Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Natural Sciences
Department of Biology

Elise Berg

Leaf it to the professionals

Branching out to restore deciduous forests in southern Norway.

Master's thesis in Natural Resources Management
Supervisor: Gunnar Austrheim, Department of Natural History
Co-supervisor: Jørund Aasetre, Department of Geography. Vegard Gundersen, NINA.

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Abstract

While restoration endeavors in Scandinavia and Northern Europe have predominantly concentrated on boreal forests, the often-overlooked boreonemoral forests, sharing similar characteristics, demand equal attention. These ecosystems significantly contribute to the economic fabric of these regions, particularly in timber production. Extending along the Oslo fjord, the boreonemoral zone encompasses Moss municipality. However, restoration initiatives in Norway have been limited, with both the general public and authorities displaying restricted awareness and experience in restoration concepts and objectives. Now, in the face of a climate crisis reshaping familiar production forests, evidenced by reports of drought and bark beetle infestations on Norway spruce in the municipality, a paradigm shift is imperative.

Ecological patterns in species distribution, oak health, and ground vegetation were nuanced, challenging assumptions with varying species richness across areas. Unexpected oak dynamics, ground vegetation influence, and severe powdery mildew cases on oaks, though not significantly impacting density, require further exploration. Examining roe deer browsing revealed intricate relationships between tree height, browsing incidents, and surrounding vegetation, with area-specific variations and unexpectedly low browsing incidence in Area 1.

Interviews unveiled a multifaceted approach to forest management, balancing economic, ecological, and recreational aspects. Landowners prioritize timber production while expressing a need of diverse forest activities, challenging traditional production-centric views. The nuanced recognition of ecosystem services emphasizes complex values in Moss's forest, highlighting a collective vision prioritizing ecological and social health. Insights into landowners' preferences envision a shift towards sustainable practices, diverse vegetation, and a landscape-friendly strategy. The inevitable impact of climate change on Moss's forests necessitates adaptive management, emphasizing the need for tangible solutions and addressing biological barriers like drought and financial constraints. Landowners' express positivity towards incorporating oak trees, emphasizing their ecological and cultural significance. The project's role in fostering innovative thoughts in forestry is crucial for a positive and sustainable future. The envisioned forest leans towards a multi-use approach, prioritizing biodiversity over production. The discussion concludes by addressing herbivore activity, particularly roe deer browsing, as a potential threat, emphasizing the need for ongoing monitoring and adaptive management to support oak regeneration and overall biodiversity. In Moss municipality, climate change, local knowledge, and biological barriers shape forest management, emphasizing the need for a multifaceted approach, integrating selective cutting, strategic tree planting, oak promotion, accessible forestry information, and financial incentives for sustainability.

Keywords: Oak Quercus robeus; Deciduous Forest; Norway, Landowner perspectives; Forest ecosystem management; Pathways; Desired States; Climate change.

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Chapter 1

Introduction

1.1 Boreal Forest, Silviculture and Climate Change.

The world's largest land biome, boreal forest, covers enormous portions of the northern hemisphere (Brandt et al., 2013; Gower et al., 2001; UNEP, 2009; Vanhanen et al., 2012). Contributing to a mixture of ecosystem services in terms of environmental, socio-cultural, and economic benefits; e.g. carbon sequestration (Canadell & Raupach, 2008; Rautiainen et al., 2011), and water- and energy regulation for further protection of the forest and climate change (Daily, 1997; IPBES, 2018). Additionally while being immense carbon sinks, boreal forests holds large portion of the worlds biodiversity (UNEP, 2009).

Nordén et al. (2019) assert that restoration efforts in Scandinavia and northern Europe have predominantly focused on boreal forests. However, boreonemoral forests, consisting of mixed forests with both deciduous and coniferous trees, particularly Norwegian spruce (*Picea abies;* hereby referred to as spruce) acting as a border toward the nemoral zone, possess similar characteristics and warrant heightened consideration. This biome extends along the coast of southern Norway, including areas around the Oslo fjord.

This investigation delves into the prospect of transitioning existing boreal forests in southern Norway, into boreonemoral forests. This shift is instigated by the ongoing climate transition in the region. A parallel study conducted in Finland elucidates the risks associated with factors such as windstorms, heavy snow loading, drought, forest fires, insect pests, and pathogens (Venäläinen et al., 2020). Notably, private landowners in Moss municipality, as indicated through personal communication during interviews in 2022, have observed an increase in drought events and a growing incidence of bark beetles (*Ips typographus*) on spruce. The climatic situation highlights the significance of any future development of i.e., boreal forests for both human welfare and global biodiversity.

As noted by Hagen et al. (2013), restoration initiatives in Norway have been relatively limited, with both the general public and authorities demonstrating restricted awareness and experience regarding the concept and objectives of restoration. Consequently, Norway should reassess the approach to managing production forest in response to evolving international directives. European Union's new forest strategy (*Communication from the commision to the European parliament, the council, the European economic and social committee and the committee of the regions.* , 2021) aims to reduce greenhouse gas emissions by 55% by 2030 and achieve carbon neutrality by 2050, further emphasizing the need for strategic reevaluation in forest management practices.

Boreonemoral forests hold immense value for timber production (Brandt et al., 2013; Gauthier et al., 2015; Vanhanen et al., 2012), serving as a crucial source of economic activity and development in the region (Haugen, 2016; Nordlund & Westin, 2011; Pohjanmies et al., 2017), comparable to the significance of boreal forests (Hanson et al., 2007; Niklasson & Granström, 2000; Svensson, 2021).

Over the last 300 years, the landscape dynamic in the boreonemoral region has changed drastically; originally dominated by deciduous trees (Björse & Bradshaw, 1998; Bradshaw et al., 2000), to the present situation, where e.g. 38% of the total land area in Norway is covered with spruce, with approximately 30% considered as "productive forest" (forest being harvested for timber production) (*Skogbruk*, 2018). However, in these forests, timber production serves as a primary anthropogenic disruption, emerging as a major contributor to ecosystem disturbances (Niemelä, 1999) and contributing to the global degradation of boreonemoral forests (Framstad et al., 2017; Lindbladh et al., 2007; Venter et al., 2016). Disturbance can be thought of as "any relative discrete event in the time of that removes one or more organisms and widens the space of which can be colonized by individuals of the same or different species" (Persson et al., 2000).

Succession is the ecological process of change in the species composition, structure, and function of a community over time after a disturbance (Connell & Slatyer, 1977; Graham et al., 2014). Early successional species, characterized by species of rapid growth and a low tolerance to shade, and disturbances from forestry contribute to an augmentation of deciduous habitats (i.e., utilizing forest gaps) (Grime, 1977; Street et al., 2015). These deciduous species will ultimately be outcompeted by coniferous species, unless new disturbances occur that allow the landscape to reset back to early successional stages, due to their inability to regenerate under their own canopy cover (Street et al., 2015). The coniferous species include spruce, Scots pine (*Pinus sylvetris;* hereby referred to as pine) which is also referred to as "late successional species" (Connell & Slatyer, 1977). However, quaking aspen (*Populus tremula*), rowan (*Sorbus aucuparia*) and downy birch (*Betula pubescens*) exhibit a potential coexistence throughout the boreal forests (Speed et al., 2013).

Populations of roe deer (*Capreolus capreolus*) and moose (*Alces alces*) have had an enormous increase during the latter century, becoming known species throughout Scandinavia (Persson et al., 2000; Speed et al., 2019). These species, as well as large-scale forestry practices construct new landscape patterns and changes in vegetation compositions, further benefiting the ungulates (Jiang et al., 2009; Lavsund et al., 2003; Niklasson & Granström, 2000). However, in southern Norway, where both roe deer and moose are hunted, they could potentially view humans as predators (Lima & Dill, 1990), with other studies demonstrating both positive and negative effects of human activity on ungulate population density, behavior, and spatial usage (Hewison et al., 2001; Panzacchi et al., 2009). As for forest compositional change, both climate and humans have a significant impact (Reitalu et al., 2013). Social expectations and valuations of the world's manageable forests differ and may even contradict as the perception of forests as resources for industrial use and economic development remains strong. Whereas human impact has favored populations of early successional taxa colonizing abandoned agricultural fields such as birch etc., it has limited taxa like spruce (Reitalu et al., 2013). The increased usage of renewable resources, biodiversity as well as ecosystem services are showing negative trends (IPBES, 2018), and that an increase of forest areas can mitigate climate change (IPCC, 2019).

To navigate the complex socio-ecological systems and address the challenges in southeastern Norway, it's imperative to delve into the various dimensions of forest ecosystem management and restoration. This exploration is essential for understanding the perspectives of landowners who play a pivotal role in shaping the future of the Norwegian forests. By unravelling their views and wishes containing their values, beliefs and attitudes, this comprehension becomes paramount for effective decision-making process and the realization of sustainable forest initiatives (Ní Dhubháin et al., 2007). Additionally, it serves to maximize the acceptability of management actions and initiatives, aligning them with the diverse needs and values of the community (Ives & Kendal, 2014).

1.2 Objectives and research questions.

The overarching goal is to re-establish a deciduous forest ecosystem that aligns with the imperatives of nature, climate, and sustainable production of deciduous material services. It's worth noting that oak and spruce, as two distinct tree species, have varying habitat requirements. Consequently, the presence of oaks within former spruce plantations is anticipated to be limited.

In line with these aspirations, we have formulated four key objectives:

(I) To investigate the early recruitment of oak within former spruce plantations.

(II) To gain insights into the forest ecosystem management from the perspective of landowners, while also discerning their perceptions concerning the aesthetic qualities and future utilization of the forest.

(III) To explore and chart possible pathways for the restoration of broadleaf-dominated forest ecosystems, guided by both existing literature and the insights drawn from discussions with the landowners.

To establish a robust understanding of early (successful) recruitment and to investigate the correspondence between interview responses and on-site conditions within the areas of interest, this study seeks to provide local stakeholders with assurance regarding the potential pathways for fostering broadleaf-dominated forests.

This study examines two contrasting, but interlinked components of the socio-ecological system. There is a scarcity of research focused on landowners' views regarding forest management, forest value, and future visions. To advance the re-establishment of a deciduous forest ecosystem that offers vital ecosystem services for sustainable production, we aim to address the following questions in relation to landowners:

I) What is their vision of the ideal forest and what values do they associate with the forest?

II) What are their primary management objectives for achieving their envisioned forest?

III) To what extent are they aware of ecosystem services, and how do considerations of biodiversity and climate challenges influence their forest management and production strategies?

IV) What are their perceptions of future forest utilization?

Furthermore, during our meetings with the landowners who have contributed to this study, an important additional question emerged:

I) What is the impact of roe deer browsing on oak recruits within clear-cut spruce plantations?

Additionally, while conducting field observations, we noted a substantial presence of sick oak trees. This observation raises the question of whether the prevalence of sick oaks has an influence on their growth and development:

II) To what extent do the health and vitality of oak trees impact their growth within clear-cut spruce plantations?

These additional inquiries further enrich our understanding of the dynamic factors influencing the early recruitment of oak within the context of clear-cut spruce plantations and forest ecosystem management.

Chapter 2

Theoretical Framework

2.1 Preserving a healthy forest.

The forests in Norway have been heavily exploited, with vast majority of the forests having at one time or another been cut down. Thus, Norway has minimal real primeval forests left. Together with the legislation (Skogbruksloven (2006), Naturmangfoldloven (2009)), environmental certification of timber (Norwegian PEFC Forest Standard) sets the framework for which environmental considerations forestry must undertake, such as choice of felling methods, use of foreign tree species, and fertilization, saying that the forest must be used and protected (*Skog*, 2022).

The nature of timber harvesting in Norway, representing approximately 90% mechanized harvesting, is primarily dominated by the widespread utilization of clear-cutting, especially in large plantations of Norwegian spruce trees (*Foryngelse og miljøhensyn*, 2022). Clear-cutting entails the comprehensive removal of nearly all trees from an inclined area, with a designated number of “seeding” trees or saplings left behind to facilitate regrowth of a new forest (S. T. Pickett & M. L. Cadenasso, 2002; *Skogbruk*, 2018). This method is characterized as the most cost-effective option available to timber producers (S. T. Pickett & M. L. Cadenasso, 2002). Despite this prevalence, Norwegian timber producers occasionally employ alternative harvesting methods, including selective logging, aimed to retain a higher number of trees (a minimum of 15 trees per daa) compared to clear-cutting. These trees left standing will then be of different heights and ages, creating a multilayered forest. However, an excessive focus on production aspects in management practices may potentially degrade or eliminate other vital benefits derived from forest ecosystems (Pohjanmies, 2018).

Now, with a broad scientific consensus emerging that climate change are entering a decreased stability period (Alverson, 2000; Bradshaw et al., 2000; Mann et al., 1998). In the context of future climate projections, Miljøstatus suggests that by 2100, the prevailing changes of the climate may render unfavorable conditions for the growth, survival, and quality of timber of commercially spruce in current habitats (Hanson et al., 2007; *Skog*, 2022; Venäläinen et al., 2020). For instance, the effect of climate extremes and raised mean temperature may be positive or negative for tree vitality, depending on tree species. Overall, preconditioning extremes, exemplified by frost- and dry spells, tend to exert a negative influence on trees, rendering the trees more susceptible to depredation of pests and pathogens (Figure 1). Notably, wet soils and winters without frozen ground, have a potential to inflict direct damage on forests, thereby compounding the adverse effects on overall forest vitality (Schlyter et al., 2006). These adverse climatic conditions are anticipated to result in weakened trees, consequently rendering them more susceptible to various stressors, including (but not limited to) bark beetles and diseases, with an expected increase in their prevalence (Hanson et al., 2007; *Skog*, 2022).

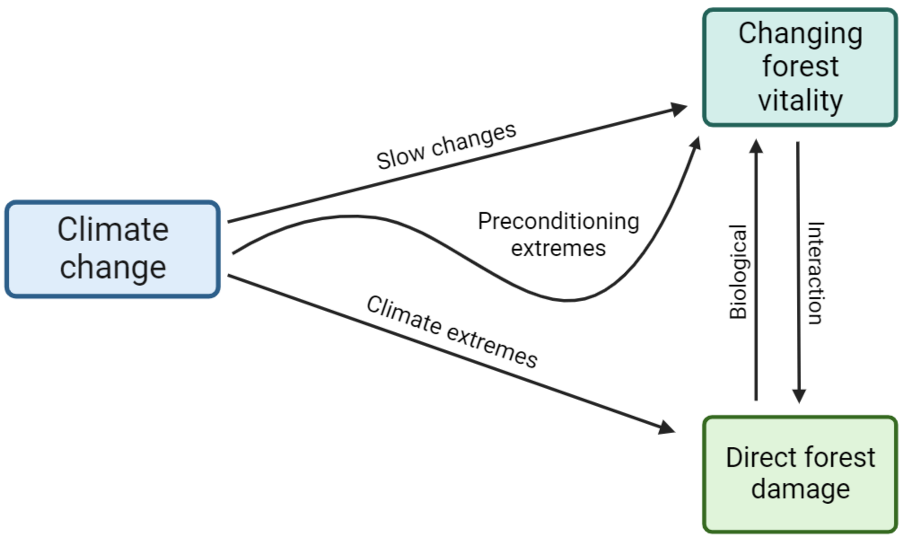

Figure 1 illustrates the multifaceted concept of relationships between climatic variables, tree species responses, and ensuing impacts on forest health. Adapted from Schlyter et al. (2006).

2.2 Restoration ecology and desired state

2.2.1 Restoration ecology

The intricate interplay between ecological restoration and societal perspectives constitutes a central theme in contemporary ecological discourse. Hagen et al. (2002) underscores diverse definitions of restoration and advocates for a 'desired state' (depicted as wishes and visions for potential pathways in this study) as an essential referencing point in defining restoration goals, and that the goal for restoration ecology (RE) is to establish a predefined state in a given site or landscape (Hagen et al., 2002). The distinction between social and scientific (e.g., ecological) value is challenging. Acknowledging that societal values constitute the bedrock of restoration, scientific values would then serve as a subsection of these values. While the effect of restoration is of ecological terminology, the criteria for a 'desired state' cannot solely derive from an ecological analysis of the landscape, but one must refer to the desires of stakeholders or a community as well (Hagen et al., 2002). Meaning that the multifaceted nature of restoration demands an understanding that extends beyond ecological parameters, integrating the nuanced desires of various stakeholders.

The importance of forests transcends to a pivotal role for both private and public actors. Presently, 88% of Norway's forests are privately owned, with an average of 5.4 daa, and the majority is represented in the Norwegian forest owner's federation (Norges skogeierforbund). The federation comprises 8 cooperatives providing forestry management services to the private owners and exerting control over the forestry industry in Norway (*The Norwegian Forest Owners Federation*, 2014; *Norwegian forests - Policy and Resources*, 2007). Forests serve as invaluable contributors of goods and services, providing sustenance for landowners and benefiting the society as a whole (Haugen, 2016; Kindstrand et al., 2008;

Sandström et al., 2011). In navigating the intricacies of the multiple roles of forests, effective forest management and decisions lies in understanding the objectives of forest landowners. These objectives, rooted in diverse perspectives, encompass values, beliefs, and attitudes, collectively constituting the dimensions of human cognition (Ní Dhubháin et al., 2007).

2.2.2 Ecological character and Limits of acceptable change

Within the context of our study, focused on restoration of deciduous forests, the concept extends beyond a simple return to historical conditions. Instead, the desired state is carefully defined visions shaped through collaboration among private and public stakeholders. The realization of this vision is constrained by various factors, encompassing biological intricacies and social barriers within an even broader system: The socioecological framework.

While the aspiration for a "desired state" in forest restoration, it is crucial to recognize the inherent limitations and challenges within the socioecological system, bringing us to the concepts of *"ecological character"* and *"limits of acceptable change".*

The foundation of an adequate understanding of ecological sites, in our case forests, necessitates a thorough comprehension of their ecological character (EC). As proposed by the Department of Sustainability, Environment, Water, Population and Communities in Australia (*Limits of acceptable change - Fact sheet*, 2012), studying the EC would offer baseline information crucial for effective forming of management strategies. Based on the best available quantitative knowledge (e.g., monitoring programs, scientific papers, technical reports, but also indigenous leaders, and oral stories may be relevant as well), 'limits of acceptable change' (LAC) act as a tool for evaluating alterations in EC. LAC emerges as a valuable mechanism to assess, monitor and maintain the EC of a given site, potentially aid to preserve the many species dependent on habitats represented in e.g., boreal forests (Angelstam & Mikusinski, 2001).

2.2.3 Human cognition and values

As elucidated by numerous studies (Eriksson, 2012; Ives & Kendal, 2014; Ní Dhubháin et al., 2007), understanding these dimensions of cognitive recollection is instrumental in deciphering the intricate interaction factors of forest management. Managers and policymakers can derive valuable insights into the rationale behind management decisions, thereby fostering an environment of informed decision-making. Furthermore, this nuanced approach of understanding facilitates the maximization of acceptability for proposed management actions and policy initiatives. By investigating the perspectives of forest landowners, stakeholders can proactively identify and address potential conflicts, promoting a collaborative approach to forest management that aligns with the diverse needs of the community. Insights derived from this investigation would unveil drivers and the consequential impact, their actions have on the future forest use (Häyrinen et al., 2017; Lindahl & Westholm, 2012).

Human cognition, often a neglected area of research, assumes heightened significance in this context. A deeper understanding of the cognitive dimensions is essential, particularly given that values, as the most stable form of human cognition, underpin people's behavior and action. This comprehension is vital for understanding their viewpoint and, consequently, how natural resources should be used, experienced, and managed (Ives & Kendal, 2014; Jones et al., 2016).

Values, defined as beliefs about desirable end states or conduct (Jones et al., 2016), serve as the foundation for both beliefs and attitudes. Beliefs represent thoughts and opinions, while attitudes involve positive or negative evaluations (Jones et al., 2016; Nordlund & Westin, 2011). These cognitive elements interact in a hierarchical manner, forming an inverted triangle (Figure 2). At the base, values are few, stable and change slowly, influencing other forms of cognition, such as beliefs, attitudes, norms, and behavioral intentions. Behaviors at the top are numerous and change rapidly (Jones et al., 2016). Theoretical distinctions exist, but in practice, values, beliefs, and attitudes are closely related and may be used similarly. Studies on cognition reveal group differences in values, with multiple pathways connecting values, beliefs, attitudes, and behaviors toward ecosystems (Ives & Kendal, 2014).

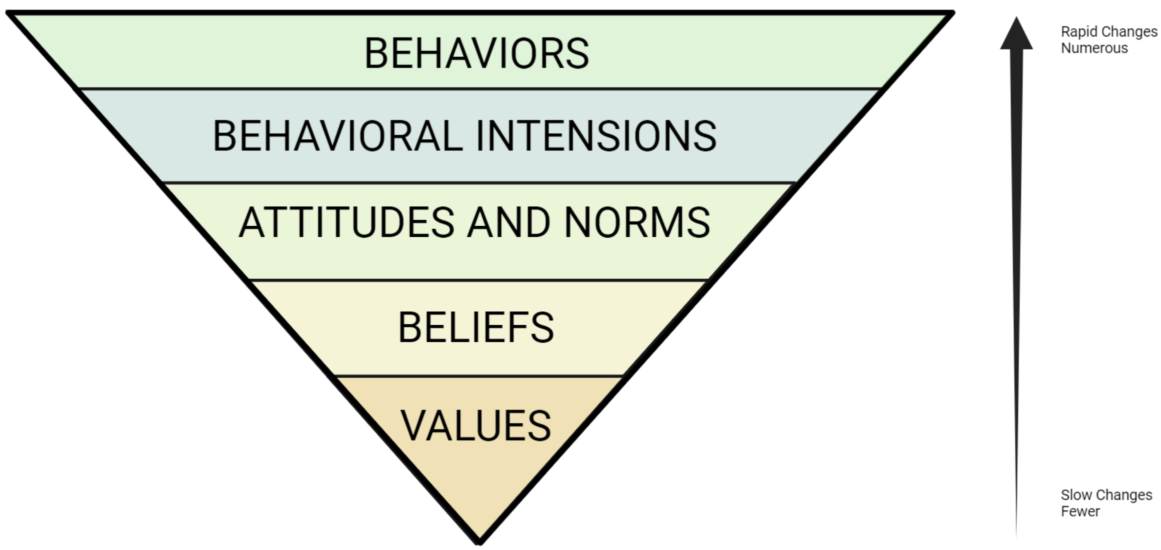

Figure 2 Cognitive hierarchy model of human behavior. Behaviors and concepts toward the top changes rapidly and are numerous, compared to those toward the bottom. Adapted from Ives and Kendal (2014), Jones et al. (2016) and Berger (2018).

Chapter 3

Methods

3.1. Study Area

This study explores both the social and ecological system of boreal forests in southeastern Norway, where two sets of data were collected and analyzed: (I) Quantitative analyses of tree species data collected from 4 privately owned forests, and (II) qualitative analyses of landowners' perspectives toward forest ecosystem management, in addition to identifying their wishes and perceptions toward forest values and future usage retrieved by questionnaires and interviews. The study was conducted as two-part research, covering both private and public forestry sector. This part aims to showcase landowner's perception on reforestation of deciduous forest, and problems associated with it.

There are four study sites (area 1-4) located in Moss municipality in Viken county, seen as suitable for this study. Viken county is located southwest in Norway, along the Oslo fjord within the boreonemoral zone. The county has varying nature with a particularly large species richness. The geographical location of Viken means that the county is especially vulnerable to new diseases and to the introduction of foreign species, which could potentially displace the current flora and fauna of the county (*Biologisk mangfold*, 2023). Additionally, between 2010 to 2015, 3.600 daa of forest and outfields were degraded to housing and pastures, in such way that the remaining areas have become threatened (*Biologisk mangfold*, 2023). The selection of oak trees as the focal point of this study is intricately tied to Moss municipality's geographical location, characterized by fertile soil and a diverse array of broadleaved trees. Oak trees emerged as a species of particular significance within this context. The municipality, emphasizing nature preservation and eco-friendly management in green spaces like parks, woodlands, and meadows, has a pronounced commitment to these principles. Notably, Moss also actively promotes the facilitation of hollow oaks, as articulated on their official website (*Kartlag forklaringer - mer natur på kommunens eiendommer*, 2023).

The four sites, each spanning from 5 – 20 daa, were selected based on their seemingly uniform quality and size, exhibiting consistent elevation at approximately 70 meters above sea level (Retrieved from *hoydedata, laserinnsyn*, 2023). The choice of sites was made due to their homogeneity, ensuring a comparable research environment. Clear-cutting activities varied across the sites, with three sites undergoing the process in 2021 and one in 2020 (Table 1). Geological attributes within the areas featured layers of marine deposition, categorized into thin layers (< 0.5m (43)) and thick layers (> 0.5 m (40-41) (Retrieved from *Løsmasser - Nasjonal løsmassedatabase*). The production level ranged from medium to high, as determined by data from *Arealinformasjon* at Kilden.no (Figure 3).

The sites had not undergone artificial fertilization, soil preparation, scarification, thinning of non-commercial deciduous trees or any other silviculture activities post clear-cutting. These consistent conditions and their location contribute to the specificity required for establishing deciduous forest in Moss.

Table 1 The study sites in Moss municipality and their characteristics.

SITE ID	*Area 1*	*Area 2*	*Area 3*	*Area 4*
Municipality	Moss	Moss	Moss	Moss
Available Area (daa)	8 daa	5.2 daa	10.7 daa	23.0 daa
Searched Area (daa)	4.5 daa	5.2 daa	5.1 daa	5.4 daa
Elevation (meters a.s.l.)	0-70 m	0-70 m	0-70 m	0-70 m
Forest type	Spruce	Spruce	Spruce	Spruce
Year of clear-cutting	2020	2021	2021	2021
Excavated materials	Various layers of marine deposition.	Various layers of marine deposition.	Various layers of marine deposition.	Various layers of marine deposition.
Productivity level	Medium	High, cultivatable land	High, cultivatable land	Medium

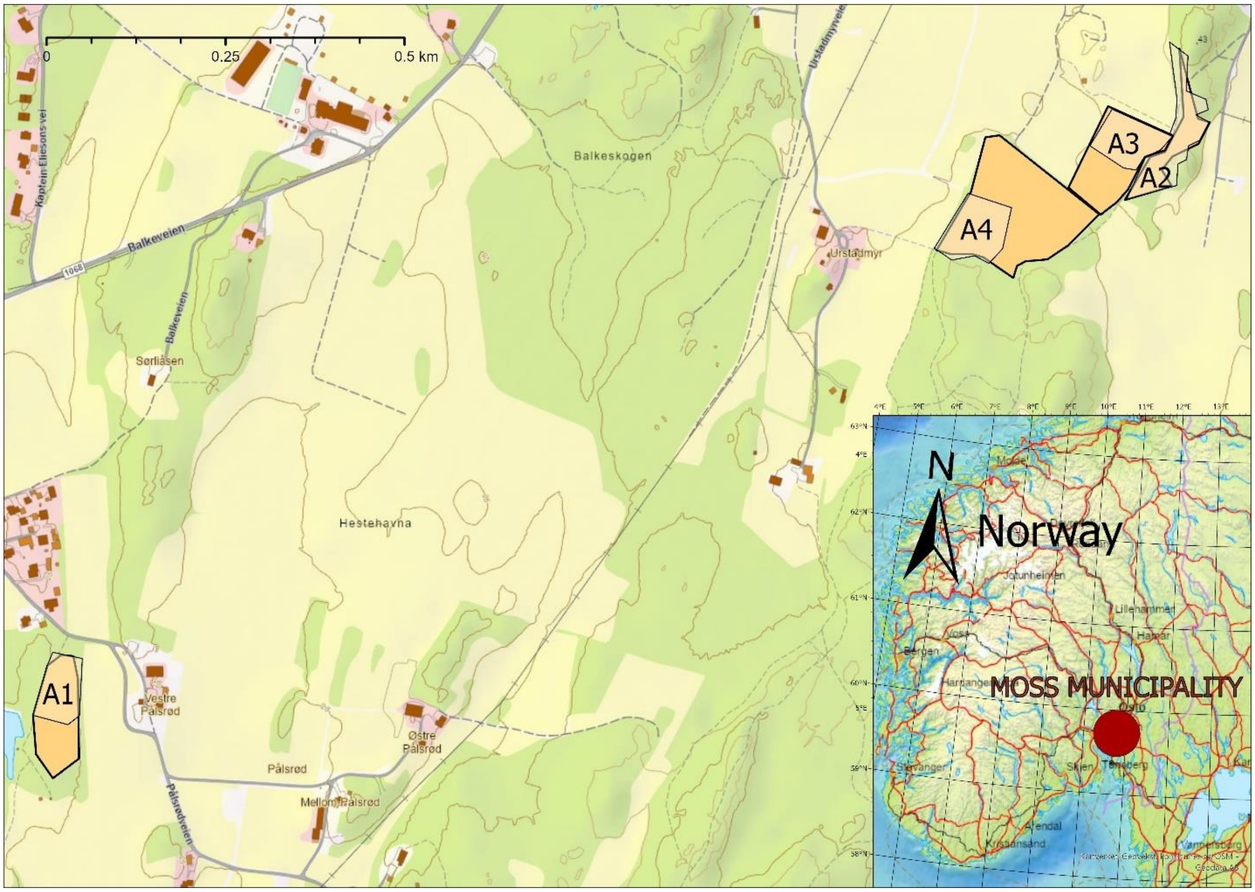

Figure 3 overview of study sites. Area 1 (A1) was clear-cut one year in advance compared to A2-A4. The light fields are the areas searched, while the darker fields are the available areas donated to this study.

2.1.1 The Post-war period

In the 19th century, forestry practices in Norway predominantly consisted of selective logging in form of dimensional logging. Dimensional logging entailed harvesting trees exceeding a certain size threshold, while smaller trees were deliberately left undisturbed. This approach led to the unintended consequence of degradation of productive forest in the country.

In the post-war period, as a part of Norway's comprehensive national reconstruction efforts, a substantial emphasis was placed on the restoration and expansion of the forest resources, entailing a collaborative partnership between forest owners (private sector) and the public sector, particularly the state. The result was a substantial afforestation initiative characterized by extensive tree planting, aiming to revitalize and augmenting the forests (*Bærekraftig skogbruk*, 2023). As of 2021 The total forest volume was three times greater than recorded in 1925 (*Rekordmye skog i Norge*, 2021).

During the interviews conducted with landowners, it was evident that the individuals engaged in agricultural activities did not identify as professional foresters. The majority possessed relatively modest forested holdings (groves), while currently maintaining extensive agricultural areas, including cultivation of crops and husbandry of livestock.

However, despite the historical context of fewer trees in the past, the aerial photos from 1955 present a seemingly paradoxical observation (Figure 4). For example, Area 1 stated that there was no forest in Moss before 1950s: *"A lot of the groves were originally infield grazing areas"* and "*Farmers do not have the tradition of forestry, they do not identify with it"*, reflecting on a shift in the amount of forested land and agricultural usage, and other landowners sharing that the first logging activities occurred between 1960 and 1970. Area 2 and 3 also mention a remarkable productive soil that could explain the significant growth in the trees throughout the decades, which potentially indicate an alteration in the afforestation initiatives, evolving forest management practices over the decades, and the cultivation efforts.

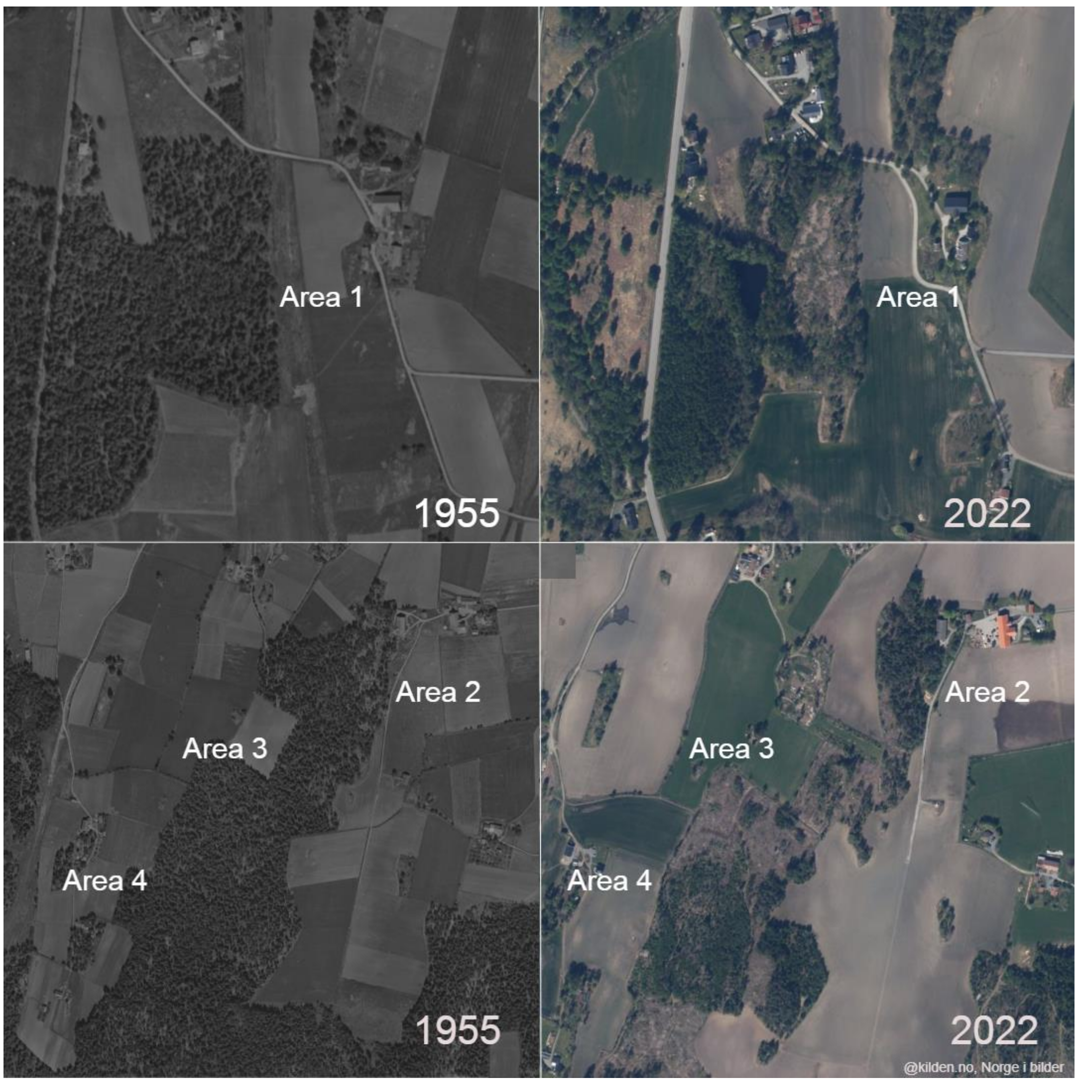

Figure 4 Aerial photo of the four areas within this study. The photos illustrate the differences between 1955 and 2022 and could potentially indicate a shift in management and usage of the areas.

3.2 Experimental design

To gain insights into the composition of plant community within the forests, it was imperative to gather information on both the abundances and species richness. The data collection process focused on two categories of tree species: target species (TS) – broadleaf species of deciduous forests that could potentially grow in the areas - including Oak (*Quercus spp*.), Beech (*Fagus sylvatica*), Linden (*Tilia cordata*), Ash (*Fraxinus excelsior*), Elm (*Ulmus glabra*), along with non-target species - frequent species that are not 'target species' – which encompassed Norway spruce (*Picea abies*), Birch (*Betula spp*.), Rowan (*Sorbus aucuparia*), and Red elderberry (*Sambucus racemosa*).

Recognizing that these communities often exhibit variation based on physical features like topography and floristic differences, a stratified sampling approach was employed. Transect walks were systematically conducted, with each transect spanning a width of 5 meters. Search areas on either side of the transects extended 2.5 meters, as illustrated in Figure 5. Along these walks, various measurements were recorded for non-target species found within a grid frame: the measurements comprised of height (above ground to the tip of leaf/shoot), and width (on the widest part of the stem above the ground). For Norway spruce, measurements included width, height, and number of seeds and tree cones if found.

In the case of target species, a comprehensive set of parameters was documented:

(I) Height,
(II) Width,
(III) Number of branches (categorized as 0 – 20 and >20),
(IV) Color of the leaves (classified as green, yellow, brown, white),
(V) The count of seeds and tree cones, in addition to identification of seed/cone species.
(VI) The extent of browsing on shoots and leaves.

This systematic approach to data collection allowed a thorough examination of both targeted and non-targeted species, contributing to a robust understanding of the forests plant community dynamics.

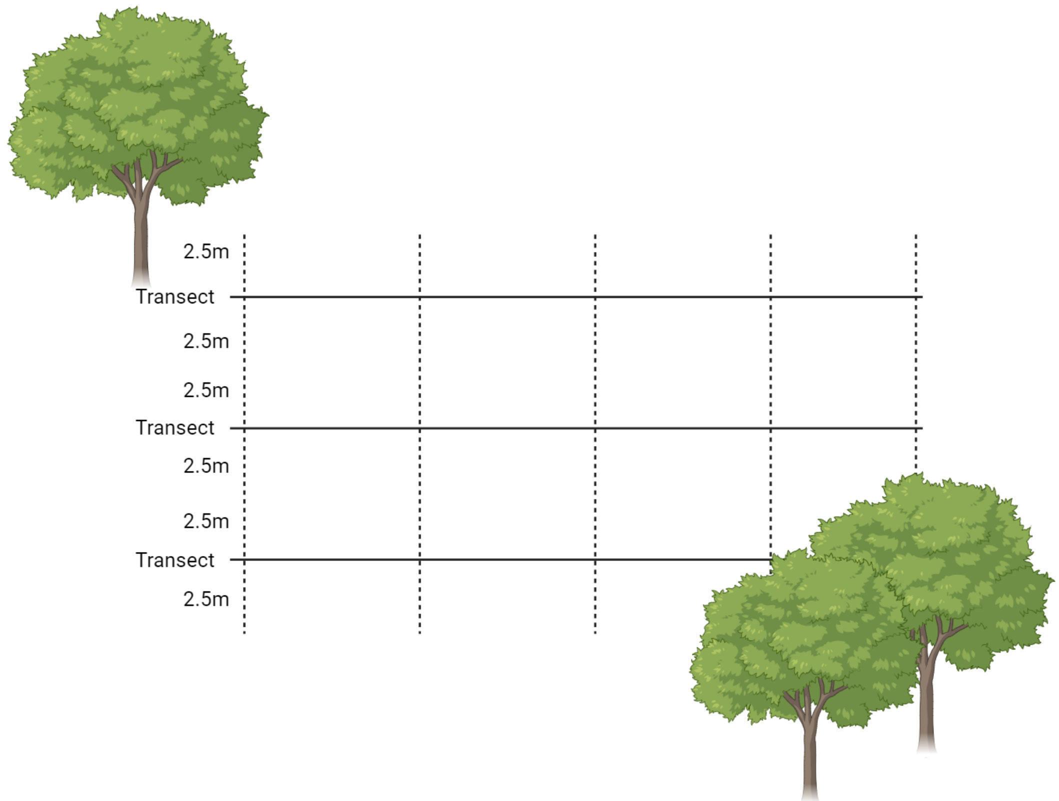

Figure 5 illustration of transects. It was five meters between the transects, and for each side of the transect, 2.5 meters were searched to cover the whole area.

The assessment of forest ground composition was conducted utilizing the point intercept method employing a standardized square frame (also called a "*grid frame*" or "*quadrat*"), specifically a quadrat measuring 50 cm x 50 cm. Data conducted for point intercept typically represents the abundance of, in this case, points, where the vegetation and species intersects the grid within the grid frame (Caratti, 2006; Jonasson, 1988). Positioned approximately 36cm above the ground in proximity to each identified TS, the grid frame facilitated a comprehensive examination of the vegetation. To ensure thorough coverage within the grid frame, a 5 mm in diameter pin, constructed from a long metal pole sharpened to create a "point", was strategically placed in each corner and the midpoint of the grid frame, as illustrated Figure 6. This method allowed the quantification of various vegetation types present in the plant community.

During data collection, each point of intersection between the pin and the vegetation type or ground cover within the grid frame was documented as a "hit" (Table 2). Additionally, the abundance for every 'non-target' species competing with TS inside the grid frame was recorded. For TS exceeding the grid frame size (> 36), they were classified as 'trees', and only visual measurements were taken, encompassing height, width, number of branches, color of leaves, and evidence of browsing. In this study, browsing will be described, in context of forest damage, as feeding damage involving removal of twigs, shoots and leaves from young oak trees. A detailed protocol for the experimental design is provided in *Appendix 7.1 Protocol for Experimental Design* for further clarity.

Table 2 Groups of species (Norwegian and English names/terms) registered in the quadrat and their definitions.

Norwegian terms for groups of species found	**English terms for groups of species found**
strø	Dead vegetation on ground
graminider	Herbaceous plants with grass like morphology (Graminoids)
andre karplanter	Other vascular plants
eik	Oak (*Quercus spp*.)
bøk	Beech (*Fagus sylvatica*)
bjørk	Birch (*Betula spp*.)
rogn	Rowan (*Sorbus aucuparia*)
rødhyll	Red elderberry (*Sambucus racemose*)
furu	Pine (*Pinus ssp*.)
gran	Spruce (*Picea abies*)
bregner	Ferns (class Polypodiopsida)
mose	Bryophytes
lav	Lichens
bringebær	Raspberry (*Rubus idaeus*)
blåbær	Blueberry (*Vaccinium myrtillus*)
tyttebær	Lingonberry (*Vaccinium vitis-idea)*
jord	Soil

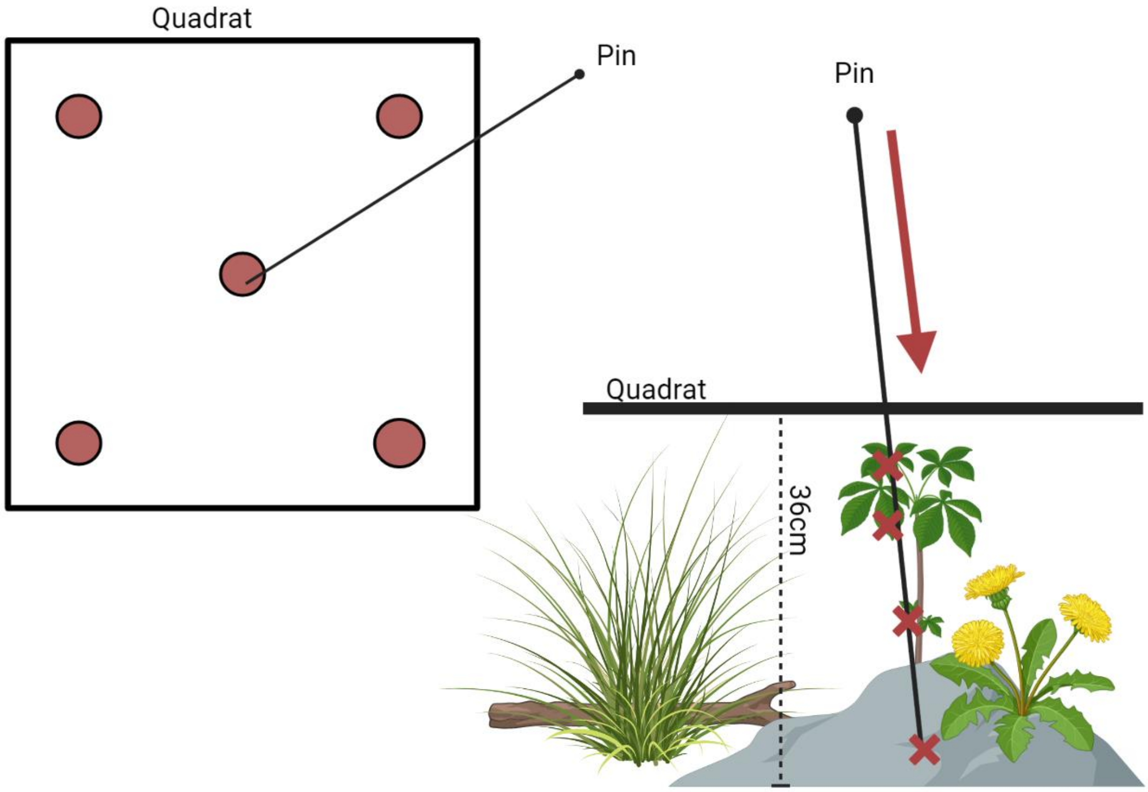

Figure 6 illustration of quadrat registration. A representative picture of the ground coverage can be done by using a pin and pointing it vertically in the four corners of the quadrat, including the middle, counting all the hits (X in the illustration) and determine the species (or group of species) hit.

3.4.1. Species within the areas

For species within the areas of this study, a summarized table of the mean and SD of the data collected was synthesized using RStudio (2023.03.0+386 "Cherry Blossom"), facilitating an overview of the vegetation composition within the areas. A similar approach was applied to both the height and width of oak trees to achieve an overview of the oaks growing.

By assuming that the density in the 'searched area' (SA) is representative for the entire 'available area' (AA). The sizes of areas in this study are given in acres (daa), thus the formula for density per AA is:

$$Density\ per\ Available\ Area = \frac{Density\ per\ Searched\ Area}{(Size\ of\ Searched\ Area\ /\ Size\ of\ Available\ Area)}$$

To determine the density per SA, the initial step involved calculating the density for each species per transect within the respective areas. Subsequently, the individual species densities were summed up to obtain the total density per SA. The integration of this density data with size-related information concerning AA and SA allowed for the computation of density per AA. This provided a comprehensive understanding of the total area for each landowner in relation to species density.

Additionally, for geographic representations and spatial analyses, ArcGIS Pro (version 3.1.3) was employed. Heatmaps depicting the distribution of oak trees across the SA were generated by Aksdal (2023)as a part of her thesis.

3.4.2 Observed sickness.

Powdery mildews, *Erysiphe alphitoides* (formely *Microsphaera alphitoides*), are characterized by spots or patches of white powder-like film on top of the leaves. It is one of the most widespread plant diseases, with severe cases in warmer and dryer climates (Newman & Pottorff, 2013). During fieldwork we **observed severe cases of powdery mildew** on both young and full-grown oak trees. Therefore, a **literature review** was conducted (Table 3), including emailing relevant people of silvicultural management regime to investigate the sickness observed on oak trees in Norway.

Table 3 Overview of some literature found conducting a literature review for powdery mildew on oak.

Searchable databases	**Search words (and combinations)**	**Number of documents found and read**	**Article sited in this study**	**Inclusion/exclusion criteria**
Google scholar	"Powdery mildew" & "oak growth"	3	Hajji et al. (2009)	Talked about how the powdery mildew could possibly reduce transpiration and photosynthesis of oak trees
			Hewitt and Ayres (1976)	Effect on powdery mildew on CO2-levels and translocation in seedlings of oak trees.
	"Biotrophic pathogens" & "oak"	1	Marçais and Desprez-Loustau (2014)	Powdery mildew, its effect on oak, and the potential climate effect.
Google	"Powdery mildew"	1	Newman and Pottorff (2013)	Powdery mildews in general.

For the **relative abundance** of healthy and infected trees (health status) we **summarized the mean (μ) and SD**. In this case, health is defined by oak trees' leaf colors and the proportion of coloration on each leaf. To be categorized as healthy, oak trees had to be noticeable green, without fields of yellow, brown, or white. To be categorized as sick, oak trees had to be noticeable yellow, brown, or white (7.1 Protocol for Experimental Design). Knowing the mean (μ) heights and widths of the oaks from the different areas, a limitation of the height and width (height = 80 cm, width = 3cm) was added to the scatter plot (interchangeably for all plots done) to narrow the focus of this study.

In order to thoroughly examine the impact of health status on oak tree density across distinct areas, a **generalized linear model (GLM)** was employed as the analytical framework (For detailed information about variables see *Table 4 Overview of variables used when conducting GLM models)*. The GLM used a **Gaussian family** due to its compatibility with the continuous nature of oak tree density data. Diagnostic assessments, **including Q-Q plots and histograms of residuals** were generated for the model to evaluate the normality of residuals and visually represent the distribution. To address deviations from normality indicated by a 'U'-shaped pattern in the Q-Q plot, a transformation of variables was explored. Note that for oak density, which is a count per unit area (daa), square root transformation was deemed more appropriate than logarithmic.

Table 4 Overview of variables used when conducting GLM models.

Variable		**Index**	**Description**	**Transformations**
Response	Numeric	Oak_Density	Number of oak trees found along transects (n) for each area (daa)	sqrt
Explanatory	Numeric	Overall_Browsing	Browsing from both insects and vertebrates along transects (n) for every area (daa)	
	Categorical	Health_status	Health of oak trees found along transects for each area. 3 levels: healthy (1), intermediate (2), sick (3)	
	Numeric	Biomass	Summed and grouped vegetations hits from PI on oak findings	
	Factor	Area	Area identifier (1-4)	

3.4.3 Point intercept

For the **relative abundance** of vegetation cover we **summarized the mean (μ) and SD** for each group of species found (7.1 Protocol for Experimental Design).

3.4.4 Browsing Behavior of Ungulates

Throughout the fieldwork, instances of browsing on targeted species and the presence of ungulates were actively observed. Signs such as footprints, rut pits, fur, and live animals in the fields were documented (Figure 22). Landowners have reported severe roe deer browsing, to the extent that establishing oak forests in Moss municipality has proven challenging, with one landowner abandoning such endeavors. To further investigate into this issue, a comprehensive literature review was undertaken (Table 5).

Table 5 Overview of some literature found conducting a literature review for browsing on oak.

Searchable databases	**Search words (and combinations)**	**Number of documents found and read**	**Article sited in this study**	**Inclusion/exclusion criteria**
Google scholar	"Browsing by roe deer on oak"	10	Birkedal (2010)	Looking at possible pathways to increase broadleaved forests
			Dobrowolska et al. (2020)	Oaks planted in between pine trees and the effect that has on browsing
			Bergquist and Örlander (1998)	Browsing damage by roe deer on Norway spruce seedlings planted on clearcuts of different ages
			Boulanger et al. (2015)	Decreasing deer browsing pressure influenced understory vegetation dynamics over 30 years
			Chevrier et al. (2012)	The oak browsing index correlates linearly with roe deer density: a new indicator for deer management?

		Cilles et al. (2016)	A Comparison of Seed Predation, Seed Dispersal, and Seedling Herbivory in Oak and Hickory Species with Contrasting Regenerating Abilities in a Bluegrass Savanna–Woodland Habitat
		Gill (1992)	A Review of Damage by Mammals in North Temperate Forests
		Van Hees et al. (1996)	Growth and development of silver birch, pedunculate oak and beech as affected by deer browsing
“Browsing increase sickness” & “oak”	5		

For the **relative abundance** of browsing, we **summarized the mean (μ) and SD** by grouping the portion of browsing to a binary variable (browsed and not browsed) (7.1 Protocol for Experimental Design).

Similar to the assessments of health status and biomass, we employed a parallel approach to evaluate **the relationship between oak tree density and browsing** (Table 4). The resulting model exhibited a residual deviance of 4.22 and an AIC of -45.89. The data did not deviate from normal distribution. This model demonstrated a lower deviance and AIC, indicating that a **GLM model with Gaussian family** would be a better fit compared to e.g., gamma model (residual deviance of 27.07, AIC of -134.7, please see appendix: *7.4 GLM-model Fit with Q-Q Plots and Histograms* for more information).

With the use of browsing as a binary variable, we **visualized the summarized mean (μ) and SD counts of vertebrates, insects, and both browsing events for each area**, providing insights into the distribution of browsing patterns across different regions.

Additionally, chi-squared tests were conducted to compare the numbers of vertebrates and insects, shedding light on potential significant differences in browsing behavior between the portion of vertebrates and insects.

Furthermore, our exploration included a focus on browsing events related to leaves and shoots by vertebrates. By **visualizing summarized mean (μ) and SD incidents of leaves, shoots, and both browsed only by vertebrates**, we could offer a comprehensive view of browsing patterns.

To explore the **association between mean height of oak trees ('Mean_Height')** and two predictor variables: The **mean number of browsing events** on oak trees across the different areas ('Mean_Overall_Browsing') and the **areas ('Area' as factor)**, a similar approach as of sickness on density was executed. The QQ-plots and histograms of residuals encompassed almost linearity of the **gaussian GLM model**. A **logarithmic transformation** of mean height addressed a linear QQ-plot and a histogram centered around zero, indicating better fit compared to the original gaussian and gamma models without transformations.

3.3 Description of the landowners

Before delving into the perspectives of landowners concerning the restoration of deciduous forests, it's sensible to consider the lens through which the local population, in this case, the landowners, might view the concept of restoration. In accordance with insights from Hagen et al. (2002) and Aasetre (2000), the inclination of the local population often leans towards a more 'use-oriented' perspective when it comes to restoration efforts.

For the purpose of formulating restoration goals and envisioning the desired future condition of Moss municipality's forests, a relevant group of four landowners, who generously offered their land for this research, take center stage in our study. The group consisted mostly of male landowners apart from one female landowner in Area 1, representing different professions. Three out of four landowners hold higher educational qualifications, with one individual (Area 3) boasting forestry-based education or related fields such as agriculture.

Beyond their role as forest owners, each landowner was involved in other businesses, including agriculture in various forms. For instance, their involvement extends to leasing their property (Area 1 and 4), cultivating vegetables (Area 2) and raising livestock (Area 3). An intriguing facet arises in Area 2, where economic dependency on agriculture from their property is reported, setting it apart from the other areas (Table 6).

Table 6 Personal information including forest property information regarding each of the four landowners suitable for this study.

SITE ID	*Area 1*	*Area 2*	*Area 3*	*Area 4*
LANDOWNER ID	Area 1	Area 2	Area 3	Area 4
GENDER	F	M	M	M
AGE	45-54	55-64	35-44	60+
PROFESSIONS	Scientist (University)	Farmer (Vegetable)	Land management (municipality)	Farmer (Retired)

ADDITIONAL FORESTRY EDUCATION	No	No	Yes	Yes
FOREST PROPERTY	Kept in family	Kept in family	Kept in family	Kept in family
FOREST MANAGEMENT PLAN	Yes	No	No	No
FOREST OWNER ORGANIZATION	Norwegian Forest Owner's Association / Norges Skogeierforbund	Unknown	None	Unknown
FOREST MANAGEMENT, usage of entrepreneurs	Glommen/Mjøsa	Glommen/Mjøsa	Glommen/Mjøsa	Glommen/Mjøsa
FOREST CERTIFICATION SCHEME	Program for the Endorsement of Forest Certification (Program for Godkjenning av Skogsertifisering)	Unknown	None	Unknown
ADDITIONAL BUSINISSES	Yes	Yes	Yes	Yes
TYPE OF AGRICULTURE	Leasing the property	Vegetables	Livestock	Leasing the property

Gender is listed as M for male and F for female.
No answer is listed as 'Unknown'

3.4 Landowners perspectives through interviews and questionnaires

Qualitative methods: interviews and questionnaires were used to explore the different perspectives and wishes of five forest landowners within the same experimental design. According to Tjora (2012), the usage of interviews is supposed to give a deeper understanding of opinions, attitudes, and experiences. Open questions are essential, allowing digressions and reflections, which one otherwise would not have thought of. In-depth interviews can be used for contexts beyond knowing the context of informants as individuals.

The data collection, from both surveys and interviews conducted in person, were in Norwegian language (native language for all landowners). The process of collecting the data started with two informal meetings at one of the field sites (Area 2 and 3 in Figure 3) earlier the same year as the experimental design were conducted (2022). The meetings were to delimit the study sites and to decide on the protocol for ecological studies (see appendix: 7.1 Protocol for Experimental Design).

Additionally, questionnaires would act as a supplement to broaden the understanding of the interviews Comprising fundamental inquiries pertaining to personal details, forest property specifics, and information regarding management plans, certification, and forest owner organizational affiliations, the questionnaire delved into multifaceted aspects of forest ownership and management.

A distinctive feature of the questionnaire involved incorporation of visual stimuli, adding a more nuanced layer to landowners' responses. Six carefully curated forest stand images, each encapsulating five unique underlayer characteristics and six different forest stand types, were presented to the landowners for evaluation. The imagery aimed to elucidate their preferences and choices regarding different forest ecosystems. Landowners were then tasked with the engaging exercise of ranking these images from 1 to 6 (Figure 7).

The images utilized in the questionnaire were adapted from a prior study examining underlayer characteristics and their impact on forest preferences in southern Norway (Nielsen et al., 2018). This strategic selection ensured a scientifically grounded approach, leveraging insights from existing research to enhance the relevance and precision of the questionnaire.

The questionnaire was structured to be completed within an estimated 15-minute time frame, acknowledging the valuable time and input of the participating landowners. For detailed look at the questionnaire, please refer to Appendix: 7.2 Questionnaire for The Landowners.

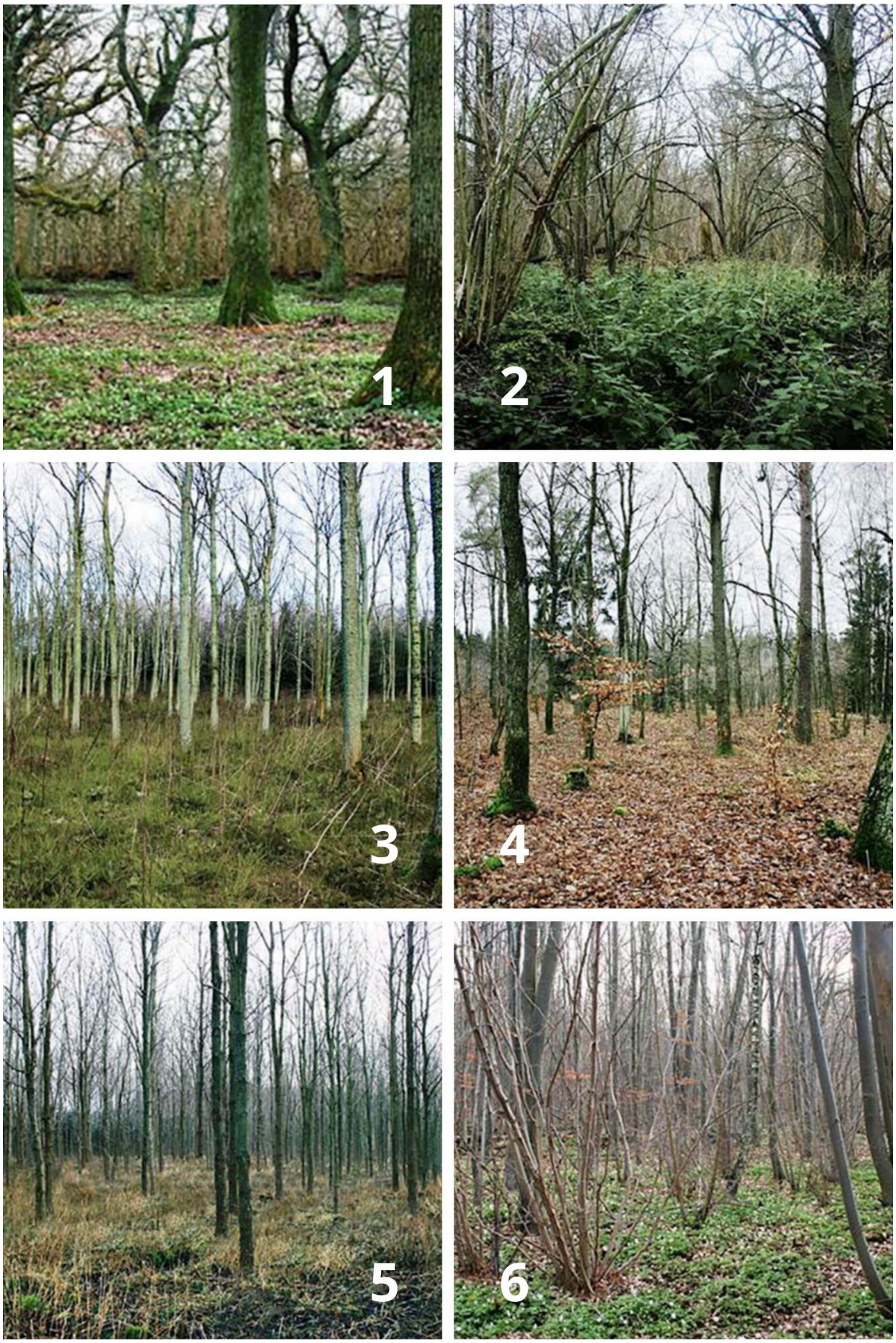

Figure 7 presents six distinct images that were shown to landowners through the questionnaire to capture their perspectives on forest dynamics. The first image (1) depicts a forest of mature oaks with an underlayer of anemones. The second image (2) portrays mature oaks with a rather rough under layer. The third image (3) features mid-aged oak with grass, and the fourth picture (4) encompasses mid-aged oak mixed with litter. The fifth picture (5) displays young oak with withered grass, while the sixth picture (6) showcases young oak with anemones.

The interview guide consisted of mostly open questions referencing back to the questionnaire, but with more in depth regarding current forest management preferences, managing timber and ungulate production, effects of roe deer browsing, managing ecosystem services, and perceptions toward future forest use and potential pathways (Appendix: 7.3 Interview Guide for The Landowners). Landowners were asked to discuss and elaborate questions from the interview guide, while still pursuing a natural course of the conversation where additional questions were asked (if necessary). Depending on the individual, some questions were not asked during the interviews due to not being relevant for the respective landowner and the flow of the interview. The interviews were one and a half hours in length. After this, interview responses were translated into English and further approved by the landowners to assure that the translations were correct, and the meaning was kept. Answers were examined for additional questions of interest. Landowners were able to provide necessary amendments.

The questionnaire as well as the interviews were a voluntary process, and the forest landowners were assured that the data and their identities that they provided would remain semi-anonymous. The landowner's contribution of property could potentially divulge their identity. Throughout the paper their names were omitted, but one cannot deny that names and identity could be known having their property on display in this study. All 4 landowners participated in the study involving the questionnaire and interview. Responses were individually reviewed before collectively finding similarities used in the results. Note that analyzing the data in relation to socio-economic aspects is beyond the scope of this study.

To analyze the interviews, we employed a step-by-step approach, blending inductive and deductive methods known as the Stepwise Deductive Induction (SDI) method (Tjora, 2012). This strategic choice aimed to prevent premature conclusions while maintaining a systematic and robust analytical process. Following Jacobsen (2005) recommendations, we adopted a predominantly inductive strategy to explore new knowledge on topics with limited prior understanding, such as querying landowners about forest management. Simultaneously, we incorporated deductive elements by addressing predefined themes like ungulate conflict and climate change.

The analysis involved extracting the essence of the interviews and condensing the data volume to facilitate idea generation based on the interview content. The creation of "in-vivo" codes played a crucial role in the inductive phase, with codes generated in real-time during interview readings. We aimed to keep the codes as empirical as possible while accurately reflecting the interview content (Table 7). Notably, this entire analytical process was conducted manually, without the assistance of any automated software.

This meticulous methodology allowed for a comprehensive and nuanced analysis of the interview data, providing a rich understanding of the diverse themes emerging from the landowners' perspectives on forest management, ungulate conflicts, and climate change.

Table 7 Overview of groups created while analyzing interviews. The table showcases 32 themes within 5 groups encompassing the intricate system of this thesis.

Groups	**Themes**	**Areas that have mentioned it**
Forest management	Management of property	1-4
	Financial benefit	1-4
	Forest information	1-4
	The value of the forest	1-4
	Forest management	1-4
	Forestry information	1-4
	Public management	1, 3, 4
	Conflicts with public management	1, 2, 4
	Usage of forest resources	1-4
	EU-directives	1, 2
	Living situation and other personal information	1, 2, 4
Nature	Wildlife in Moss	1-4
	Ecological aspect	1-4
	Historic perspective of the areas	1, 2, 4
Hunting	Conflicts with roe deer	1-4
	Conflicts with moose	1-4
	General ungulate conflicts	4
	Ungulate management (hunting in particular)	1-4
	Utilization of hunting quota	1-3
Future forest	Management of the landscape	1, 2, 4
	Research related	1-4
	Sustainable thinking	3
	Help manage the future forest	1-4
	Available schools and knowledge	1, 2, 4
	Wishes and thoughts for the future forest	1-4
	Time perspective	4
	Transformative change	1
Potential threats	The public	2, 4
	Pests and sickness	1-4
	Invasive species	2-4
	Cabin development	4
	Climate change	1-4

Chapter 4

Results

4.1 Forest composition

4.1.1 Species within the areas

The study covered four distinct areas, showcasing a variation in the number of species found per grid frame, ranging from a minimum of one individual per species to a maximum of 356 individuals per species. Notably some regions exhibited high numbers of individuals per species, while some areas demonstrated remarkably high species richness, with Area 2 featuring the highest count (n = 979), suggesting possible ecological diversity patterns (Figure 8).

Among areas, Area 1 had broader species composition than Area 2, 3 and 4, being the only area with both elm and birch in addition to beech, oak, spruce, red elderberry, and rowan, encompassing seven targeted species (TS). Despite its greater species variety, Area 1 contained the lowest total number of species found (n = 649). Area 2, in contrast, displayed the highest total number of species found (n = 979) with the highest occurrence of oak (n = 356), spruce (n = 281) and red elderberry (n = 326). Area 3 and 4, which are connected geographically, revealed the least variation.

Explicitly, Area 3 had the highest occurrence of spruce (n = 326), while Area 4 had the greatest occurrence of rowan (n = 20). Oak exhibited the highest mean (µ) at 271, despite initial expectations. Oak remained relatively consistent across the areas (standard deviation, SD: 73.8). Individuals of oaks were identified in all four areas examined during this study, and the observed counts notably exceeded anticipated numbers as well. Specifically, Area 2 yielded a total of 356 oak trees, while Area 4 exhibited 310 individuals. In similar vein, Area 3 contained 214 oak trees, and Area 1 boasted a count of 205.

In contrast, elm had the lowest mean (µ) of 1 (SD: 0), reflecting its rarity with only one occurrence in area 1. Spruce and red elderberry demonstrated a relatively high means (µ) of 237 and 217, respectively, but also exhibited greater variability across the areas (SD: 95.4 and 113.0). Birch and rowan displayed intermediate means (µ) of 6.33 and 14, with moderate variability (SD: 3.21 and 7.12).

Density assessments per available and searched areas revealed pattern variations. Oak density per available area, total size of the area (daa) used for this study, was highest within Area 4 (Available Area (AA): 10.21, Searched Area (SA): 0.44) and lowest in Area 1 (AA: 2.5, SA: 0.32). Beech density (AA: 0.00-0.26, SA: 0.00-0.03) was minimal across all the areas, and elm showcased negligible occurrence. Spruce density per available area was highest in Area 4 (AA: 7.74, SA: 0.33) and lowest in Area 1 (AA: 1.29, SA: 0.16) (Figure 10).

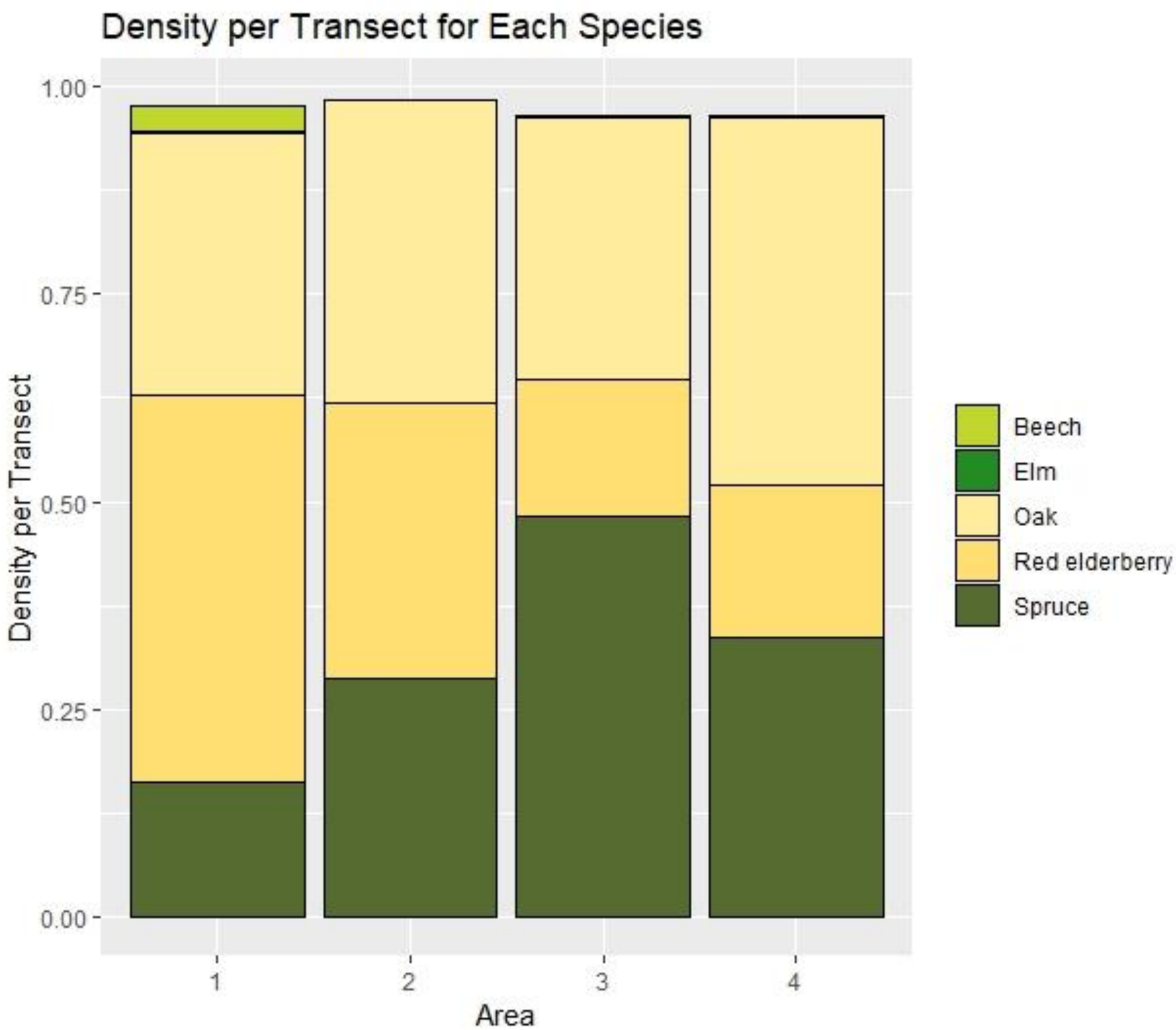

Figure 8 Tree species density within 'Searched Areas'. The density is calculated by the number of species divided by the size in acres (daa) of the respective areas (1, 2, 3 and 4). There are high occurrences of red elderberry, spruce, and oak.

In unraveling the intricate tapestry of forest composition and competition, our investigation delved into the distribution patterns of oak. A graphic distribution of the most prevalent species found across the unique areas includes three species: oak, spruce, and red elderberry. These maps offer a comprehensive overview, contribution to the interpretation of the subsequent heatmaps below (Figure 10). Field notes indicated a higher abundance of oak saplings than initially anticipated. Areas 1-4 exhibited varying numbers of oak trees in the buffer zone, potentially accounting for the observed oak occurrences within the areas (Figure 9). Further investigation is needed to determine the occurrence of oak saplings related to the buffer trees. Field notes displayed a noticeable tendency of oak saplings in grass (categorized as graminoids) and under red elderberry exhibiting richer, green leaves and less evidence of browsing compared to oak saplings in more open areas.

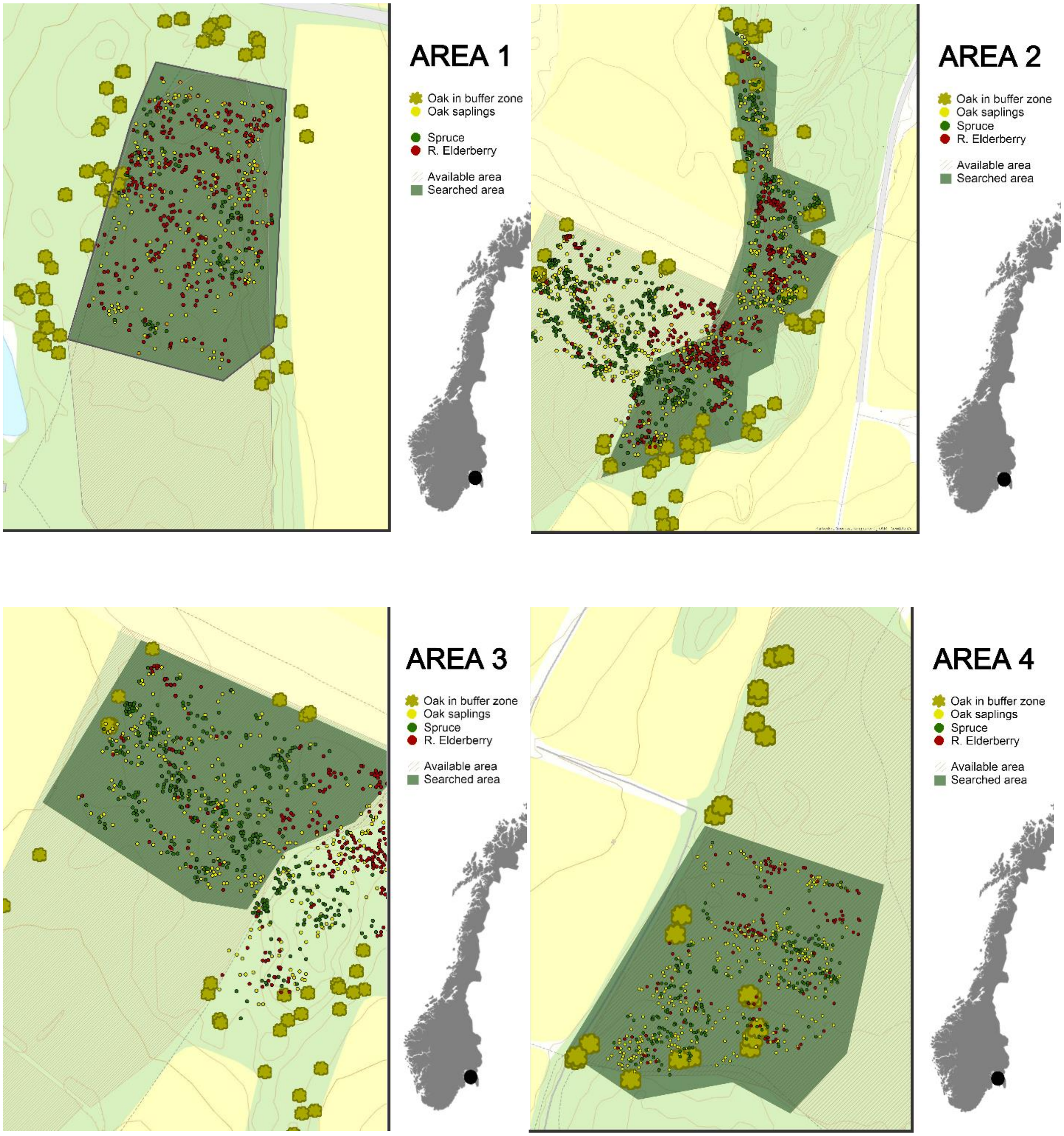

Figure 9 Occurrences of oak saplings within the unique areas (1-4), additional buffer trees (potential seed producing oak trees), together with occurrences of spruce and red elderberry.

By quantifying the density of oak trees- and dividing the number of oak trees per square meters (Sqm) at each site – heatmaps were generated for visual representation (Figure 10). The observed oak density exhibited a consistent range from 0.04-0.07 trees per sqm across the areas, accompanied by a slightly elevated occurrence of red elderberry (0.05-0.08 trees per sqm). Notably, our expectations were challenged by the unexpected density of spruce, ranging from 0.02 to 0.06 trees per sqm within the unique areas (Aksdal, 2023).

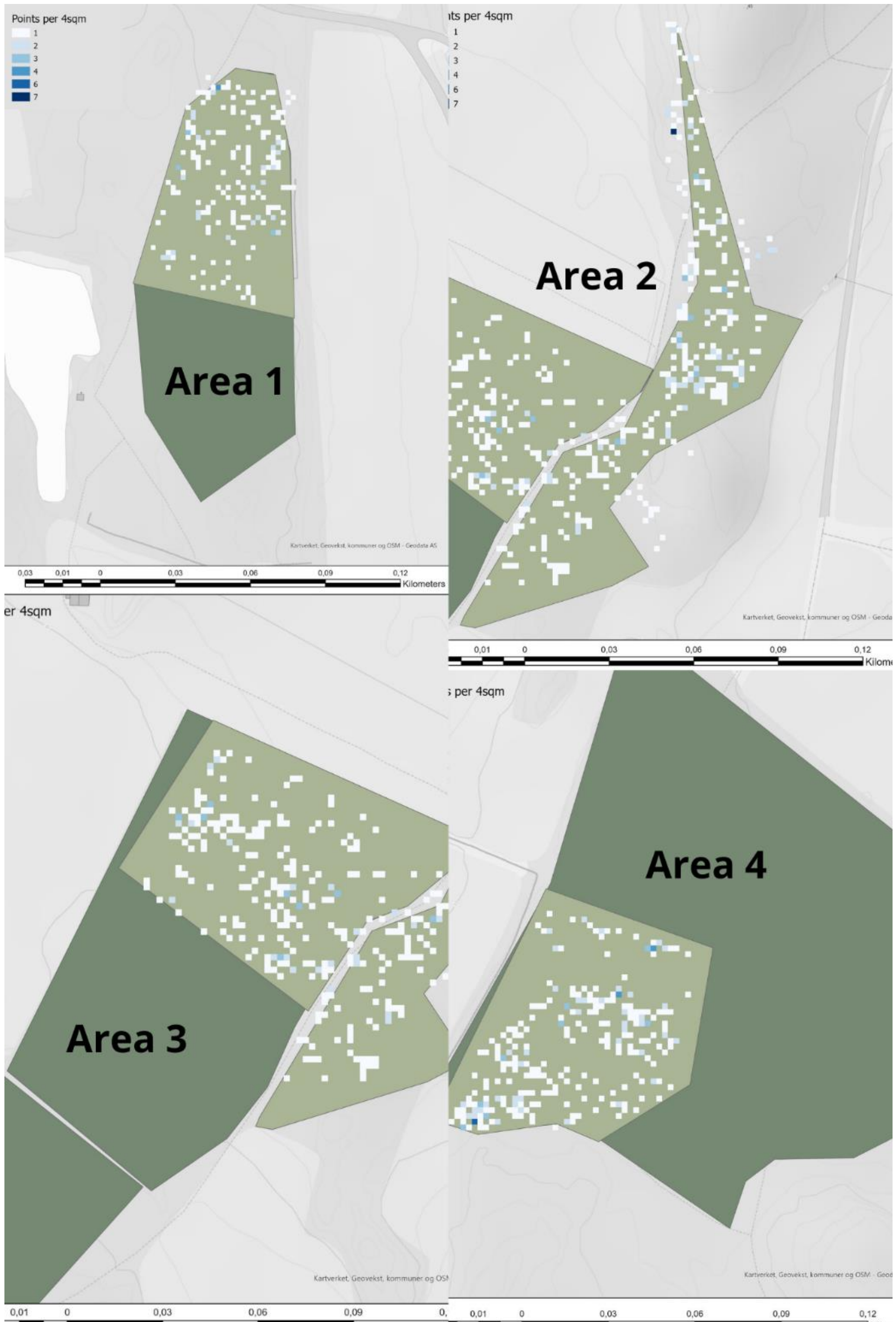

Figure 10 Heatmap of oak density for the unique areas of this study. The map showcases points of oak trees per 4 sqm, with white indicating 1 tree and navy indicating 7 oak trees within 4 sqm. Created by Aksdal (2023).

4.1.2 Height and width of oak

The extent of variation in both height and width of oak trees within the study areas is presented in Table 8. The range of tree height spans from 3.00 cm to 199.00 cm, highlighting the considerable diversity among oak trees within the study. The mean height (μ) at 44.95 cm, with a median of 31.20 cm, suggests a positively skewed distribution, with some trees being particularly higher. Additionally, the standard deviation (SD) for tree width was recorded at 1.145 cm, underscoring the substantial variability in tree girth across the individual oak trees and the study areas.

Table 8 Abundance of oak trees in the different areas. The abundance is much higher than anticipated. The biggest trees were located within Area 3

Areas	**Number of oak trees**	**Mean (µ) height of oak trees (cm)**	**Mean (µ) width of oak trees (cm)**
1	205	69.0	1.87
2	356	69.2	1.73
3	214	84.0	1.75
4	310	57.2	1.47

Subsequently, to present a consolidated depiction of oak trees, scatter plots were generated for the mean height (80 cm) and mean width (3 mm) across areas. This focused approach allowed for a clearer visualization of the general characteristics of oak trees within the study areas. The data displayed a positively skewed relationship with respect to both height and diameter, as depicted in Figure 11. As oak height and width increase, the observations become progressively more sporadic. The sporadic nature of these occurrences could be explained by the year of clear-cutting and/or influenced by other variables such as the competition with other species related to early succession.

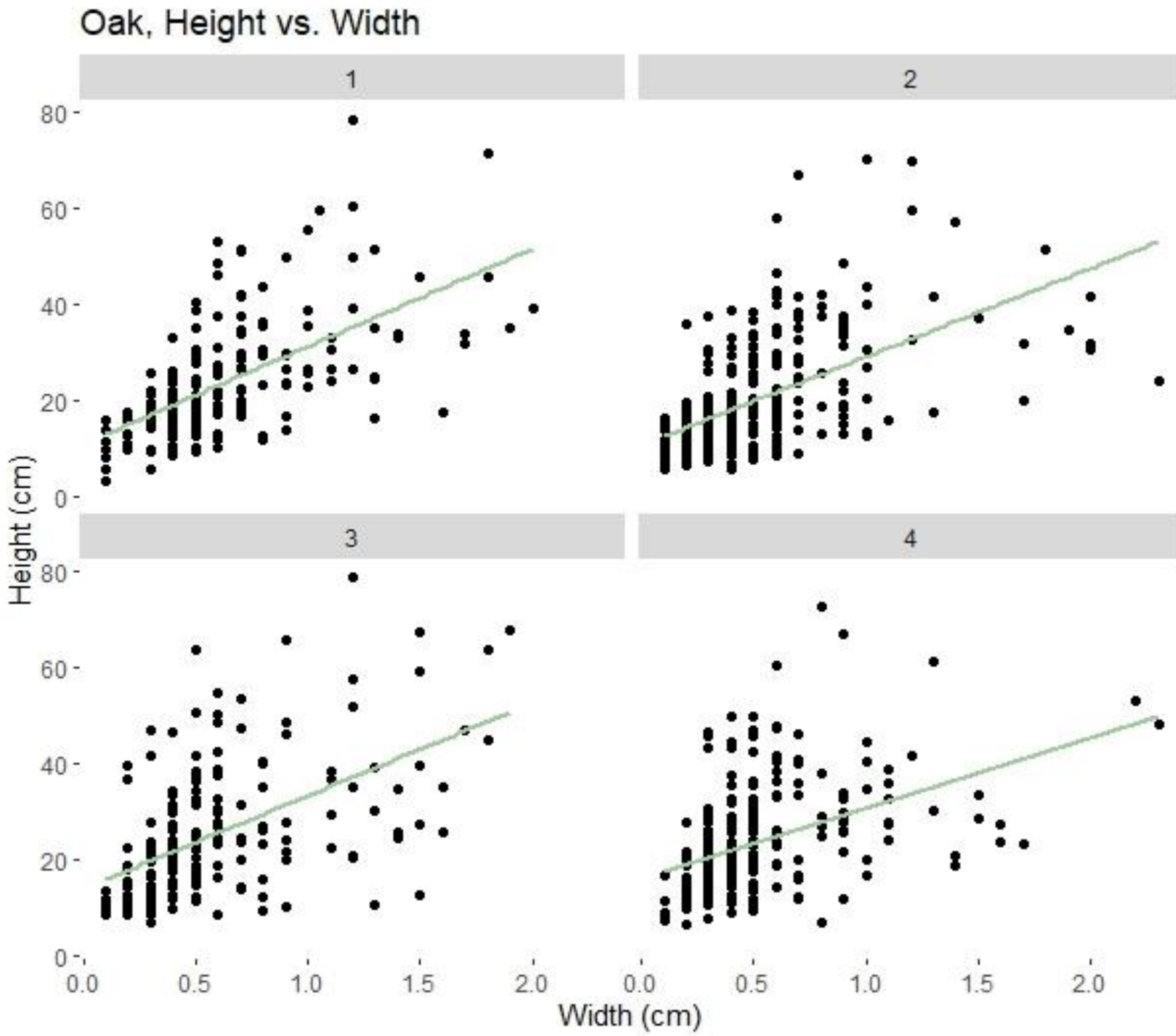

Figure 11 Distribution of oak height and width. The relationship is positively skewed, with increased height, the width will increase as well.

4.1.3 Observed sickness

The gaussian model exhibited a lower residual deviance (4.236) compared to other GLM families with similar fulfilled assumptions (e.g., gamma: 124.4). The AIC value, closer to zero (- 45.74), indicated a favorable fit relative to the null model (Appendix: 7.4 GLM-model Fit with Q-Q Plots and Histograms). Additionally, an **interaction term between health status and areas** was incorporated to investigate whether the impact of oak health on oak density varied across the different areas.

Some considerations guided the choice of GLM:

1. **Non-normal distribution:** Given the nature of oak density data, which might not follow a normal distribution (Frost & Rydin, 2000), a GLM with an appropriate family and link was preferred.

2. **Non-linear relationship:** Recognizing the potential for a non-linear relationship between independent variables and oak density, the flexibility of a GLM with various link functions was advantageous (The Pennsylvania State University, 2023).

The relative abundance of healthy and infected trees within the study areas displayed the highest number of healthy oak trees within Area 2, totaling 176 individuals. In Area 4, 118 healthy oak trees were observed, while Area 3 featured 117 healthy oak trees. Conversely, Area 1 exhibited the lowest count of healthy oak trees with 86 individuals.

In terms of intermediate oak trees, characterized as in between those of healthy and sick trees, Area 3 exhibited the fewest instances with only 17 individuals. Area 2 and 1 had 59 and 60 intermediate oak trees, respectively, while Area 4 displayed the highest count with 77 intermediate oak trees.

As for sick oak trees, which displayed characteristics falling within white fields and/or regions of yellow and brown on their leaves, were the most abundant within Area 2 (n =87). Following this, Area 4 contained 77 sick oak trees, while Area 1 encompassed 57, Area 3 had the fewest sick oak trees, totaling 62 individuals (Figure 12).

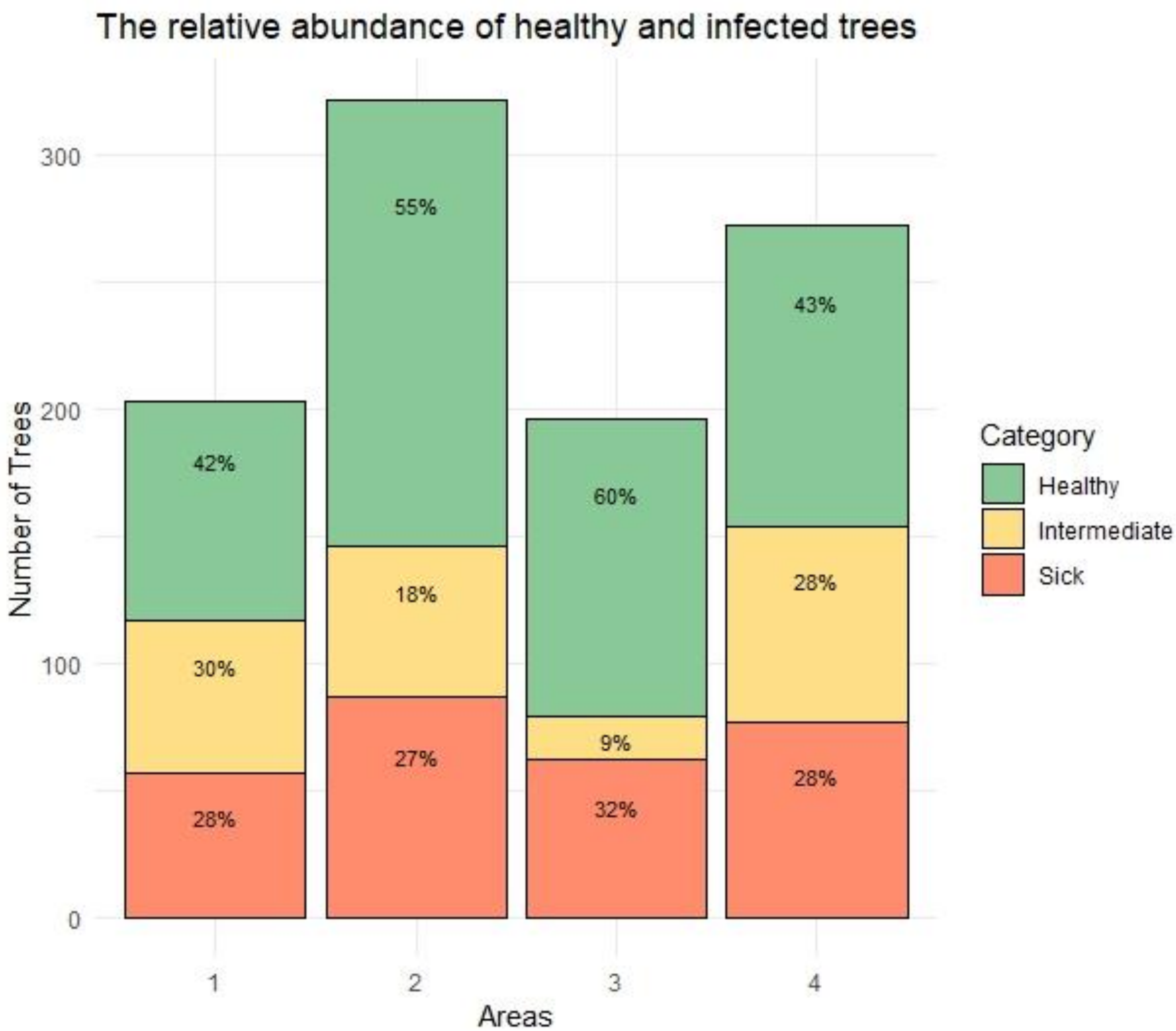

Figure 12 The relative abundance of healthy and infected oak trees within the 'searched' areas. distribution

To investigate the intricate relationship between oak density and health of oak trees is crucial for understanding the dynamics of oak ecosystems. A GLM regression analysis was conducted to examine oak density and the influence of their health status within the respected study areas. The model included predictors such as 'Mode_Health' and the four distinct areas: 1, 2, 3, and 4 (Table 4).

The result suggests that the health of the oaks did not exert a statistically significant influence on oak density (P-value = 0.50). Although the lack of significance suggests that oak health may not play a substantial role in determining the density, the effect size (n^2 = 0.01) indicate a small effect, which in terms mean that health have little to say on the density of oak trees within the areas. A GLM model of interaction terms between health and area [density ~ health * area] further indicate that the effect of health on density does not significantly vary across different areas (P-value > 0.05).

Additionally, area (1-4) had a notable impact on oak density, with Area 1 exhibiting a positive association with the density. However, it's worth mentioning that the same area experienced logging one year prior could potentially explain the observed association. Future research is imperative to unravel the nuanced interplay of factors influencing oak densities within these areas, and such findings could potentially provide valuable insights into the complex dynamics of oak ecosystems.

Furter exploring the intricate dynamics between health status and oak trees, a GLM model with gaussian family and log-transformed oak tree height was utilized to investigate the association with health on oak trees across the different areas (Refer to Table 4 for variable details).

The model reveals a highly significant intercept (CV = 3.17, SE = 0.11, P-value <2e-16), indicating a strong relationship. Among the areas, only Area 2 exhibited a statistically significant negative association (CV = -0.20, SE = 0.10, P-value = 0.04), indicating a lower proportion of sick oak trees in comparison. However, further investigation and caution are warranted, especially in interpreting non-significant coefficients. It is recommended to explore additional factors or refine the model to enhance understanding.

4.1.4 Point intercept and the effect of ground vegetation on oak density

A similar analytical approach for sickness was applied to assess the relationship between oak tree density, height, and biomass (Table 4). The model for density on biomass showed a residual deviance of 91.74 with an AIC of -268.5. The Deviance is higher, and the AIC is lower, which is common for gamma models, suggesting that the gamma distribution might be a better fit for the data. The model for height on biomass showed a residual deviance of 15.90 (df: 101). In-depth model diagnostics, including null deviance (17.761 on 117 degrees of freedom), dispersion parameter (0.212), and the number of Fisher scoring iterations (7), further support the appropriateness of the chosen models. The Q-Q plots and histograms for the same models indicated linearity (see appendix: 7.4 GLM-model Fit with Q-Q Plots and Histograms).

The summarized statistics of point intercept data grouped by vegetation types (
Table 9), showcased that beech on average is sparsely distributed, and its composition varies moderately across the areas. Birch had a relatively higher presence with substantial variability than beech. Oak and spruce signified a moderate presence and a noticeable variability. While pine indicated a sparse presence with moderate variability. On average, dead vegetation had a substantial presence and variability among the compositions. Blueberries and raspberries had a moderate presence and variability, while lingonberries had a more sparce presence with relatively low variability. For ferns, lichens, and other vascular plants a moderate presence and variability were observed. The same goes for moss but with a lower occurrence. Red elderberries had sparse presence with notable variability, while graminoids had a relatively higher presence with a considerable variability. Soil had a substantially higher presence for two of the areas (area 1 and 2), though, indicating a prevalent presence and significant variability (Figure 13).

Table 9 Summarized statistics of ground vegetation data done by point intercept.

Species	Mean (μ)	SD
Beech	3	2.98
Birch	4.64	4.56
Oak	7.41	5.91
Rowan	5.47	5.32
Spruce	5.81	6.41
Pine	2.14	3.76
Dead vegetation	10.2	6.32
Blueberry	7.02	5.66
Raspberry	6.76	5.85
Lingonberry	2.76	2.55
Ferns	6.08	5.45
Lichens	7.59	6.82
Other vascular plants	7.44	5.85
Moss	3.67	3.29
Red elderberry	3.47	5.24
Graminoids	9.81	6.34
Soil	28.6	16.4

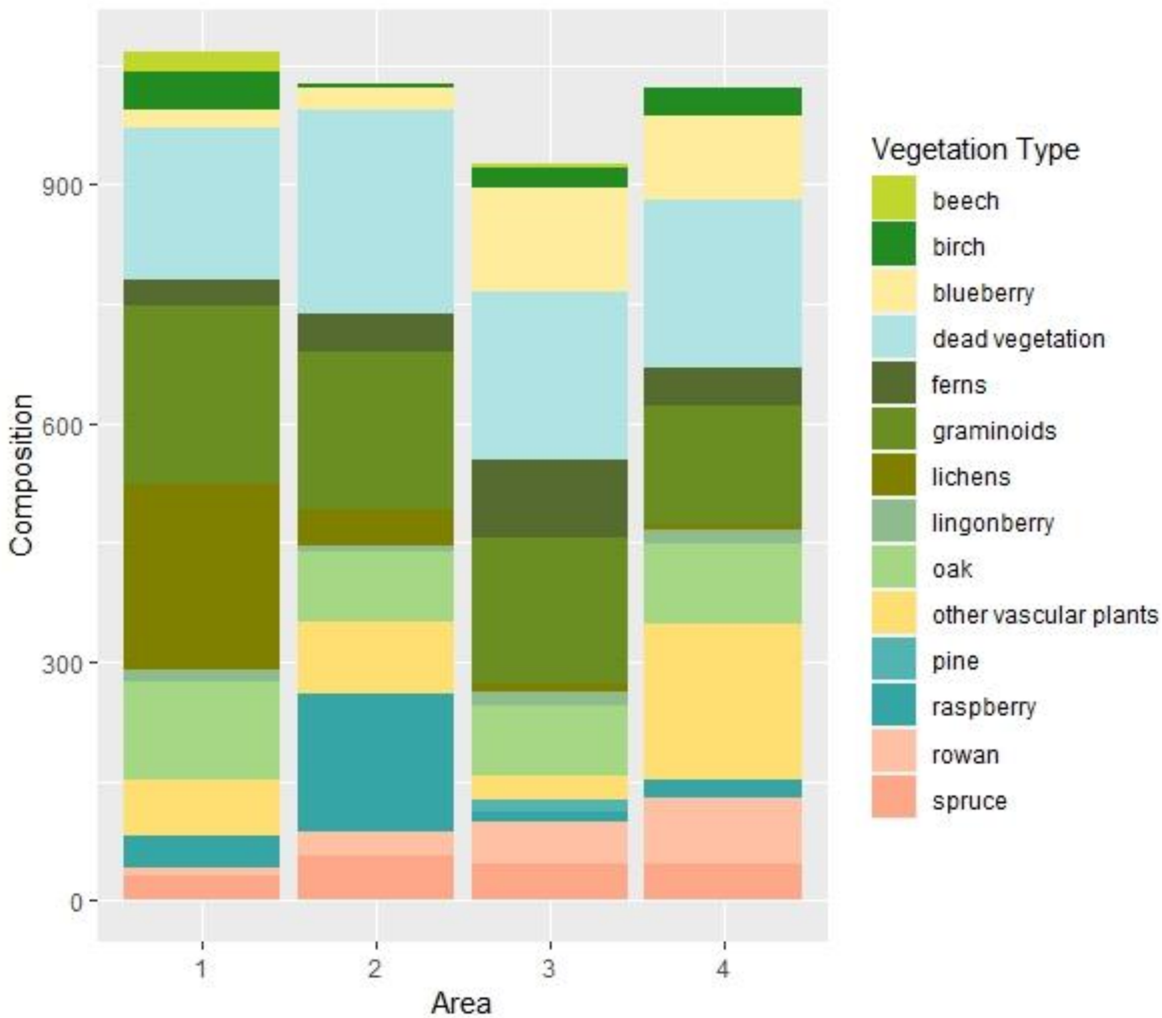

Figure 13 The abundance of different species within each area found inside grid frames for each target species done by point intercept.

Unraveling the intricate relationship between biomass and oak density is crucial in understanding the nuanced dynamics of forests ecosystems with oak trees. A gamma GLM was employed to investigate the effect of biomass on oak density across the unique areas (please see Table 4 for details about variables).

The overall results for biomass displayed a limited influence on oak density (dead vegetation, graminoids, other vascular plants, birch, rowan, pine, spruce, ferns, lichens, raspberries, and blueberries did not exhibit statistically significant effect). Among all the biomass components, beech (CV = 0.87, p-value = 0.12) and lingonberries (CV = 0.06, p-value = 0.09) stood out as the only variables with p-values approaching the significance threshold of 0.05. This suggests a noteworthy trend, indicating a potential association between beech and lingonberries and oak density. Although the p-values did not reach conventional levels of significance. Like sickness, Areas did not have any statistically significant effect on oak density (p-value > 0.05).

Similar to the relationship between oak density and biomass across the unique areas, a gamma regression model was employed to investigate the relationship of biomass on oak height across areas. The various biomass components showed a diverse association on tree height (CV = -2.05 – 0.87), and none of the components encompassed a statistical significance (p-value: 0.11 -0.94) except from the intercept (CV = 3.10, P-value = 0.001). Further refinement and exploration are recommended to better understand the intricate relationship within the studied areas.

4.1.5 Browsing behavior of roe deer.

As depicted in Figure 14Figure 14, browsing behavior from vertebrates was not uniform across the study areas. There are additional varieties, suggesting that other factors may influence the browsing, indicating both spatial and individual variability. The area with the highest browsing count was Area 2 (n = 126 of 356 oak trees), in contrast you have Area 3 with the lowest browsing count of 87 in total. However, compared to total number of oak trees (n = 214) had the highest percentage browsed (40 %), indicating an almost 1:1 ratio of 'browsed' and 'not browsed'. Similarly, Area 2 and 4 boasted a browsing percentage of 35 % and 29 %, respectively. For Area 1, the number of individual oaks that were 'not browsed' was 142 against 51 for oaks that were browsed, exhibiting a browsing percentage of 24.88 %.

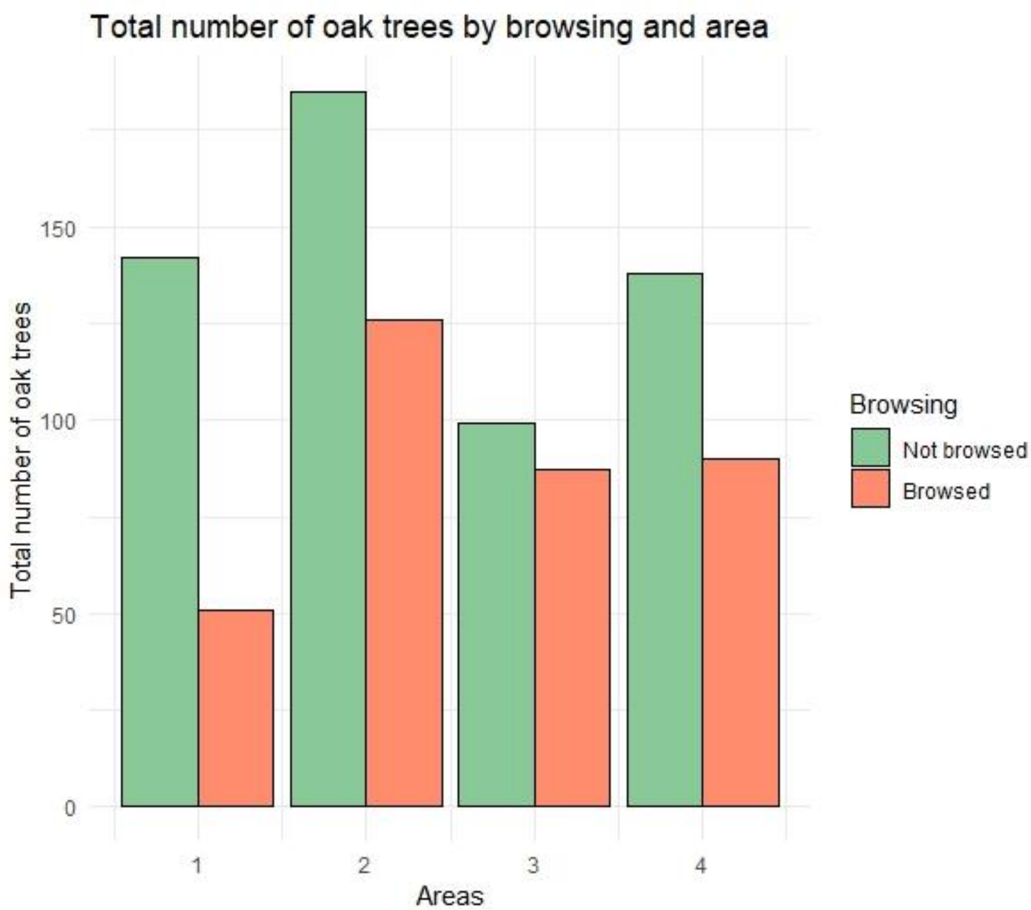

Figure 14 Browsing incidents of ungulates across the areas 1-4. Area 3 showcases an almost 1:1 ratio of oaks browsed and not browsed.

Delving into the realm of browsing on forest ecosystems with a mix of oak trees, a calculated total count of browsing events for both vertebrates and insects on oak trees within each study area revealed that Area 2 exhibited the highest combined browsing count, with a sum of 1066 browsing events in total, involving 617 insect incidents and 449 vertebrate incidents.

Following, Area 4 reported a total browsing count of 885, with 510 instances of insects browsing and 375 browsing incidents of vertebrates. Area 3, in comparison, displayed 377 instances of insects browsing and 290 counts of vertebrates browsing.

Finally, Area 1 exhibited the lowest combined browsing count, with a total of 575, with 329 insects browsing and 246 vertebrates browsing. This total browsing count of Area 1 is half the browsing events observed in Area 2 (Figure 15).

In summary, the total count reveals that the majority of browsing incidents on oak trees is subsequently of insects, with over 50 % of the occurrence. Though, these results do not contain the degree of browsing, and with the vertebrate browsing incident being above 40%, one can assume that the extent of vertebrate browsing could potentially be of harm to oak trees.

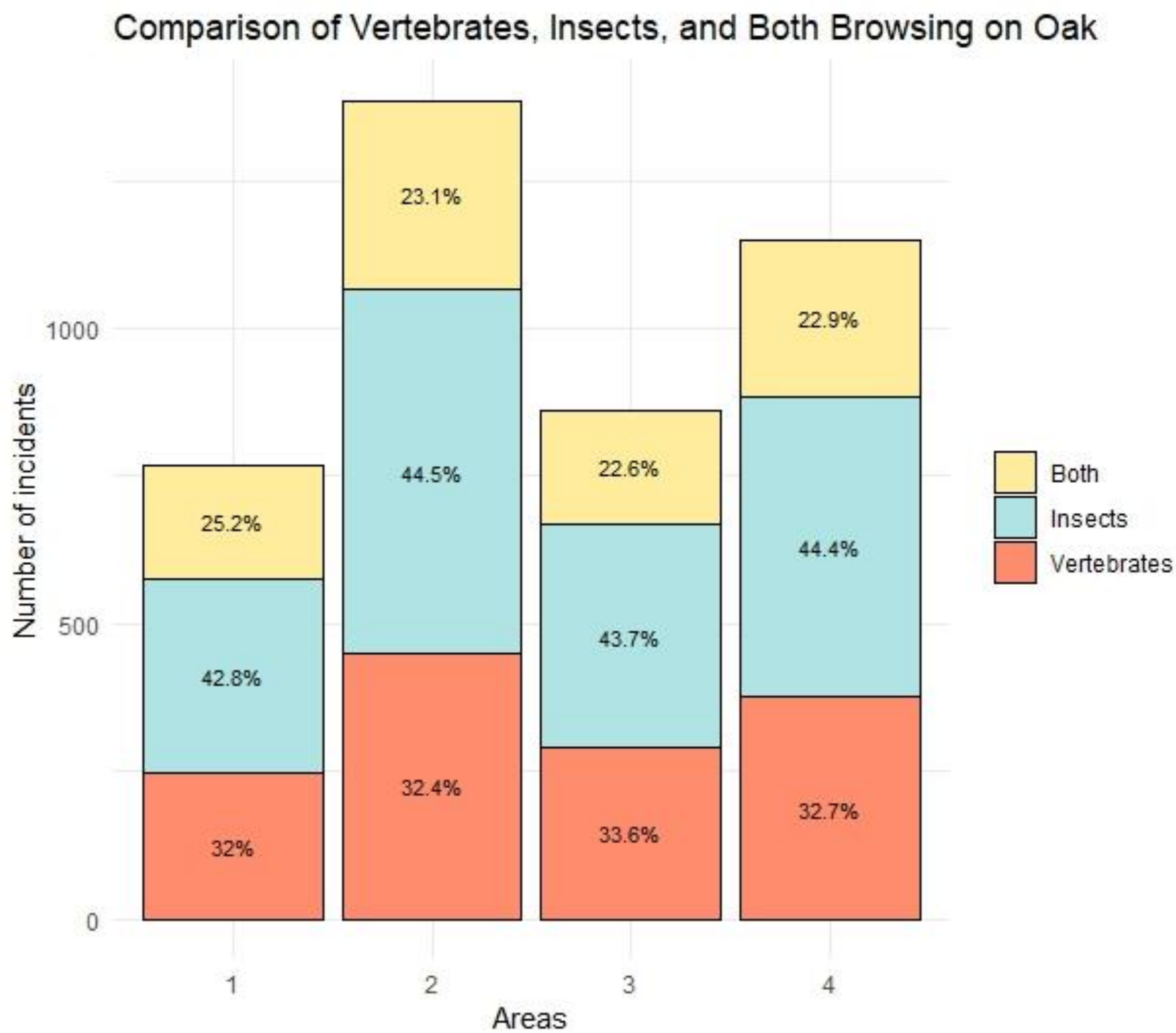

Figure 15 Incidents of insect- and vertebrate browsing recorded within the study areas.

The number of incidents for leaves browsed by vertebrates varied in the different areas (Figure 16Figure 16). Area 1 primarily exhibited incidents of shoot browsing (112 recorded instances and 3 recorded instances of leaves browsed), constituting a significant portion (96.6%) of the observed browsing behavior. Area 2 displayed the most browsing incidents, with a notable presence of 33 leaves browsed (8.9%), and 327 shoots browsed (87.9%), with a smaller portion of cases of browsing of both insects and vertebrates (3.2 %). Similarly, Area 3 had a combination of all three categories of incidents (1 incident being leaves browsed, while number of shoots browsed was 234), with shoots being of prior with 99.2% of the recorded incidents. Area 4 exhibited browsing exclusively composed of 254 shoots incidents (100%), with no instances of leaves or both.

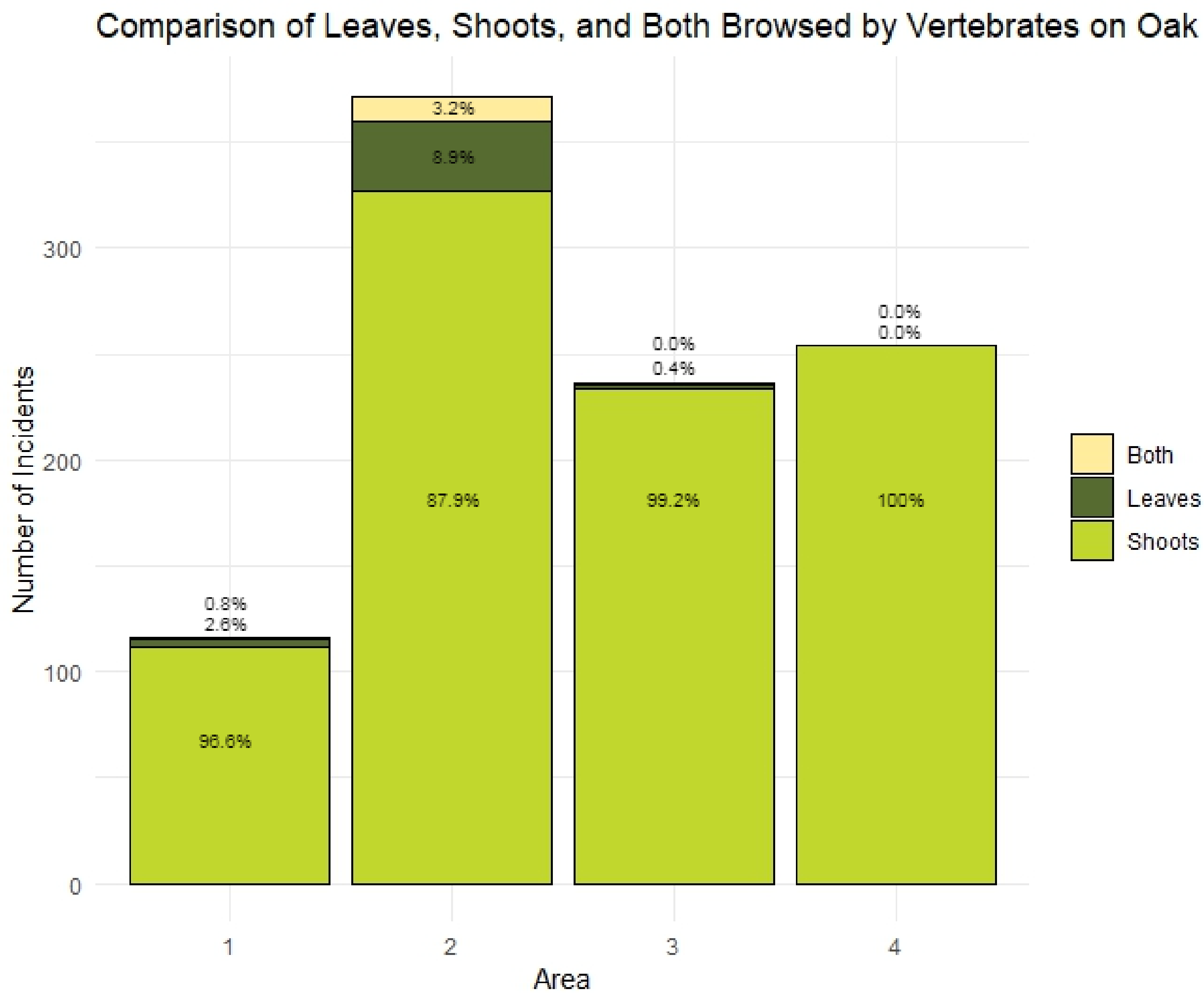

Figure 16 Overview of browsing on shoots and leaves across the study areas.

Embarking on the exploration of the interplay between oak density and factors influencing the density, a gaussian GLM was employed to investigate the relationship between oak density and browsing (both insects and vertebrates) across the areas.

The model revealed a statistically significant intercept (estimate = 0.13, p-value = 0.03), indicating a non-zero predicted density when browsing and area are both set to zero. Browsing displayed a coefficient of -0.01 (SE = 0.02). However, the effect was not statistically significant (p-value = 0.44). While browsing alone did not show strong evidence of direct impact on oak density, the presence of a non-zero intercept implies that other factors not included in the model might contribute to the baseline of oak density. Further investigation is necessary to comprehensively understand the determinants of oak density within the areas.

Furthermore, the intricacies of the forest ecosystems with oaks pose a more comprehensive analytical approach poised to dissect the statistical nuances underlying the relationship between browsing events and the height of oak trees. For this a Gaussian regression model with a log-transformed response variable, 'log_Mean_Height', was employed.

The Gaussian regression model with log-transformed response variable ('log_Mean_Height') showed that the relationship of mean browsing events and height is not statistically significant (P-value = 0.53, CV = 0.02, SE = 0.05, meaning that browsing does not reliably predict changes in mean height. Areas had a negative coefficient (-0.02), implying a potential decrease in mean height. However, similar to browsing events, area does not have a statistically significant relationship with mean height of oak trees (p-value = 0.59).

4.2 Landowners perspectives

4.2.1 Forest ecosystem management preferences and objectives

The intricate interplay of economic, ecological, and recreational considerations among landowners serves as a nuanced backdrop for an exploration of their forest management practices, shedding light on the diverse roles that foresters hold.

All landowners currently manage their forests for timber production. The utilization of forests for hunting larger ungulates is relevant but not as important for the landowners, with statements preferencing against game meat. Roe deer are being categorized by the landowners as a problematic animal, known for causing damage to crop and flowerbeds. Within the framework of Limits of Acceptable Change (LAC), the number of roe deer emerges as a potential limit within the landowners' preferred forest composition. The challenges posed by roe deer, categorized as a problematic species due to their impact on crops and flowerbeds, represent a threshold that influences the acceptable change within these forested landscapes.

All landowners enlist the services of contractors for forestry operations, including planting, cutting, and harvesting timber. Their reliance on contractors stems from time constraints that preclude hands-on forest management. Despite this reliance, all landowners affirm that their forests yield no substantial financial benefits, and they depend on alternative income sources. This financial independence affords them the flexibility to engage in diverse activities within their forests (such as this project). Financial independence encourages reflections on the desired state, freeing landowners from adhering to conventional forestry practices. This prompts consideration of whether this vision is universally shared among landowners with small forests or is influenced by individual preferences of the landowners in Moss municipality.

While spruce dominates the plantations across all four sites, landowners acknowledge the presence of additional groves within their ownership, featuring pine trees and birch, indicating the ecological character within the forests. Interestingly, in Area 3, one landowner intentionally plants fir (*Abies alba*) alongside spruce.

Accompanied by timber production and hunting of roe deer or other types of wild game, all landowners manage their forest for recreational opportunities (e.g., walking, hiking, harvesting berries and mushrooms), resonating to the concept of desired state. Despite areas being officially designated as production forests, the emphasis on recreation over purely economic goals highlights a collective vision that prioritizes community well-being through activities like walking and hiking. In essence, the landowners' desired state leans towards a forest that meets recreational needs more than it focuses on economic gains.

The municipality (Area 3) adopts a more comprehensive approach, managing the forest for multi-use with a focus on ecological health. Areas 1, 2, and 4 express a desire to pursue a similar comprehensive approach. The commitment of the municipality is evident in their choices, encompassing timber and hunting sales, biodiversity conservation, recreation, and outdoor experiences. These forests are also viewed as contributing to the well-being of the community, serving as a "health benefit" for residents.

While the areas are officially designated as production forests, the landowners unanimously emphasized that the primary value of the forest lies in its recreational purposes. This consistent perspective emerged across all landowners. While the landowners in Area 1 and 3 did stress the importance of ecological and social aspects, including biodiversity, well-functioning ecosystems, and hiking, landowners in Area 2 and 4 contextualized their acknowledgement of these aspects by observing gradual changes in the biodiversity composition of their forests.

Ultimately, landowners are primarily motivated by community well-being, seeking benefits such as economic gains through the sale of timber or firewood, personal consumption of forest resources (e.g., game meat, firewood, berries, and mushrooms), and participation in outdoor activities like hiking and jogging. Their actions are driven by a collective commitment to enhance the forest for the broader community, balancing the need for economic sustainability with the desire for positive communal outcomes.

4.2.2 Forest values and recognition of ecosystem services

Private landowners emphasized the value of timber, roe deer, and agricultural land leasing (Leasing only applies to Area 1 and 4). Conversely, representatives from the municipality (Area 3) prioritized wildlife and the ecological aspect over timber. These resources were perceived, valued, and utilized differently: agricultural land was primarily assigned economic value, timber held social value, and wildlife was important for the ecosystem in the area for all landowners. Timber production had cultural value for all landowners, serving as a small-scale “family business” passed down through generations. Forests contributed to a smaller income through timber sales and facilitated socially oriented outdoor activities, such as hiking. The recognition of diverse values implies that there are limits to the changes landowners find acceptable within each value category.

All four categories of ecosystem services, encompassing supporting, regulating, provisioning, cultural aspects, were thoroughly discussed and recognized during the interviews (Table 10). While all categories were touched upon, the discussions predominantly gravitated toward supporting and cultural services. Notably, cultural services emerged as the most frequently cited by the landowners.

The recurring theme in responses was centered around cultural services, particularly in the context of recreation and outdoor experiences shared with family and friends, often involving physical exercise. One noteworthy example highlighted during the interviews was 'Ryggejoggen', an informal fitness route traversing the landowners' properties (see Figure 17). 'Ryggejoggen' has evolved into a local phenomenon, hosting annual runs during both winter and summer months. Remarkably, these runs have maintained an unbroken tradition since their inception in 1982 (*Ryggejoggen*, 2020). In particular, Area 1 discussed 'Ryggejoggen' in relation to conflicts arising from forestry activities: "*It (logging the area) has led to many unfortunate encounters with hikers"*. Areas 2, 3, and 4, on the other hand, actively manage the route, with Area 4 expressing a theory about its broader impact on forest usage. They believe that 'Ryggejoggen' serves as a valuable addition to local society: *"If people use it (the forest) more, then there would be more animals there as well",* emphasizing a belief of interrelation between human activities and ecosystem dynamics. Area 2 explicitly stated that 'Ryggejoggen' is their primary focus, underscoring its significance in their forest management strategy. The emphasis on the interrelation between human activities (specifically, the use of 'Ryggejoggen') and ecosystem dynamics aligns with the ecological character and desired state concepts. The landowners in Areas 2, 3, and 4 actively manage 'Ryggejoggen' because they see it as a valuable addition to local society, indicating a desired state where the forest serves multiple purposes, including recreational and ecological aspects.

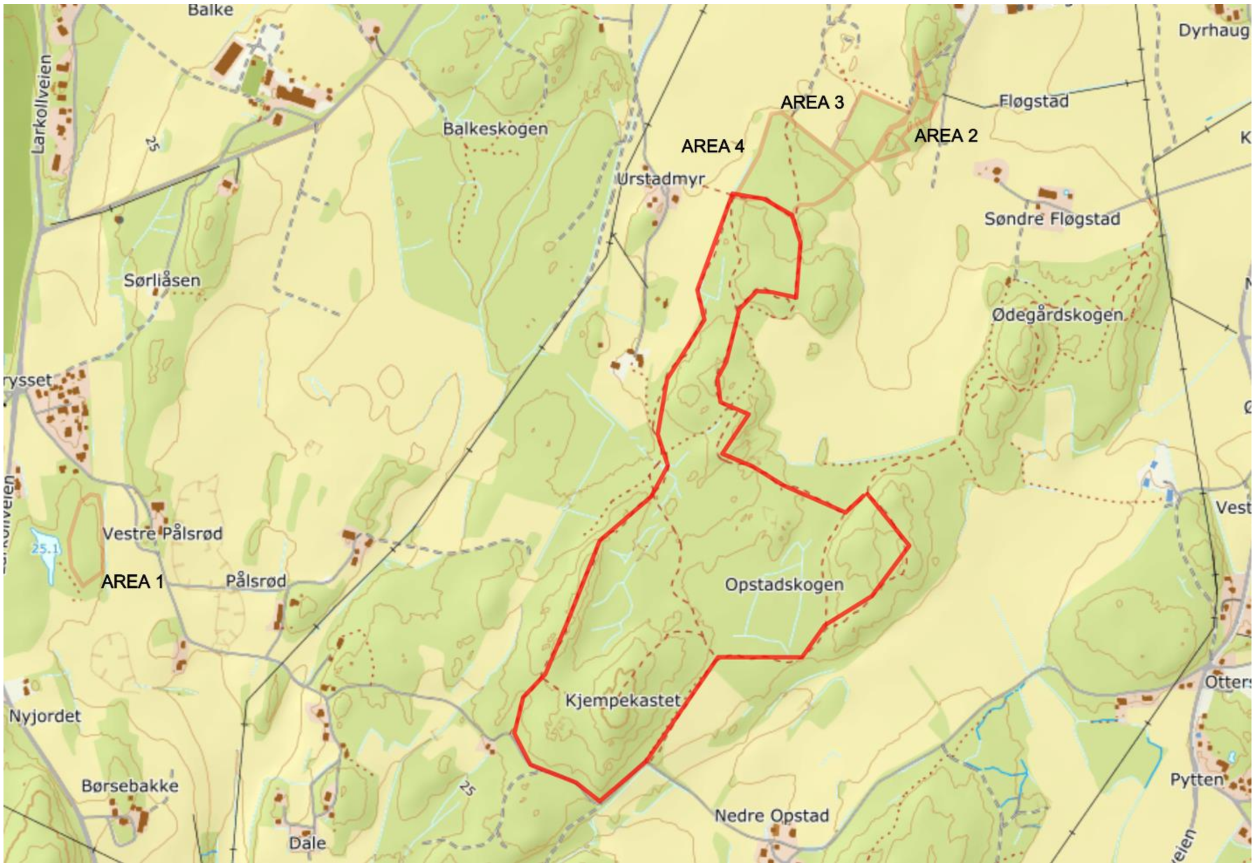

Figure 17 Ryggejoggen: A community fitness route connecting the areas within this study by its many entrances.

In terms of supporting services, landowners have expressed a desire for well-functioning ecosystems and an emphasis on preserving or, ideally, enhancing biodiversity. They recognize that the natural landscape, including the smaller forests within their property, serves as crucial habitats for both animals and plants. Moreover, they believe that fostering an abundance of deciduous tree species can create more diverse habitats, contributing to increased biodiversity.

However, the less frequently mentioned services were provisioning and regulating, with an incidental remark from Area 4 about operating a garden center for 40 years, delivering willow trees to prevent erosion. The landowners articulate a keen interest in clean air and water. They understand the role of trees in sequestering carbon dioxide (CO_2) and producing oxygen (O_2). Additionally, they emphasize climate mitigation, highlighting how an increased number of trees in the areas can contribute to reducing CO_2 levels. Landowners acknowledge that trees are essential for mitigating erosion, particularly as they discuss the benefits of transitioning from a previous spruce plantation to a deciduous forest. It's worth highlighting that landowners share a collective aspiration for these services. However, some express reservations about the global impact, emphasizing that a restoration effort in Moss alone won't save the world, with a consensus that global contributions are essential for a widespread impact.

Regarding provisioning services, landowners emphasize their aspiration to use the forest for timber, preferring selective cutting over clear-cutting. They view selective cutting as both more beneficial and aesthetically pleasing. However, they note that the option of selective cutting is not always available, and when it is, it can be more expensive than clear-cutting. Additionally, Area 4 expresses a positive view of provisioning services related to berries and mushrooms. They express a desire for more opportunities to stroll in the forest and enjoy these natural resources, although other landowners (e.g., Area 2) think that it would not be feasible with dense field layer vegetation within the forests of this study.

In the realm of cultural services, landowners prioritize recreation, seeking more outdoor experiences with family and friends. They observe that 'Ryggejoggen,' utilized as a jogging trail by residents in the municipality, contributes to better public health. The emphasis on these cultural services is seen as a positive contribution to the overall well-being of the community.

An in-depth exploration of mentioned ecosystem services, along with specific references, is provided in Table 10. In view of the foregoing results, the landowners identify recreational, cultural, economic, ecological, and social health values within their forests.

Table 10 Landowners' noted ecosystem services: An overview of mentioned types and specific references from interviews.

Ecosystem service type	**Specific references of wishes and wants**
Supporting	Well-functioning ecosystems Biodiversity in general Habitats for animals and plants Abundance of deciduous tree species
Regulating	Clean air and water Climate mitigation Demote Erosion
Provisioning	Timber as a raw material Berries and mushrooms
Cultural	Recreation Outdoor experiences with family and friends Exercise
Human well-being	Positive effect on public health

4.2.3 Potential conflicts and the effects of roe deer browsing

In exploring the intricate dynamics of forest ecosystems in Moss, it becomes evident that the region has an optimal climate and soil quality for cultivation, fostering a diverse wildlife population (as Area 3 reported throughout the interview process). The landowners recount captivating tales of wolves, owls, doves, common pheasants, and an array of other creatures inhabiting their properties. These firsthand observations provide a rich tapestry of the area's biodiversity, with each landowner offering unique insights into the ebb and flow of species over time.

However, beneath the surface of this natural abundance lies a nuanced narrative. The landowners note not only the fascinating coexistence of species but also the changing landscape of their surroundings. Cyclic fluctuations between foxes and hares (Area 2), the majestic presence of common buzzards, and even the watchful gaze of an eagle owl from above a garage in Area 4 paint a vivid picture of the local ecosystem's dynamism. Yet, as the landowners delve into the details, they reveal a subtle transformation. The once-thriving populations of dragonflies and salamanders are on the decline, making room for an increase in ticks and other insects. Moreover, the unmistakable signs of climate change manifest, with earlier springs marked by the premature blooming of peonies. As Area 1 describes: *"peonies bloom much earlier than they used to do"*. This prompts a deeper consideration of the environmental impact and the delicate balance between human activities, climate shifts, and the well-being of local flora and fauna.

Amidst these reflections, the landowners demonstrate a profound awareness of ecological terms such as 'renewable resources' and 'ecological services'. They advocate for the dedication of specific areas to animal well-being while recognizing the intrinsic value of every component within the ecosystem. The concept of a dead tree serving as a habitat for multiple species resonates, highlighting the interconnectedness of life within the forest.

However, the narrative takes a pragmatic turn as the essential needs of the areas come into focus. Recreation and maintaining clear paths, especially for the popular 'Ryggejoggen', emerge as fundamental priorities for the landowners. This prompts a thoughtful suggestion: the possibility of dividing the forest into sections for natural rejuvenation and sections designed for recreation, providing a strategic approach to both ecological preservation and human enjoyment.

Yet, amidst these considerations, a common concern unifies all landowners—the persistent challenge posed by bark beetle infestations, prompting a proactive response through clear-cutting.

All landowners mentioned roe deer as a source for conflicts in the area. Beliefs toward the density of roe deer differed slightly among the landowners but leaned in the direction of an acceptable level or too high production of roe deer in the area. Three landowners (Area 1, 2 and 4) stated that the roe deer production had exceeded today's quota (number of roe deer of each gender and age that can be hunted during the hunting season). Area 3 assumes the pivotal role of allocating hunting quotas to the landowners, a process intricately tied to the hunters' dynamics. The quotas, carefully calibrated, undergo readjustments based on the actual number of animals shot during the hunting season. It's worth noting that none of the landowners personally partake in hunting activities; instead, they opt to lease or lend their hunting rights to interested individuals or hunting teams. This delegation ensures that hunting responsibilities align with the landowners' preferences and broader wildlife management strategies.

Three of the landowners (Area 1, 2 and 4) possessed neutral to slightly negative attitudes toward roe deer browsing, affirming that the conflict today is not between forestry and roe deer, but agriculture and roe deer. No-one believed the density of roe deer was too low. Among the landowners, only Area 1 and 2 mention that the density is too high, the other 2 stated they believed the current density is acceptable, believing that moose may be of a bigger economic disadvantage than roe deer, due to crop damage. Roe deer may cause damage as well, but not to the same extent as moose.

The landowners unanimously mention that moose are a rarity after E6 was built (The road was built in the period 2001-2008 and is one of the country's most important road connections – to and from abroad (*E6 gjennom Moss*, 2020). The opinions about roe deer unify the landowners with statements like *"… the roe deer population behave as they should be tame, living in gardens and on the side of roads", and "… Even the weak individuals would survive".* They all (Area 1-4) believe that a higher number of roe deer would lead to an increase in collisions, diseases, and grazing damage (on both forests and agriculture). Areas 1 and 3 share a concern about the potential impact of roe deer density on the local vegetation, foreseeing possible damages in the future. In contrast, Area 2 acknowledges this concern, qualifying it by emphasizing that the perceived impact would be more significant if the forest held greater economic value than it currently does.

The belief that a balance can be obtained in managing for timber production and roe deer was agreed upon by 4 out of 5 landowners. All private landowners expressed the belief that a balance could be achieved, as the current browsing damage primarily occurred within the confines of their private properties, such as gardens, flower beds, and/or agricultural crops. Nevertheless, they acknowledge the potential for conflicts, especially regarding the threat posed by roe deer browsing to broadleaved saplings. The delicate balance they envision is contingent upon the specific forest type and the composition of its tree community. In the event of an issue, landowners propose potential solutions, such as fencing (mentioned by Area 1 and 3) or the concept of cultivating 'browsing trees'—trees intentionally grown for roe deer alongside desired commercial tree species (as mentioned by Area 3). These measures are considered essential to prevent lasting damage to the forest ecosystem. Area 3 provided a valuable perspective, emphasizing that natural lag is an inherent aspect of forest management. Managing based on quotas for hunting takes into account daily variations, making it challenging to immediately observe the effects due to the inherent lag in the system.

Furthermore, as Area 1 specifies, removal of the forest would be of potential conflict with wildlife. Three out of five landowners experience harvesting by clear-cutting to be harmful to the landscape, that the harvesters are driven by the money, saying *"They are "cowboy-ish", like an oil sheik on a mission for more oil"*. On the contrary, two of the landowner's mention clear-cutting could be a positive occurrence for the landscape, stating *"we suppress natural fires, so you can sort of defend clear-cutting in that way"* and *"Now everything is done by machines, and they clear-cut to minimize injuries on the root systems. Clear-cutting would therefore be better for the trees in the long run"*. Given that none of the landowners engage in timber harvesting for commercial purposes, relying solely on personal use such as firewood, the conventional approach of deliberate spruce planting followed by clear-cutting is deemed inadequate for the current context. One landowner argumentatively stated *"… It's all about the **same procedure every year**"* and *"… **the state is not interested in changing the strategy** since the traditional way of* *doing it still works for the bigger foresters".* The focus is mainly on machines and efficiency but should, according to Area 1, be about the produce; the public health benefit; and the biodiversity, and further suggests that Norway should take inspiration from France where they do industrial farming, but still manage to maintain focus on the produce. Having politics that is accommodated by the strong agricultural forces (e.g., doing what benefit the bigger actors in forestry and agriculture) is looked upon as unfavorable by the landowners: *"It seems like it is **one model fits all.** It feels like the politics are controlled by the bigger farmers in Jæren and for the forestry its Hedemark and Trøndelag".* Referring to now Innlandet and Trøndelag as main actors of forestry in Norway.

The landowners are not thought of as an economic benefit to the property and it is a consensus belief that no one in Moss has a sufficient expanse of forest to derive a livelihood from it. While some landowners may not explicitly label clear-cutting as detrimental to the land, a unanimous sentiment prevails that it detracts from the aesthetic appeal when forests undergo such practices. Area 4, in particular, expresses profound aversion to the use of harvesting machines, emphasizing strong negative sentiments: "*It's illegal to cause harm to the forest – that you are supposed to preserve and conserve, but that doesn't happen! These big machines are ruining the forest, making it ugly and hard to walk in",* referring to the Norwegian Forest Act (2005, §8): *"In connection with felling, regard shall be paid to the future production and regeneration of the forest and to environmental values. It shall be ensured that the use of footpaths, cross-country skiing tracks and other rights of way is not unduly impeded for the general public after completion of the felling. The municipality may order the forest owner to repair damage made by vehicles and other damage following activities in the forest"* (Translations of the Norwegian Forest Act were carried out by the Norwegian government). Parallel viewpoints have been articulated by both Area 1 and 2, querying the absence of a landscape-friendly approach – a management strategy harmonizing with the needs and characteristics of the areas. The municipality (Area 3) concurs with comparable perspectives to other landowners, underscoring the significance of small groves alongside their agricultural land and affirming the municipality's commitment to the protection of forests. Asserting a distinction between Moss and other municipalities like those in Innlandet, the landowners posit the necessity for a divergent approach to the management regime, with Area 2 stating *"You cannot make a living on 300 daa, and when you have 10 acres on your neighbor's property, and other patches somewhere else, and a road that stretches across your crop, then it starts getting difficult to maintain. The topography here would not allow that kind of production"* (

Table 11).

Table 11 Comparing harvesting for sale in 2022 between Moss municipality and Elverum municipality (which has the most logging in Norway). Source: SSB.no

		Harvesting for sale (m³), 2022
Spruce	**K-3002 Moss**	13060
	K-3420 Elverum	232128
Pine	**K-3002 Moss**	3999
	K-3420 Elverum	122813
Broadleaved	**K-3002 Moss**	1140
	K-3420 Elverum	10071

4.3 Perception toward future forests

4.3.1 The preferred forest composition according to landowners

In order to gain insights into the preferred composition of future forests in The Moss municipality, we engaged landowners in a visual exploration of potential forest scenarios. Utilizing the questionnaire featuring six distinct images depicting various underlayer characteristics and tree stands, we sought to understand landowners' preferences on the desired forest landscape, aiming to inform decisions related to deciduous forest restoration.

The questionnaire presented landowners with six images, each portraying a unique forest composition. The first image, featuring mature oak with anemones, emerged as the most preferred among the landowners, with positive comments highlighting its cleanliness, accessibility, and biodiversity. In contrast, the second image, depicting mature with rough field layer, received lower rankings (two landowners ranked it '5' out of 6), with comments emphasizing its untidiness and limited recreational appeal. One landowner ranked the image quite high ('2'), defending the forest with *"since we would like to restore the forest back to an oak forest, its preferable but less accessible for recreation"* (**Error! Reference source not found.**).

Figure 18 Two out of six images presented to the landowners for in-depth perception information. The landowners showcased positivity towards the first image (mature oak with anemones), highlighting its airiness. The second image depicted young oak trees with rough underlayer. The landowners were more skeptical to the second image due to the forest being less accessible.

The third image, showing mid-aged oak trees with grass, elicited varied responses, with comments such as "*a feeling of production forest with high productivity*" and *"oak trees in growth",* reflecting divergent perceptions of untidiness and high productivity. Picture four, displaying mid-aged oaks mixed with litter, received predominantly positive feedback, with landowners expressing appreciation for its natural appearance with comments like "*a good mix and a closer feeling to what forest looks like in our case" and* "*leaves are natural things in a broadleaved forest".* Further, they appreciated its accessibility and suitability for recreation and birdlife (**Error! Reference source not found.**).

Figure 19 encompasses two out of six images presented for the landowners. The third picture illustrates a forest with mod-aged oak trees and grass as underlayer characteristics. The fourth image, being the most preferred picture out of these two, depicts mid-aged oak trees with mixed litter.

The fifth image, featuring a forest with young oak trees and withered grass, prompted mixed reviews pushing in a negative direction. Landowners expressed concerns about forest vitality, management needs, and perceptions of low-production forest. One landowner rated the image '1' out of '6', with a comment defending the image as *"oak trees still in growth".* The final image, portraying a young oak forest with anemones, garnered controversially positive remarks (two landowners rated the sixth picture '1' out of '6'), emphasizing its lightness, potential for biodiversity, and the ongoing growth of oak trees (Figure 20).

Figure 20 features two out of six pictures presented to the landowners. The fifth picture portrays young oak trees and withered grass had mixed reviews. The sixth, and last, picture portrayed a young oak forest with anemones, had mixed reviews as well, but leaned towards more positive comments compared to the fifth picture.

None of the landowners exclusively prioritize roe deer production in their forest management, rather adapting to them being there in the future and continue choosing roe deer as an extra source of utility, lending the hunting rights to interested parties (e.g., individuals and hunting teams). The forests are subsequently viewed as hobbies for the landowners - *"expensive hobby"* as one landowner mentions. Area 1 and Area 3 report running deficits every year, expressing a collective desire for a net-zero outcome. They express a preference for a tidy multi-layered forest accessible to the public, with tidy defined as easy to access with no obstructions like small bushes or branches in the way when walking. The forest should be managed in such a way that you could *"stay and take a break".*

The landowners draw inspiration from cultural landscapes in Moss, such as Kaialunden, envisioning forests that are airy and light. By "light," they mean that the trees allow natural sunlight to shine through, creating a brighter atmosphere compared to the darker appearance of spruce-dominated forests. Additionally, they desire an airy forest, characterized by ample space between plants to avoid overcrowding, similar to the concept of "tidy." This aspiration reflects their wish for an additional variation and a more natural, woodland aesthetic in their groves. Three out of five landowners express an interest in planting pine trees, envisioning a harmonious blend with broadleaved trees (Figure 21Figure 21 illustrates the aspirations expressed by potential forests, derived from interviews with landowners.). Drawing inspiration from pine forests in Innlandet County, characterized by tall pine trees and a well-maintained underlayer predominantly composed of lichens and moss, the landowners aspire to replicate a similar aesthetic, expressing wishes for "neat ground vegetation". Neat ground vegetation is articulated as vegetation that neither obstructs pathways nor detracts from the visual appeal, ensuring a pleasing and unobstructed forest experience. Some landowners, particularly those in Area 1 and 4, primarily emphasize the regeneration and accessibility of the forest. In contrast, Area 3 envisions a more sustainable economic future by advocating for an environmental shift, including active participation in the "green" movement and engagement in relevant political initiatives. This perspective reflects a broader approach to forest management that integrates environmental considerations and aligns with evolving socio-political trends: *"Central guidelines and how the economic and political lines are stimulated in relation to climate will have great importance outside the economic framework- If you influence the economy – in a way – the will to it"*.

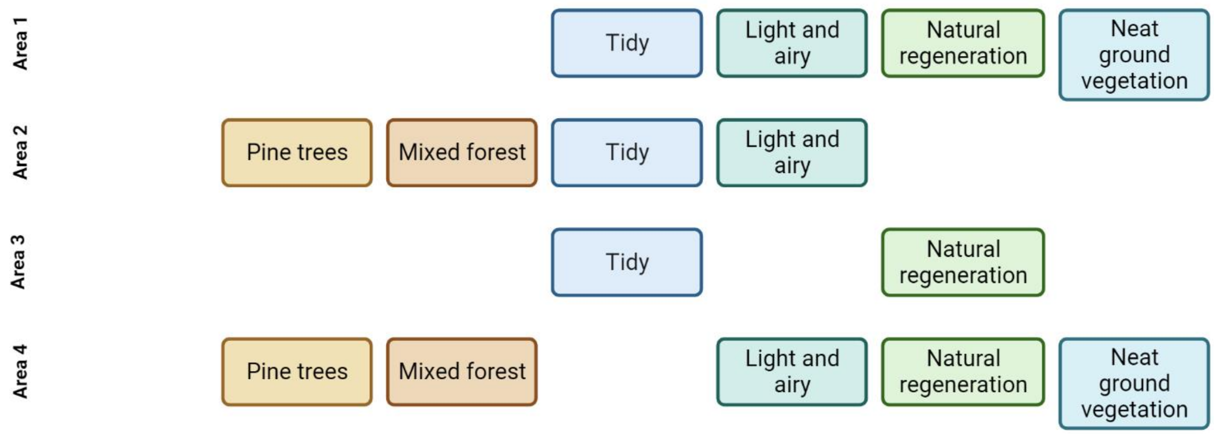

Figure 21 illustrates the aspirations expressed by potential forests, derived from interviews with landowners. It is important to note that the colors employed in the figure do not signify any specific coding; rather, they are used to distinguish the various groups of statements made by different landowners.

The landowners expressed a positive attitude regarding forestry and the use of forests. They shared a collective belief in the necessity of changing the forest composition, foreseeing an increased adoption of selective cutting in areas with small groves. In alignment with other landowners advocating for more broadleaves, Area 4 envisions a growing number of entrepreneurs playing a larger role in the future. This perspective aligns with Area 3's view that landowners would have limited time and/or knowledge for forest management, leading to an increased dependence on entrepreneurs. When asked about the knowledge gap, the landowners conveyed a sense of having to navigate it independently. In contrast, the municipality (Area 3) mentioned organizing events for landowners, although attendance has been low. Additionally, the municipality communicates with landowners through newsletters, providing information among other topics.

To envision a future long after their passing is challenging for the landowners, as reflected in statements such as: *"One cannot plan 200 years ahead. One must make sure the demands of today are met"* and "*It's hard to see what will be in 80 years' time, but it will be more important than ever for the development- and management of the property".* Some negative attitudes and concerns did exist, especially toward current management of forest properties. Area 1 expressed the importance of area quality and landscape management, and that transformative change in the forestry sector is inevitable: *"It's not necessarily about protection, but since they (broadleaved trees in general) are growing so slowly, one has to think differently".* In the long term, spruce will be phased out, at least in Moss, in exchange for e.g., pine trees mixed with broadleaved trees. Landowners expressed concerns about hiring assistance for forest management, emphasizing the need to engage individuals with the requisite knowledge and experience. They noted that schools offering such expertise already have sufficient forested areas to manage. Given their financial constraints, highlighted by the ongoing deficit, the landowners are reluctant to incur additional costs for help, particularly considering the relatively smaller size of their forests. While many landowners prefer hands-on forest management, Area 1 attempted to hire charity workers approximately five years ago but hasn't seen them since.

Exploring potential pathways to realize their visions, the landowners predominantly considered changes in forest management practices, favoring a shift from clear-cutting to selective cutting. Additionally, altering the forest composition by incorporating more broadleaved trees was deemed crucial. Area 3 emphasized the importance of active management, including post-cutting planting and proper thinning, to prepare the forest for selective cutting. Interestingly, none of the landowners mentioned the use of fertilizers as a management option.

Furthermore, all four areas, namely Area 1, 2, 3, and 4, outlined pathways that involve increased funding and education at various levels, spanning from the private to the public sector. This collective approach aims to ensure a more robust and sustainable forest management framework in the future.

The landowners' visions for the future of forest management center around strategic shifts in practices and a comprehensive focus on funding and education across sectors. These pathways signify their commitment to fostering a sustainable and thriving forest ecosystem.

Chapter 5

Discussion and conclusions

5.1 Discussion of the biological results

Our study delves into the intricate dynamics of Norway's future forests, focusing on species distribution, oak prominence, health, ground vegetation, and browsing behavior. The findings offer a nuanced understanding of the ecological patterns within the four areas studied.

The observed variation in species richness across the areas indicates unique ecological dynamics. Despite a broader species composition, Area 1 exhibited the lowest total number of species found. Conversely, Area 2 showcased the highest species count. This variation prompts further investigation into the factors influencing species distribution and richness.

Oak, a key species in the studied areas, exhibited unexpected density, challenging initial expectations. Additionally, the considerable variation in oak tree height and width highlights the complex interplay of environmental factors, including clear-cutting history and competition with other species.

Our investigation into oak health unveils intriguing patterns. While the health of oaks does not significantly impact oak density, geographic areas exhibit a notable influence, particularly in Area 1. The unexpected positive association between Area 1 and oak density, coupled with its recent logging history, suggests a nuanced relationship that requires deeper exploration.

Ground vegetation and biomass analysis indicate a limited influence on oak density. Beech and lingonberries show a positive association, emphasizing the need for a nuanced understanding of the interplay between ground vegetation, biomass, and oak density.

Browsing incidents, predominantly by insects, vary across study areas. The relationship between oak density and browsing, while not statistically significant, suggests the presence of unexplored factors influencing oak density. Understanding the potential impact of browsing on oak health and growth requires further investigation. The examination of incidents involving leaves and shoots provides insights into the browsing behavior of vertebrates. Area-specific variations highlight the complexity of browsing dynamics and their implications for oak regeneration and overall forest health.

5.1.1 Species within the areas

Moss municipality, especially the areas within this study, exhibited various layers of marine deposition which underlines the statements retrieved from interviews that the areas within this study have rich soil (According to *Kvartærgeologisk kart over Vannsjø* (1991)), marine and coastal depositions are often related to arable land). When describing the cultivated areas in 1743, they used words as "fertile, but impure sour, cold and damp", and the maps at the end of the 18th century contained many marshes and scattered broad-leaved forests where most of it is cultivated today (Hardeng, 2021). By this description one would think that spruce would have a higher density (max 0.6) than oak (max 0.7), especially since it is a previous spruce plantation. This revelation prompts a reevaluation of our assumptions and a deeper exploration of the ecological dynamics shaping the distribution of these key species.

The unexpectedly high number of oak trees across the areas did not align with our initial expectations. This is particularly positive considering the historical decline of deciduous forests in Europe (Blindheim et al., 2015; Ellenberg & Leuschner, 2010; Frivold, 2008; Olsen et al., 2020). There is need to address this ecological decline, and an examination of effective restoration strategies is in fact pressing. Not only for ecological significance through targeted restoration initiatives but also with the broader goal of adapting the forest landscape to the challenges presented by climate change.

In line with the findings of another study (Frost & Rydin, 2000), the spatial distribution of seedlings and saplings were associated with species richness and tree cover rather than specific vegetation types. Their research elucidates that the elevated occurrence of oaks in areas devoid of canopy cover may be attributed to seed dispersing animals, particularly Jays, showing a preference for open environments (Bossema, 1979), while at the same time, the risk of predation on seeds and saplings by rodents in open areas are low (Kollmann & Schill, 1996). Results of this study exhibited a larger species composition in Area 1. This could be due to the area being in a later successional stage than the other since it got clear-cut one year in advance. However, the unexpected discrepancy arises when considering the conventional understanding that areas with lower canopy cover, the areas that recently got clear-cut, tend to exhibit higher species richness. As Frost and Rydin (2000) further explained, areas with lower canopy cover had more species, and that oaks often occurred within these open areas which were located in edge-zones, where activity of seed dispersing animals also is high (Fraver, 1994). Consequently, one would anticipate higher species counts in the other areas with lower canopy cover, challenging the expectations derived solely from successional stage assessments. In essence, our study's results, when viewed through the lens of Frost and Rydin's insights, introduce a complex interplay of ecological variables influencing species composition. This calls for a more comprehensive understanding of the intricate relationships between canopy cover, seed dispersal dynamics, and successional stages to understand the growth of oak trees within these areas.

5.1.2 Sickness on oak trees

When doing fieldwork, we observed severe cases of sickness (on approximately 30% of all oaks found in the areas). Powdery mildew, a biotrophic plant pathogen, maintains a prolonged feeding relationship with the living cells of its host, appropriating the photosynthetically active leaf cells to photosynthate to support its own development (Bert et al., 2016).

The effect of disease on growth highly depends upon intricate mechanisms that interconnect infection with growth processes, operating across various temporal and spatial scales (Bert et al., 2016). A moderate impact of powdery mildews has been related to a small decrease the net CO_2 assimilation rate (Hewitt & Ayres, 1976) and on tree transpiration, however, the severe reduction in leaf lifespan of heavily impacted leaves could be potentially led to decreased carbon uptake over the growth seasons (Hajji et al., 2009). Consequently, young trees face an elevated risk of infection, with possible reduced growth and large seedling mortality (Soutrenon, 1998). For mature trees afflicted by the disease, the effects are considerably less damaging. However, it is worth mentioning that the presence of other factors, defoliation caused by insects, can compromise the vitality of the trees (Hajji et al., 2009).

According to Marçais & Desprez-Loustau (2014), powdery mildew stands as one of the prevailing diseases affecting oak trees in Europe, often leading a great disease impact characterized by "modified growth patterns" (e.g., environmental factors such as insects or frost but could be of silvicultural practices as well). Often, powdery mildew holds relevance in context of natural regeneration and plays a significant role in deterioration of mature oak trees. Although its widespread occurrence, the impact of powdery mildew has historically been considered as minor (Marçais & Desprez-Loustau, 2014).

Delving into the intricacies of powdery mildew occurrences is paramount to gaining a holistic perspective on its implications for the overall health and vitality of oak populations. This imperative inquiry will contribute crucial insights into the complex interactions between oak trees and powdery mildew, shedding light on ecological dynamics. Notably, even though the results from this study showed no significant impact on oak density or height across the areas, an in-depth exploration of powdery mildew remains essential for a nuanced comprehension of its ecological role and potential ramifications for oak ecosystems.

5.1.3 Ground vegetation

The strategic selection of tree regeneration locations is of paramount importance. A noteworthy result from this study revealed that Area 2 exhibited the highest number of trees per species. Interestingly, within this specific area, there was observed though notes a significant presence of grass.

According to Birkedal (2010), two of the greatest complications related to successful, natural regeneration of oaks are seed removal and competition from ground vegetation. Surrounded by woody vegetation (e.g., shrubs and trees, including herbaceous vegetation as well), oak trees had a 20% decreased survival rate, which in contrast to oaks surrounded by only herbaceous vegetation, had a survival rate close to 100% (Jensen & Löf, 2017). When doing field work in 2022 we noticed that oak trees in-between grass had a relatively greener appearance than the individuals growing outside the grass fields. Another study found that coniferous trees had the highest survival and growth in grasslands, while broad-leaved trees had a better chance of survival under sparse canopy in mid-successional oak forest. Oak trees grew taller in areas without any canopy cover (Quintana-Ascencio et al., 2004), and had a higher survival rate (Ovington & Murray, 1964). However, none of these studies specifically investigated the influence of ungulates. This factor might elucidate the higher vitality observed in oak trees growing in grassy areas of this study.

A call for further research is essential to delve deeper into the intricacies of forest ecosystems. These additional studies will not only expand our understanding of the intricate relationships among various components within forest environments but also unveil essential insights that could potentially shape more informed and sustainable forest management practices.

5.1.4 Browsing: an ecological disturbance

As previously mentioned by the landowners, roe deer pose a recurring challenge for farmers and other private actors in Moss municipality. Deer cause damage by browsing, stripping the bark, and fraying trees with their antlers. Given the selective foraging of roe deer, the specific parts of a tree browsed will highly depend on the tree species and time of the year (Gill, 1992). According to Holloway (1967) and Löyttyniemi and Piisilä (1983), deer typically browse at an intermediate level between ground and full reach, suggesting that trees higher and lower than this range would be relatively protected.

Although, our study did not uncover any statistically significant relationship between height and browsing, a study by Dobrowolska et al. (2020) observed consistent increases in oak height, strongly influenced by the surrounding vegetation.

The number of browsing incidents on oak trees was high in most of the areas (2-4), except for Area 1, which exhibited a significantly low number of incidents (51 browsing incidents compared to 141 individuals not browsed, resulting in 24.88% of oak trees in that area being browsed). Considering that Area 1 underwent clear-cutting a year in advance, it might have progressed to a later stage of succession, promoting a higher number of species to cover the oak saplings, aligning with the findings of Holloway (1967) and Löyttyniemi and Piisilä (1983). Advancing to a later successional stage could increase over all species diversity, introducing additional vegetation susceptible to browsing, thereby explaining the low incidence of browsing in this area.

The occurrence of herbivore browsing on oak trees may be a result of browsing from various herbivores. However, our current understanding of these interactions remains limited (Ohgushi, 2005). The edge-zones, as discussed in Chapter 4.1.1 on species distribution, establish environmental gradients that influence both vegetation composition and herbivore behavior. Herbivores in particular, ungulates, can exert significant negative impact on oak regeneration (Kellner & Swihart, 2017). Further, Kellner and Swihart (2017) suggests a spatial variation in browsing, that depends on herbivore taxa, with insect browsing peaking within the forest, while deer browsing remains constant along the edge. Interestingly, the presence of these insects is positively correlated to past herbivore browsing.

In our investigation, 70% of the oak was browsed, with 30% attributed to herbivores and 40% to insects. In contrast to the referenced study, only 20% of the oak was browsed by both insects and vertebrate herbivores. The areas (1-4) within this study were either surrounded by other forests or agricultural land, potentially contributing to edge-zones and more incidents of insect browsing.

It’s important to note that our study documented incidents of browsing rather than quantifying the extent of it. Consequently, even a 10% reduction in herbivory incidents could potentially result in more significant damage than insect-related browsing.

Despite the limited success of the motion-activated cameras in capturing desired results, our on-site observations proved instrumental. Live animals were observed during our field presence, and we identified various signs such as breeding pits, footprints, hair, and excrement, suggesting the presence of roe deer and to some extent moose (Figure 22).

Figure 22 Photographs capturing distinctive tracks left behind by wildlife in the study areas. (A) Breeding pits created by roe deer, showcasing the characteristic marks left during the breeding season. (B) Roe deer footprints. The human foot, marked by size 38, offers a reference point for size comparison in each image. (C) Footprints of moose, displaying the substantial size of these tracks.

Although these findings were not incorporated into the master thesis due to the absence of immediate results, it is recommended that future investigations include the establishment of camera traps to monitor and quantify roe deer browsing extents in the study areas. This proactive approach would contribute to a more comprehensive understanding of the dynamics of roe deer activity and its potential impact on the local ecosystem.

5.2 How to preserve a healthy forest

In exploring the forest management practices of landowners in Moss, a nuanced interplay of economic, ecological, and recreational considerations emerges. All landowners prioritize timber production for firewood. Notably, roe deer are perceived as problematic due to their impact on crops and flowerbeds, influencing the preferred forest composition within the framework of Limits of Acceptable Change (LAC). Despite relying on contractors for critical tasks, landowners assert that their forests yield limited financial benefits, fostering a dependence on alternative income sources. Recreation, particularly walking, hiking, and berry/mushroom harvesting, emerges as a crucial aspect of forest management, challenging the conventional perception of these areas viewed previously as purely production forests.

The areas express the desire of a forest for multi-use, including timber, biodiversity conservation, and recreation, emphasizing the importance of recreation over purely economic goals. This collective vision reflects a commitment to community well-being through diverse forest activities, echoing a desired state that prioritizes ecological and social health.

While all ecosystem service categories are acknowledged, discussions predominantly focus on supporting and cultural services. 'Ryggejoggen,' a community fitness route, exemplifies the intersection of human activities and ecosystem dynamics, emphasizing the importance of cultural services in forest management. Additionally, Landowners express a keen interest in well-functioning ecosystems, biodiversity conservation, and clean air/water, showcasing an understanding of the forest's role in supporting life. The emphasis on timber as something that *"has been done in the family"*, coupled with the desire for sustainable practices like selective cutting, reflects a cultural connection to the landscape. The nuanced recognition of ecosystem services illustrates the multifaceted values landowners attach to their forests.

The rich biodiversity of Moss's forest ecosystem is shadowed by nuanced conflicts and changing landscapes. Landowners exhibit a profound awareness of ecological terms and advocate for the coexistence of human activities with the natural environment. However, pragmatic considerations arise, with recreation and the possibility for forest hikes emerging as fundamental priorities.

Roe deer browsing poses a persistent challenge, with opinions on acceptable density varying among landowners. Concerns extend beyond forestry conflicts to potential impacts on vegetation, collisions, diseases, and grazing damage. The delicate balance envisioned by landowners involves strategic forest zoning for natural rejuvenation and recreation, offering a harmonious approach to ecological preservation and human enjoyment.

While a consensus exists on the detrimental effects of bark beetle infestations, clear-cutting evokes mixed sentiments. Landowners criticize the conventional approach, emphasizing the need for a landscape-friendly strategy that considers public health, biodiversity, and local contexts. The landowners' unique perspective challenges the prevailing forestry model and calls for a more tailored and sustainable approach to forest management in Moss.

Landowners' preferences for future forests in Moss were gauged through a visual exploration using a questionnaire featuring six images. The most preferred image featured mature oak with anemones, praised for cleanliness, accessibility, and biodiversity. The aspiration is for tidy, multi-layered forests accessible to the public, drawing inspiration from Moss's cultural landscapes.

The desired forest composition involves diverse vegetation, with three out of five landowners interested in planting pine trees together with oak. Area 3 envisions a sustainable future by participating in the "green" movement. Landowners are positive to forestry, foreseeing a shift to selective cutting and a larger role for entrepreneurs. Despite acknowledging a knowledge gap, they emphasize transformative change, envisioning a shift from spruce to pine trees mixed with broadleaved trees.

Proposed changes in forest management practices include a shift from clear-cutting to selective cutting and incorporating more broadleaved trees. Active management, funding, and education are emphasized, reflecting landowners' commitment to a sustainable and thriving forest ecosystem.

5.2.1 Climate crisis Navigating Climate Change Through Innovative Thinking.

Climate change is an inevitable phenomenon, as emphasized throughout this discussion. It is widely believed that nature, as we currently understand it, will undergo significant and dramatic transformations in the coming years. The increasing presence of invasive species, pest animals, drastic temperature fluctuations, and unpredictable weather patterns underscores the urgency for innovative thinking and transformative changes at both local and governmental levels. Historically, Moss municipality has managed its forests based on the boreal forest model. However, considering the observable shifts in Moss, it is conceivable that the municipality's forests will align more with temperate forests in the future, necessitating corresponding adjustments in management strategies (IPCC, 2019).

When addressing the climate crisis, individuals often struggle to perceive it as a real and immediate threat. This difficulty is attributed to the extended time span of climate change, making it challenging for people to comprehend and witness the changes directly. As mentioned by the landowner at Area 3, there is a concept of lagging, where the effects of certain actions become apparent only after a considerable period. Climate change, being a consequence of past decades, adds to the uncertainty about its full extent and impact. This temporal gap contributes to psychological and physical distancing (Richter et al., 2023; Van Lange & Huckelba, 2021), a phenomenon observed in human psychology, leading to tendencies such as NIMBYism (Not In My Backyard) (Michaud et al., 2008).

Psychological distancing manifests when individuals find it challenging to conceptualize the distant consequences of their actions, resulting in a lack of immediate concern. Climate change may be perceived as a global issue, leading individuals to believe that it is not directly affecting their local surroundings (Van Lange & Huckelba, 2021). Addressing these psychological aspects is crucial when promoting transformative change and fostering an environment for innovative solutions.

Steindl et al. (2015) introduce reactance theory, which highlights the impact of threats to individuals' freedom to decide for themselves. Social influence attempts that challenge this freedom can trigger a state of motivational arousal, prompting individuals to restore their perceived freedom. In the context of climate change management, understanding and acknowledging people's perceptions are essential. Creating a positive narrative about the future can contribute to making sense of the situation, providing a sense of meaning that stimulates cognitive evaluation and fosters the desired engagement needed to turn climate change into a positive force.

As elucidated by Bostrom et al. (2018) in their study, the motivation to address complex issues like climate change is driven by the necessity for concrete answers. Individuals are more inclined to act when provided with clear and tangible solutions to navigate the intricate challenges associated with climate change. By delving into the intricacies of the forestry sector and its interactions with climate change, our initiative can offer valuable insights and solutions. Concrete answers can serve as motivation for individuals to actively engage in addressing climate challenges.

The project's role in paving the way for innovative thoughts within the forestry sector becomes even more significant, as it not only contributes to a positive and sustainable future but also empowers people with tangible information. This empowerment can foster a sense of understanding and agency, motivating individuals to take meaningful actions in response to climate change. Through our project, the complex issues surrounding climate change can be demystified, providing a foundation for informed decision-making and impactful contributions to climate solutions. Therefore, projects like the one at hand play a crucial role in paving the way for innovative thoughts within the forestry sector, contributing to a positive and sustainable future.

5.2.2 Biological Barriers Acting as Limits for Potential Changes

As discussed, the motivation of landowners is pivotal in shaping the vision for a new forest. This project aims to convert a spruce plantation into a forest that aligns with the desires of the landowners, focusing on creating a more recreational environment for the well-being of the people in Moss municipality while enhancing the biodiversity of the forests. However, our aspirations encounter biological barriers that delineate the boundaries of what we can achieve—a concept akin to the Limits of Acceptable Change (Figure 23).

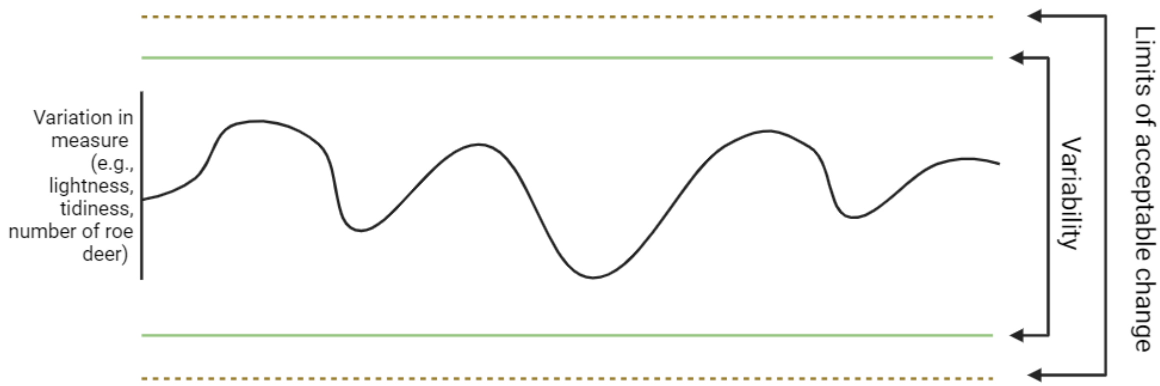

Figure 23 Limits of acceptable change. Adapted from Phillips (2006).

Drought has emerged as a significant threat to the established spruce trees, resulting in both direct and indirect losses of timber. The forests have become a financial burden for certain landowners who personally fund them, which raises a financial limit. Their preference leans towards achieving a net-zero income while investing time in managing the forest. Thus, an essential aspect to explore is effective drought management for these forests.

Drought is not the focus of this study but plays a pivotal role in the context of forest management. As we delve into the exploration of transforming previous spruce-dominated plantations to a mixed forest including broadleaves, it is essential to understand the historical context that has shaped the forest landscapes in Norway. Deciduous forests, known for their richness and diversity, have faced significant stagnation over the years. These forests, in comparison to other types of forests (e.g., coniferous forests) possess higher plant species diversity, stratification (Shrestha, 2003), and particularly rich and diverse understory vegetation (Kaeser et al., 2008), creating complex food webs (Bargali et al., 2015), making them hotspots for biodiversity (Bugalho et al., 2011). Often established on fertile soil, these forest ecosystems witnessed extensive clear-cutting in favor of agricultural expansion, further compounded by afforestation practices (e.g., planting commercial spruce), diminishing the prevalence of i.e., oak-covered land (Ellenberg & Leuschner, 2010; Olsen et al., 2020). Especially in accessible regions such as Østfold in southern Norway, the existing broadleaved forest sites, although being numerous compared to other regions of Norway, exhibit a notable reduction in average size due to intensified land utilization in these areas (Blindheim et al., 2015; Olsen et al., 2020).

All landowners are positive to oak trees in their forests, and they collectively considered the idea of having a mixed forest. Several landowners specifically mentioned pine as a favorable substitute for spruce. In terms of managing drought, pine employs a drought-avoidance strategy characterized by deep root systems and an immediate closure of stomata (Martínez-Vilalta et al., 2004), making it less susceptible to air embolism (gas bubbles that stop the flow of fluid) (Richardson, 2000). In contrast, common oak exhibits a unique resilience to drought, maintaining a high stomatal conductance and photosynthetic rates even under arid conditions (Epron & Dreyer, 1993), due to its deep rooting system and low vulnerability to air embolism (Cochard, 1992; Rosengren et al., 2006). Compared to spruce and pine, oak has demonstrated better growth during summer droughts (Cochard, 1992; Zang et al., 2011). This discovery is particularly noteworthy, given the unexpectedly abundant presence of oak trees within the areas of this study, surpassing initial expectations. This prompts a consideration on facilitating the development of oak forests with interspersed pine, fostering a lighter and, as the landowners expressed, a more 'welcoming' forest environment that enhances the recreational aspect as well as biological aspect of the forests.

Since 2011, large hollow oaks have been afforded special protection under the Nature Diversity Act §52, designating them as a selected nature type. Establishing a forest with a focus on oak trees could play an important role in the preservation of hollow oaks, an imperative task given their declining numbers in Norway (Nossen, 2015). In Norway, approximately 1,500 species are associated with oak trees, many being oak specialists, finding habitat in the unique environment of these trees (e.g., dead trees, cavities, and rotten wood) (Artsdatabanken, 2021; Nossen, 2015).

According to old sayings, it is said that oaks take 500 years to grow and another 500 years to die. In Norway, a living statement to this notion is 'Mollestadeika', a big, hollow oak tree considered one of the country's oldest, estimated to be around 1000 years old (Grundt & Tollefsrud, 2011). While big hollow oaks may not be suitable for timber, they significantly contribute to biodiversity, hosting numerous red-listed species throughout (Artsdatabanken, 2021) . Within the hollows of oak trees, a substrate known as "vedmuld" (Norwegian) is formed, consisting of a mix of decomposed wood, fungal hyphae, and remnants of bird or insect nests. This creates a nutritional substrate and habitat for various species, underscoring the ecological significance of preserving dead wood in oak forests. Moreover, these oaks hold immense cultural and experiential value, further justifying their preservation (Nossen, 2015).

Most landowners express a desire for a forest that serves practical needs like firewood and occasional construction materials rather than a fully commercial forest. Establishing hollow oaks and oaks, in general, requires a long-term perspective, resulting in a multigenerational forest with trees of various shapes, widths, heights, and ages as illustrated in Figure 24. The illustration depicts the forest perception of each landowner, derived from the insights gathered during interviews. The consensus among landowners leans heavily towards prioritizing biodiversity and promoting recreational use of the forest. This inclination provides a clear indication that the envisioned new forest is intended to function as a multi-use forest without the focus on production.

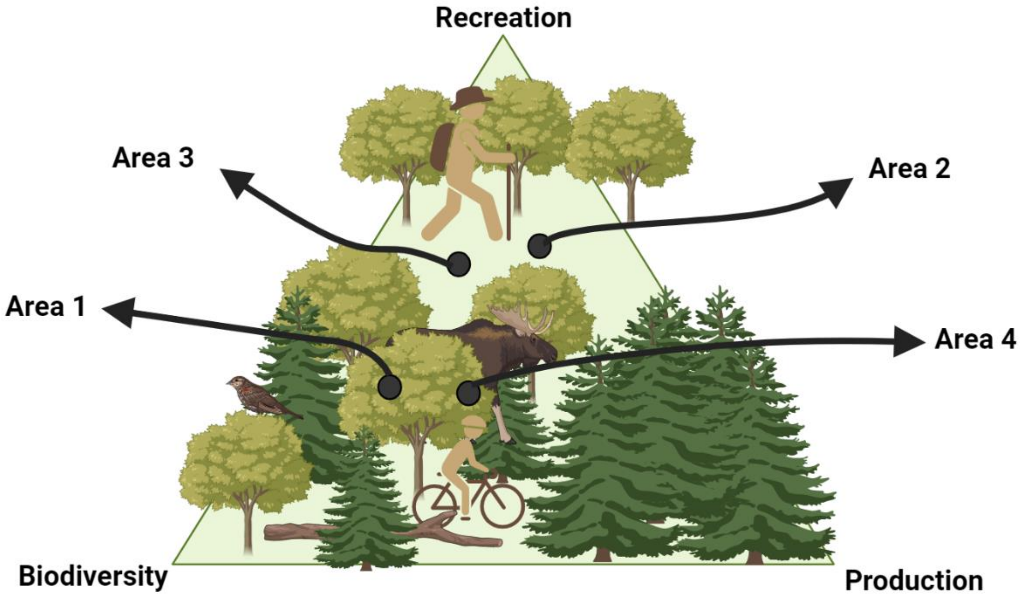

Figure 24 Forest perceptions drawn from interviews with the landowners. The answers given indicate that the envisioned new forest is intended to function as a multi-use forest without focus on production.

However, certain considerations arise when establishing hollow oaks. Dead wood can pose challenges to the recreational aspect, necessitating forest management to enhance both safety and accessibility for the people using the forest. Though, it's crucial to recognize that dead wood serves as potential habitats for species and is essential for the ecological health of an older forest, and should, consequently, be preserved, rather than harvested for firewood. This raises the prospect of cultivating a mixed forest, as discussed earlier, incorporating additional trees like pine or birch that could serve as potential sources of firewood and construction materials, while still preserving the vital ecological role of oak trees and their associated species.

Similar to the vegetation found within the areas of this study, herbivore activity, particularly browsing by roe deer, has the potential to impede the envisioned future forest of the landowners. As previously discussed, roe deer, in particular, pose a threat to oak saplings and the surrounding vegetation in the forests. Understanding the extent of damage caused by roe deer and other factors is crucial for determining suitable plantations and growth within the study areas. According to Gill (1992), Scots pine is the least preferred by roe deer, while moose exhibit varying preferences for different clones of these pine trees (Danell et al., 1990). Notably, oaks surrounded by planted pines have been observed to be significantly higher than those surrounded by sown pines, providing protection to the saplings from potential harm (Dobrowolska et al., 2020). Johnson et al. (2019) found that various silvicultural approaches can be employed to promote oak regeneration. However, alterations in environmental conditions, such as transitioning from spruce plantations to deciduous forests following silvicultural disturbances, may create new edge habitats, impacting the herbivore community and potentially leading to additional indirect effects on oak recruitment (Kellner & Swihart, 2017).

Furthermore, roe deer contribute to a structuring effect on vegetation composition, as demonstrated by Boulanger et al. (2015). The study highlights a substantial increase in the frequency of nitrophilous plant species, with the community composition shifting towards lightly browsed characteristics, concurring with a reduction of deer densities, an incomplete recovery of vegetation communities was observed. Consequently, future monitoring of forest biodiversity should incorporate assessments of browsing pressure to mitigate potential effects of wild ungulates, particularly when facilitating conditions for oak growth.

5.2.3 Fostering Local Expertise: Timber Production and Harvesting Practices.

After delving into discussions on climate change, motivating factors for change, and biological constraints, it becomes imperative to explore the wealth of local knowledge. Despite forests covering a substantial portion of the EU, the responsibility for implementing forestry strategies is largely placed in the hands of local government institutions (Brosius et al., 1998). In alignment with the Forestry Act §4, individual landowners bear the responsibility of ensuring that all measures align with laws and regulations. This entails having a comprehensive understanding of the environmental values within their forests and determining appropriate management practices to safeguard these values. Such considerations may limit certain activities in the forest.

Within the established frameworks, forest owners have the freedom to manage their forests according to their preferences (Brosius et al., 1998; Eurpoean *Communication from the commision to the European parliament, the council, the European economic and social committee and the committee of the regions.* , 2021). Brosius et al. (1998) identifies public forest workers as the key actors in executing forestry policies. Recognizing that forest management practices profoundly influence both forests and their ecosystems, and that the way forests are managed can potentially mitigate climate change (e.g., by acting as net carbon sources or sinks) (Birdsey et al., 2006), it becomes crucial to acknowledge the influential role of those on the ground.

However, as highlighted by Lebel et al. (2004) in their study examining four contrasting perspectives (state-knows-best, market-knows-best, greens-know-best, and local-knows-best), historical battles between these perspectives persist. This resonates with our interview findings, where dissatisfaction with the forest management practices became apparent in the surveyed areas. Lebel et al. (2004) further argue that each perspective, whether old or new, has limitations and may not effectively address ecological and socio-political uncertainties. The central message of their study is that in the face of recurrent crises, rigid management plans and fixed regulations are likely to fail. Embracing uncertainty, acknowledging the temporary nature of solutions, and recognizing the limits of scientific knowledge is suggested as a more realistic approach to forest governance, summarized by the phrase “Nobody knows best”, emphasizing the need for humility and flexibility in managing complex ecological and social systems. Understanding these dynamics is essential as we navigate the complexities of forest management in the context of evolving environmental challenges.

Diverse forest strategies and management objectives can exert varying impacts on ecosystem services, yielding dissimilar outcomes for land-use (Haugen, 2016). The landowners don't share a complete unanimous vision for the future forest, but a recurring theme is the prioritization of the Moss municipality residents and biodiversity. They emphasize that these forests should serve as a model, inspiring others to adopt similar practices and create a positive ripple effect that contributes to mitigating climate change. Achieving the envisioned forest requires a more coordinated management plan, considering both biological constraints and the "social" aspects—reflecting the wishes and desires of the landowners.

Drawing from Finland's extensive forestry history, there is an opportunity to leverage this expertise to develop and implement management practices that extend beyond timber production, focusing on ecosystem services (Moen et al., 2014). Thinning, its frequency, and intensity are crucial factors influencing timber production, carbon sequestration (Hynynen et al., 2005; Moen et al., 2014) and even berry production (Miina et al., 2010), which aligns with some landowners' preferences. Regulating rotation length (the number of years a forest stand is allowed to grow before it is harvested) also emerges as an effective strategy for enhancing forest carbon sequestration and berry production (Hynynen et al., 2005). If Moss municipality decides to establish an oak forest, careful consideration of the rotation length becomes crucial. The landowners acknowledge that oaks require significantly more time to mature compared to spruce; in fact, spruce plantations in southern Sweden typically undergo a rotation period of 50–80 years, in contrast to the significantly longer lifespan of retained oaks, which may extend for several hundred years (Lariviere et al., 2023). Consequently, it is imperative to implement effective long-term management strategies to ensure the preservation of oaks and the diverse species associated with these ecosystems.

Clear-cutting is controversial even among the landowners we interviewed. Primary concerns raised against it include the perceived reduction in biodiversity and the visual displeasure associated with extensive cut areas. Conversely, proponents argue that clear-cutting allows the forest to naturally regenerate over time, providing fertile ground and shelter for flora and fauna in nearby forest stands. An additional argument in favor points to the significant increase in Norway's forest volume since the introduction of stand forestry around 1950. The historical discourse on clear-cutting has deep historical roots (Nygaard & Øyen, 2020).

In the 1800s, J. B. Barth, a pivotal figure in the development of the public forest system and practical forest management, opposed clear-cutting in Norway. His argument revolved around landscape variations and uneven tree stock ratios after dimensional cutting. He advocated for "group logging," a method blending clear-cutting and selective cutting, historically considered common in larger Norwegian forest areas (Nygaard & Øyen, 2020). Nygaard and Øyen (2020), further highlight Martens' (Norwegian forester and politician) critique of monocultural forests, deeming them unsuitable for Norway due to storm damage risks and insufficient protection for young forests. Martens proposed "group logging" as an alternative cutting method in his 1887 book, "Veiledning I Skogstel". Different cutting techniques is illustrated in Figure 25.

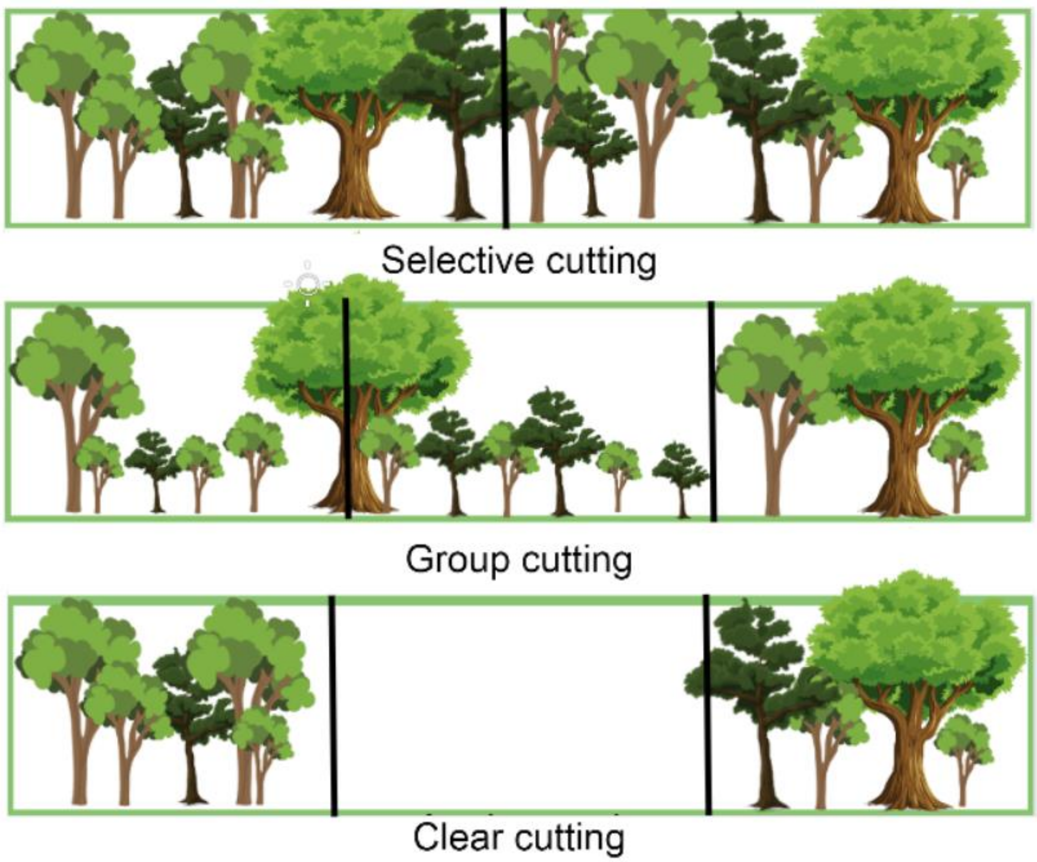

Figure 25 Illustrations of different logging methods: Selective, with single tree selection; Group, a mix of selective and clear-cutting, where only a small part of the forest will be cut; and Clear cutting, where bigger area or the whole area is cut. Adapted from Lapointe-Gagner (2018).

New governance systems are evolving in the forestry sector aiming to secure sustainability of timber production and forest ecosystems through the integration of biodiversity and nature's contributions to people (Olschewski et al., 2018). Concerning voluntary initiatives, forest certification, such as Norwegian PEFC Forest Standard, is often considered as one of the most important private or self-governance initiatives, due to the broad inclusion of stakeholder groups (environmental non-governmental organizations, and social groups such as indigenous people and labor organizations) as well as private forest owners (Johansson et al., 2013). Interviews highlighted a desire for the flexibility to choose a suitable cutting method, emphasizing Norway's diverse landscapes where a one-size-fits-all approach may not be applicable. In March 2023, a renewed PEFC forest standard was introduced, specifying that group certificate holders, like Glommen Mjøsen, must possess the necessary expertise and employ closed cutting methods. They are required to outline strategies for increasing the proportion of closed cuttings and small-area cuttings (PEFC, 2022). Closed logging, defined as *"leaving at least 16 trees per hectare after felling or limiting felled areas to less than 2 daa",* is particularly suitable for younger, heterogeneous spruce forests due to its compatibility with shade-tolerant species (Lunde et al., 2022). Successful implementation of closed cutting also relies on a well-established forest access road network surrounding the entire forest area (PEFC, 2022).

Selective coppicing, a prevalent management technique for oak trees, involves cutting the tree trunk at nearly ground level and utilizing the wood for various purposes. The regenerated sub-trunks are periodically harvested for building materials, firewood, or charcoal production (Darenova et al., 2016). The traditional practice of coppicing contributes to habitat diversity, positively influencing the ecosystem's structure, composition, species richness, and overall biodiversity of the forests (Santoro et al., 2020). In many traditionally coppiced systems, biodiversity has been observed to decline when this management practice is discontinued (Hédl et al., 2017). While modern coppicing methods are generally considered sustainable, it is acknowledged that, under specific conditions, they may have adverse effects on ecosystem functioning (Stavi et al., 2022).

For the landowners in Moss Municipality, diverse silvicultural approaches can be employed to enhance oak regeneration, as suggested by Johnson et al. (2019). One strategy involves the underplanting of nursery-grown seedlings into existing stands to supplement the existing advance reproduction (Dey et al., 2012). Simultaneously, the creation of new canopy openings through timber harvesting can positively influence seedling growth and survival by increasing the availability of light. However, it's crucial to acknowledge that altered environmental conditions resulting from silvicultural disturbance, such as the creation of new edge habitat, also influence the herbivore community, potentially leading to additional indirect impacts on oak recruitment. Transitioning to alternative cutting methods can enhance ecosystem health and support sustainable land use practices (Kellner & Swihart, 2017).

However, these alternative harvesting techniques often demand more labor and are comparatively costlier for timber producers. This may explain why Norwegian timber producers, in contrast to clear-cutting, do not commonly employ these methods (Pickett & Cadenasso, 2002). While the new certification opens the door to alternative cutting methods, economic and biological conditions must be considered for suitability (PEFC, 2022).

5.3 The way forward (recommendations)

In conclusion, herbivores possess the capability to influence the structural and compositional aspects of regenerating trees through selective browsing in recently disturbed clear-cut areas (Chevrier et al., 2012). Although our study did not yield scientifically significant results for browsing by any herbivorous species, one cannot draw definitive conclusions regarding the impact of deer browsing on oak. However, the elevated proportion of oak trees browsed, coupled with additional information (Bergquist & Örlander, 1998; Boulanger et al., 2015; Chevrier et al., 2012; Cilles et al., 2016; Ezebilo et al., 2012; Van Hees et al., 1996), strongly suggests that deer browsing constitutes a substantial constraint on the establishment of oak. Assuming that the desired forest composition in the research areas includes a mix of oak trees, employing an oak browsing index could prove to be a reliable "indicator of ecological change" for monitoring the roe deer population in relation to natural regeneration (Chevrier et al., 2012). Potentially identify a density that is both socio-economically viable and aligns with ecological boundaries.

While landowners acknowledged a diverse array of ecosystem services and held a variety of forest values, our analysis revealed that their central management objective is focused on recreation, coupled with a desire for a net-zero outcome. Given the absence of direct economic ties to the forests in Moss municipality, aligning projects with forestry, as is the case in these forested areas, proves beneficial. Moss municipality serves as a noteworthy example, showcasing the potential for other municipalities to facilitate similar opportunities for foresters and landowners with similar aspirations. The essence of this study suggests the necessity of considering the municipality as a whole—evaluating its needs, whether they lean towards recreation, forestry, a heightened focus on biodiversity, or a combination of these elements. The landowners in Moss municipality appear more geared towards recreation, with biodiversity serving as an additional benefit. Given the lack of emphasis on the production aspect while still requiring financial support for forest maintenance, individuals should contemplate suitable incentives. Exploring options that may not strictly align with forestry but lean towards outdoor recreation could be a viable approach. Subsequently, it becomes essential to identify potential sources for such incentives, assess the feasibility of application, and determine eligibility—particularly considering that Skogfond is production-oriented.

One noteworthy concern voiced by landowners is the scarcity of accessible knowledge and support to acquire such information. A plausible remedy to this challenge involves the development of an online user manual tailored for landowners in each municipality. This initiative aims to foster a comprehensive understanding of forestry practices, thereby ensuring alignment with the collective visions and preferences of each municipality. The website could further incorporate features allowing individuals to enroll in or explore various courses that cater to their specific needs in forest management. Moreover, an informative section outlining potential financial incentives would prove invaluable for both municipalities and private landowners, thereby reinforcing the realization of a shared vision for the forest. In the same vein, providing insights into pertinent research opportunities, if known by the municipality, could serve as a valuable resource for landowners interested in participating in such endeavors.

Prioritizing landscape management, especially in smaller forest areas, should involve considering a form of selective cutting. This becomes particularly relevant when incentives are equal, resulting in an economic outcome of zero. Alternatively, if entrepreneurs, such as Glommen Mjøsen, could offer the same pricing for selective cutting in smaller areas as they do for clear-cutting in similar locations, it would encourage a more sustainable approach.

Last, our study meticulously identifies pivotal management strategies for shaping the future forest in Moss municipality, drawing insights from enlightening interviews with landowners. These strategies encompass various dimensions, embodying a comprehensive and integrated approach toward sustainable social-ecological forest management:

1. Selected Cutting:

Landowners underscore the significance of selective cutting as a judicious management strategy. This approach empowers precise control over the trees harvested, fostering a more sustainable and diversified forest structure. Selected cutting stands out as a crucial component in achieving the envisioned multi-use forest.

2. Browsing Trees:

A strategic consideration that emerges is the concept of "browsing trees." Informed by an understanding of herbivore behavior, particularly roe deer, landowners strategically incorporate trees that act as bait. This innovative approach aims to manage herbivore impact while concurrently fostering the growth of desired species, notably the resilient oak.

3. Promoting Oak Growth:

The resounding interest of landowners in promoting oak growth is a testament to their recognition of its ecological significance and resilience. This strategic objective involves a nuanced approach, including the underplanting of nursery-grown seedlings and the creation of canopy openings through timber harvesting. These practices align with the broader goal of enhancing oak regeneration.

4. Forestry Information:

Landowners emphasize the crucial need for accessible forestry information. In response, there is a call for the development of an online user manual tailored to each municipality. This comprehensive resource is envisioned to bridge the knowledge gap, offering meticulous guidance on forestry practices. It serves as a cornerstone in fostering a cohesive understanding among landowners, contributing to informed decision-making.

5. Financial Support and Incentives:

Financial considerations take center stage, with landowners stressing the necessity of robust financial support and incentives. The study advocates for an exploration of options beyond traditional forestry, proposing incentives for outdoor recreational activities. In light of production-oriented forest standards like Skogfond, the importance of identifying potential sources for incentives, assessing feasibility, and determining eligibility is underscored.

As illustrated in Figure 26, these management strategies symbolize the interconnected and symbiotic relationship between ecological and social knowledge in achieving sustainable forest management. By adopting an integrated approach, these strategies aim to craft a forest that not only addresses the diverse needs of the community but also ensures the enduring maintenance of ecosystem services and functions. The figure visually represents the visions of landowners and their thoughts on coexistence of ecological principles and social considerations in shaping the future forest landscape.

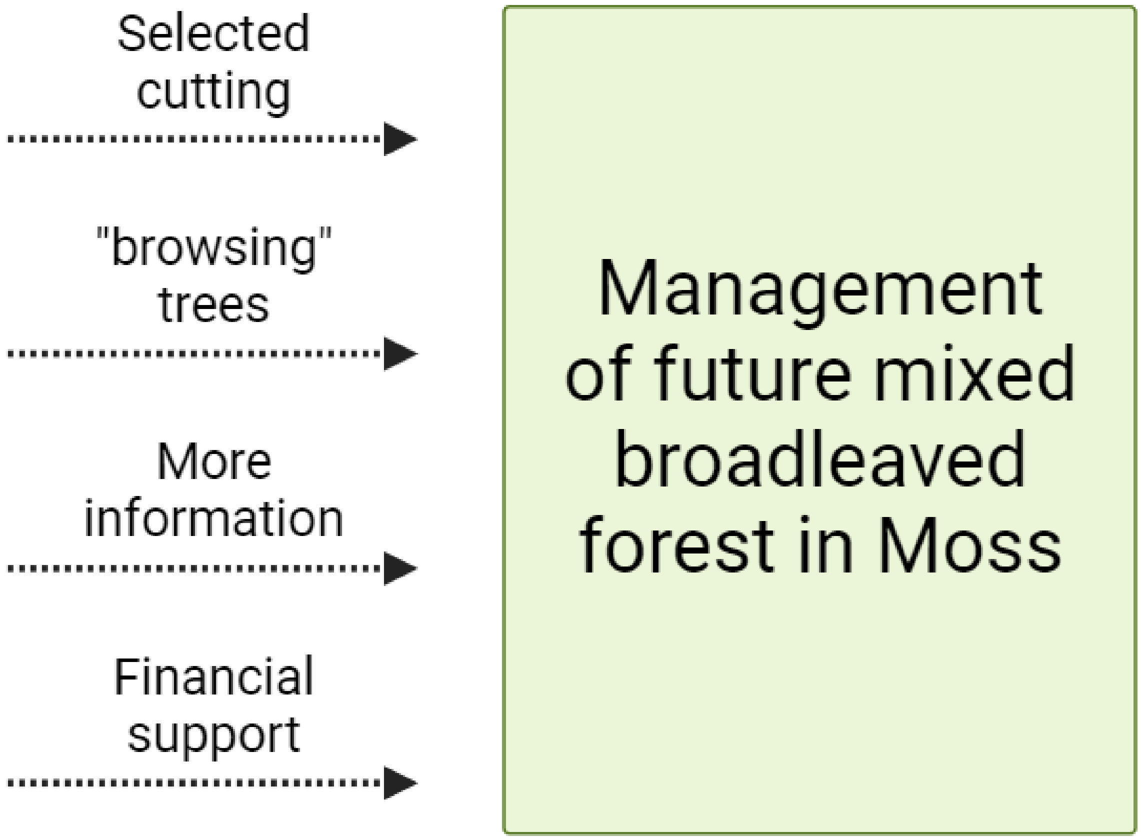

Figure 26 Management strategies for future forest drawn from interviews with landowners

Chapter 6

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Chapter 7

Appendix

7.1 Protocol for Experimental Design

Codes	Explanation	Definition	
SM	soil moisture	dry	1
		intermediate	2
		humid	3
broi	browsed insects	yes	1
		no	0
brov	browsed vertebrate	yes	1
		no	0
vpos	vertebrate shoots eaten	nothing	0
		A little	1
		intermediate	2
		A lot	3
vpol	vertebrate leaves eaten	nothing	0
		A little	1
		intermediate	2
		A lot	3
ipol	insects leaves eaten	nothing	0
		A little	1
		intermediate	2
		A lot	3
bd	Bark damage	yes	1
		no	0
t	Number of transects		
q	Number of quadrat		
w	Width in cm		
h	Height in cm		
nsq	number of species in quadrant		
sq	species in quadrat		
lat	latitude		
long	longitude		
nb	number of branches		
20	By twenty we mean twenty and over		
300	By 300, we mean 300 and over		
cc	canopy coverage with mobile app		
cacx	concave and convex	convex	-1

		neutral	0
		concave	1
color	G (green)	"healthy"	1
	Gul (yellow), bf (brown spotted), and gulf (yellow spotted)	"intermediate"	2
	Hvit (white), vissen (dry and dead), b (brown), hf (white spotted), hb (white and brown), hfbf (white spotted and brown spotted)	"sick"	3

Point intercept is written as 20 are 20+ hits. This is in need of a upper limit when the number could exceed hundreds of hits.

By defining the color with three levels: healthy, normal and sick, we can indicate if sickness affect the growth, but not the degree of sickness.

7.2 Questionnaire for The Landowners

Spørreskjema for Grunneiere

Section 1

Personlig Informasjon

Personal Information

1

Grunneier, Navn ELLER Selskapsnavn:
Landowner Name(s) OR Company Name:Single line text.

Enter your answer

2

Alder:
Age:Required to answer. Single choice.

18-24

25-34

35-44

45-54

55-64

60+

3

Høyeste Utdanningsnivå:
Highest Level of Education:Required to answer. Multi Line Text.

Enter your answer

4

Har du noen utdanning som var skogbruksbasert eller relaterbart til skogbruk?
Do you have any education that is forestry based or related?Required to answer. Single choice.

Ja/Yes

Nei/No

5

I tillegg til å være skogeiere, er du bonde eller involvert i andre næringsvirksomheter?
In addition to being a forest owner, are you a farmer or involved in other businesses? Required to answer. Single choice.

Ja / Yes

Nei / No

Ikke aktuelt / Not applicable

6

Hvilken andel av tiden din brukes på skog, jordbruk og andre næringer?
What proportion of your time is for forest, farming, or other work? Required to answer. Multi Line Text.

Enter your answer

7

Hva slags landbruk gjør du? Her kan du svare flere alternativ
What type of agriculture do you do? You can check of multiple answers
Required to answer. Multiple choice.

Husdyr / Livestock

Kornproduksjon / Cereal Production

Ikke aktuelt / Not applicable

8

Hvilke type dyr har du?
What type of animals do you have?Required to answer. Multi Line Text.

Enter your answer

9

Er det innmark eller utmarksbeite?
Is it infield or outfield grazing?Required to answer. Single choice.

Innmarksbeite / Infield

Utmarksbeite / Outfield

Begge / Both

Ikke aktuelt / Not applicable

10

Går det husdyr på beite i skogen?
Does livestock grazing occur within the forest?Required to answer. Single choice.

Ja / Yes

Nei / No

Ikke aktuelt / Not applicable

11

Hvor mye tid bruker du i skogen (enten din egen eller andre skoger)?
How much time do you spend in the forest (either your own or other forests)?Required to answer. Single choice.

Mye / A lot

Noe / Some

Litt / A little

Ingen / None

Ikke aktuelt / Not applicable

Section 2

Skog informasjon

Forest information

12

Plassering av skogseiendommen & stedsnavn:
Location of Forest & Site Name(s):Required to answer. Multi Line Text.

Enter your answer

13

Skogstørrelse:
Forest size:Required to answer. Multi Line Text.

Enter your answer

Section 3

Hvis privat grunneier:

If a private landowner:

14

Hvor lenge har skogen vært eid av deg?
How long has the forest been owned by you?Multi Line Text.

Enter your answer

15

Har skogen blitt holdt i familien?
Has the forest been kept in the family?Single choice.

Ja / Yes

Nei / No

Ikke aktuelt / Not Applicable

16

Hvor lenge har skogen vært i familien?
For how long has the forest been in the family?Multi Line Text.

Enter your answer

17

Hvilken prosentandel av inntekten kommer fra skogen?
What percentage of your income comes from the forest?Multi Line Text.

Enter your answer

Section 4

Hvis skogen er eid av bedrift:

If the forest is company owned:

18

Hvor lenge har selskapet eid og forvaltet skogen?
How long has the company owned and managed the forest?Multi Line Text.

Enter your answer

19

Hvilken prosentandel av selskapsinntekten kommer fra skogen?
What percentage of company income comes from the forest?Multi Line Text.

Enter your answer

Section 5

Skogsforvaltningsplan, Sertifiseringsordning, & Organisasjoner

Forest Management Plan, Certification Scheme, & Organizations

20

Har du en skogsforvaltningsplan?
Do you have a forest management plan?Required to answer. Single choice.

Ja / Yes

Nei / No

Ukjent / Unknown

21

Er du en del av en sertifiseringsordning? Her kan du svare flere alternativ
Are you part of a certification scheme? You can check of multiple answersRequired to answer. Multiple choice.

Programme for the Endorsement of Forest Certification (Program for Godkjenning av Skogsertifisering)

FSC (Forest Stewardship Council)

None / Ingen

22

Er du en del av en skogsbedriftsorganisasjon? Her kan du velge flere alternativ
Are you part of a forest owner organization? You can check of multiple answersRequired to answer. Multiple choice.

Norskog

Norwegian Forest Owner's Association / Norges Skogeierforbund

Ingen / None

Section 6

Informasjonsstrategi

Information strategy

23

Hvem spør du om råd når det oppstår problemer i skogbruket?
Who do you turn to for advice on forestry issues?Required to answer. Multi Line Text.

Enter your answer

24

Hvilken kanaler benytter du for å innhente informasjon om skogbruk? eksempelvis ulike internettsider (regjeringen, wikipedia etc.), bøker, muntlig samtaler.
Which channels are used to obtain information about forestry? E.g. different web-pages (governmental, wikipedia etc.), books, conversation.Required to answer. Single line text.

Enter your answer

Section 7

Skogpreferanser / illustrasjonsevaluering

Forest preferences / photograph evaluation

25

På en skala fra 1-6, hvor en er det mest foretrukne og 6 er minst, hva ville du ha rangert eldre eik med hvitveis?
On a scale from 1-6, where 1 is the most preferred and 6 is the least, what would you rank mature oak with anemone? Required to answer. Single choice.

26

Og hvorfor ga du illustrasjonen denne verdien?
And why did you give the illustration this rating?Required to answer. Multi Line Text.

Enter your answer

27

På en skala fra 1-6, hvor 1 er det mest foretrukne og 6 er minst, hva ville du ha rangert eldre eik blandet med røffere bunndekke?
On a scale from 1-6, where 1 is the most preferred and 6 is the least, what would you rank mature oak mixed with rough field layerRequired to answer. Single choice.

28

Og hvorfor ga du illustrasjonen denne verdien?
And why did you give the illustration this rating?Required to answer. Multi Line Text.

Enter your answer

29

På en skala fra 1-6, hvor 1 er det mest foretrukne og 6 er minst, hva ville du ha rangert middelaldrende eik med gress?
On a scale from 1-6 what would you rank mid-aged oak with grass? Required to answer. Single choice.

30

Og hvorfor ga du illustrasjonen denne verdien?
And why did you give the illustration this rating?Required to answer. Multi Line Text.

Enter your answer

31

På en skala fra 1-6, hvor 1 er det mest foretrukne og 6 er minst, hva ville du ha rangert middelaldrende eik med løv?
On a scale from 1-6 what would you rank mid-aged oak mixed with litter?Required to answer. Single choice.

32

Og hvorfor ga du illustrasjonen denne verdien?
And why did you give the illustration this rating?Required to answer. Multi Line Text.

Enter your answer

33

På en skala fra 1-6, hvor 1 er det mest foretrukne og 6 er minst, hva ville du ha rangert ung eik med visnet gress?
On a scale from 1-6 what would you rank young oak with withered grass?Required to answer. Single choice.

34

Og hvorfor ga du illustrasjonen denne verdien?
And why did you give the illustration this rating?Required to answer. Multi Line Text.

Enter your answer

35

På en skala fra 1-6, hvor 1 er det mest foretrukne og 6 er minst, hva ville du ha rangert ung eik med hvitveis?
On a scale from 1-6 what would you rank young oak with anemone? Required to answer. Single choice.

36

Og hvorfor ga du illustrasjonen denne verdien?
And why did you give the illustration this rating?Required to answer. Multi Line Text.

Enter your answer

7.3 Interview Guide for The Landowners

Interview Guide – Moss County Forest Landowners

Start section: The importance of the forest

Firstly, we want to ask you some more general questions on you and how you run your farm, and if it is okay that we record this conversation for research purposes?

Can you briefly tell us how you run your farm / land, and its economically importance (for you)?

To what extent does your forest mean to you?

How important is the forest to you?

How would you range the management of your forest in comparison with other activities done by you as a landowner?

Regarding trade-offs and synergies, what do you generally think of the economic, ecological, and social values (landscape and recreation) when managing your forests?

Section 1: Usage of the forest

What is your main use/management of the forest? [e.g. timber production, wildlife, other] /Hva er hovedvirksomheten

Has the forest always been used / managed in this way? If not, how was the forest used / managed in the past?

Section 1A: Timber / Tømmer

How do you harvest timber? [e.g. use of contractor, other?]

What are your environmental predictions on harvesting timber?

After harvesting, do you plan to plant new trees? If so, what species are you planting?

Section 1B: Game for hunting / Jaktbart vilt

What are your main arguments for hunting in your forest?

What game is hunted in your forest?

How is the hunting organized? Who participates in the hunting? [e.g. hunt alone, hunting team, sell hunting rights]

Section 1C: Management for wider ecological and social values

Do you think your forest has an ecological importance for the area?

What social values and needs (as recreation, beautiful landscape etc.), if any, does your forest play for the local and regional community?

Section 2: Forest management for timber and game production

What are your thoughts on hunting?

Do you have the right to hunt on your property?

Do you hunt?

Why or why not?

If no, have you considered hunting?

Are there any conflicts regarding timber production, game hunting or browsing, or other wildlife you would like to emphasize?

What is your relationship with moose?

Do you think the density of moose is too low or too high?

What is your opinion on today's quotas regarding moose density?

What is your relationship with roe deer?

Do you think the density of roe deer is too low or too high?

What is your opinion on today's quotas regarding roe deer density?

Is it possible to reach a balance between managing game and managing forestry?

Why or why not?

Are these two resources equally important for you / your company?

Section 3: Managing ecosystem services in forest

In terms of the different nature benefits to people, what are the most important nature benefits to people provided by the forest? [e.g. timber for firewood, meat, berries, mushrooms, the feeling of happiness]

To what degree does biodiversity and climatic challenges play a role in the management and production of your forest?

How do you envision the future of Norway's forests and your forest property?

How would you reach this future?

Are there any management changes needed? [e.g. business as usual, need of management changes]

What are your thoughts on hiring services to manage your forest?

Do you think it is possible incorporating schools, teams, or different associations to help manage the forest?

How important are forests to sustainable development in Norway? Please explain your answer.

What are your thoughts on changing the forest from mainly spruce to deciduous forest or a mix of both spruce and broadleaved trees?

How do you think your forest will look like in 30 years?

Section 4: Forest preferences / photograph evaluation

How would you describe a beautiful forest?

Can you short describe forest elements you find beautiful / aesthetically valuable in your forest

And opposite – What would you consider ugly / less attractive elements in your forest?

You received a questionnaire where you were supposed to rank different forests with underlays. Do you have any comments or thought?

Ending Section

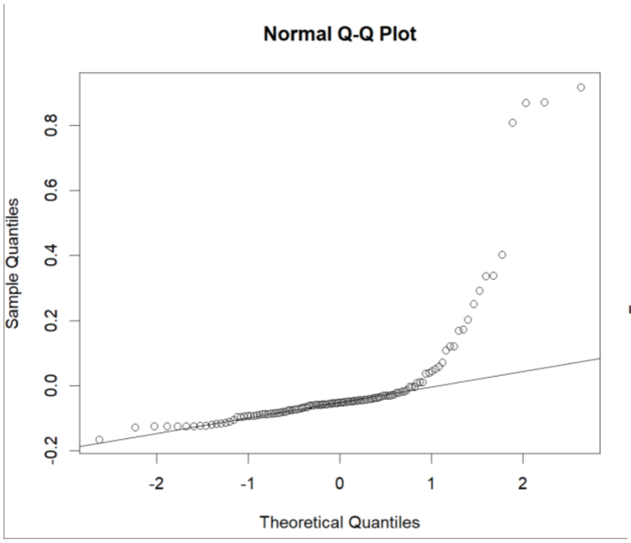
If you have additional inputs, feel free to give comments on that now! [e.g. the questionnaire or other things from what we already have discussed]

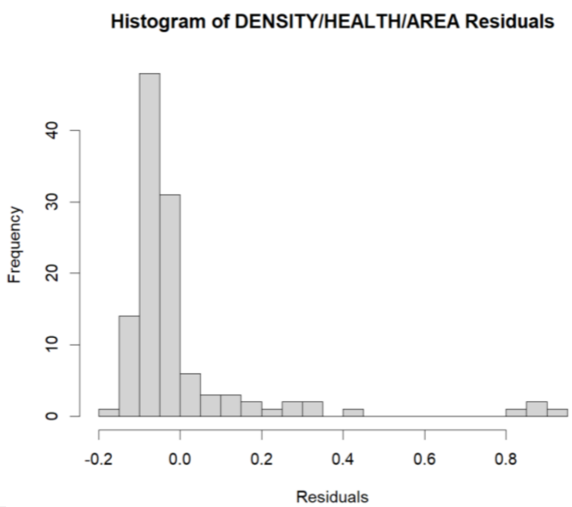
Or … you could mail me feedbacks to … mail address.

Thank you for letting me use your time

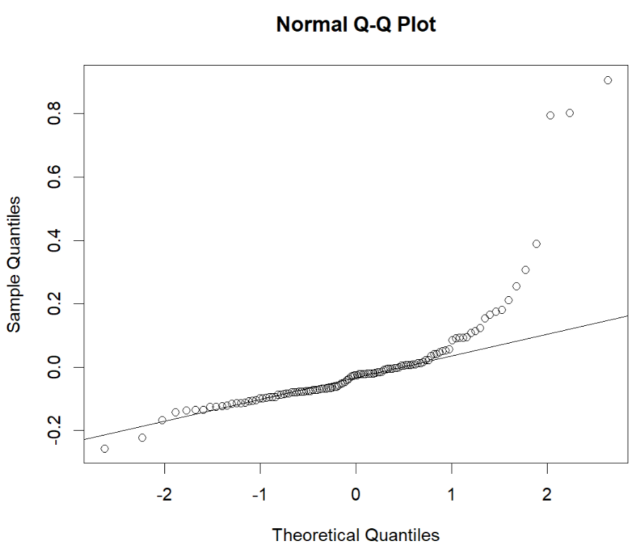
7.4 GLM-model Fit with Q-Q Plots and Histograms

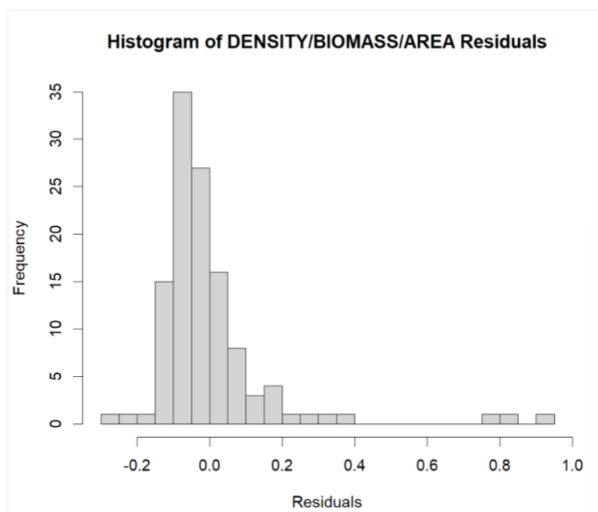
7.4.1 GLM-model fit of density and sickness.



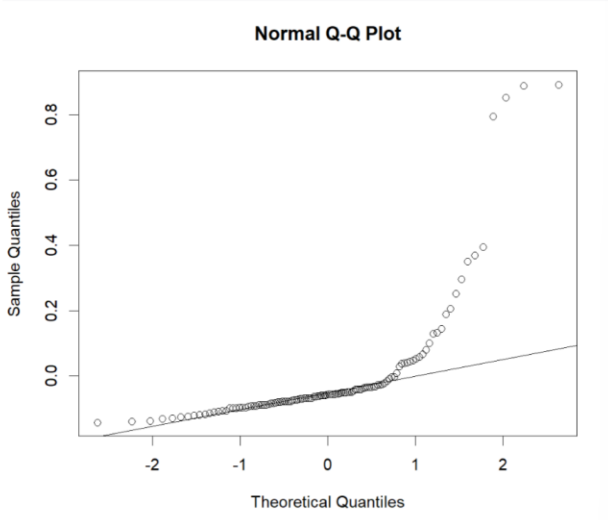


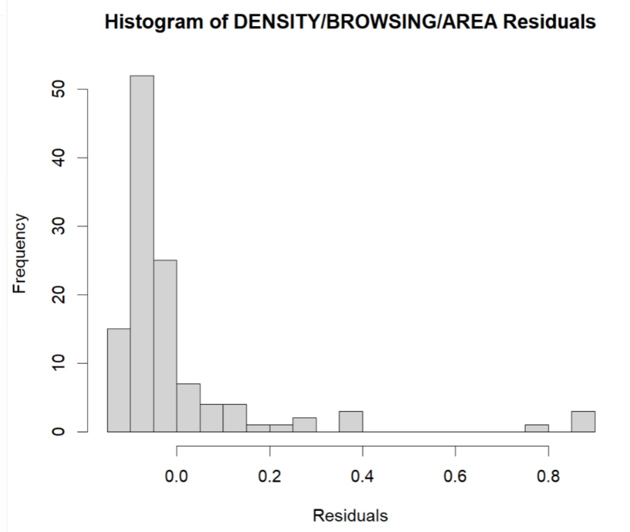
7.4.2 GLM-model fit of density and biomass.



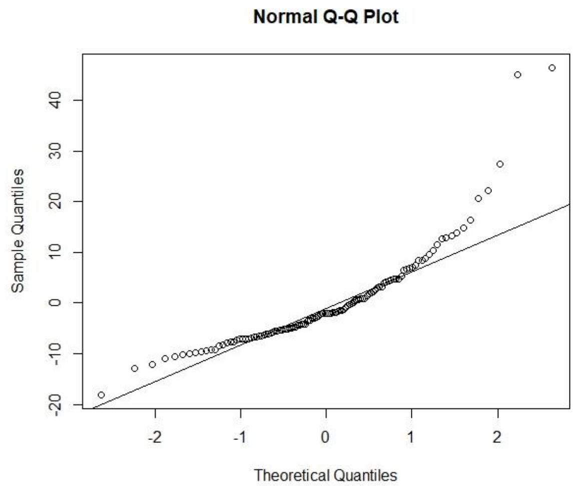


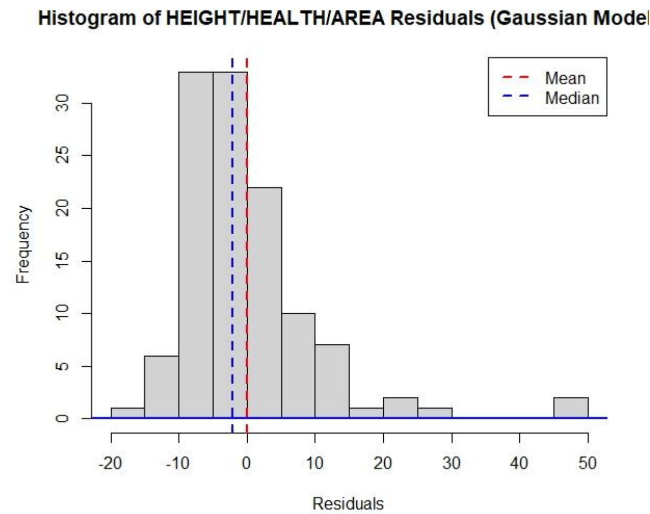
7.4.3 GLM-model fit of density and browsing.

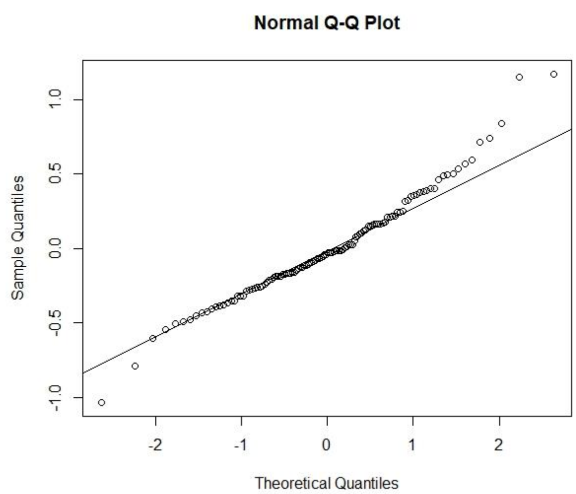


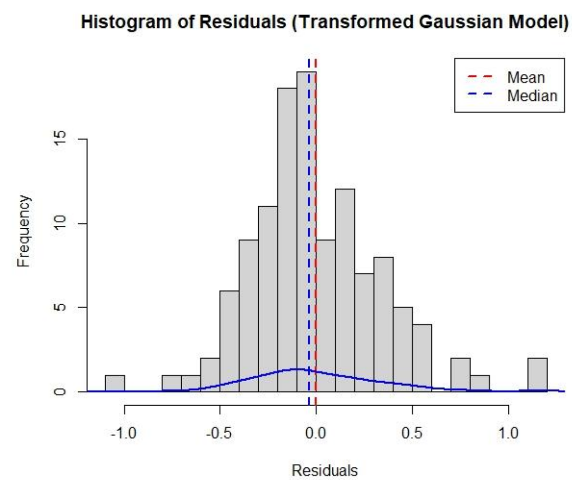


7.4.4 Height and sickness (Gaussian and log transformed height for Gaussian)

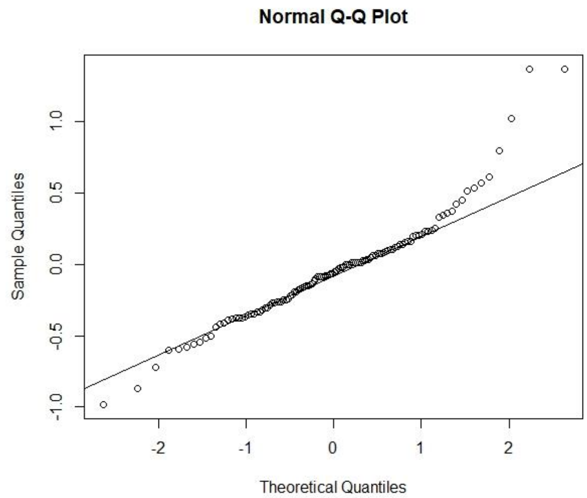


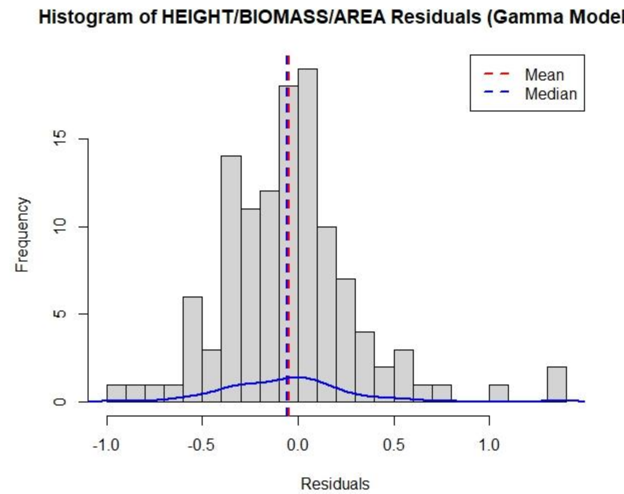




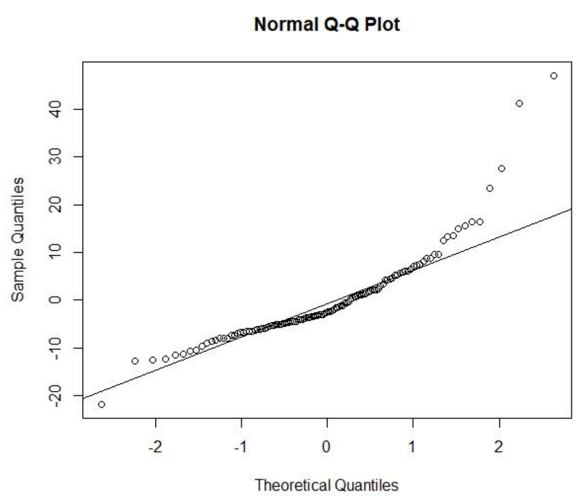


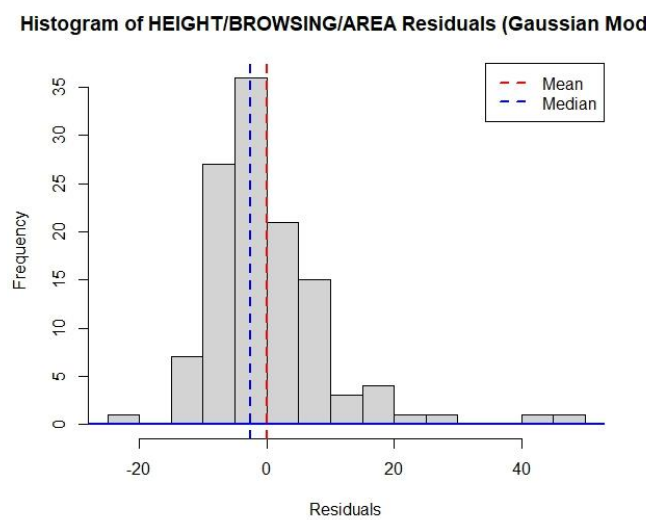
7.4.5 Height and biomass (Gamma)

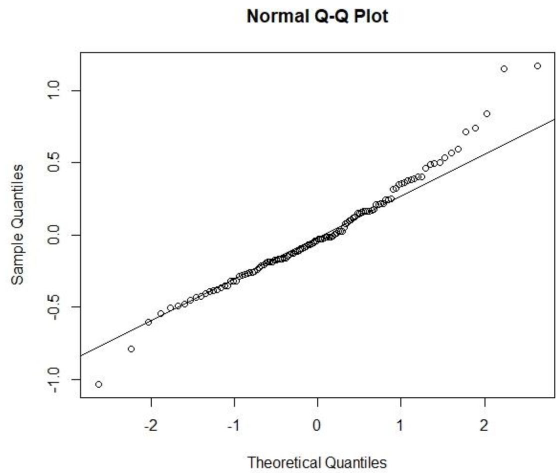


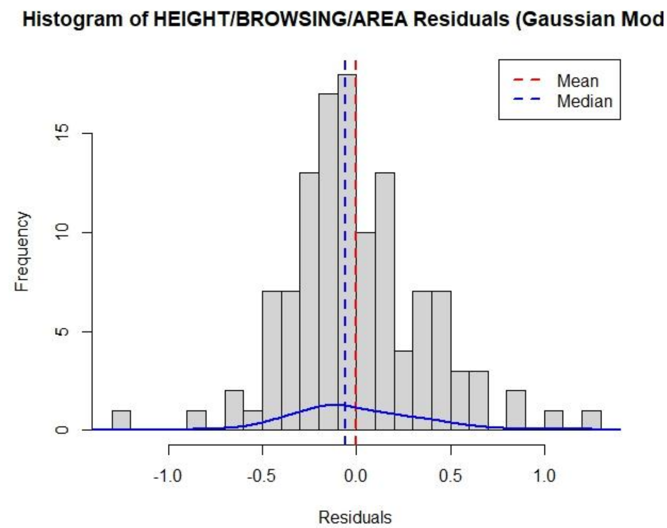


7.4.6 Height and browsing (Gaussian and log transformed height for Gaussian)






Normal Q-Q Plot
Sample Quantiles
Theoretical Quantiles
-1.0
-0.5
0.0
0.5
1.0
-2
-1
0
1
2


Histogram of HEIGHT/BROWSING/AREA Residuals (Gaussian Mod
Mean
Median
Frequency
Residuals
0
5
10
15
-1.0
-0.5
0.0
0.5
1.0

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