The registered owner was a municipality
Private individual (Privatperson)	The registered owner was one private individual
Joint ownership (Sameie)	The registered owners were two or more private individuals and/or legal persons, where each owner owned an ideal fraction of the property
Cooperative (Samvirkeforetak)	The registered owner was a cooperative
State (Statlig)	The registered owner was either fully or mostly owned by the state, in the form of state companies, agencies, or departments.
State commons (Statsalmenning)	The property was a common, and the registered owner was a state actor.
Foundation (Stiftelse)	The registered owner was a foundation

Some larger areas lacking cadastral numbers were categorised with the help of local agricultural offices. However, the ownership information of smaller areas was not possible to acquire, and areas without an identifiable owner were thereafter excluded. The rest of the data were delimited to only forests, thus excluding freshwater and wetlands, using the forest mask layer from the FEB (Ørka et al., 2022). The exclusion of wetland and freshwater areas lead to the minimum polygon size being below ten hectares, and a total of 2182 properties. Properties with the same owner were aggregated, which revealed that the study area had 1518 forest owners in total. This also meant that 1518 was the population of sample units used for analysing the landscape and habitat indicators.

The ownership categories differed both in number of properties and hectares covered, with private individuals, parish commons, general partnerships, municipalities, and joint ownerships dominating in total area (Table A2 in Appendix A). In addition, some ownership types were mainly in high elevation areas, for example parish commons (Figure 3).

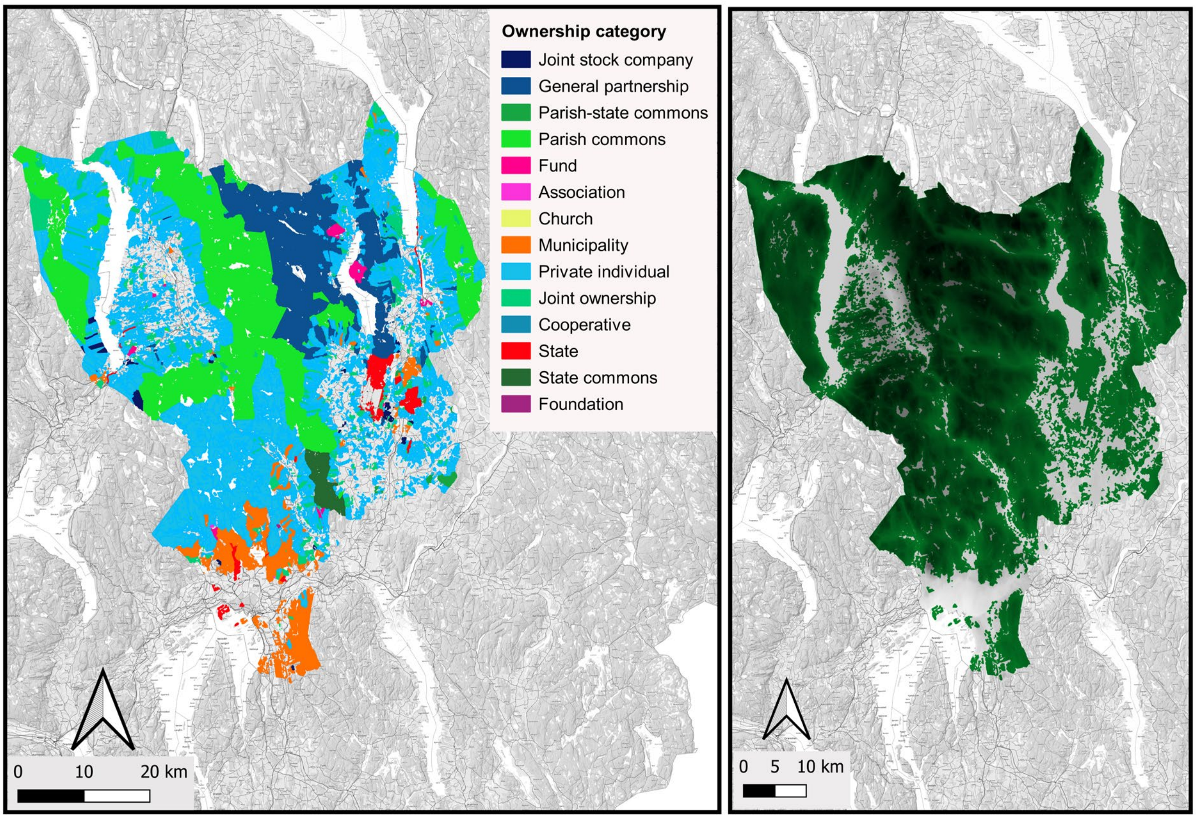


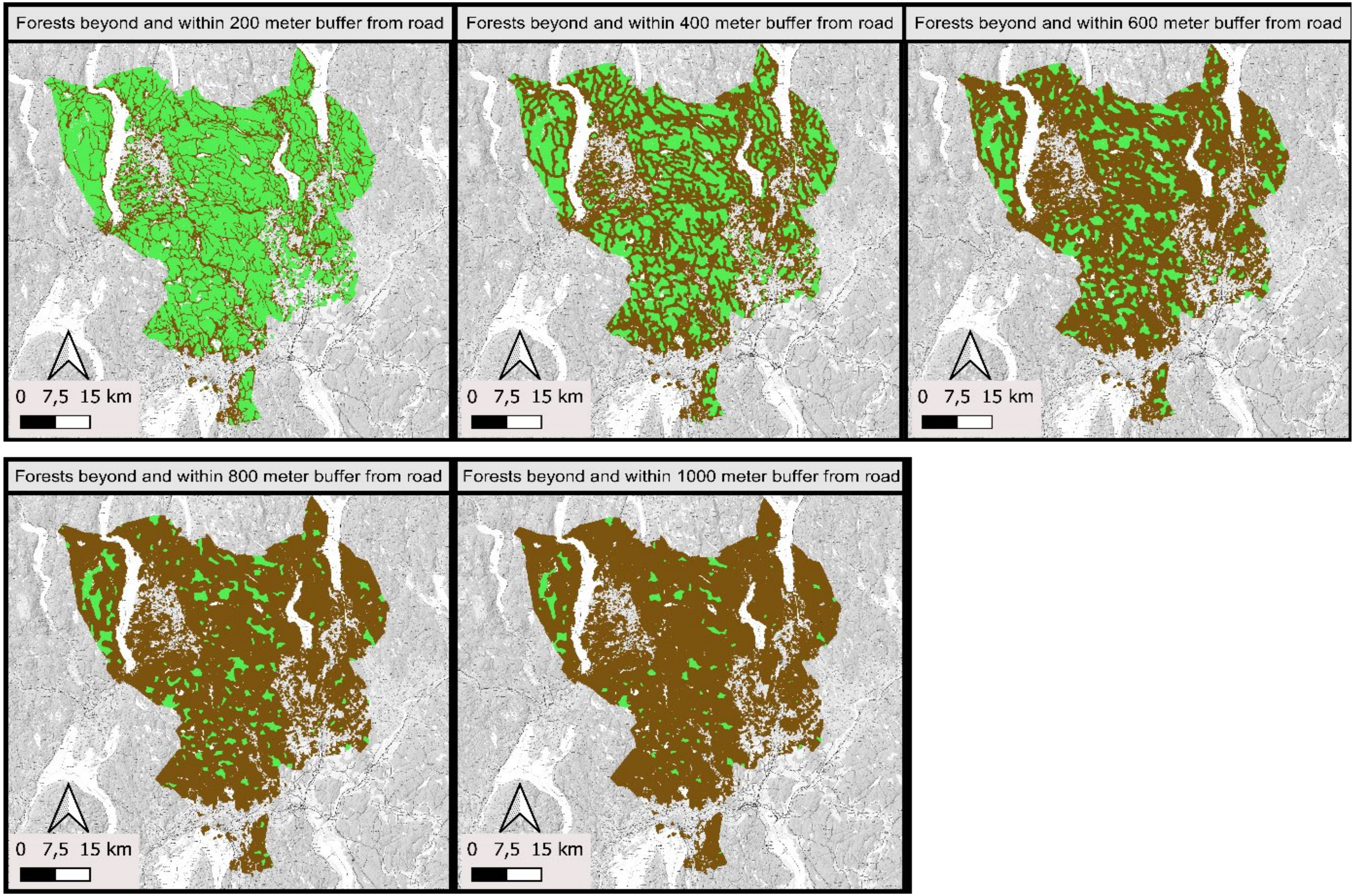
Figure 3: Maps of ownership categories (left) and digital terrain model (right) within the study area. The digital terrain model shows elevation from 0 to 800 m.a.s.l. for forests (green) and non-forest areas (grey). The elevation gradient is visualised for forested areas in light green (low elevation) to dark green (high elevation) and for non-forested areas in light grey (low elevation) to dark grey (high elevation)

Municipalities

The unique municipality numbers included in the ownership data were used to group the properties by municipality. The amount of forest varied between the municipalities, with the highest total area being in Gran and the lowest being in Gjerdrum (Figure 1, Table A3 in Appendix A). Ullensaker, however, had the highest area proportions of high productive forests (Table A4 in Appendix A).

Distance to roads

Road data was downloaded for all municipalities in the study area, and all neighbouring municipalities, using the Elveg 2.0 dataset (Kartverket, 2023). Neighbouring municipalities were included to account for edge effects of roads close to the study area. The roads were buffered in widths of 200, 400, 600, 800, and 1000 meters. This resulted in maps of how much forest in the study area was beyond or within the different buffer zones (Figure 4, Table A5 in Appendix A).



Forests beyond and within 200 meter buffer from road

Forests beyond and within 400 meter buffer from road

Forests beyond and within 600 meter buffer from road

Forests beyond and within 800 meter buffer from road

Forests beyond and within 1000 meter buffer from road

Figure 4: *Forests beyond (green) and within (brown) 200-, 400-, 600-, 800- and 1000-meter buffer zones from roads.*

Forest productivity

The data on forest productivity was retrieved from site indices in AR5 maps of each municipality (Geonorge, n.d.-a). The data were merged and intersected with the forest mask layer and ownership map, resulting in a map of forests in different forest productivity classes (Figure 5).

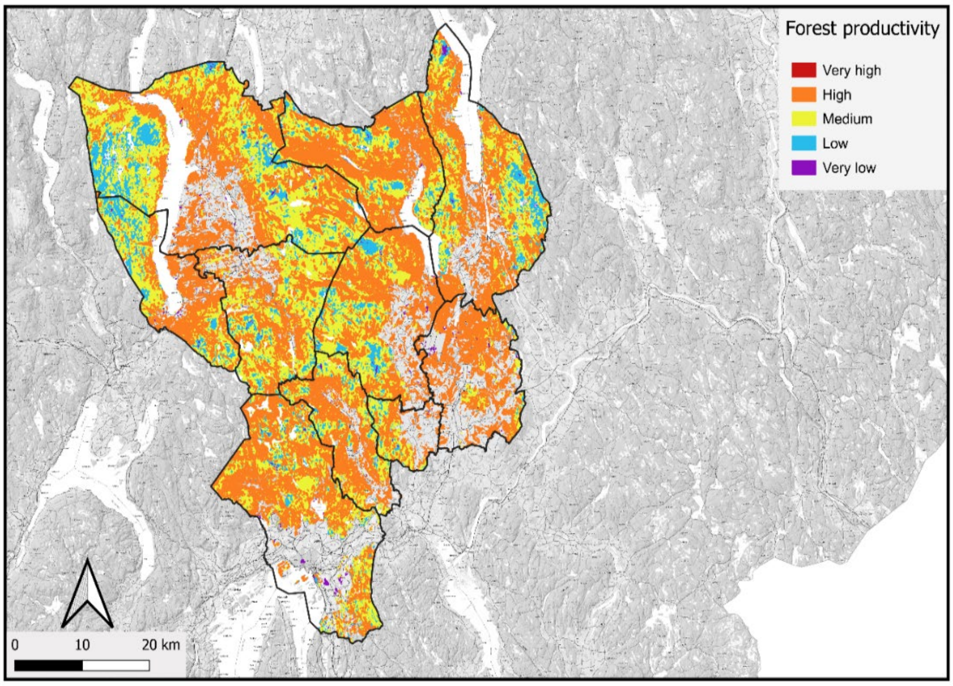


Figure 5: *Forests in different forest productivity classes within the study area, delimited by the forest mask layer. Very low productivity forests shown in purple, low productivity forests in light blue, medium productivity forests in yellow, high productivity forests in orange, and very high productivity forests in red.*

The total area of forests varied between the different forest productivity classes, with the largest areas being medium and high productivity forests and the least being very high productivity forests (Table A6 in Appendix A). I decided to merge the very high productivity areas with the high productivity areas before further analysis. This was due to the very low count of owners and total area of forests in the "very high" productivity class (Table A6 in Appendix A). In addition, the "not relevant" forest productivity class was excluded from the analyses of forest productivity, since it did not contain a productivity value due to the area supposedly not having forest land cover (Ahlstrøm et al., 2019). These areas were, however, not removed from the analyses of other explanatory variables, since they were included in the forest mask layer (Ørka et al., 2022) and thus could be forested areas.

Social science section

Preparatory work

I made a questionnaire (Appendices B and C), which was originally sent out in September 2023, through some of the local agricultural offices in the study area. However, other ways of distribution were sought after two weeks, due to few responses. The alternative distribution method found was utilising the Norwegian Agriculture Agency's ØKS-database, which contained email addresses of several forest owners in my study area. In total 1538 email addresses were provided by the agency.

The provided email addresses contained duplicates, and lacked some email addresses of known forest owners in the study area. The total number of email addresses ended up at 1472, after having removed duplicates and amended the email list with known forest owners. The questionnaire was thereafter sent out to the forest owners on 11th October 2023. The initial email was followed up with two reminders, and email addresses were removed if they had been automatically rejected, discontinued, or the respondent replied that they were not eligible to participate. Cases of non-eligibility included when the respondent no longer owned any forests, or if the respondent replied that they owned so little forest that they did not consider themselves eligible. The total population size ended up at 1389, after having removed the rejected, discontinued, and non-eligible email addresses.

The questionnaire was open until 1st November 2023, and by that time it had been answered by 270 people. However, three of the respondents did not consent to their responses being used in the project. In addition, four of the respondents assumedly did not own any forest, since they had not stated any area of productive nor unproductive forest, when this was asked for in the questionnaire. Thus, these seven were not eligible to be included in the study, which reduced the sample of eligible responses to 263. This entailed a response rate of approximately 19%.

Forest management data

The explanatory variables were looked at in relation to forest management goals and practises. Management goals were looked at by comparing how the different groups ranked six different management goals (Table D1 in Appendix D). The management goals regarded economic profit (ECON), preservation of biodiversity (BIO), facilitation for recreation and nature-use (REC), preservation of the cultural history and landscape (CUL), climate friendly silviculture (CLIM), and preserving the hunting possibilities (HUNT).

Management practises were looked at by comparing the mean proportions of different felling methods used by forest owners. The felling methods included were clear-cutting, seed tree felling, shelterwood felling, selective felling, and other felling methods. The category "other felling methods" was included in case some of the forest owners used felling methods outside of the specific options included in this questionnaire. The owners did not always submit answers that resulted in the sum of proportions being 100%. I did not correct this, because I regarded such an act as inappropriate data manipulation. Thus, sometimes the sum of mean percentages of each felling method in a group, within the explanatory variables, could be above or below 100%, but still give an impression of the relative proportions.

Explanatory variables

All data used in the explanatory variables were checked for number of counts, to see if there was any skewness. A threshold of minimum ten counts per group was set, to reduce the risk of outliers influencing the results.

Ownership categories
The ownership categories were almost the same in the social science and natural science sections (Table 1, and Appendices B and C). However, all forests owned by private companies or the state were aggregated into just two categories in the social science section, due to expected smaller sample size in the questionnaire data. Even with this aggregation, all categories except private individuals had counts below the minimum threshold of ten (Table D2 in Appendix D). It was therefore decided not to analyse differences between ownership categories, and the respondents in the other explanatory groups were delimited to just private individuals.

Forest property size
The explanatory variable based on forest property size was made using the same size categories used by Statistics Norway (2023a). It was decided to merge the three largest categories into one, due to low counts of owners with property sizes of 500 hectares or more. This resulted in six size categories, ranging from 2 – 9.9 hectares up to and above 200 hectares (Table D3 in Appendix D).

Municipalities
Owners from all ten municipalities were represented in the dataset. However, some municipalities had far more respondents than others (Table D4 in Appendix D). It was decided to exclude Oslo and Gjerdrum from the analyses, because they had counts below the minimum threshold of ten.

Methods of analysis

All statistical analyses were conducted in R version 4.2.0 (R Core Team, 2022) using the platform R studio (Posit team, 2023). The alpha value used in all statistical analyses was set to 0.05, but p-values ranging between 0.05 and 0.1 were denoted as strong trends. The landscape and habitat data were checked for skewness in their untransformed state, and when transformed by the natural logarithm and square root, to find the best fitting models using diagnostic plots. Transformed data were used in the analyses, but the resulting estimates were back-transformed to the geometric mean values, for increased interpretability in graphs and tables. Natural logarithm data were back-transformed by calculating the exponent of the transformed values, whilst the square-rooted data were squared for back-transformation.

Analyses of species data

The species data were analysed by calculating Shannon diversity indices of each category within the explanatory variables. The Shannon index was chosen because it puts more weight on less frequently observed species than the Simpson index, and thus gives a more accurate estimate of the current diversity in the species composition (Fedor & Zvaríková, 2019). The indices were computed using the diversity function in the Vegan data package (Oksanen et al., 2022).

Analyses of habitat and landscape data

The values in the habitat and landscape data were thereafter analysed for differences between the explanatory variables, using deviation coding. Deviation coding is a linear regression model that uses the grand mean as its intercept and estimates how much the different group mean values of the dependent variable deviate from the grand mean. The group mean values were calculated from the area proportions of the biodiversity indicators, on the forest property of each owner, within the different explanatory variables. The use of forest properties in this regard also meant that the group means, and grand mean, would be derived from within the forest properties as sample units. This could potentially differentiate it from the proportions in the raw data of the indicators (Tables 7 and 9), since the raw data were not confined by forest properties as the sample units. In addition, ordinal or binary values, like the site indices and distance to roads, would not add up to 100% when summarising the values. This was due to the means being calculated for each category in the explanatory variable individually, and not in relation to each other in the deviation coding. The formula for deviation coding can be expressed as:

$$y = \mu + \tau_i + \varepsilon$$

In this formula y is the dependant variable, μ is the estimated grand mean, τ_i is the estimated deviation from the grand mean for group i, and ε is the estimated error.

Ownership categories were also analysed for correlation between the proportion of biodiversity area and forest property size, using primarily Spearman's rank correlation test. Kendall's rank correlation test was used for the landscape indicators, due to tied ranks prohibiting the use of Spearman's test. If the correlation test gave a significant p-value, then a regression model was made to see if there were any significant trends. The regression models were either linear or quadratic regressions, depending on the observed pattern of the plotted data. The quadratic regression created a better fitting model when the plotted data exhibited a parabola (quadratic) pattern. The regression models best fitted for all biodiversity habitats, structural biodiversity habitats, logs and old trees were quadratic, whilst the rest were linear. The formula for linear regressions can be expressed as:

$$y = \beta_0 + \beta_1 * x + \varepsilon$$

In this formula y is the dependent variable, β_0 is the estimated intercept, β_1 is the estimated slope, x is the explanatory variable, and ε is the estimated error. The formula for quadratic regressions, on the other hand, can be expressed as:

$$y = \beta_0 + \beta_1 * x + \beta_2 * x^2 + \varepsilon$$

The quadratic formula is identical to the linear regression's, except for the added section $\beta_2 * x^2$. This section introduces the squared value of x to the formula, and creates an additional slope related to x^2. Thus, the equation gets two slopes, which better fit the regression to a parabola data pattern.

Analyses of questionnaire data

The proportion of responses, regarding forest management goals, were visualised in graphs, whilst the mean group percentages were calculated for felling methods used in the different forest property sizes and municipalities. Deviation coding was also used to see if there were any statistical differences in felling methods used, within the explanatory variables.

Results

Natural science section

Ownership categories

At the landscape level, associations had a higher proportion of near-natural forests than the grand mean, whilst general partnerships had a strong trend for having a lower proportion (Table 11, Appendix E). Joint stock companies and parish commons, however, had significantly lower proportions of near-natural and tree size diverse forests, compared to the grand means. None of the other ownership categories had strong or significant deviations from the grand mean, when looking at these two indicators. In addition, no ownership categories deviated strongly or significantly from the grand mean regarding tree height diverse forests.

When looking at all biodiversity habitats, and all structural biodiversity habitats, only state forests deviated from the grand mean. State forests showed a strong trend for having lower proportions when looking at all habitats, and significantly lower proportions than the grand mean when only looking at structural habitats. Many individual biodiversity habitats were not present in certain ownership categories, whilst some ownership categories exhibited deviations of one or many habitats. General partnerships had a strong trend for having lower proportions of late successional deciduous trees, whilst parish-state commons had a strong trend for lower proportions of old trees. Joint stock companies had significantly less logs, municipalities had significantly less trees with nutrient-rich bark, the state had significantly less old tree habitats, and state commons had significantly less habitats of trees with pendant lichens. Parish commons had significantly lower proportions of late successional deciduous trees and trees with nutrient-rich bark, whilst joint ownership had significantly higher proportion of habitats with logs, trees with pendant lichens, trees with nutrient-rich bark, and old trees. Private individuals also had significantly higher proportions of habitats with logs, trees with nutrient-rich bark, and old trees. In addition, private individuals had a strong trend for having above grand mean proportions of habitats with late successional deciduous trees.

At the species level, joint ownerships, private individuals, municipalities, and state forests exhibited the highest biodiversity score, expressed as Shannon index values for red-listed species, ranging between 4.11 and 4.26. The lowest index values were in forests owned by associations, churches, parish-state commons, and state commons, ranging from 0.64 to 1.97. The rest of the ownership categories ranged in index values from 2.4 to 2.8. In addition, cooperatives and foundations in the study area had no observations of the red-listed species included in my study.

Although there were significant differences, the R^2 values of each analysis at the habitat and landscape levels were close to 0 or negative, which indicated that the models explained little of the variance in the data.

__Table 11:__ Deviation in mean proportions of biodiversity indicators, in each ownership category, from the grand mean. Strength of significance is indicated by number of asterisks, and strong trends are indicated with a period mark. Red (↓) indicates significant negative deviation, orange (↓.) indicates a strong trend for negative deviation, yellow (-) indicates no significant deviation, light green (↑.) indicates a strong trend for positive deviation, and green (↑) indicates significant positive deviation. Black (■) indicates that the biodiversity indicator was not present in the ownership category, and higher values of Shannon indices indicate higher diversity of red-listed species. See Appendix E for more detailed statistical information.

Level		**Biodiversity indicator**	**Ownership categories**													
			Association	**Church**	**Cooperative**	**Fund**	**Foundation**	**General partnership**	**Joint ownership**	**Joint stock company**	**Municipality**	**Parish commons**	**Parish-State commons**	**Private individual**	**State**	**State commons**
Landscape		**Near-natural forests**	-	-	-	-	-	-	-	↓*	-	↓**	-	-	-	-
		Tree size diverse forests	↑*	-	-	-	-	↓.	-	↓*	-	↓*	-	-	-	-
		Tree height diverse forests	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Habitat	Merged	**All biodiversity habitats**	-	-	-	-	■	-	-	-	-	-	-	-	↓.	-
		Structural biodiversity habitats	■	-	-	-	■	-	-	-	-	-	-	-	↓*	-
	Individual	**Snags**	■	■	■	■	■	-	-	-	-	-	-	-	-	-
		Logs	■	■	■	-	■	-	↑*	↓*	-	-	-	↑**	-	-
		Trees with pendant lichens	■	■	■	■	■	-	↑**	■	■	-	■	-	■	↓*
		Late successional deciduous trees	■	-	-	-	■	↓.	-	-	-	↓***	-	↑.	-	-
		Trees with nutrient-rich bark	■	■	■	-	■	■	↑***	■	↓**	↓*	■	↑**	■	■
		Old trees	■	■	■	-	■	-	↑***	-	-	-	↓.	↑**	↓*	-
Species		**Shannon index**	1.39	1.33	■	2.8	■	2.78	4.11	2.56	4.22	2.4	0.64	4.26	4.21	1.97

Deviation from grand mean (%)

Forest property size

There were significant negative correlations between the proportions of near-natural forests and forest property sizes. However, the correlation coefficient was almost zero (Kendall's $\tau = -0.04$), indicating a very weak correlation, and the best fitting linear regression model resulted in a strong, but non-significant, negative trend. This trend was heavily influenced by heteroscedasticity in the model's residuals, indicating that it was a poor model. Tree size diverse forests, on the other hand, had a significant, and slightly stronger, negative correlation (Kendall's $\tau = -0.05$), and a significant negative trend. This trend, however, also exhibited heavy heteroscedasticity in the model's residuals, indicating that it too was a poor model. Finally, tree height diverse forests had no significant correlation or trends regarding forest property sizes.

Forest property size explained relatively much of the variation in area proportions of all and structural biodiversity habitats in the study area (Figure 6), and even more for the individual biodiversity habitats (Figure 7). The results revealed significant negative correlations between biodiversity habitats and forest property size, where smaller forest properties had higher proportions of biodiversity habitats than larger forest properties.

However, the negative trend turned into a weaker positive trend for some of the habitat indicators, after having passed approximately 1100 hectares in forest property size. This was the case for all biodiversity habitats and all structural biodiversity habitats (Figure 6), and apparently the same approximate threshold applied for logs and old trees (Figure 7). This indicated that forest properties above 1100 hectares in size started to have higher proportions of the mentioned indicators, but this was not the case for snags, trees with nutrient-rich bark, trees with pendant lichens, nor for late successions of deciduous trees (Figure 7). In addition, the percent values only increased by about 1.7% regarding all and structural biodiversity habitats (Figure 6), and about 0.7% for logs and old trees (Figure 7), when forest property size increased from 1100 to over 13900 hectares. Thus, the negative trends were the main trends, and the positive trends were minor deviations caused by small clusters of atypically large forest properties in the study area, which influenced the regression models. In addition, most of the forest owners within these clusters were commons (Figures 6 and 7).

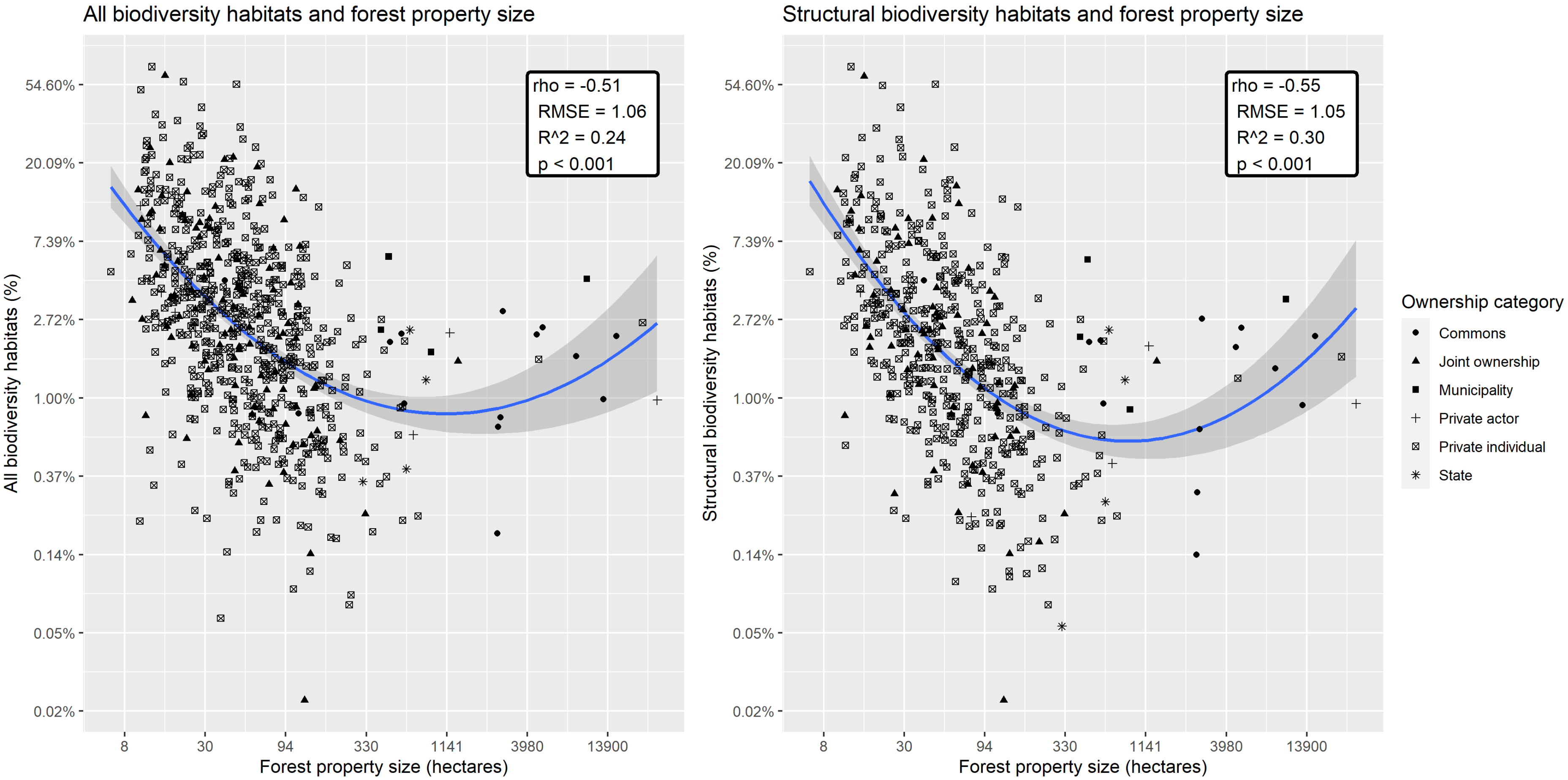


Figure 6*: Quadratic regressions of back-transformed (ln) area proportions (%) of all biodiversity habitats (left) and structural biodiversity habitats (right), in relation to the size of forest properties in back-transformed (ln) hectares. Grouped by aggregated ownership categories. The values of Spearman's rho, RMSE, adjusted* R^2*, and the* p*-value have been annotated on each figure.*

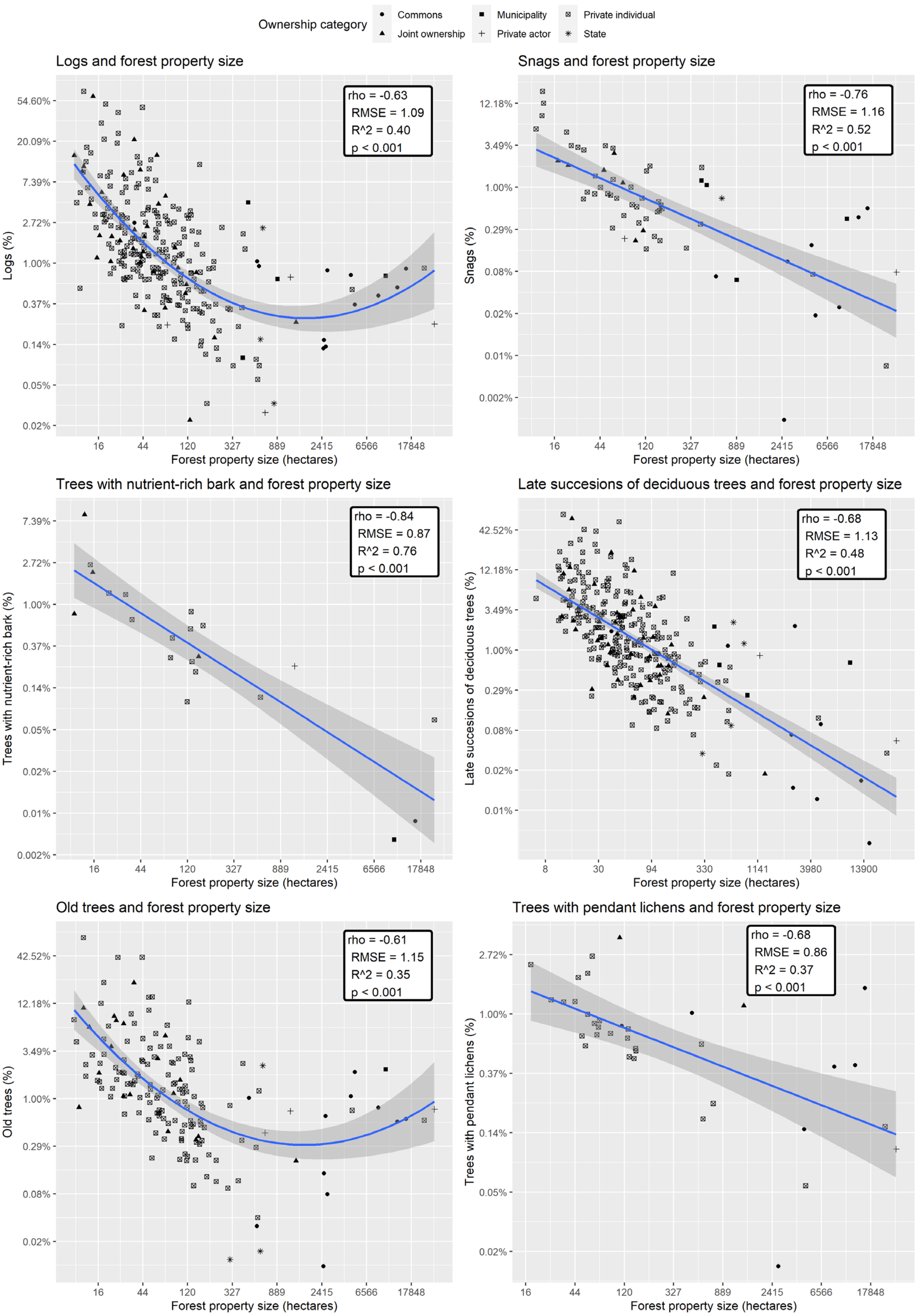


***Figure 7:** Quadratic and linear regressions of back-transformed (ln) area proportions (%) of individual biodiversity habitats, in relation to the size of forest properties in back-transformed (ln) hectares. Grouped by aggregated ownership categories. The values of Spearman's rho, RMSE, adjusted R^2, and the* p*-value have been annotated on each figure.*

Municipalities

At the landscape level, Gjerdrum and Jevnaker had strong trends for higher area proportions of near-natural and tree size diverse forests, whilst Ullensaker had significantly higher proportions of both (Table 12, Appendix F). Gran and Hurdal, however, had significantly lower proportions of both indicators, whilst Lunner only had a significantly lower proportion of near-natural forests. Nittedal, on the other hand, exhibited conflicting results, with a significantly lower proportion of tree size diverse forests, but a significantly higher proportion of near-natural forests. The last indicator at the landscape level, the tree height diverse forests, was significantly higher in Gran and Lunner, although they had significantly lower proportions of near-natural and/or tree size diverse forests. In contrast, Nittedal had a significantly lower proportion of tree height diverse forests, which corresponded to its results for tree size diverse forests but not for near-natural forests. The only other municipality with significantly lower proportions of tree height diverse forests was Oslo, which was the lowest proportion of all.

At the habitat level, Gran and Jevnaker had significantly lower area proportions when looking at all biodiversity habitats and structural biodiversity habitats. Ullensaker, on the other hand, had significantly higher proportions for both indicators. Nannestad and Hurdal both had significantly higher proportions of structural biodiversity habitats, whilst Gjerdrum had a strong trend for having lower proportions of all biodiversity habitats. When looking at the individual habitats, then Eidsvoll had significantly higher proportions of trees with pendant lichens and late successional deciduous trees, and a strong trend for higher proportions of snags. Hurdal also had significantly higher proportions of late successional deciduous trees and trees with nutrient-rich bark, as well as a strong trend for higher proportions of logs. Gjerdrum also had significantly higher proportions of trees with nutrient-rich bark, whilst Nannestad had significantly higher proportions of late successional deciduous trees, logs, and old trees. Ullensaker also had significant higher proportions of logs and late successional deciduous trees, but significantly lower proportions of snags. On the other hand, Gran had significantly lower proportions of both late successional deciduous trees and trees with nutrient rich bark, but significantly higher proportions of trees with pendant lichens. Jevnaker exhibited the most significant negative deviations regarding individual habitats, with lower proportions of snags, logs, and late successional deciduous trees. Lunner, however, only had significantly lower proportions of late successional deciduous trees.

At the species level, Oslo stood apart from the rest of the municipalities, spouting the highest Shannon index value at 4.51. Nittedal, Eidsvoll, Jevnaker, Gran exhibited the next cluster of values, ranging from 3.51 to 3.7. Lastly, Hurdal, Gjerdrum, Nannestad, Ullensaker and Lunner made up the lowest cluster, with values ranging from 2.55 to 3.05.

Overall, there were more observed differences between the municipalities, than between ownership categories. In addition, the municipality models had higher adjusted R^2 values than the ownership category models, but none of them exceeded a value of 0.41, and most were between 0.10 and 0.21.

Table 12: *Deviation in mean proportions of biodiversity indicators, in each municipality, from the grand mean. Strength of significance is indicated by number of asterisks, and strong trends are indicated with a period mark. Red (↓) indicates significant negative deviation, yellow (-) indicates no significant deviation, light green (↑.) indicates a strong trend for positive deviation, and green (↑) indicates significant positive deviation. Black (■) indicates that the biodiversity indicator was not present in the municipality, and higher values of Shannon indices indicate higher diversity of red-listed species. See Appendix F for more detailed statistical information.*

Hierarchical level		**Biodiversity indicator**	**Municipalities**									
			Eidsvoll	**Gjerdrum**	**Gran**	**Hurdal**	**Jevnaker**	**Lunner**	**Nannestad**	**Nittedal**	**Oslo**	**Ullensaker**
Landscape		**Near-natural forests**	-	↑.	↓***	↓***	↑.	↓**	-	↑**	-	↑***
		Tree size diverse forests	-	↑.	↓***	↓**	↑.	-	-	↓*	-	↑***
		Tree height diverse forests	↑*	↑.	↑**	-	-	↑***	↑***	↓***	↓***	-
Habitat	Merged	**All biodiversity habitats**	-	↑.	↓***	-	↓***	-	-	-	-	↑***
		Structural biodiversity habitats	-	-	↓***	↑*	↓***	-	↑*	-	-	↑***
	Individual	**Snags**	↑.	-	-	-	↓*	-	-	-	-	↓**
		Logs	-	↑*	-	↑.	↓***	-	↑**	-	-	↑***
		Trees with pendant lichens	↑**	-	↑**	-	-	-	-	-	-	-
		Late successional deciduous trees	↑**	-	↓**	↑*	↓***	↓*	↑*	-	-	↑***
		Trees with nutrient-rich bark	-	↑*	↓*	↑*	■	■	■	-	-	■
		Old trees	-	-	-	-	-	-	↑**	-	-	-
Species		**Shannon index**	3.59	2.55	3.7	2.37	3.62	3.05	2.76	3.51	4.51	2.91

Deviation from grand mean (%)

Distance to roads

The synthesised results, of areas where the direction of the significant deviations turned (Appendix G), showed that the highest area cover range, for all biodiversity indicators except for the Shannon indices, included the range between 200 and 400 meters from roads (Table 13).

At the landscape level, the highest area cover range was between 200 and 400 meters from roads for all the indicators. At the habitat level, the highest area cover ranges were also concentrated in the same range as the landscape indicators, but there were some differences when looking at the individual habitats. Snags, logs, and old trees had their highest area cover range between 200 and 600 meters from roads, whilst trees with pendant lichens had their highest between 200 and 800 meters. On the other hand, late successional deciduous trees had their highest area cover range from 0 to 400 meters from roads, whilst trees with nutrient rich bark had its highest from 0 up until 600 meters. At the species level, the highest Shannon index value was from 0 to 200 meters from roads, and this range also had the highest count of observations.

The adjusted R^2 values varied a lot for the same indicators, between the different distances from roads, ranging from negative values to values up to 0.61 for certain indicators (Appendix G). Larger buffer zones often had higher R^2 values, up until a turning point (Appendix G). This turn was probably due to more non-biodiversity indicator areas being included within larger buffer zones, thus reducing the explanatory power. In addition, the highest adjusted R^2 values for trees with nutrient-rich bark and trees with pendant lichens were also within their highest area cover ranges (Appendix G, Table 13).

Table 13: Synthesis table of highest area cover range of biodiversity indicators, in different distances from roads, derived from deviation coding (Appendix G). Dark green (🟩) indicates the highest area cover range of the different indicators. See Appendix G for detailed statistical information.

Hierarchical level		Biodiversity indicator	Distance to roads						
			0 - 200 meters	200 - 400 meters	400 - 600 meters	600 - 800 meters	800 - 1000 meters	> 1000 meters	
Landscape		Near-natural forests		🟩					Highest area cover range
		Tree size diverse forests		🟩					
		Tree height diverse forests		🟩					
Habitat	Merged	All biodiversity habitats		🟩					
		Structural biodiversity habitats		🟩					
	Individual	Snags		🟩	🟩				
		Logs		🟩	🟩				
		Trees with pendant lichens		🟩	🟩	🟩			
		Late succesional deciduous trees	🟩	🟩					
		Trees with nutrient-rich bark	🟩	🟩	🟩				
		Old trees		🟩	🟩				
Species		Shannon index	🟩						

Forest productivity

All biodiversity indicators across the hierarchical levels had their highest area proportions in high productive forests, except for trees with pendant lichens (Table 14, Appendix H). This indicator had its highest proportion in sites with low productivity, whilst all other indicators had their highest proportions in high productivity forests (Appendix H). The adjusted R^2 values were overall higher than for any of the other models, but none exceeded 0.53 and most were between 0.20 and 0.32.

Table 14: *Deviation in mean proportions of biodiversity indicators, in each forest productivity class, from the grand mean. Strength of significance is indicated by number of asterisks, and strong trends are indicated with a period mark. Red (↓) indicates significant negative deviation, orange (↓.) indicates a strong trend for negative deviation, yellow (-) indicates no significant deviation, light green (↑.) indicates a strong trend for positive deviation, and green (↑) indicates significant positive deviation. Higher values of Shannon indices indicate higher diversity of red-listed species. See Appendix H for more detailed statistical information.*

Hierarchical level		**Biodiversity indicator**	**Forest productivity**			
			Very low	**Low**	**Medium**	**High**
Landscape		**Near-natural forests**	↓***	↓***	-	↑***
		Tree size diverse forests	↓***	-	↑***	↑***
		Tree height diverse forests	↓***	↑*	↑***	↑***
Habitat	Merged	**All biodiversity habitats**	↓***	↓**	↑.	↑***
		Structural habitats	↓***	↓.	↑**	↑***
	Individual	**Snags**	↓***	-	↑*	↑***
		Logs	↓***	-	↑***	↑***
		Trees with pendant lichens	↓***	↑***	↑*	-
		Late succesional deciduous trees	↓*	↓***	-	↑***
		Trees with nutrient-rich bark	↓*	-	-	↑***
		Old trees	↓***	-	-	↑***
Species		**Shannon index**	3.73	3.6	4.15	4.50

Deviation from grand mean (%)

Social science section

Forest property sizes

Management goals

The proportion of respondents with non-economic primary management goals decreased as the forest property size increased (Figure 8). One exception from this trend was for forest owners with property sizes of 200 hectares or more. They had a slight increase in the proportion of non-economic primary goals, when compared to owners with 100-199.9 hectares of forest. However, there were very few owners with forest properties of 200 hectares or more in the study area, which created larger margins of error for this group relative to the other property sizes. Furthermore, this trend largely corresponded with the trends in the natural science section for all biodiversity habitats, structural biodiversity habitats, logs, and old trees (Figures 6 and 7). It was also discerned that the proportion size of economic goals decreased with the ranking level, having the largest proportion in the primary management goal and the smallest in the sixth-place management goal (Figure I1 in Appendix I).

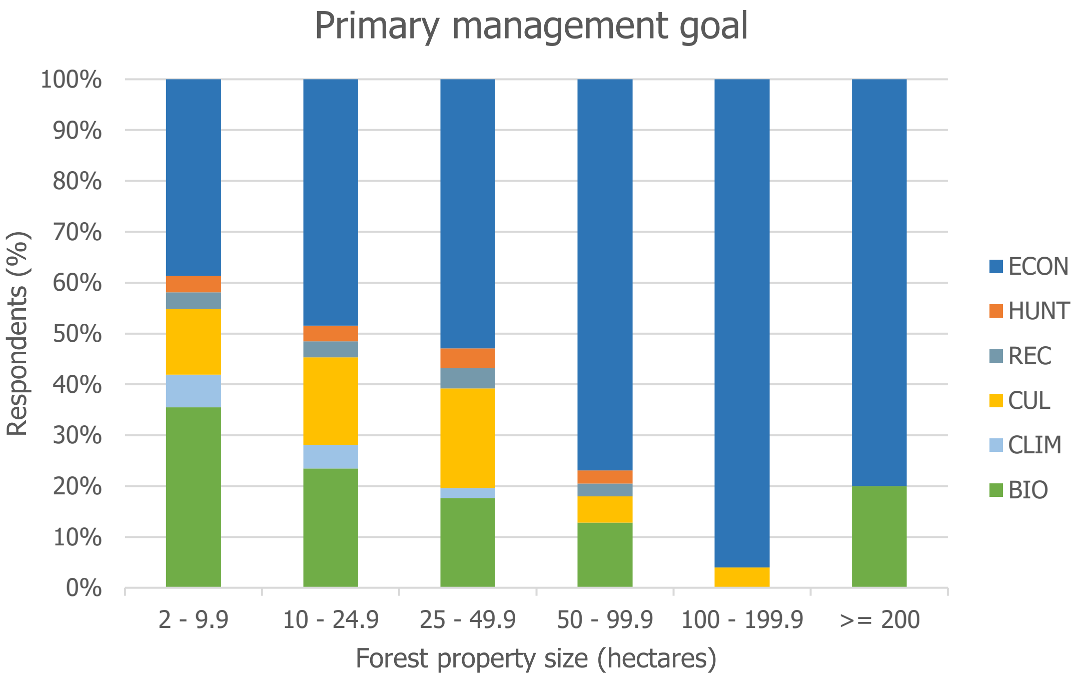


Figure 8: *Primary management goal of respondents (%), grouped by forest property sizes. The goals, in short, were economic (ECON), hunting (HUNT), recreation (REC), cultural (CUL), climate (CLIM), and biodiversity (BIO). See Table D1 in Appendix D for more details about the defined goals.*

Management practises

A similar pattern was also discovered, regarding reported felling methods (Figure 9). Selective felling decreased with increasing property sizes, up until properties of 200 hectares where they increased slightly. On the other hand, the proportion of clear cuttings increased with increasing property sizes up to properties of 200 hectares, and then decreased.

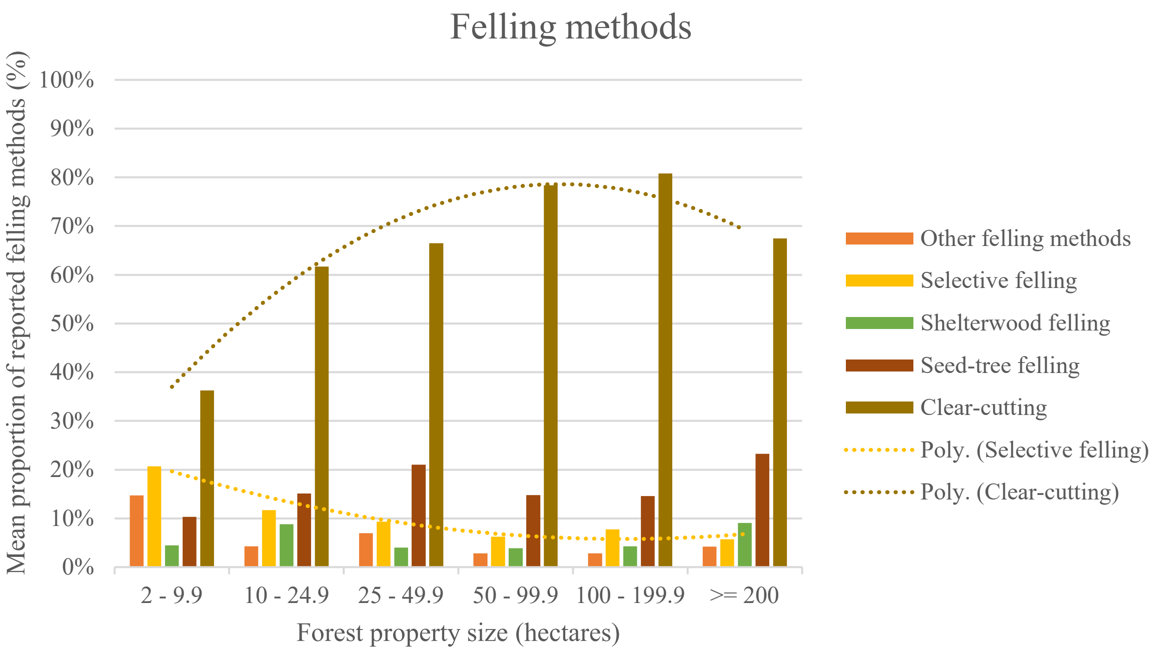


***Figure 9**: Mean proportions of reported felling methods used by the respondents (%), grouped by forest property sizes in hectares. Each felling method is visualised by bars, and the polynomial (quadratic) trend lines have been drawn for selective felling (dashed yellow) and clear cutting (dashed light brown).*

Comparing the forest property sizes to the grand mean, revealed significantly less clear-cutting in properties at 2-9.9 hectares, and significantly more in properties at 50-99.9 and 100-199.9 hectares (Table 15). In addition, there was significantly less seed tree felling in properties at 2-9.9 and 10-24.9 hectares, whilst there was a strong trend for more seed-tree felling in the largest properties at or above 200 hectares. On the other hand, no significant or strong deviations were observed regarding selective felling. Furthermore, both the untransformed and transformed data of shelterwood felling and other felling methods were too skewed to produce accurate deviation models.

***Table 15**: Deviation in mean proportions of felling methods, in each forest property size in hectares, from the grand mean. Strength of significance is indicated by number of asterisks, and strong trends are indicated with a period mark. Red (↓) indicates significant negative deviation, yellow (-) indicates no significant deviation, light green (↑.) indicates a strong trend for positive deviation, and green (↑) indicates significant positive deviation. White rows indicate that both the untransformed and transformed data were too skewed to produce accurate deviation models. See Table I1 in Appendix I for detailed statistical information.*

Felling method	**Forest property size (hectares)**					
	2-9.9	**10-24.9**	**25-49.9**	**50-99.9**	**100-199.9**	**>=200**
Clear cutting	↓***	-	-	↑**	↑**	-
Seed tree felling	↓*	↓*	-	-	-	↑.
Shelterwood felling						
Selective felling	-	-	-	-	-	-
Other felling methods						

Deviation from grand mean (%)

Municipalities

Management goals

No large differences were observed regarding the primary management goal of respondents, in the different municipalities. However, Lunner was the only municipality where more than 50% of the respondents had non-economic goals as their primary goal, closely followed by Gran, Jevnaker and Ullensaker, which were just below 50% (Figure 10). No more differences were discerned, regarding the other ranked management goals (Figure J1 in Appendix J).

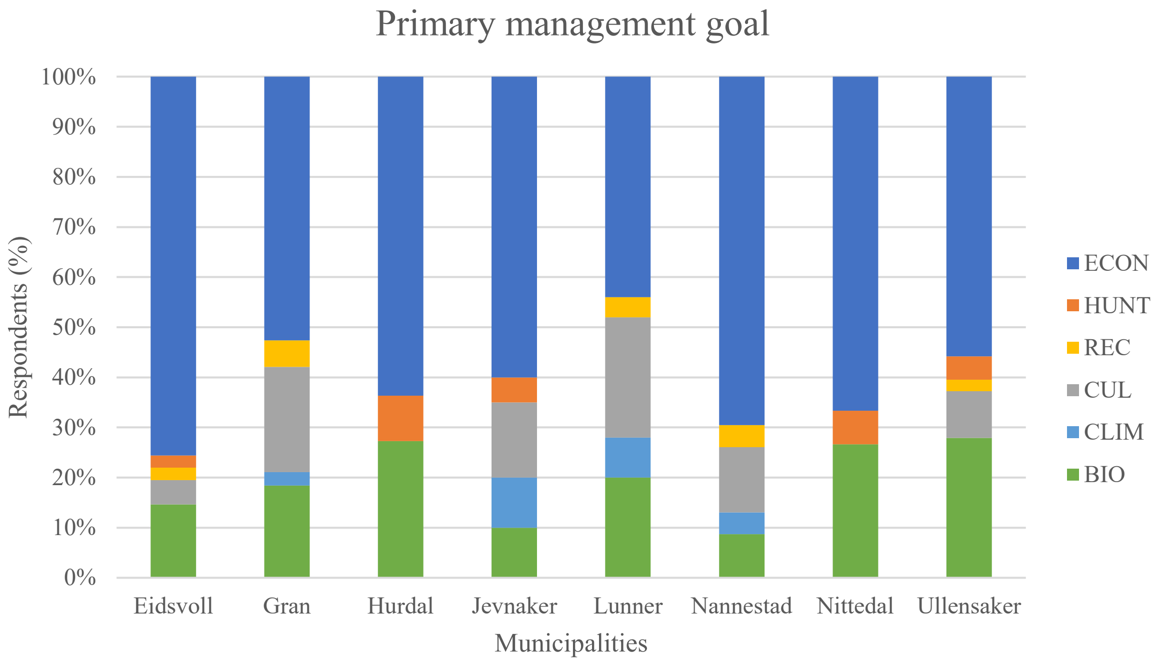


Figure 10*: Primary management goal of respondents (%), grouped by municipalities. The goals, in short, were economic (ECON), hunting (HUNT), recreation (REC), cultural (CUL), climate (CLIM), and biodiversity (BIO). See Table D1 in Appendix D for more details about the defined goals.*

Management practises

The felling method with the highest proportion in all municipalities was clear-cutting (Figure 11). However, Ullensaker was the only municipality with a reported clear-cutting proportion below 50%. In addition, Ullensaker had the highest proportion of selective felling, compared to the other municipalities.

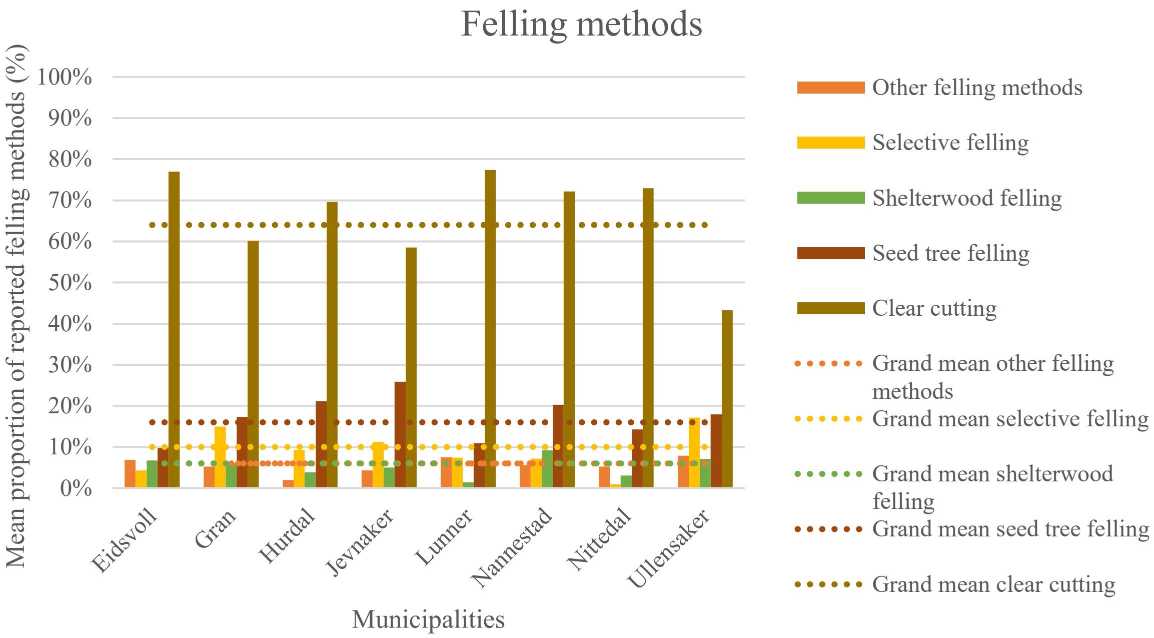


Figure 11*: Mean proportions of reported felling methods (%), grouped by municipalities. Each proportion is visualised by bars, and the grand mean of each felling method is drawn in dashed lines, with alike colors for the same felling methods.*

There was a significantly higher proportion of reported clear-cutting in Eidsvoll, and significantly lower in Ullensaker, when compared to the grand mean (Table 16). In addition, Lunner had a strong trend for higher proportions of clear-cutting. None of the municipalities deviated significantly or strongly regarding seed tree felling, and the data were too skewed to produce accurate deviation models of shelterwood felling and other felling methods. However, Nittedal had significantly lower proportions of selective felling, whilst there was a strong trend for higher proportions in Ullensaker.

Table 16*: Deviation in mean proportions of felling methods, in each municipality, from the grand mean. Strength of significance is indicated by number of asterisks, and strong trends are indicated with a period mark. Red (↓) indicates significant negative deviation, yellow (-) indicates no significant deviation, light green (↑.) indicates a strong trend for positive deviation, and green (↑) indicates significant positive deviation. White rows indicate that both the untransformed and transformed data were too skewed to produce accurate deviation models. See Table J1 in Appendix J for detailed statistical information.*

Felling method	**Municipalities**								
	Eidsvoll	**Gran**	**Hurdal**	**Jevnaker**	**Lunner**	**Nannestad**	**Nittedal**	**Ullensaker**	
Clear cutting	↑*	-	-	-	↑.	-	-	↓***	Deviation from grand mean (%)
Seed tree felling	-	-	-	-	-	-	-	-	
Shelterwood felling									
Selective felling	-	-	-	-	-	-	↓*	↑.	
Other felling methods									

Discussion

Ownership categories and forest property size

Public forests did not have overall higher biodiversity indicator values than privately owned forests, which stood in contrast to my hypothesis and the findings of Mölder et al. (2021). However, it is important to point out that the spatial level chosen for biodiversity indicators can affect the results. In my thesis this can be illustrated by state forests. State forests did not have more, or less, areas with high biodiversity at the landscape level. However, they did have significantly less areas of structural biodiversity habitats at the habitat level, whilst on the other hand having high Shannon index values at the species level. Hence, the spatial level chosen can influence findings and conclusions substantially.

I therefore advocate for using a multi-level approach to biodiversity indicators, as done in my thesis, to account for potential differences in results between indicators at different spatial levels. Using several indicators related to biodiversity at the landscape level (Mienna et al., 2019), habitat level (Gjerde et al., 2007; Hekkala et al., 2023; Sætersdal et al., 2016), and species level (Fedor & Zvaríková, 2019; Hekkala et al., 2023), also makes it possible to observe differences within each spatial level as well as between them. I used several indicators at all levels, except for the species level. This level only had Shannon indices to give an estimate of the species diversity in my study. Hence, further research should also include more indicators of species diversity, to gain information about potential differences in biodiversity indicators at the species level.

My results for ownership categories could potentially be explained by forest property size. Some ownership categories predominantly had small forest properties, like joint ownerships and private individuals, or large properties, like parish commons. I found indications of slightly higher area proportions of near-natural and tree-size diverse forests in small forest properties. These indications, however, were very weak, and the models were too poor to give credible estimates. Thus, I did not find support for my hypothesis about there being higher values of the landscape indicators in smaller forest properties.

However, forest property size explained the distribution of biodiversity habitats better than ownership categories in my study area, in line with my hypothesis. Furthermore, I found higher proportions of biodiversity habitats on small forest properties, which was in line with my hypothesis and the findings of Mölder et al. (2021). Mölder et al. (2021) found that there were more conservation values on the properties of small-scale private forest owners than large-scale private forest owners. These findings were linked by Mölder et al. (2021) to differences in forest management. Large-scale private forest owners had more intense management regimes, and a higher focus on the economic viability of the management, than small-scale private forest owners (Mölder et al., 2021). This corresponds with my results, where private individuals with large forest properties more often had economic profit as their primary goal, and to a larger degree used clear-cutting in their forestry activities. Thus, differences in forest management goals and practises could potentially explain the results of biodiversity indicators across forest property sizes, in line with my hypothesis.

However, both trends in biodiversity habitats, and forest management goals and practises, showed a slight deviation from the main trends for the largest forest owners in my study. These deviations, however, were minor in the actual percent differences of the biodiversity indicators. In addition, there were very few owners in the largest property size category, which created larger margins of error. Thus, these deviations represented minor differences, with larger margins of error, and are therefore viewed as negligible compared to the main trends.

On another note, Mölder et al. (2021) reviewed studies from different countries, with different types of forests, forestry history, and species. Therefore, their results may not be directly applicable to my thesis or to Norwegian forests, due to context dependent differences like environmental conditions. However, studies from countries within the boreal zone may be more applicable to Norway, due to similarities in the environmental conditions. The study performed on biodiversity indicators between ownership categories by Holmgren et al. (2010) in Sweden is probably the most directly relatable to Norway, out of the studies reviewed by Mölder et al. (2021). This is due to close geographical proximity, and similarities in the proportions of private and public forest owners (Aggarwal et al., 2020), between Sweden and Norway.

Holmgren et al. (2010) found differences in biodiversity indicators between state, private, and common forests, within some of their study areas, where commons had higher levels of deadwood, forests with a large deciduous element, and forests older than 140 years. The differences were, however, not consistent across the study areas, where the patterns were opposite in some areas and neutral in others (Holmgren et al., 2010). In addition, commons had significantly lower proportions of forests with large deciduous elements older than 80 years, but they barely passed the significance level (Holmgren et al., 2010). Thus, Holmgren et al. (2010) did not observe any overall significant differences in biodiversity indicators between the ownership categories.

My results showed significantly lower area proportions of late stage deciduous forest habitats in parish commons, which can be viewed in concurrence with the results of Holmgren et al. (2010). The lower proportions may be related to elevation above sea level, seeing that parish commons were mostly located at relatively high elevations in my study area (Figure 3), and late-stage deciduous forest habitats may occur less frequently at high elevations (Sætersdal et al., 2016). Parish commons did not exhibit any higher values of deadwood habitats, old trees, or near-natural forests in my results, where the latter two were the closest indicators to old forest in my thesis. Rather, I found that parish commons had less near-natural forests, and a neutral result regarding old trees and deadwood in the form of both snags and logs. In addition, commons forests did not have overall higher biodiversity than privately owned forests, in contrast to my hypothesis.

Thus, my findings differ from the overall patterns observed by Mölder et al. (2021) and Holmgren et al. (2010), except for the observation of forest property size as an underlying influencer on the biodiversity indicators. In addition, elevation may also have acted as an underlying influencer, and should be accounted for in future research.

Parish commons, joint ownerships, private individuals, and municipalities had the highest diversity of red-listed species. However, joint ownerships and private individuals had the highest scores for most indicators, but still ranked almost the same as municipal and parish common forests regarding species diversity. This was despite the latter two having some of the lowest overall landscape and habitat indicator values. Potential explanations are differences in registration efforts, or that the landscape and habitat indicators used in my study were not good indicators for some of the species. Further research is needed to explain these diverging results, and investigate if there are other underlying factors than forest property size influencing the observed differences in biodiversity indicators between the ownership categories.

Municipalities

The analyses of municipalities showed that they explained the distribution of biodiversity indicators better than ownership, and that Ullensaker had the overall highest levels of biodiversity indicators at the landscape and habitat level. This supported my hypothesis that there would be differences between the municipalities, but not that ownership would explain the distributions better. The results for Ullensaker, however, may be explained by the municipality's overall high forest productivity (Figure 5, Table A4 in Appendix A). High productive forests have been linked to both higher species richness (Hekkala et al., 2023) and higher amounts of the biodiversity habitats included in my thesis (Sætersdal et al., 2016). Ullensaker had the relatively highest proportion of high productive forests in my study area (Figure 5, Table A4 in Appendix A), which may explain why there were higher levels of the biodiversity indicators at the landscape and habitat level in this municipality. However, Ullensaker did not have the highest Shannon index value for species diversity. This may again be because of differences in registration efforts between the municipalities, or mismatches between the habitat and landscape indicators included in my thesis, and the habitat and substrate requirements of the red-listed species found within the municipality. In addition, there might be many species related to the high values of habitat and landscape indicators, but this might be offset by low species evenness, leading to lower Shannon index values.

Ullensaker, however, also differentiated itself regarding felling methods used in the municipality. Forest owners in Ullensaker reported that they used significantly less clear-cutting and had a strong trend for more selective felling. Granhus et al. (2024a) found that using selective felling instead of clear-cutting may have a positive effect on ground vegetation, bryophytes, mycorrhiza fungi, and species that prefer more shaded or mesic environments like some epiphytic lichens (Storaunet et al., 2024). However, an increase of selective felling may negatively impact other species (Storaunet et al., 2024), and will have no or a limited effect on the amount of biodiversity habitats like logs, snags, late successional deciduous forests, and old trees (Jansson et al., 2024b). On the other hand, continuous-cover forestry, instead of clear-cutting, may result in higher proportions of forests in a two-layered stage (shelterwood felling) or multi-layered stage (selective felling) (Jansson et al., 2024a). Further research is nevertheless needed on the impacts of continuous cover forestry (Granhus et al., 2024b). Further research is also needed to see if differences in forest productivity and felling methods are the sole underlying variables explaining my results for municipalities, or if other variables such as elevation (Sætersdal et al., 2016), or local forestry policies also have a significant impact.

Distance to roads

Overall, distance to roads did not seem to explain the distribution of the different biodiversity indicators very well. However, some ranges explained more of the distribution of certain biodiversity indicators than ownership categories, which partially concurred with my hypothesis. On the other hand, the highest area cover ranges of the biodiversity indicators were found relatively close to roads, thus weakening my hypothesis about there being lower values closer to roads. The two habitat indicators with the highest values closest to roads were trees with nutrient-rich bark and late successional deciduous trees, which corresponded with the findings of Sætersdal et al. (2016). They also found that logs, old trees, and trees with pendant lichens were overrepresented further away from roads (Sætersdal et al., 2016). Trees with pendant lichens had the furthest area cover range out of all the indicators in my study, ending at 800 meters from roads. However, this range still had a starting point at 200 meters from roads. Old trees and logs also had the same starting point, but with even shorter area cover ranges from roads, ending at 600 meters.

Thus, the clearer differences observed by Sætersdal et al. (2016) in distance from roads, regarding old trees, logs, and trees with pendant lichens versus trees with nutrient-rich bark and late successional deciduous trees, were not as apparent in my study. The higher amount of late successional deciduous trees and trees with nutrient-rich bark close to roads may be explained by previous human activities, such as grazing, firewood harvest, and summer farming, leading to establishment of deciduous forests, as suggested by Sætersdal et al. (2016). These factors may explain the area cover ranges of these habitat indicators in my study, but it is uncertain whether they could explain the ranges of the landscape indicators in my study.

Another element of uncertainty, regarding the landscape indicators, are model uncertainties in the FEB data. The FEB data by Ørka et al. (2022) are based on lidar, which gives high accuracy data on forest structure. Using these data to create estimates of forest naturalness, tree size diversity, and tree height diversity, however, involves creating predictions with error margins attached to them. Thus, these predictions should be used with some caution, and not taken for granted to be 100% accurate representations of the real world. Therefore, these uncertainties should be kept in mind regarding my analyses of distance to roads, and other explanatory variables.

Yet another element of uncertainty is registration efforts, regarding biodiversity habitats and red-listed species. For instance, not all forests in my study area have been inventoried, and areas closer to roads may have been easier to gain access to for registrations. Differing registration efforts of the biodiversity indicators may apply for both distance to roads, and the other explanatory variables in my study. Therefore, further research is needed, with the bias of registration efforts accounted for in the analyses. This could, for example, be done by delimiting the dataset to the range of a coverage map, consisting of areas known to have been inspected for the relevant biodiversity indicators.

Forest productivity

Forest productivity had a clear positive relationship with the values of almost all indicators (Table 14), and explained the distributions better than ownership categories. This corresponds with my hypothesis and previous ecological research (Hekkala et al., 2023; Sætersdal et al., 2016). Almost all indicators had higher values in higher forest productivity classes, as was also found by Sætersdal et al. (2016). However, Sætersdal et al. (2016) observed an exception from this trend regarding old trees, which had higher abundance in low productivity forests. In addition, trees with pendant lichens had mostly no significant difference between forest productivity classes, and one case of higher abundance in low productivity forests (Sætersdal et al., 2016). My raw data on old trees (Table 4) aligned with the findings of Sætersdal et al. (2016). However, I found that old trees had significantly higher area proportions in high productivity forests, within a forest owner's property, and that there were significantly higher proportions of trees with pendant lichens in low productivity forests (Table 8).

The differences between my results and the results found by Sætersdal et al. (2016), regarding old trees, may be because I analysed for differences using each forest owner's property as sample units, or due to differences in forestry history. Sætersdal et al. (2016) suggested that more forestry activities in high productivity forests may have led to less old trees in those areas. Thus, there may not have been a higher intensity of forestry activities in the high productive forests in my study area, compared to the study areas looked at by Sætersdal et al. (2016). This could explain why there were higher levels of old trees in the high productive forests, but further research should investigate if any other factors, for example elevation and slope, have an interactive effect on these results.

Trees with pendant lichens having higher area proportions in low productive forests, however, is largely in agreement with the trend observed by Sætersdal et al. (2016). On the other hand, the relationship between pendant lichens and forest productivity may be largely dependent on the species of lichen (Gjerde et al., 2005). Some lichen species may prefer high or low productive forests, based on their habitat and substrate requirements. The groups of pendant lichens characteristic to the biodiversity habitat included in my thesis, and by Sætersdal et al. (2016), however, are prone to appear in old-growth forests in nutrient-poor environments (Baumann et al., 2002b). Thus, it makes ecological sense that trees with pendant lichens had their highest abundance in low productivity forests, whilst the other indicators had their highest values in high productivity forests.

Conclusion

I found overall differences in biodiversity indicators between ownership categories in my study area. Public forest owners and common forests did not have overall higher biodiversity than private actors. However, private individuals with large forest properties had in general lower area proportions of biodiversity habitats, than small-scale private individual forest owners. This correlation may be explained by large-scale private individual forest owners using more clear-cutting and focusing more on economic profit than small-scale individual forest owners. Potential negative effects of clear-cutting were also indicated, regarding differences between municipalities, where Ullensaker had the overall highest values of the biodiversity indicators, and the respondents reported less clear-cutting. However, further research is needed to investigate the impacts of clear-cutting versus continuous-cover forestry in relation to biodiversity. In addition, forest productivity had the clearest trend, where the highest values of most biodiversity indicators correlated with increasing productivity. To conclude, overall differences in biodiversity indicators were observed within all the explanatory variables. However, differences in forest productivity and correlations with forest property sizes seemed to explain the distribution of indicators better than ownership categories, distance to roads, and municipalities. Furthermore, forest property sizes seemed also to have influenced the primary management goal and practises of the forest owners. Further research is needed to see how forest property sizes influence forest owners, and whether there are any other interactions influencing the explanatory variables looked at in this thesis.

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Appendix A – Explanatory variables (natural science section)

Table A1: *Area of forest in hectares (ha) within different AR5 forest productivity classes, excluding areas with the "not relevant" class due to these areas supposedly not having a forest land cover (Ahlstrøm et al., 2019)*

Forest productivity	Sum (ha)
Very low	9024
Low	45469
Medium	80950
High	75960
Very high	3

Table A2: *Area of forest within all and individual ownership categories, in hectares (ha).*

Ownership category	Owner count	Min (ha)	Max (ha)	Mean (ha)	Sum (ha)
All categories	1518	2.9	29917.2	139.5	211808.6
Private individual	1234	4.7	23891.7	76.1	93951.6
Parish commons	12	36.4	15865.7	4665.1	55980.8
General partnership	3	28.3	29917.2	10010.6	30031.8
Municipality	9	14.6	10070.4	1346.6	12119.1
Joint ownership	225	2.9	1353.5	50.7	11399.0
State commons	1	2734.7	2734.7	2734.7	2734.7
State	7	21.0	826.1	373.9	2617.0
Fund	1	1195.9	1195.9	1195.9	1196.0
Joint stock company	19	9.9	677.6	56.7	1078.0
Parish-state commons	1	566.2	566.2	566.2	566.2
Cooperative	2	8.6	73.0	40.8	81.5
Association	2	9.8	10.4	10.1	20.2
Church	1	16.9	16.9	16.9	16.9
Foundation	1	15.9	15.9	15.9	15.9

Table A3: *Descriptive information about the area of forest owned by each forest owner between municipalities, in hectares (ha). Sorted from highest to lowest sum.*

Municipality	Owner count	Min (ha)	Max (ha)	Mean (ha)	Sum (ha)
Gran	429	5.8	10096.2	117.0	50198.1
Eidsvoll	426	6.5	5026.8	62.8	26741.9
Oslo	193	0.3	6102.1	134.1	25881.0
Nannestad	218	4.7	2704.1	105.3	22952.3
Hurdal	128	9.6	4848.6	177.1	22663.3
Lunner	162	8.4	4431.0	127.6	20662.9
Jevnaker	119	9.1	2572.5	134.2	15968.8
Nittedal	163	6.2	1797.5	80.5	13125.4
Ullensaker	287	8.3	480.4	33.3	9566.2
Gjerdrum	57	9.2	2734.7	71.0	4048.9

***Table A4**: Descriptive information about the forest area grouped by forest productivity classes, in each municipality in hectares (ha), excluding areas with the "not relevant" productivity class, due to these areas supposedly not having a forest land cover (Ahlstrøm et al., 2019).*

Forest productivity	Municipality	Mean (ha)	Total area (ha)	Municipality's forest area (ha)	Proportion (%)
Very low	Eidsvoll	3.06	1116.77	26718.13	4.18
Low	Eidsvoll	21.22	7172.57	26718.13	26.85
Medium	Eidsvoll	25.77	9765.43	26718.13	36.55
High	Eidsvoll	21.08	8663.36	26718.13	32.43
Very low	Gjerdrum	3.83	145.45	4037.29	3.60
Low	Gjerdrum	30.79	831.20	4037.29	20.59
Medium	Gjerdrum	51.02	1734.61	4037.29	42.96
High	Gjerdrum	23.68	1326.03	4037.29	32.84
Very low	Gran	7.47	2697.98	50118.10	5.38
Low	Gran	42.10	11999.74	50118.10	23.94
Medium	Gran	54.96	20885.45	50118.10	41.67
High	Gran	36.42	14533.18	50118.10	29.00
Very high	Gran	1.75	1.75	50118.10	0.003
Very low	Hurdal	7.15	650.63	22633.00	2.87
Low	Hurdal	47.71	3530.57	22633.00	15.60
Medium	Hurdal	70.66	8125.89	22633.00	35.90
High	Hurdal	80.67	10325.91	22633.00	45.62
Very low	Jevnaker	6.38	676.32	15935.07	4.24
Low	Jevnaker	60.66	4670.54	15935.07	29.31
Medium	Jevnaker	51.52	5357.97	15935.07	33.62
High	Jevnaker	46.29	5230.24	15935.07	32.82
Very low	Lunner	6.86	1015.51	20602.54	4.93
Low	Lunner	34.14	4130.94	20602.54	20.05
Medium	Lunner	63.58	9918.33	20602.54	48.14
High	Lunner	35.05	5537.76	20602.54	26.88
Very low	Nannestad	5.03	810.38	22895.22	3.54
Low	Nannestad	35.99	4499.19	22895.22	19.65
Medium	Nannestad	51.68	8578.46	22895.22	37.47
High	Nannestad	43.10	9007.19	22895.22	39.34
Very low	Nittedal	2.73	354.89	13087.85	2.71
Low	Nittedal	23.21	2761.80	13087.85	21.10
Medium	Nittedal	31.31	4758.79	13087.85	36.36
High	Nittedal	32.58	5212.37	13087.85	39.83
Very low	Oslo	8.07	1372.05	25789.18	5.32
Low	Oslo	32.02	5379.41	25789.18	20.86
Medium	Oslo	54.04	10050.55	25789.18	38.97
High	Oslo	48.06	8986.29	25789.18	34.85
Very high	Oslo	0.44	0.88	25789.18	0.003
Very low	Ullensaker	1.15	186.64	9537.40	1.96
Low	Ullensaker	5.02	437.17	9537.40	4.58
Medium	Ullensaker	11.13	1781.16	9537.40	18.68
High	Ullensaker	24.94	7132.43	9537.40	74.78

***Table A5**: Descriptive information about the area of forest owned by each forest owner, between different distances to roads, in hectares (ha).*

Buffer zones	Occurence	Owner count	Min (ha)	Max (ha)	Mean (ha)	Sum (ha)
0-200 m	Beyond	1484	72	17665.9	82.9	123033.1
	Within	1491	4	12251.4	59.5	88775.7
0-400 m	Beyond	1112	6	9534.8	57.4	63854.8
	Within	1512	263	20382.4	97.9	147954.0
0-600 m	Beyond	655	4	4801.2	45.9	30043.2
	Within	1518	340	25116.0	119.7	181765.6
0-800 m	Beyond	335	41	2191.5	38.3	12814.1
	Within	1518	29379	27725.8	131.1	198994.7
0-1000 m	Beyond	145	5	820.3	34.4	4982.5
	Within	1518	29379	29097.0	136.3	206826.3

***Table A6**: Descriptive information about the area of forest owned by each forest owner, between different forest productivity classes, in hectares (ha).*

Forest productivity	Owner count	Min (ha)	Max (ha)	Mean (ha)	Sum (ha)
Very Low	1241	<1	1331.2	7.3	9026.6
Low	996	<1	5032.2	45.6	45413.1
Medium	1276	<1	11059.5	63.5	80956.6
High	1481	<1	12656.4	51.3	75954.8
Very High	2	<1	1.8	1.3	2.6

Appendix B – Original questionnaire in Norwegian

Spørreundersøkelse om eierforhold og biomangfold i skog

Spørreundersøkelse til masterprosjekt om eierforhold og biomangfold i skog

Bakgrunnsinformasjon om prosjektet

Mitt navn er Kim André Nielsen, og jeg tar en mastergrad i naturforvaltning på Norges miljø og biovitenskapelige universitet (NMBU). Dette spørreskjemaet er del av kunnskapsinnsamlingen til masterprosjektet mitt, som handler om hvorvidt det er noen forskjeller eller sammenhenger i biomangfold mellom ulike eierforhold i skog. Skogeiendommene i prosjektet har blitt avgrenset til eiendommer på over 100 dekar, bestående av skog, myr og/eller ferskvann etter NIBIOs AR5-ressurskart, i følgende kommuner: Oslo, Nittedal, Jevnaker, Gran, Lunner, Gjerdrum, Nannestad, Hurdal, Eidsvoll, og Ullensaker.

I prosjektet vil jeg i hovedsak se på forskjeller og sammenhenger mellom eierformer (f.eks. skog eid av en kommune, privatperson, eller bygdealmenning), men også mellom individuelle eiere, og de som har eid skog i lengre og kortere tid. Dette er for å se om det også er noen forskjeller eller sammenhenger mellom individuelle eiere og biomangfold i skogene deres, for å se om biomangfold nivåene kan forklares av eierformen som sådan eller mer på grunn av individuelle forskjeller.

I tillegg vil jeg se om andre faktorer, som bonitet og nærhet til infrastruktur, også er med på å forklare eventuelle forskjeller eller likheter i biomangfold. Informasjon om biomangfold består av kartlegginger med flybårne laserskanninger, artsregistreringer fra Artsdatabanken, og MiS- kartlegginger.

Målet med oppgaven er altså å finne ut om det er noen forskjeller eller sammenhenger i biomangfold mellom ulike eierforhold i skog, og om disse forklares best av eierforholdene eller av andre årsaker. For eksempel, dersom det er mer biomangfold i en skog eid av privatpersoner eller skog eid av en kommune, om disse forskjellene forklares best av eierforholdet eller av andre årsaker.

Formål med spørreskjema

Ønsket med dette spørreskjemaet er å få dypere innsikt i eierforholdene i studieområdet, samt om hvordan eierne drifter skogene sine. Formålet med å innhente denne informasjonen er for å se om det er noen forskjeller eller sammenhenger mellom eierforhold og skogforvaltning, som også kan være med på å forklare eventuelle likheter, sammenhenger eller ulikheter i biomangfold.

Utfylling og bruk av informasjon fra spørreskjema

Utfylling av dette skjemaet er fullstendig anonymt, og ingen personopplysninger vil bli lagret eller behandlet. Behandlingen av oppgitt informasjon vil være i tråd med forskningsetiske retningslinjer, og informasjonen vil bli brukt i tråd med formålet beskrevet ovenfor.

Masteroppgaven vil bli skrevet på engelsk, men spørreundersøkelsen utføres på norsk. Spørsmålene vil derfor bli oversatt og referert til på engelsk i oppgaven. Det vil derimot være både engelske og norske ubesvarte versjoner av spørsmålene tilgjengelig som vedlegg i oppgaven, for å kunne forsikre om likhet i ordlyd mellom den originale og oversatte versjonen.

Det er mulig å reservere seg gjennom hele prosjektperioden, fram til mai 2024, slik at informasjonen du/dere har oppgitt blir fjernet fra oppgaven. På grunn av fullstendig anonymitet, så betyr det at du/dere må oppgi nok informasjon til at besvarelsen kan identifiseres blant de resterende for å få den fjernet.

Spørreskjemaet er åpent for besvarelser fra og med når du/dere har mottatt lenken, til og med 1. november. Da stenges spørreskjemaet, og det vil ikke være mulig å sende inn besvarelser lenger. Hvis du/dere har noen videre spørsmål om prosjektet, så kan du/dere sende en epost til kim.andre.anstensen.nielsen@nmbu.no

Samtykker du/dere til at informasjonen som oppgis brukes i prosjektet?

Ja/Nei

I hvilken av følgende kommuner eier du/dere mest skog?

Nannestad
Ullensaker
Oslo
Nittedal
Gjerdrum
Jevnaker
Gran
Lunner
Eidsvoll
Hurdal

Eier du/dere skog i mer enn én av de nevnte kommunene i forrige spørsmål?

Ja/Nei/Vet ikke

Omtrent hvor mange år har du/dere eid skog?

Hvordan ervervet du/dere eiendommene?

Hvis dere har ervervet skog på flere måter, så velg det alternativet som representerer måten mesteparten av skogarealet har blitt ervervet på.

Gave

Kjøp

Arv

På annet vis

Vet ikke

Hvis skogen(e) har gått i arv, hvor mange år har de vært eid av familien?

Er skogen din/deres del av et kombinert gårdsbruk med innmark og skog?
Ja/Nei/Vet ikke

Omtrent hvor stor er hele eiendomsmassen i dekar? (inkl. innmark + utmark)
Om eiendommens bruttoareal (innmark+utmark) har blitt mindre gjennom at skog har blitt vernet, så vil vi at du/dere oppgir arealet før dette skjedde.

Omtrent hvor mange dekar er det produktive skogarealet, i henhold til skogbruksplan?
Med produktiv skog menes skog som i gjennomsnitt for en normal omløpsperiode kan produsere minst 0,1 kubikkmeter trevirke per dekar og år.

Omtrent hvor mange dekar uproduktiv skog eier du/dere?
Med uproduktiv skog menes skog som i gjennomsnitt for en normal omløpsperiode ikke kan produsere minst 0,1 kubikkmeter trevirke per dekar og år.

Hvilken gruppe av skogeiere er du del av eller representerer?

Eier du skog alene som enkeltperson, privat eier utenom enkeltperson (f.eks. fond, selskap, eller annen privat institusjon), representerer du en statlig aktør (eks. statsalmenning, statseid selskap eller organ) eller en kommune, representerer du en bygdealmenning, eller er du del av et sameie? Velg det alternativet hvor du/dere eier mest skog, eksempelvis om du eier mest skog som enkeltperson, men også litt i et sameie, så krysser du av på enkeltperson.

Enkeltperson

Privat eier utenom enkeltperson

Kommunal

Statlig eie

Bygdealmenning

Sameie

Annet

Eier du/dere skog i en av følgende former for felles eie?

Bygdealmenning

Ja/Nei/Vet ikke

Statsalmenning

Ja/Nei/Vet ikke

Sameie

Ja/Nei/Vet ikke

Aksjeselskap

Ja/Nei/Vet ikke

Er du/dere medlem av et skogeierlag?

Ja/Nei/Vet ikke

Hvis du/dere er eier eller medeier i en skog/skogeierlag, i hvilken grad mener dere at dere kan påvirke forvaltningen (avvirkning, skjøtsel, miljøhensyn, osv.) av skogen?

Oppgi i hvor stor grad du/dere synes at dere personlig kan påvirke skogforvaltningen som skogeier, i ulike former for selvstendig eierskap, medeierskap og felles forvaltning. Dersom du/dere ikke eier skog i en av eierformene, eller ikke ønsker å svare, så kryss av for "ikke relevant/ønsker ikke å svare".

Enkeltperson

Svært liten grad
Liten grad
Middels grad
Stor grad
Svært stor grad
Ikke relevant/ønsker ikke å svare

Fond

Svært liten grad
Liten grad
Middels grad
Stor grad
Svært stor grad
Ikke relevant/ønsker ikke å svare

Skogeierlag

Svært liten grad

Liten grad

Middels grad

Stor grad

Svært stor grad

Ikke relevant/ønsker ikke å svare

Ansvarlig selskap

Svært liten grad

Liten grad

Middels grad

Stor grad

Svært stor grad

Ikke relevant/ønsker ikke å svare

Aksjeselskap

Svært liten grad

Liten grad

Middels grad

Stor grad

Svært stor grad

Ikke relevant/ønsker ikke å svare

Sameie

Svært liten grad

Liten grad

Middels grad

Stor grad

Svært stor grad

Ikke relevant/ønsker ikke å svare

Bygdealmenning

Svært liten grad

Liten grad

Middels grad

Stor grad

Svært stor grad

Ikke relevant/ønsker ikke å svare

<u>*Statsalmenning*</u>

Svært liten grad

Liten grad

Middels grad

Stor grad

Svært stor grad

Ikke relevant/ønsker ikke å svare

<u>*Kommune*</u>

Svært liten grad

Liten grad

Middels grad

Stor grad

Svært stor grad

Ikke relevant/ønsker ikke å svare

<u>*Annet statlig eierskap (skog eid av statseide selskaper, organer, etater, osv.)*</u>

Svært liten grad

Liten grad

Middels grad

Stor grad

Svært stor grad

Ikke relevant/ønsker ikke å svare

<u>*Annet privat eierskap (andre former for privat eie enn de nevnt ovenfor, slik som foreninger og samvirker)*</u>

Svært liten grad

Liten grad

Middels grad

Stor grad

Svært stor grad

Ikke relevant/ønsker ikke å svare

I hvor stor grad vil du angi at du/dere ønsker å være involvert i skogforvaltningen?

Svært liten grad

Liten grad

Middels grad

Stor grad

Svært stor grad

Vet ikke/ønsker ikke å oppgi

Omtrent hvor stor del av arbeidsinnsatsen med avvirkning og skogskjøtsel utfører du/dere som eier eller nærmeste?

På en prosentskala fra 0% til 100%, oppgi omtrent hvor mye av arbeidet du/dere selv utfører som eier eller nærmeste

Hva gjør du/dere selv i skogforvaltningen?

Omtrent hvor stor del av arbeidsinnsatsen med avvirkning og skogskjøtsel utfører andre aktører (skogeierlag, entreprenører, osv.) på din/deres eiendom?

På en prosentskala fra 0% til 100%, oppgi omtrent hvor mye av arbeidet andre aktører utfører på din/deres eiendom.

Hva slags andre aktører er inkludert i skogforvaltningen?

Oppgi hva slags andre aktører som er involvert i skogforvaltningen deres, for eksempel hva slags aktører som er involvert i hogst og andre tiltak i skogene. Det er ikke ønsket at det oppgis konkrete navn på noen aktører, men heller hva slags aktør det er. For eksempel om et skogeierlag tar seg av hogst, så er det nok å skrive at et skogeierlag er involvert, uten å oppgi navn på laget.

Hvilke oppgaver utfører andre aktører i forvaltningen av skogene dine/deres, og hva slags aktører gjør hva?

Her ønsker vi at du/dere beskriver hva andre aktører gjør i forvaltningen av skogene, samt hva de ulike aktørene gjør. Eksempelvis om et skogeierlag (eller annen aktør) utfører hogst, så skrives det ned her.

Har noen av disse hogstmetodene blitt benyttet i dine/deres skoger de siste 30 årene?

Kryss av om du/dere har tatt i bruk noen av disse hogstmetodene de siste 30 årene, samt om det tas i bruk andre metoder enn de nevnte. Dersom ingen hogst har blitt utført i denne perioden, så kryss av ja for dette og nei for alle de andre alternativene.

Flatehogst

Ja/Nei/Vet ikke

Frøtrestillingshogst

Ja/Nei/Vet ikke

Skjermstillingshogst
Ja/Nei/Vet ikke

Bledningshogst/selektiv hogst
Ja/Nei/Vet ikke

Andre hogstmetoder
Ja/Nei/Vet ikke

I hvor stor grad benyttes flatehogst i dine/deres skoger?
Dersom all hogst utføres som flatehogst, så oppgi 100%. Hvis ingen flatehogst utføres i dine/deres skoger, så oppgi 0%. Dersom flere hogstmetoder tas i bruk, så oppgi omtrent hvor stor prosentandel flatehogst står for av hogstmetodene som blir brukt.

I hvor stor grad benyttes frøtrestillingshogst i dine/deres skoger?
Dersom all hogst utføres som frøtrestillingshogst, så oppgi 100%. Hvis ingen frøtrestillingshogst utføres i dine/deres skoger, så oppgi 0%. Dersom flere hogstmetoder tas i bruk, så oppgi omtrent hvor stor prosentandel frøtrestillingshogst står for av hogstmetodene som blir brukt.

I hvor stor grad benyttes skjermstillingshogst i dine/deres skoger?
Dersom all hogst utføres som skjermstillingshogst, så oppgi 100%. Hvis ingen skjermstillingshogst utføres i dine/deres skoger, så oppgi 0%. Dersom flere hogstmetoder tas i bruk, så oppgi omtrent hvor stor prosentandel skjermstillingshogst står for av hogstmetodene som blir brukt.

I hvor stor grad benyttes bledningshogst/selektiv hogst i dine/deres skoger?
Dersom all hogst utføres som bledningshogst/selektiv hogst, så oppgi 100%. Hvis ingen bledningshogst/selektiv hogst utføres i dine/deres skoger, så oppgi 0%. Dersom flere hogstmetoder tas i bruk, så oppgi omtrent hvor stor prosentandel bledningshogst/selektiv hogst står for av hogstmetodene som blir brukt.

I hvor stor grad benyttes andre hogstmetoder enn de nevnt ovenfor i dine/deres skoger, på en skala fra 0% til 100%?
Dersom all hogst utføres som andre hogstmetoder enn de nevnt ovenfor, så oppgi 100%. Hvis ingen andre hogstmetoder utføres i dine/deres skoger, så oppgi 0%. Dersom andre hogstmetoder tas i bruk i tillegg til noen av de nevnt ovenfor, så oppgi omtrent hvor stor prosentandel andre hogstmetoder enn de nevnt ovenfor står for av metodene som blir brukt.

Har du/dere utført tradisjonell skogskjøtsel i skogene, f.eks. styving, stubbestyving eller kvisting?
Ja/Nei/Vet ikke

Hvis du/dere har tatt i bruk tradisjonell skogskjøtsel før, blir det fremdeles aktivt tatt i bruk?
Ja/Nei/Vet ikke

Kunne du/dere vært positive til å ta i bruk noen av følgende former for skogskjøtsel på skogeiendommene dine/deres?

Lukkete hogster som alternativ til flatehogster

Ja/Nei/Vet ikke

Tynninger og ungskogpleie som tar vare på variasjonen i skogen (fri tynning)

Ja/Nei/Vet ikke

Bredere kantsoner og mer hensyn til vann-vassdrag, våtmark og sumpskoger

Ja/Nei/Vet ikke

Bedre forvaltning av infrastruktur for friluftslivet

Ja/Nei/Vet ikke

Gamle skjøtselsmetoder som styving/lauving og stubbeskuddskogbruk

Ja/Nei/Vet ikke

Hvilke av disse målene anser du/dere som viktigst i forvaltningen av skogene dine/deres?

Kryss av i rangert rekkefølge for hvor viktig du/dere anser de ulike målene nevnt under i skogforvaltningen deres. OBS! Hvert av målene kan kun ha én plass i rangeringen, for eksempel kan ikke økonomisk avkastning både være det viktigste og det nest viktigste målet. Istedenfor må man velge ett av de seks målene som viktigst, og deretter velge hvilket av de resterende målene som er nest viktigst, og så videre.

Forklaring av målene:

Økonomisk avkasting: skogen skal forvaltes på en måte som gir et økonomisk overskudd og økt inntekt til deg/dere.
Bevare biologisk mangfold: skogforvaltningen skal bevare det biologiske mangfoldet, gjennom skjøtsel som tar særlig hensyn til biomangfoldet og bevarer områder med stor biologisk verdi.
Tiltrettelegge for friluftsliv og naturbruk: skogforvaltningen skal utføres slik at man ivaretar skogens rekreasjonsverdi, og tilrettelegger for friluftslivet og aktiv bruk av naturen fra enkeltmennesker.
Ivareta kulturhistorien og landskapet: skogforvaltningen skal videreføre tradisjonene med forvaltning av skog til fremtidige generasjoner, og ivareta kulturhistorien og landskapet som har tatt form over flere tiår.
Klimavennlig skogbruk: skogforvaltningen skal gjøres på en måte som reduserer utslipp av klimagasser, og på annet vis bidrar med å stanse klimaendringene.
Ta vare på jaktmulighetene: skogforvaltningen skal sørge for at jaktmulighetene på små- og storvilt ikke forringes av måten skogen forvaltes på, blant annet ved å bevare habitat viktig for viltartene og skjøtte skogen for å tilrettelegge for arter som viltartene livnærer seg av.

Viktigste mål

Økonomisk avkastning

Bevare biologisk mangfold

Tilrettelegge for friluftsliv og naturbruk

Ivareta kulturhistorien og landskapet

Klimavennlig skogbruk

Ta vare på jaktmulighetene

Vet ikke/ønsker ikke å oppgi

Nest viktigste mål

Økonomisk avkastning

Bevare biologisk mangfold

Tilrettelegge for friluftsliv og naturbruk

Ivareta kulturhistorien og landskapet

Klimavennlig skogbruk

Ta vare på jaktmulighetene

Vet ikke/ønsker ikke å oppgi

Tredje viktigste mål

Økonomisk avkastning

Bevare biologisk mangfold

Tilrettelegge for friluftsliv og naturbruk

Ivareta kulturhistorien og landskapet

Klimavennlig skogbruk

Ta vare på jaktmulighetene

Vet ikke/ønsker ikke å oppgi

Fjerde viktigste mål

Økonomisk avkastning

Bevare biologisk mangfold

Tilrettelegge for friluftsliv og naturbruk

Ivareta kulturhistorien og landskapet

Klimavennlig skogbruk

Ta vare på jaktmulighetene

Vet ikke/ønsker ikke å oppgi

Femte viktigste mål

Økonomisk avkastning

Bevare biologisk mangfold

Tilrettelegge for friluftsliv og naturbruk

Ivareta kulturhistorien og landskapet

Klimavennlig skogbruk

Ta vare på jaktmulighetene

Vet ikke/ønsker ikke å oppgi

Sjette viktigste mål

Økonomisk avkastning

Bevare biologisk mangfold

Tilrettelegge for friluftsliv og naturbruk

Ivareta kulturhistorien og landskapet

Klimavennlig skogbruk

Ta vare på jaktmulighetene

Vet ikke/ønsker ikke å oppgi

Hvilke andre mål har du/dere for skogforvaltningen?

Appendix C – Questionnaire translated to English

Questionnaire on ownership and biodiversity in forests

Questionnaire for master's project on ownership and biodiversity in forests

Background information about the project

My name is Kim André Nielsen, and I am taking a master's degree in nature management at the Norwegian University of Life Sciences (NMBU). This questionnaire is part of the data collection for my master's project, which is about whether there are any differences or correlations in biodiversity between different kinds of ownership in forests. The forest properties in the project have been limited to properties of more than 100 decares, consisting of forest, wetlands and/or freshwater according to NIBIO's AR5 resource map, in the following municipalities: Oslo, Nittedal, Jevnaker, Gran, Lunner, Gjerdrum, Nannestad, Hurdal, Eidsvoll, and Ullensaker.

In the project I will mainly look at differences and relationships between ownership forms (e.g. forest owned by a municipality, private individual, or parish commons), but also between individual owners, and those who have owned forests for longer and shorter periods. This is to see if there are also any differences or correlations between individual owners and biodiversity in their forests, to see if biodiversity levels can be explained by the form of ownership as such or more due to individual differences.

In addition, I will see if other factors, such as forest productivity and proximity to infrastructure, also contribute to explaining any differences or similarities in biodiversity. The data on biodiversity consists of data produced from airborne laser scans, species registrations from the Norwegian Species Data Bank, and MiS registrations.

The aim of the thesis is thus to find out whether there are any differences or relationships in biodiversity between different ownership relationships in forests, and whether these are best explained by ownership conditions or for other reasons. For example, if there is more biodiversity in a forest owned by private individuals or forest owned by a municipality, whether these differences are best explained by ownership or by other reasons.

Purpose of questionnaire

The aim of this questionnaire is to gain deeper insight into the kinds of ownership in the study area, as well as how the owners manage their forests. The purpose of collecting this information is to see if there are any differences or correlations between ownership and forest management, which may also help explain any similarities, correlations or differences in biodiversity.

Filling out and use of information from the questionnaire

Filling out this form is completely anonymous and no personal data will be stored or processed. The processing of the information provided will be in line with research ethics guidelines, and the information will be used in line with the purpose described above.

The master's thesis will be written in English, but the survey will be conducted in Norwegian. The questions will therefore be translated and referred to in English in the thesis. However, there will be both English and Norwegian unanswered versions of the questions available as appendices to the thesis, to make it possible to validate the similarity in wording between the original and translated versions.

It is possible to opt out of the project throughout the project period, until May 2024, so that the information you have provided is removed from the assignment. Due to complete anonymity, this means that you must provide enough information for the answer to be identified among the remainder to have it removed.

The questionnaire is open for responses from the time you have received the link, up to and including November 1st. Then the questionnaire will be closed, and it will no longer be possible to submit answers. If you have any further questions about the project, you can send an email to kim.andre.anstensen.nielsen@nmbu.no.

Do you consent to the information provided being used in the project?

Yes/No

In which of the following municipalities do you own the most forest?

Nannestad
Ullensaker
Oslo
Nittedal
Gjerdrum
Jevnaker
Gran
Lunner
Eidsvoll
Hurdal

Do you own forest in more than one of the municipalities mentioned in the previous question?

Yes/No/Don't know

Approximately how many years have you owned the forests?

How did you acquire the properties?

If you have acquired forests in several ways, choose the option that represents the way most of the forest areas have been acquired.

Gift
Purchase
Inheritance
Other methods
Don't know

If the forest(s) have been inherited, how many years have they been owned by the family?

Is your forest part of a combined farm with infields and forests?

Yes/No/Don't know

Approximately how large is the entire property mass in decares? (incl. infields + forests)

If the property's gross area (inland + uncultivated land) has decreased as a result of forests being protected, we want you to state the area before this happened.

Approximately how many decares is the productive forest area, according to the forestry plan?

Productive forest refers to forests that, on average for a normal turnaround period, can produce at least 0.1 cubic metres of wood per decare and year.

Approximately how many acres of unproductive forest do you own?

By unproductive forest it is meant forests which, on average for a normal turnover period, cannot produce at least 0.1 cubic metres of wood per decare and year.

Which group of forest owners are you part of or represent?

Do you own forest alone as an individual, private owner other than an individual (e.g. fund, company, or other private institution), do you represent a state actor (e.g. state commons, state-owned company or institution) or a municipality, do you represent a parish commons, or are you part of a joint ownership? Choose the option where you own the most forest, for example if you own most of your forest as an individual, but also a little bit in a joint ownership, then you tick off for individual.

Individual
Private owner except individual
Municipal
State ownership
Parish commons
Joint ownership
Other

Do you own forests in one of the following forms of co-ownership?

Parish commons

Yes/No/Don't know

State commons

Yes/No/Don't know

Joint ownership

Yes/No/Don't know

Joint stock company

Yes/No/Don't know

Are you a member of a forest owner association?

Yes/No/Don't know

If you own a forest or are a co-owner in a forest owner association, to what extent do you believe that you can influence the management (felling, management, environmental considerations, etc.) of the forest?

State to what extent you think that you can personally influence forest management as a forest owner, in various forms of independent ownership, co-ownership and joint management. If you do not own forest in one of the ownership forms, or do not wish to respond, then tick the box "not relevant/do not want to answer".

Individual

Very small degree
Small degree
Intermediate degree
Large degree
Very large degree
Not relevant/do not want to answer

Fund

Very small degree
Small degree
Intermediate degree
Large degree
Very large degree
Not relevant/do not want to answer

Forest owner association

Very small degree

Small degree

Intermediate degree

Large degree

Very large degree

Not relevant/do not want to answer

General partnership

Very small degree

Small degree

Intermediate degree

Large degree

Very large degree

Not relevant/do not want to answer

Joint stock company

Very small degree

Small degree

Intermediate degree

Large degree

Very large degree

Not relevant/do not want to answer

Joint ownership

Very small degree

Small degree

Intermediate degree

Large degree

Very large degree

Not relevant/do not want to answer

Parish commons

Very small degree

Small degree

Intermediate degree

Large degree

Very large degree

Not relevant/do not want to answer

State commons

Very small degree
Small degree
Intermediate degree
Large degree
Very large degree
Not relevant/do not want to answer

Municipality

Very small degree
Small degree
Intermediate degree
Large degree
Very large degree
Not relevant/do not want to answer

Other state ownership (forests owned by state-owned companies, institutions, agencies, etc.)

Very small degree
Small degree
Intermediate degree
Large degree
Very large degree
Not relevant/do not want to answer

Other private ownership (other forms of private ownership than those mentioned above, such as associations and cooperatives)

Very small degree
Small degree
Intermediate degree
Large degree
Very large degree
Not relevant/do not want to answer

To what degree would you say that you want to be involved in the forest management?

Very small degree
Small degree
Intermediate degree
Large degree
Very large degree
Don't know/don't want to state

Approximately how much of the felling and forest management work do you carry out yourself as owner or closest relatives?

On a percentage scale from 0% to 100%, state approximately how much of the work you perform as owner or closest relatives.

What do you do in the forest management?

Approximately how much of the felling and forest management work do other actors (forest owner associations, contractors, etc.) perform on your property?

On a percentage scale from 0% to 100%, state approximately how much of the work other actors perform on your property.

What kind of other actors are included in the forest management?

State what kind of other actors are involved in the forest management, for example what kind of actors are involved in felling and other management activities in the forests. We do not want specific names of any actors, but rather what kind of actor it is. For example, if a forest owner association takes care of logging, it is enough to write that a forest owner association is involved, without giving its name.

What tasks do other actors perform in the management of your forests, and what kind of actors do what?

Here we would like you to describe what other actors are doing in the management of the forests, as well as what the various actors are doing. For example, if a forest owner association (or other actor) carries out logging, it is written down here.

Have any of these logging methods been used in your forests in the last 30 years?

State whether you have used any of these logging methods in the last 30 years, and whether other methods than those mentioned have been used. If no logging has been carried out during this period, then tick yes for this and no for all the other options.

<u>Clear-cutting</u>

Yes/No/Don't know

Seed tree felling
Yes/No/Don't know

Shelterwood felling
Yes/No/Don't know

Selective felling
Yes/No/Don't know

Other felling methods
Yes/No/Don't know

To what extent is clear-cutting used in your forests?
If all fellings are carried out as clear-cutting, then state 100%. If no clear-cutting is carried out in your forests, then state 0%. If several felling methods are used, state approximately what percentage clear-cutting accounts for of the felling methods used.

To what extent is seed tree felling used in your forests?
If all fellings are carried out as seed tree fellings, then state 100%. If no seed tree felling is carried out in your forests, then state 0%. If multiple logging methods are used, state approximately what percentage seed tree felling accounts for of the felling methods used.

To what extent is shelterwood felling used in your forests?
If all fellings are carried out as shelterwood fellings, then state 100%. If no shelterwood felling is carried out in your forests, then state 0%. If multiple logging methods are used, state approximately the percentage of harvesting methods used.

To what extent is selective felling used in your forests?
If all fellings are carried out as selective fellings, then state 100%. If no selective felling is carried out in your forests, then state 0%. If multiple felling methods are used, state approximately what percentage selective felling accounts for of the felling methods used.

To what extent are felling methods other than those mentioned above used in your forests, on a scale from 0% to 100%?
If all fellings are carried out as other felling methods than those mentioned above, then state 100%. If no other felling methods are performed in your forests, then state 0%. If other felling methods are used in addition to any of the ones mentioned above, state approximately what percentage other felling methods than those mentioned above accounts for of the methods used.

Have you carried out traditional forest management in the forests, e.g. pollarding, coppicing or limbing?
Yes/No/Don't know

If you have used traditional forest management before, is it still being actively used?

Yes/No/Don't know

Would you be positive about using any of the following forms of forest management on your forest properties?

Closed felling methods as an alternative to clear-cutting

Yes/No/Don't know

Thinning and juvenile care of forests that takes care of the variation in the forest (free thinning)

Yes/No/Don't know

Wider edge zones and more consideration regarding watercourses, wetlands and swamp forests

Yes/No/Don't know

Better management of outdoor recreation infrastructure

Yes/No/Don't know

Old management methods such as pollarding/leaf gathering and stump shot forestry

Yes/No/Don't know

Which of these goals do you consider most important in the management of your forests/theirs?

State the ranked order of how important you consider the various goals mentioned below in your forest management. NOTE! Each goal can only have one place in the ranking, for example, economic profit cannot be both the primary and the second most important goal. Instead, you have to choose one of the six goals as the primary goal, and then choose which of the remaining goals is second most important, and so on.

Explanation of the goals:

Economic profit: the forest must be managed in a way that provides a financial surplus and increased income for you.

Preserving biodiversity: the forest management shall preserve biodiversity, through management that pays particular attention to biodiversity and preserves areas of great biological value.

Facilitate outdoor recreation and nature use: the forest management shall be carried out in such a way as to safeguard the recreational value of the forest, and facilitate outdoor recreation and active use of nature by individuals.

Safeguard the cultural history and landscape: the forest management must pass on the traditions of forest management to future generations, and safeguard the cultural history and landscape that has taken shape over several decades.

Climate-friendly forestry: the forest management must be done in a way that reduces greenhouse gas emissions and in other ways contributes to stopping climate change.

Take care of the hunting opportunities: the forest management must ensure that the hunting opportunities for small and large game are not impaired by the way the forest is managed, for example by preserving habitats important for game and managing the forest to accommodate for species that the game feed on.

Primary goal

Economic profit

Preserving biodiversity

Facilitate outdoor recreation and use of nature

Safeguard the cultural history and landscape

Climate-friendly forestry

Take care of the hunting opportunities

Don't know/don't want to answer

Second most important goal

Economic profit

Preserving biodiversity

Facilitate outdoor recreation and use of nature

Safeguard the cultural history and landscape

Climate-friendly forestry

Take care of the hunting opportunities

Don't know/don't want to answer

Third most important goal

Economic profit

Preserving biodiversity

Facilitate outdoor recreation and use of nature

Safeguard the cultural history and landscape

Climate-friendly forestry

Take care of the hunting opportunities

Don't know/don't want to answer

Fourth most important goal

Economic profit

Preserving biodiversity

Facilitate outdoor recreation and use of nature

Safeguard the cultural history and landscape

Climate-friendly forestry

Take care of the hunting opportunities

Don't know/don't want to answer

Fifth most important goal

Economic profit

Preserving biodiversity

Facilitate outdoor recreation and use of nature

Safeguard the cultural history and landscape

Climate-friendly forestry

Take care of the hunting opportunities

Don't know/don't want to answer

Sixth most important goal

Economic profit

Preserving biodiversity

Facilitate outdoor recreation and use of nature

Safeguard the cultural history and landscape

Climate-friendly forestry

Take care of the hunting opportunities

Don't know/don't want to answer

What other goals do you have for the forest management?

Appendix D – Questionnaire data

***Table D1**: Description of each of the management goals the respondents could rank in the questionnaire.*

Management goal	Description
Economic profit (ECON)	The forest shall be managed in a way that gives an economic surplus and increased income to yourself/yourselves.
Preserve biodiversity (BIO)	The forest management shall preserve the biodiversity of the area, through management practises that take special care of biodiversity and preserves areas with great biological value.
Facilitate for outdoor recreation and the use of nature (REC)	The forest management shall be executed in a way that preserves the forest's recreational value, and facilitates for outdoor recreation and active use of nature by individuals.
Preserve the cultural history and landscape (CUL)	The forest management shall carry on the traditions of forest management to future generations, and preserve the cultural history and landscape that has taken shape over decades.
Climate friendly silviculture (CLIM)	The forest management shall be done in a way that reduces emissions of greenhouse gasses, and in other ways contribute to stopping climate change.
Preserve the hunting possibilities (HUNT)	The forest management shall make sure that the hunting possibilities on small and large game are not degraded due to the way the forest is managed, amongst other things by preserving important habitats for game and manage the forests to facilitate for species that the game sustains themselves from.

***Table D2**: Counts of respondents between ownership categories, sorted from highest to lowest counts.*

Ownership category	**Counts**
Private individual	237
Joint ownership	7
Municipality	6
Private actor	6
Parish commons	6
Other	1

***Table D3**: Counts of private individual forest owners, between different size categories of forest properties, sorted from lowest to highest size category.*

Forest size category	**Counts**
2 - 9.9 ha	35
10 - 24.9 ha	71
25 - 49.9 ha	58
50 - 99.9 ha	44
100 - 199.9 ha	29
> = 200 ha	26

***Table D4**: Counts of private individual forest owners between municipalities, sorted from highest to lowest counts.*

Municipality	**Counts**
Ullensaker	47
Eidsvoll	42
Gran	41
Lunner	26
Nannestad	25
Jevnaker	21
Nittedal	15
Hurdal	11
Gjerdrum	8
Oslo	1

Appendix E – Ownership category results

Table E1: *Back-transformed mean percent values of biodiversity indicator values across ownership categories, based on data for each forest owner's property. Strength of significance in deviation from grand mean is indicated by number of asterisks, and strong trends are indicated with a period mark. Higher values of Shannon indices indicate higher diversity of red-listed species, and cells with only a hyphen indicates that the biodiversity indicator was not present in the ownership category.*

Level		Biodiversity indicator	Data transformation for best fit	Back-transformed grand mean (%)	Ownership categories													
					Association	Church	Cooperative	Fund	Foundation	General partnership	Joint ownership	Joint stock company	Municipality	Parish commons	Parish-State commons	Private individual	State	State commons
					Back-transformed group means (%)													
Landscape		**Near-natural forest**	Square-root	**27.04**	42.90	24.30	36.00	34.34	17.56	21.34	27.77	18.75*	29.38	16.56**	28.94	28.09	33.29	26.21
		Tree size diverse forest	Square-root	**26.52**	45.70*	33.76	37.21	30.14	25.70	15.60 .	27.88	20.16*	24.21	19.18*	20.98	28.30	27.98	21.72
		Tree height diverse forest	Square-root	**31.47**	38.44	42.64	31.92	28.30	47.33	26.21	33.99	29.92	26.73	36.84	19.36	34.46	24.21	26.21
Habitat	Merged	**All habitats**	Natural logarithm	**2.32**	11.59	2.97	4.22	2.29	-	0.97	2.77	1.09	3.29	1.23	2.27	2.51	0.80 .	2.77
		Structural habitats	Natural logarithm	**1.65**	-	2.97	4.22	1.92	-	0.92	1.99	0.71	2.48	1.08	2.08	1.84	0.45*	2.75
	Individual	**Snags**	Natural logarithm	**0.23**	-	-	-	-	-	0.08	1.03*	0.22	0.42	0.05*	0.07	0.85**	0.73	0.11
		Logs	Natural logarithm	**0.53**	-	-	-	0.70	-	0.22	1.88***	0.07*	0.68	0.45	1.04	1.39**	0.23	0.84
		Trees with pendant lichens	Square-root	**0.52**	-	-	-	-	-	0.10	2.19**	-	-	0.64	-	0.77	-	0.01
		Late successional deciduous trees	Natural logarithm	**0.83**	-	2.97	4.22	0.84	-	0.06 .	1.54	3.82	0.68	0.04***	1.14	1.84 .	0.32	2.10
		Trees with nutrient-rich bark	Natural logarithm	**0.08**	-	-	-	0.23	-	-	1.43***	-	0.00	0.01*	-	0.41**	-	-
		Old trees	Natural logarithm	**0.41**	-	-	-	0.73	-	0.76	2.14***	0.41	2.16	0.44	0.04 .	1.30**	0.09	0.08
Species		**Shannon index values**	N/A	N/A	1.39	1.33	-	2.8	-	2.78	4.11	2.56	4.22	2.4	0.64	4.26	4.21	1.97

Appendix F – Municipality results

***Table F1**: Back-transformed mean percent values of biodiversity indicator values across municipalities, based on data for each forest owner's property. Strength of significance in deviation from grand mean is indicated by number of asterisks, and strong trends are indicated with a period mark. Higher values of Shannon indices indicate higher diversity of red-listed species, and cells with only a hyphen indicates that the biodiversity indicator was not present in the ownership category.*

Level		Biodiversity indicator	Data transformation for best fit	Back-transformed grand mean (%)	Municipalities										
					Eidsvoll	Gjerdrum	Gran	Hurdal	Jevnaker	Lunner	Nannestad	Nittedal	Oslo	Ullensaker	
Landscape		Near-natural forest	Square-root	**27.25**	27.35	30.47 .	22.85***	21.25***	29.81 .	24.11**	26.52	31.02**	28.41	31.81***	Back-transformed group means (%)
		Tree size diverse forest	Square-root	**26.83**	27.88	29.81 .	23.91	23.72**	29.16 .	26.11	27.98	24.30*	25.20	30.80***	
		Tree height diverse forest	No transformation	**33.19**	34.88*	36.38 .	35.43	32.98	35.16	38.27***	36.92***	26.94***	21.72***	33.21	
Habitat	Merged	All habitats	Natural logarithm	**2.51**	2.20	3.97 .	1.49***	2.69	1.06***	2.72	2.86	2.61	3.39	3.86***	
		Structural habitats	Natural logarithm	**1.60**	1.70	2.59	0.99***	2.46*	0.33***	1.51	2.48*	1.40	2.05	2.89***	
	Individual	Snags	Natural logarithm	**0.25**	0.64 .	0.11	0.50	0.39	0.02*	0.07	0.37	0.15	0.81	1.22**	
		Logs	Natural logarithm	**0.94**	0.83	2.29*	0.85	1.70 .	0.13***	0.70	2.12**	0.68	0.76	2.01***	
		Trees with pendant lichens	Square-root	**0.21**	1.02**	0.01	0.76**	0.20	0.15	0.10	0.05	0.01	0.09	0.70	
		Late successional deciduous trees	Natural logarithm	**0.98**	1.82**	2.56	0.44**	2.03*	0.24***	0.29*	2.03*	0.71	0.88	2.18***	
		Trees with nutrient-rich bark	Natural logarithm	**0.14**	0.37	1.22*	0.01*	2.27*	-	-	-	0.02	0.08	-	
		Old trees	Natural logarithm	**0.89**	1.04	0.76	0.62	0.88	0.32	1.55	2.25**	0.59	1.27	0.84	
Species		Shannon index	N/A	N/A	3.59	2.55	3.7	2.37	3.62	3.05	2.76	3.51	4.51	2.91	

Appendix G – Results for distance to roads

Table G1*: Back-transformed group mean percent values of biodiversity indicators within and beyond 200 m buffer from roads, based on data for each forest owner's property. Strength of significance in deviation from grand mean is indicated by number of asterisks, and strong trends are indicated with a period mark. Higher values of Shannon indices indicate higher diversity of red-listed species.*

Level		Biodiversity indicator	Data transformation for best fit	R^2	Back-transformed grand mean (%)	200-meter buffer from roads	
						Within 200 m	Beyond 200 m
Landscape		Near-natural forest	Square-root	0.002	**13.16**	12.71*	13.62*
		Tree size diverse forest	Square-root	0.006	**13.26**	12.44***	14.11***
		Tree height diverse forest	Square-root	0.02	**16.11**	14.64***	17.64***
Habitat	Merged	All habitats	Natural logarithm	0.005	**1.49**	1.35*	1.65*
		Structural habitats	Natural logarithm	0.01	**1.13**	0.95***	1.33***
	Individual	Snags	Natural logarithm	0.04	**0.29**	0.19*	0.46*
		Logs	Natural logarithm	0.04	**0.78**	0.56*	1.09*
		Trees with pendant lichens	Natural logarithm	0.2	**0.26**	0.13***	0.53***
		Late successional deciduous trees	Natural logarithm	-0.002	**0.89**	0.87	0.92
		Trees with nutrient-rich bark	Natural logarithm	-0.01	**0.22**	0.31	0.15
		Old trees	Natural logarithm	0.03	**0.72**	0.53**	0.99**
Species		Shannon index	N/A	N/A	N/A	4.68	3.74

Back-transformed group means (%)

Table G2*: Back-transformed group mean percent values of biodiversity indicators within and beyond 400 m buffer from roads, based on data for each forest owner's property. Strength of significance in deviation from grand mean is indicated by number of asterisks, and strong trends are indicated with a period mark. Higher values of Shannon indices indicate higher diversity of red-listed species.*

Level		Biodiversity indicator	Data transformation for best fit	R^2	Back-transformed grand mean (%)	400-meter buffer from roads	
						Within 400 m	Beyond 400 m
Landscape		Near-natural forest	Square-root	0.31	**13.25**	21.18***	7.17***
		Tree size diverse forest	Square-root	0.29	**13.48**	20.88***	7.69***
		Tree height diverse forest	Square-root	0.27	**16.73**	24.81***	10.23***
Habitat	Merged	All habitats	Natural logarithm	0.06	**1.50**	2.11***	1.06***
		Structural habitats	Natural logarithm	0.02	**1.23**	1.50***	1.00***
	Individual	Snags	Natural logarithm	-0.01	**0.40**	0.45	0.35
		Logs	Natural logarithm	0.001	**0.91**	0.99	0.83
		Trees with pendant lichens	Natural logarithm	-0.02	**0.36**	0.33	0.38
		Late successional deciduous trees	Natural logarithm	0.04	**0.84**	1.29***	0.55***
		Trees with nutrient-rich bark	Natural logarithm	0.11	**0.12**	0.37 .	0.04 .
		Old trees	Natural logarithm	-0.002	**0.84**	0.90	0.78
Species		Shannon index	N/A	N/A	N/A	4.69	3.23

Back-transformed group means (%)

***Table G3**: Back-transformed group mean percent values of biodiversity indicators within and beyond 600 m buffer from roads, based on data for each forest owner's property. Strength of significance in deviation from grand mean is indicated by number of asterisks, and strong trends are indicated with a period mark. Higher values of Shannon indices indicate higher diversity of red-listed species.*

Level		**Biodiversity indicator**	**Data transformation for best fit**	**R^2**	**Back-transformed grand mean (%)**	**600-meter buffer from roads**	
						Within 600 m	**Beyond 600 m**
Landscape		**Near-natural forest**	Square-root	0.51	**12.67**	25.33***	4.35***
		Tree size diverse forest	Square-root	0.52	**12.96**	25.32***	4.70***
		Tree height diverse forest	Square-root	0.54	**16.54**	30.55***	6.80***
Habitat	Merged	**All habitats**	Natural logarithm	0.09	**1.33**	2.31***	0.77***
		Structural habitats	Natural logarithm	0.05	**1.14**	1.69***	0.77***
	Individual	**Snags**	Natural logarithm	0.05	**0.33**	0.56*	0.20*
		Logs	Natural logarithm	0.02	**0.87**	1.18**	0.64**
		Trees with pendant lichens	Natural logarithm	0.26	**0.38**	0.48	0.30
		Late successional deciduous trees	Natural logarithm	0.09	**0.45**	1.34***	0.15***
		Trees with nutrient-rich bark	Natural logarithm	0.48	**0.03**	0.40***	0.002***
		Old trees	Natural logarithm	0.02	**0.76**	1.04*	0.55*
Species		**Shannon index**	N/A	N/A	N/A	4.62	2.89

Back-transformed group means (%)

***Table G4**: Back-transformed group mean percent values of biodiversity indicators within and beyond 800 m buffer from roads, based on data for each forest owner's property. Strength of significance in deviation from grand mean is indicated by number of asterisks, and strong trends are indicated with a period mark. Higher values of Shannon indices indicate higher diversity of red-listed species.*

Level		**Biodiversity indicator**	**Data transformation for best fit**	**R^2**	**Back-transformed grand mean (%)**	**800-meter buffer from roads**	
						Within 800 m	**Beyond 800 m**
Landscape		**Near-natural forest**	Square-root	0.54	**11.58**	27.03***	2.58***
		Tree size diverse forest	Square-root	0.56	**11.98**	27.12***	2.94***
		Tree height diverse forest	Square-root	0.61	**15.22**	33.00***	4.24***
Habitat	Merged	**All habitats**	Natural logarithm	0.1	**1.10**	2.47***	0.49***
		Structural habitats	Natural logarithm	0.09	**0.88**	1.78***	0.43***
	Individual	**Snags**	Natural logarithm	0.15	**0.19**	0.56***	0.06***
		Logs	Natural logarithm	0.09	**0.60**	1.28***	0.28***
		Trees with pendant lichens	Natural logarithm	0.15	**0.30**	0.59**	0.15**
		Late successional deciduous trees	Natural logarithm	0.09	**0.27**	1.36***	0.05***
		Trees with nutrient-rich bark	Natural logarithm	0.22	**0.05**	0.40*	0.01*
		Old trees	Natural logarithm	0.1	**0.57**	1.14***	0.28***
Species		**Shannon index**	N/A	N/A	N/A	4.56	2.56

Back-transformed group means (%)

Table G5: Back-transformed group mean percent values of biodiversity indicators within and beyond 1000 m buffer from roads, based on data for each forest owner's property. Strength of significance in deviation from grand mean is indicated by number of asterisks, and strong trends are indicated with a period mark. Higher values of Shannon indices indicate higher species diversity.

Level		Biodiversity indicator	Data transformation for best fit	R^2	Back-transformed grand mean (%)	1000-meter buffer from roads		
						Within 1000 m	Beyond 1000 m	
Landscape		**Near-natural forest**	Square-root	0.41	**10.90**	27.59***	1.82***	Back-transformed group means (%)
		Tree size diverse forest	Square-root	0.45	**11.25**	27.75***	2.08***	
		Tree height diverse forest	Square-root	0.53	**14.18**	33.89***	2.92***	
Habitat	Merged	**All habitats**	Natural logarithm	0.1	**0.76**	2.51***	0.23***	
		Structural habitats	Natural logarithm	0.1	**0.60**	1.79***	0.20***	
	Individual	**Snags**	Natural logarithm	0.15	**0.13**	0.55***	0.03***	
		Logs	Natural logarithm	0.15	**0.35**	1.28***	0.10***	
		Trees with pendant lichens	Natural logarithm	0.3	**0.16**	0.57***	0.04***	
		Late successional deciduous trees	Natural logarithm	0.06	**0.17**	1.36***	0.02***	
		Trees with nutrient-rich bark	Natural logarithm	0.25	**0.02**	0.32*	0.001*	
		Old trees	Natural logarithm	0.13	**0.37**	1.12***	0.12***	
Species		**Shannon index**	N/A	N/A	N/A	4.52	2.15	

Appendix H – Forest productivity results

Table H1: Back-transformed mean percent values of biodiversity indicators across forest productivity classes, based on data for each forest owner's property. Strength of significance in deviation from grand mean is indicated by number of asterisks, and strong trends are indicated with a period mark. Higher values of Shannon indices indicate higher diversity of red-listed species, and cells with only a hyphen indicates that the biodiversity indicator was not present in the ownership category.

Level		Biodiversity indicator	Data transformation for best fit	Back-transformed grand mean (%)	Forest productivity				
					Very low	Low	Medium	High	
Landscape		**Near-natural forest**	Natural logarithm	3.18	0.41***	3.29	6.69***	11.25***	Back-transformed mean (%)
		Tree size diverse forest	Natural logarithm	3.46	0.51***	3.53	7.24***	10.80***	
		Tree height diverse forest	Natural logarithm	4.68	0.81***	4.95*	9.78***	11.94***	
Habitat	Merged	**All habitats**	Natural logarithm	0.61	0.24***	0.46**	0.69 .	1.13***	
		Structural habitats	Natural logarithm	0.45	0.15***	0.36 .	0.59**	1.27***	
	Individual	**Snags**	Natural logarithm	0.11	0.01***	0.15	0.20*	0.45***	
		Logs	Natural logarithm	0.26	0.04***	0.23	0.47**	0.95***	
		Trees with pendant lichens	Natural logarithm	0.12	0.03***	0.35***	0.23*	0.08	
		Late successional deciduous trees	Natural logarithm	0.22	0.13*	0.07***	0.22	1.21***	
		Trees with nutrient-rich bark	Natural logarithm	0.02	0.00*	0.01	0.02	0.37	
		Old trees	Natural logarithm	0.33	0.11***	0.42	0.36	0.73***	
Species		**Shannon index**	N/A	N/A	3.73	3.6	4.15	4.50	

Appendix I – Forest management results of forest property size

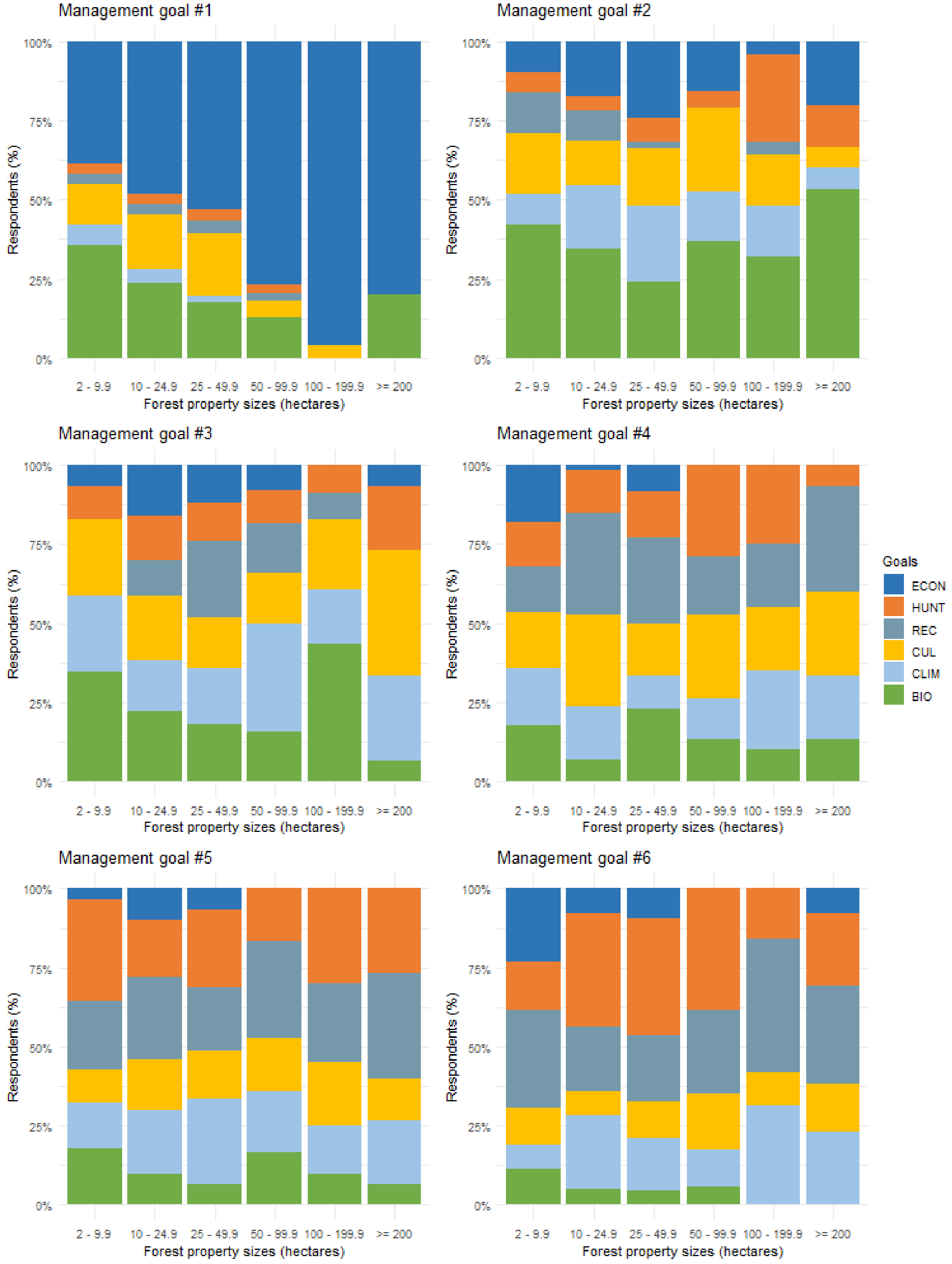

Figure I1: Ranked management goals, grouped by forest property size. The goals, in short, were economic (ECON), hunting (HUNT), recreation (REC), cultural (CUL), climate (CLIM), and biodiversity (BIO). See Table D4 in Appendix D for more details about the defined goals.

Table I1: Back-transformed mean percent values of felling methods in each forest property size category in hectares. Strength of significance is indicated by number of asterisks, and strong trends are indicated with a period mark. White rows indicate that both the raw and transformed data were too skewed to produce accurate deviation models.

Felling method	Data transformation for best fit	Back-transformed grand mean (%)	Forest property size (hectares)						
			2-9.9	**10-24.9**	**25-49.9**	**50-99.9**	**100-199.9**	**>=200**	Back-transformed group means (%)
Clear-cutting	No transformation	**65.16**	36.87***	62.25	**67.10**	78.95**	81.40**	68.04	
Seed-tree felling	Natural logarithm	**5.78**	3.41*	3.86*	6.12	6.11	6.51	11.59 **.**	
Shelterwood felling									
Selective felling	Natural logarithm	**3.21**	4.48	3.56	3.15	2.33	2.83	3.28	
Other felling methods									

Appendix J – Forest management results of municipalities

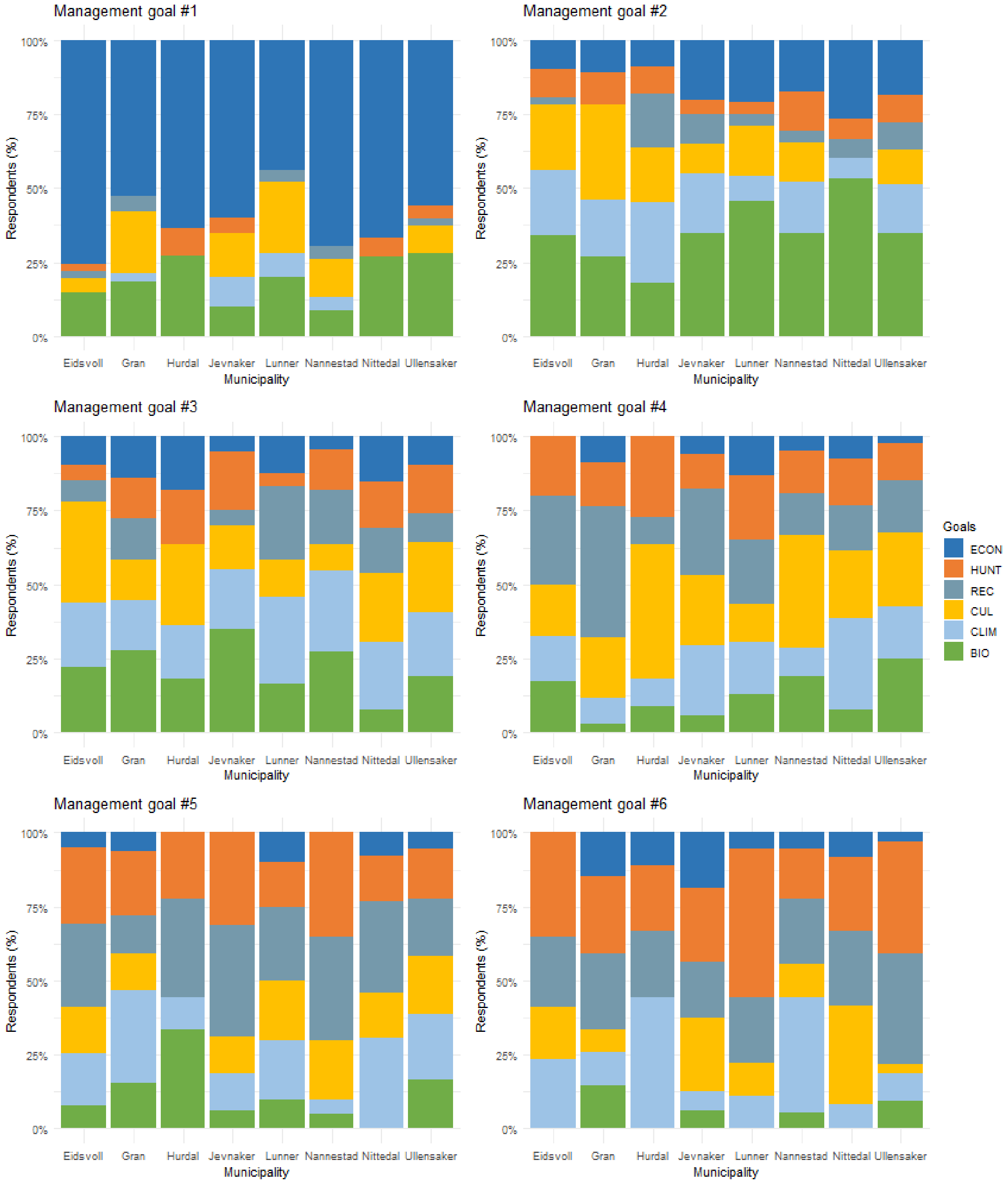

Figure J1*: Ranked management goals, grouped by municipality. The goals, in short, were economic (ECON), hunting (HUNT), recreation (REC), cultural (CUL), climate (CLIM), and biodiversity (BIO). See Table D4 in Appendix D for more details about the defined goals.*

Table J1*: Back-transformed mean percent values of felling methods in each municipality. Strength of significance is indicated by number of asterisks, and strong trends are indicated with a period mark. White rows indicate that both the untransformed and transformed data were too skewed to produce accurate deviation models .*

Felling method	**Data transformation for best fit**	**Back-transformed grand mean (%)**	**Municipalities**								
			Eidsvoll	**Gran**	**Hurdal**	**Jevnaker**	**Lunner**	**Nannestad**	**Nittedal**	**Ullensaker**	
Clear-cutting	No transformation	**66.37**	77.00*	60.17	69.55	58.52	77.38 **.**	72.16	72.93	43.28***	Back-transformed group means (%)
Seed-tree felling	Square-root	**7.51**	4.12	8.88	6.49	14.00	3.80	10.26	6.21	8.87	
Shelterwood felling											
Selective felling	Natural logarithm	**3.07**	2.36	3.96	3.65	3.10	3.00	3.67	1.50*	4.53 **.**	
Other felling methods	Natural logarithm										

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