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Tailoring forest management to local socio-ecological contexts

Addressing climate change and local stakeholders' expectations of forests

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Cover: The view from Vättaberget in Sundsvall, Sweden, which has inspired my studies. Photo: Isabella Hallberg-Sramek

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Abstract

Forests are expected to provide multiple ecosystem services and mitigate climate change whilst also being adapted to the impacts of climate change. This thesis aims to analyse these competing expectations placed on forests in Sweden and how to tailor forest management locally to meet them by (i) applying machine learning to analyse forest conflicts in daily media from 2012 to 2022 and (ii) collaborating with local forest stakeholders to co-produce locally-tailored forest management pathways in two study areas in Sweden. The results showed that media coverage of forest conflicts has increased over time and that the conflicts concerned *why* and *for whom* forests should be managed. The co-production processes additionally highlighted expectations of *how* forests should be managed. Overall, the local stakeholders wanted to diversify forest management to enable more multifunctional and climate-smart forests, whilst they also stressed several conditions that may enable or disable its implementation in practice, depending on how they are handled. To adapt forest management to climate change impacts, the stakeholders emphasised the value of learning from past experiences and continuously improving management in line with an adaptive forest management approach. To limit climate change, they argued that it is necessary to consider climate change mitigation holistically and in conjunction with climate change adaptation and forests' provision of ecosystem services. By collaborating with local stakeholders and combining their context-based local knowledge with forest science, this thesis developed a broader and pluralistic understanding of forest management while enabling collaborative learning. In summary, this thesis highlights competing expectations placed on forests in Sweden and the value of co-production processes to tailor forest management to local socio-ecological contexts in collaboration with local stakeholders.

Keywords: sustainable forest management, climate-smart forestry, ecosystem services, media analysis, machine learning, co-production processes, local knowledge, forest policy, forest stakeholders, scenario modelling.

Anpassning av skogsskötsel till lokala socio-ekologiska sammanhang

Sammanfattning

Skogar förväntas tillhandahålla flera ekosystemtjänster samt mildra och hantera klimatförändringar. Denna avhandling syftar till att analysera sådana förväntningar som sätts på skogar i Sverige och hur skogsskötseln kan anpassas lokalt för att möta dem genom i) att tillämpa maskininlärning för att analysera skogskonflikter i dagsmedia mellan 2012 och 2022, och ii) samarbeta med lokala skogsintressenter för att samproducera lokalt skräddarsydda skogsskötselstrategier i två studieområden i Sverige. Resultaten visade att mediebevakningen av skogskonflikter har ökat över tid, och att konflikterna handlade om *varför* och *för vem* skogar bör skötas. Samarbetet med lokala intressenter lyfte också fram förväntningar på *hur* skogar bör skötas. Övergripande ville de lokala intressenterna diversifiera skogsskötseln för att möjliggöra mer mångfunktionella och klimatsmarta skogar, samtidigt som de betonade flera förutsättningar som kan möjliggöra eller hindra dess genomförande i praktiken, beroende på hur de hanteras. För att anpassa skogsskötseln till klimatförändringarnas påverkan betonade intressenterna värdet av att lära av tidigare erfarenheter och kontinuerligt förbättra skogsskötseln, i linje med en adaptiv skogsskötselstrategi. För att begränsa klimatförändringarna argumenterade de för att det är nödvändigt att betrakta klimatförändringarna holistiskt, och i samband med skogarnas tillhandahållande av ekosystemtjänster och klimatanpassning. Genom att samarbeta med lokala skogsintressenter och kombinera deras kontextbaserade lokala kunskap med skogsvetenskap utvecklade denna avhandling en bredare och pluralistisk förståelse för skogsskötsel samtidigt som gemensamt lärande möjliggjordes. Sammanfattningsvis belyser denna avhandling konkurrerande förväntningar som ställs på skogar i Sverige och värdet av samproduktionsprocesser för att skräddarsy skogsskötseln till lokala socioekologiska sammanhang i samarbete med lokala intressenter.

Nyckelord: hållbar skogsskötsel, klimatsmart skogsbruk, ekosystemtjänster, medieanalys, maskininlärning, samproduktionsprocesser, lokal kunskap, skogspolicy, skogsintressenter, scenariomodellering.

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. **Hallberg-Sramek, I***., Lindgren, S., Samuelsson, J., Sandström, C. Applying machine learning in media analysis improves our understanding of forest conflicts (submitted).

II. **Hallberg-Sramek, I***., Reimerson, E., Priebe, J., Nordström, E. M., Mårald, E., Sandström, C., & Nordin, A. (2022). Bringing "Climate-Smart Forestry" Down to the Local Level—Identifying Barriers, Pathways and Indicators for Its Implementation in Practice. Forests, 13 (1), 98. https://doi.org/10.3390/f13010098

III. Reimerson, E*., **Hallberg-Sramek, I****., Priebe, J. "Here and now, by us": Co-production of climate action pathways in forest landscapes (submitted).

IV. **Hallberg-Sramek, I***., Nordström, E-M., Priebe, J., Reimerson, E., Mårald, E., Nordin, A. (2023). Combining scientific and local knowledge improves evaluating future scenarios of forest ecosystem services. Ecosystem Services, 60, 101512. https://doi.org/10.1016/j.ecoser.2023.101512

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Contributions

The contribution of Isabella Hallberg-Sramek to the papers included in this thesis according to Contributor Roles Taxonomy (CRediT) was as follows:

I. Conceptualisation, methodology, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualisation, project administration.

II. Conceptualisation, methodology, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualisation, project administration.

III. Conceptualisation, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualisation, project administration

IV. Conceptualisation, methodology, validation, formal analysis, investigation, data curation, writing—original draft preparation, writing—review and editing, visualisation, project administration

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1. Introduction

Forest management in the 21st century faces multiple challenges: connecting forest science, policy and practice; meeting multiple competing expectations of forests; dealing with different rights holders and stakeholders; and addressing climate change. To deal with these challenges, we need to reconnect forest management with local contexts, where forests and people have co-evolved over time, and where the social and natural dimensions of forest management meet. This thesis focuses on how these challenges are dealt with in local contexts within Sweden, a country located in northern Europe, while also considering the national and international contexts within which these local contexts are embedded.

Forest science is carried out and evaluated in an international context, in which forest research from all over the world is compared and reviewed to develop general knowledge about forest management. Typically this type of general knowledge, or objective knowledge, aims to provide a "gaze from nowhere" (Haraway 1988, p. 581) which can guide forest management activities everywhere (Fortmann & Ballard 2011). At the same time, this knowledge is actually produced somewhere, and may need to address forest management somewhere else. Such is the case for forest management in Sweden, which has historically been shaped by forest management science and practice in central Europe (Lisberg Jensen 2011; Mårald & Westholm 2016; Jönsson 2019; Lundmark 2020), even though the social contexts and natural conditions are quite different. For this reason, in Chapter 2 I briefly review the historical contexts and rationales that have shaped current forest management systems and approaches across Europe, while in Chapter 3 I describe forest management and governance in the Swedish context. These chapters will provide a background for the methods and a lens for analysing and discussing the results.

While forests have been managed both intentionally and unintentionally since the origin of the human species, scientific forest management is often dated to the 18th century in central Europe (Hölzl 2010; Dargavel & Johann 2013; Innes 2016). It was initially focused on providing a continuous supply of wood for fuel and construction, shaped by an 18th century central European idea of sustainable use (Von Carlowitz 1713; Hölzl 2010). Sustainable forest management today aims to enable a wide range of forest ecosystem services (Innes 2016; Forest Europe 2022), i.e., "contribution[s] that ecosystems make to human well-being" (Haines-Young & Potschin 2018). This includes both ecosystem services of global relevance, such as biodiversity, climate change mitigation, and wood production, and those of more local relevance, such as recreation and local livelihoods. However, the management of forests for multiple ecosystem services involves multiple inherent trade-offs and goal conflicts, and current European and national forest policies have been criticised for not adequately addressing these trade-offs and conflicts (Beland Lindahl et al. 2017; Kröger & Raitio 2017; Mårald et al. 2017; Aggestam & Pülzl 2018; Elomina & Pülzl 2021; Pietarinen et al. 2023). Instead, they are left to be tackled case-by-case through forest management.

Thus, forest management today needs to be able to manage multiple competing expectations of forests. These expectations also relate to different types of rights holders and stakeholders. Rights holders are people or organisations with legal rights to use and/or manage forests, such as forest owners, the public, and Indigenous Sami reindeer herders. Stakeholders are people or organisations with an interest in the use and management of forests, which include those both with and without legal rights. An example of a stakeholder who is not a rights holder is environmental non-governmental organisations (ENGOs), who typically do not have any rights to forests, although they sometimes claim to speak for nature's rights. What is particularly interesting in the Swedish forest arena is that there are several layered land-use rights to forests (Sandström *et al.* 2016a), and these rights are relatively strong from an international perspective (Nichiforel *et al.* 2018; Allard 2022). At the same time, there are numerous ongoing conflicts related to the strengths and extent of these rights (Sténs & Sandström 2013; Sténs *et al.* 2016; Beland Lindahl *et al.* 2018; Sténs & Mårald 2020; Allard & Brännström 2021; Allard 2022; Bjärstig *et al.* 2022). Several of these conflicts have centred on north-western Sweden, due to its unique environment, resources, and management history (Beland Lindahl 2008; Westling 2012; Bjärstig *et al.* 2019; Hallberg-Sramek *et al.* 2020; Bjärstig *et al.* 2022), although some of them relate to land-use in general rather than forest management in particular. For this reason, a central part of this thesis is to study competing expectations placed on forests in Sweden, while also analysing which of these conflicts that require attention in forest management.

In addition to managing multiple expectations and forest stakeholders, forest management also needs to address climate change. The impacts of climate change may influence the future provision of ecosystem services both positively and negatively, depending on how they are handled (Kauppi *et al.* 2014; Keenan 2015; Keskitalo *et al.* 2016; Reyer *et al.* 2017; Seidl *et al.* 2017; Venäläinen *et al.* 2020; Patacca *et al.* 2023). Forests are important carbon sinks, and have the potential to limit climate change by providing carbon sequestration and carbon storage, and renewable materials and energy that can replace the use of fossil resources (Song *et al.* 2018; Friedlingstein *et al.* 2022; Hetemäki & Kangas 2022; Kauppi *et al.* 2022; Schulte *et al.* 2022). The recent concept of "climate-smart forestry" highlights the need for forest management to both adapt to and limit climate change, while also enabling forests to continue to provide multiple ecosystem services (Bowditch *et al.* 2020; Verkerk *et al.* 2020). However, it is still unclear what climate-smart forestry will mean in practice in the diverse national and local contexts across Europe. Thus, this thesis aims to understand what a climate-smart forest management would entail if tailored to Swedish contexts, and its potential for being implemented locally.

1.1 Aim and research questions

This thesis aims to inform how forest management can be tailored to local contexts, by addressing the local socio-ecological conditions, climate change, and stakeholders' competing expectations of forests in Sweden. This will be guided by the following research questions:

I. How can we understand the multiple competing expectations placed of forests and forest management at the local level? (Papers I-IV)

II. What expectations are placed on forests and forest management at the local level in Sweden? (Papers I-IV)

III. How can we develop and evaluate locally tailored climate-smart forest management pathways together with local stakeholders? (Papers II-IV).

IV. What climate-smart forest management pathways are preferred by local forest stakeholders in Sweden and what are the opportunities and challenges for their implementation? (Papers II-IV).

V. What can we learn from tailoring forest management to local contexts? (Papers II-IV)

By addressing this aim and these research questions, this thesis will hopefully offer better guidance for forest managers, policy makers, and researchers on how we can address present day challenges in forest management, such as reconnecting forest science with local contexts, managing competing interests and multiple stakeholders, and addressing climate change.

2. Forest management in Europe

Science-based forest management has, since its origin in the 18th century, relied on forest inventories, mathematics, biology, and economics – the so-called "cameral sciences"[1] - to supply society with sustained yields of wood (Lowood 1990; Hölzl 2010; Dargavel & Johann 2013). As well as having practical knowledge about forest management, forest managers of the 18th and 19th centuries were effectively applied scientists, bringing together local and scientific knowledge to enable sustainable management of forests. Over time, various science-based management systems, approaches, and philosophies have developed in different parts of Europe, some shaped by a primarily ecological rationale, to enable and maintain healthy forests, and some shaped by an economic rationale, to support the needs of society. In this section, I describe the history and current use of these forest management systems, approaches, and philosophies, highlighting the contexts and conditions in which they have been shaped and applied in Europe. This will provide a theoretical background for understanding the competing ideas on forest management that still are influencing forest management today.

2.1 Historical development

Sustainable forest management in the 18th century was initially understood as producing sustained yields of wood for future generations (Von Carlowitz 1713; Hölzl 2010). This idea was introduced during a time when there was a great demand for wood, and parts of Europe had been deforested due to

[1] The focus on cameral sciences persists in present-day forestry education, both in undergraduate education, as highlighted by Mårald (2018), and in postgraduate education, as emphasised by the following quote from the syllabus for the doctoral programme in forest management at the Swedish University of Agricultural Sciences (SLU.sfak.2016.1.1.1-285) "Within the subject forest management, biological, geographical, technological, statistical and financial theory and methodology are used" (last updated: 2018-12-18).

overharvesting to supply mining industries (Johann 2006; Dargavel & Johann 2013). To enable sustainable harvests, the idea of even-aged forestry systems was born (Johann 2006; Hölzl 2010; Dargavel & Johann 2013). The basic principle, suggested in an early forest management textbook by Georg Grünberger (1749–1820), was to divide the forest into sections (stands) based on how many years it took for the forest to mature, and to only clear-cut one section each year (Grünberger 1788; Hölzl 2010). This was a mathematical approach to ensuring sustained yield. However, implementing it was harder than it sounded as simply measuring out a forest area could be challenging at the time (Dargavel & Johann 2013). Over time, several variants of even-aged forestry developed: these included shelterwood systems, where trees are left to provide seed and improved micro-climate for the seedlings, and strip and gap cuttings, where stands were clear-cut in more fine-grained patterns (Dargavel & Johann 2013).

During the early 19th century, even-aged forestry methods were mainly applied by industrialised forest owners, while the harvesting practiced by small-scale forest owners was less structured (Johann 2006). Small-scale farmers typically harvested trees of large dimensions when they were in need of wood. This was referred to as jardinage in France, or Plenterung in Germany, and it became forbidden in the respective countries as it had become synonymous with "picking trees anywhere without proper planning or control" (Schütz *et al.* 2012). As an alternative to clear-cutting in mountainous areas of France, Adolphe Gurnaud (1825–1898) developed a more systematic version of selective felling known as the Méthode du Controle (check method), later referred to as Plenterwald (Adolphe 1882; Schütz *et al.* 2012; Nocentini *et al.* 2021). Plenterwald is similar to even-aged forestry, in that it builds on the idea that harvests should not exceed the yearly growth. However, in Plenterwald the ideal volume of each stand is first determined, and then every 5-6 years the volume that exceeds that ideal is selectively cut. To decide which trees to cut, Henri Biolley (1858–1939) suggested that the proportion of smaller trees should be exponentially greater than the proportion of bigger trees, meaning that the trees in a stand should be distributed in line with an "inverted j-curve" (Dargavel & Johann 2013). Plenterwald was not well received in France at the time, but it became the dominant management approaches in the mountainous areas of Switzerland, where Biolley further developed Gurnaud's ideas (Schütz *et al.* 2012).

Both even-aged forestry and Plenterwald were driven by an economic rationale, in which forests were managed as cropping systems, inspired by the recent developments in agriculture. Karl Gayer (1822-1907) did not agree with this view of forest management, and was very critical of the large-scale use of clear-cuts, particularly as his work had focused on forests in mountainous areas where clear-cuts created problems related to soil erosion, avalanches, and forest damage (Gayer 1882; Gayer 1886; Gamborg & Larsen 2003; Hölzl 2010; Bauhus *et al.* 2013). He argued that forest management should achieve more diverse outcomes, with more continuous cover forestry and mixed species forests, and that tree species should be chosen for their suitability to local climate and soil conditions rather than their financial value.

Inspired by Gayer's ecological rationale, Alfred Möller (1866–1922) developed a new management philosophy referred to as the Dauerwald idea (Möller 1922; Gamborg & Larsen 2003; Pommerening & Murphy 2004). According to the Dauerwald philosophy, the following principles should guide forest management: no clear-felling; vigorous trees are retained while slow growing trees are cut; regeneration should not be the main concern; concepts such as age class and rotation period should be abandoned; and silvicultural ideals should guide management, not timber demand (Möller 1922; Helliwell 1997). While Möller was much inspired by Gayer, Möller's work and ideas were developed around the Bärenthoren estate which was a rather flat pine-dominated area, a context which contrasted with the mountainous areas of spruce, fir, and beech-species that had shaped Gayer's ideas. These principles were also the opposite of those guiding management at the time: hence, Möller received significant attention and critique from his peers (Gamborg & Larsen 2003; Pommerening & Murphy 2004). The general interest in Dauerwald in northern and central Europe faded with Möller's death and the end of World War II, at which time there was great demand for wood. The ideas of Dauerwald have since been revived in the sustainable forest management debates of the 1980s and 1990s, and by ProSilva, a forest managers' association founded in 1989, which promotes close-to-nature forestry inspired by Möller's ideas (Pommerening & Murphy 2004; Johann 2006; Pro Silva 2012).

Based on the economic rationale of forestry, non-native tree species have been part of European forestry since the 16th and 17th centuries, when they were mainly introduced from eastern North America to favour wood production (Dargavel & Johann 2013; Pötzelsberger 2018; Brus *et al.* 2019). Since then, species from all over the world have been introduced into Europe, and today c. 4% of European forests consist of non-native tree species, with particularly high proportions in parts of central and western Europe (Pötzelsberger 2018; Brus *et al.* 2019). Due to the ecological risks associated with the use of non-native tree species, regulations have now been introduced to restrict their use, although these vary across Europe in terms of restrictiveness (Pötzelsberger *et al.* 2020). While the introduction of non-native tree species was originally guided by an economic rationale, there has recently been a shift in the debate, as it is now seen as a means for forests to adapt to climate change, through so-called assisted migration, motivated by an ecological rationale (Aubin *et al.* 2011; Hewitt *et al.* 2011; Leech *et al.* 2011; Hagerman & Pelai 2018; St-Laurent *et al.* 2018). This means that with changing conditions, also the ideas relating to forest management may change, emphasising the importance of being able to reassess different forest management practices.

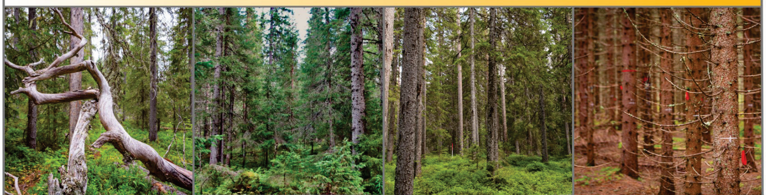
Since the early 20th century, some forests in Europe have been set aside from forestry, based on an ecological rationale, initially in national parks and later in nature reserves and as voluntary set-asides by forest owners (Duffey 1990; Widman 2016). The first national parks in Europe were established in Sweden in 1909, and the environmental non-governmental organisation "Swedish Society for Nature Conservation" was established at around the same time (Jönsson 2019). The aim of the parks was to preserve primary forests and to gain knowledge about the natural development of unmanaged forests, while recently, the aim of nature conservation has shifted towards species protection and biodiversity conservation (Jönsson *et al.* 2021).

Forest restoration refers to "bringing back forest where it has disappeared or restoring the conditions of forests to how they were before degradation had occurred" (de Jong *et al.* 2021). Restoration has historically sought to restore both forests' productive capacity and their ecology, thus being motivated by both ecological and economic rationales, while more recently it has promoted the restoration of forests' biodiversity, adaptive capacity, and ability to mitigate climate change (Lisberg Jensen 2011; Bastin *et al.* 2019; de Jong *et al.* 2021; Jönsson *et al.* 2022; Hjältén *et al.* 2023; Kuuluvainen & Nummi 2023).

2.2 Current forest management

Today, the aim of "sustainable forest management" is often considered to be to maintain and enhance forests multifunctionality to provide social, ecological and economic benefits for current and future generations (Forest Europe 2022), and there is a wide range of forest management systems, approaches, and philosophies in use in Europe. In Figure 1 these are arranged according to how much they typically rely on human influence. Thus, continuous cover forestry systems, which rely on natural regeneration, have less reliance on human influence than short-rotation forestry, which relies on the planting or seeding of non-native tree species and/or forest fertilisation (see also Duncker *et al.* 2012). This gradient also relates to resilience, with some management systems relying more on ecological resilience i.e., forests' "ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling 1973), and others relying on human-induced resilience, or "coerced resilience", where "supporting ecological processes have been replaced to

Human influence	Increasing →							



Management systems	Unmanaged *Fri utveckling*		Uneven-aged forestry Continuous cover forestry *Kontinuitetsskogsbruk*		Even-aged forestry Rotational forestry *Trakthyggesbruk*		Short rotation Forestry Plantation forestry *Intensivskogsbruk*	
Management approaches	Unmanaged	Forest restoration	Unsystematic selective felling *Plenterung* *Plockhuggning*	Systematic selection felling *Plenterwald* *Blädning*	Shelterwood *Skärmställning* Strip and gap cuttings *Kant- eller luckhuggning*	Clear-cut forestry (can include seed trees)	Clear-cut forestry with non-native tree species and/or fertilization	Clear-cut forestry with non-native tree species, fertilization, pesticides, herbicides
Management philosophies			Close-to-nature forestry *Dauerwald* *Hyggesfritt skogsbruk* *Naturnära skogsbruk*				Cropping *Kalhyggesbruk*	

Figure 1. Types of forest management systems, approaches, and philosophies applied in Europe and their reliance on human influence. Photos (from left to right): Andreas Palmén, Lars Lundqvist, Jenny Svennås-Gillner, Andreas Palmén.

varying degrees by human-controlled processes that maintain a system in a particular desired state" (Rist *et al.* 2014).

Several of the management systems and philosophies go by multiple names, such as continuous cover forestry and uneven-aged forestry, which most often refer to management approaches that include selective felling (Figure 1). Figure 1 reflects how these terms are generally used, although the management approaches associated with those philosophies do not necessarily share an ideology. For example, Möller, the founder of the Dauerwald idea, would probably not include Plenterwald systems as a management approach within Dauerwald, as he was very critical of production-focused management. According to Heyder (1986, p. 433), Möller even stated that Plenterwald systems are a "dream, not even a nice one" (Gamborg & Larsen 2003). However, selection systems such as Plenterwald are today frequently considered as an example of close-to-nature forestry, which is inspired by Möller's Dauerwald ideas (Bauhus *et al.* 2013; Brang *et al.* 2014; Puettmann *et al.* 2015).

While there is limited information available about which management systems are applied in different places, Mason *et al.* (2022) gathered data from National Forest Inventories, Official Statistics, and personal communication to map the use of even-aged forestry and continuous cover forestry in Europe. According to Mason *et al.* (2022), even-aged forestry dominates management in Scandinavia, the Baltics, Portugal, and Ireland, while continuous cover forestry dominates in the south-eastern parts of Europe. In central Europe, both even-aged forestry and continuous cover forestry approaches are applied. Overall, 28% of European forests are uneven-aged while the rest are even-aged, and the dominant tree species are pine (*Pinus ssp.*, 30%), spruce (*Picea ssp.*, 23%) and beech (*Fagus ssp.*, 12%) (Korhonen & Ståhl 2020). The main causes of damage are pests and pathogens, wildlife and grazing, and storm, wind and snow, while forest fires are generally uncommon (Ferretti 2020). 15% of European forests are protected for biodiversity, while a further 9% are managed to support the "protection of landscapes and specific natural elements" (Lier & Schuck 2020). Most of the protected forest in northern Europe, Fennoscandia, is left unmanaged or with minimum management, while protected forests in other parts of Europe are generally under active management.

3. Forest management and stakeholders in Sweden

Sweden is a country in northern Europe with ca. 10.5 million inhabitants and 28 million hectares of forests (Nilsson *et al.* 2019; Statistics Sweden 2023). Since the 19th century, Sweden's forests have mainly been managed for wood production, while environmental considerations in forestry were not regulated for until the 1990s when the new forestry act required that equal concern should be given to both wood production and biodiversity (Appelstrand 2012). Compared to other parts of Europe, Sweden has high proportions of forest land (Korhonen & Ståhl 2020), even-aged forestry (Mason *et al.* 2022), and privately owned forests (Pulla *et al.* 2013; Nilsson *et al.* 2019). Sweden also has multiple strong rights holders and stakeholders with different interests in and relationships to forests (Sandström *et al.* 2016a; Nichiforel *et al.* 2018; Allard 2022), including forest owners, the public, Sami reindeer herders, hunters, tourism entrepreneurs, forest industry, and environmental non-governmental organisations (ENGO). To meet the multiple expectations of these stakeholders, forest policy has over time added various goals that should be met through forest management and governance (Beland Lindahl *et al.* 2017; Mårald *et al.* 2017). In recent years, the tensions and conflicts between different stakeholder groups seem to be increasing. To understand the contexts in which forests are managed in Sweden, I will in the following briefly describe the past and current approaches to forest management and governance in Sweden, and the multiple stakeholders who are active in the Swedish forest arena. This will provide background for the methods and a lens for analysing and discussing the results.

3.1 History of forest management

The Swedish forest industry started booming in the late 18th and 19th centuries, when there was great international demand for timber, particularly from Britain (Bunte *et al.* 1982). Before this, forests had generally been managed either by local farmers or by the mining industry, but the new demand for timber opened up the opportunity for exporting timber internationally. Thus, over a hundred-year period, a wood extraction movement spread across Sweden, starting in the southwest of the country in the late 18th century and successionally moving north, finishing in the mountainous areas of north-western Sweden at the end of the 19th century. While this movement initially focused on extracting timber, the establishment of saw mills and pulp mills in the late 19th century slowly shifted practice towards also extracting wood of lesser dimensions (Lundmark 2020). Thus, Sweden's forests were already being clear-cut during the 19th century, to support forest industries, although this did not become the dominant management approach until the mechanisation of forestry in the 1950s (Lisberg Jensen 2011; Lundmark 2020). To secure the future provision of wood, the first Swedish Forestry Act came into force 1903 and required that harvested areas be regenerated, to support future wood production.

Forest sciences in Sweden developed in parallel with the increasing demand for wood, and the Swedish Forest Institute was established in 1828 by the forester Israel Adolf af Ström (1778-1856), inspired by the German forest institutes (Jönsson 2019). Af Ström was known for practicing and teaching about clear-cutting practices, and introducing concepts such as forest management plans and rotation periods. Although these practices did not become dominant until much later, he is considered to have had great influence on their eventual implementation. Following af Ström, several later influential foresters and biologists argued for the application of clear-cuts, including Holmgren, Örtenblad, and Hesselman, based on their studies of forest regeneration in the late 19th and early 20th centuries (Lundmark 2020). Hesselman also visited Schwartzwald and Bärenthoren in Germany, where Gayer and Möller were working, to compare their conditions to those in Sweden, and concluded that Sweden's soil conditions and climate for forest regeneration were very different (Jönsson 2019). However, their studies and ideas were contested at the time, one of their opponents being Uno Wallmo (1860-1946), who argued for non-clear cut methods to support the production of high-quality timber (Lundqvist *et al.* 2014; Jönsson 2019). While Wallmo is known for having been a promoter of selective felling, he was not a fan of this as practiced according to Gurnaud and Boilley, so called Plenterwald, but rather more in line with Gayer and Möller's ideas of adapting management to the local conditions and avoiding clear-cuts, so called Dauerwald or non-clear-cut forestry.

While it is clear that important scientific discussions were going on in Sweden at this time, much like those going on in Germany, it is not clear what influence they had on the management of privately owned forests, particularly before the first forest regulation came into force in 1903. It took another 44 years for forest management approaches to be regulated, and in 1948 selective felling was prohibited as it had become associated with creating sparsely stocked stands of low quality timber, so called "restskogar" (residual forests) or "skräpskogar" (garbage forests) (Lisberg Jensen 2011; Jönsson 2019). This was similar to what had happened in Germany and France 120 years earlier (section 2.1)(Schütz *et al.* 2012), when selective management approaches were prohibited in favour of clear-cutting practices, with regeneration requirements. Although it is legal to apply continuous cover forestry today, it is not commonly practiced, particularly by forest companies (Swedish Forest Agency 2023).

3.2 Current forest management

Since the 1950s, forests in Sweden have mainly been managed through even-aged forestry approaches, and then regenerated with Norway spruce (*Picea abies* H. Karst) and Scots pine (*Pinus sylvestris* L.)(Lisberg Jensen 2011; Mårald & Westholm 2016; Mårald *et al.* 2017). Between 1948 and 1984, forest companies and the state used herbicides to reduce the competition from deciduous trees on clear-cuts (Östlund *et al.* 2022). This practice was later replaced by mechanical cutting of deciduous trees, although over recent years there has been increasing interest in the regeneration and management of birch (*Betula pendula* Roth. and *Betula pubescence* Ehrh.), mainly to enhance biodiversity (Dahlgren Lidman 2022). About 98% of Swedish forests are dominated by native tree species, of which Norway spruce, Scots pine, and birch are most prevalent (Table 1) (Nilsson *et al.* 2019), and some 2% are dominated by non-native Lodgepole pine (*Pinus contorta* ssp. latifolia LP), which was introduced to Sweden from North America in the

1970s and today covers over 520 000 ha of northern Sweden (Nilsson *et al.* 2019; Jacobson & Hannerz 2020). Fertilisation is applied more sparsely today than it was in the 1970s and 1980s, when it was widely applied to increase wood production and compensate for previous overharvesting (Lindkvist *et al.* 2011). Both the use of non-native species and forest fertilisation have largely been carried out by forest companies and the state. Approximately 4% of forests are estimated to be managed through "non-clear-cut" forestry, which typically includes selective felling, gap and edge-cutting, and shelterwood systems (Swedish Forest Agency 2022), similar to close-to-nature forestry or Dauerwald (Section 2.1; Figure 1). Most of the non-clear-cut forestry is carried out on land belonging to small-scale forest owners. Some 6% of productive[2] forests are formally protected, while an additional 6% is voluntarily set-aside by forest owners for nature conservation (Statistics Sweden 2023). Further, about 2% of productive forests are set aside as retention patches on clear-cuts (Gustafsson *et al.* 2020; Statistics Sweden 2023). Forestry in all unproductive forests[3] is prohibited under the Swedish Forestry Act.

3.3 Forest regulations and governance

Compared to other parts of Europe, Sweden stands out as having relatively weak forest regulations (Appelstrand 2012; Beland Lindahl *et al.* 2017; Lawrence *et al.* 2020). The first forest regulation came into force in 1903, to secure forest regeneration and future wood production. Subsequently, several further regulations were added, mainly to enable wood production, until 1993 when the new Forestry Act removed several of the existing regulations and added an environmental objective to forestry in Sweden (Beland Lindahl *et al.* 2017). The Forestry Act of 1993 marks a shift from "government to governance", or from traditional steering to collaboration, and forest owners were given "freedom under responsibility" (Appelstrand 2012). This meant that forest owners obtained the freedom to manage forests as they like, within certain limits, on the proviso that they also take responsibility for the implementation of sector goals, which today are rather wide-ranging and include forest production, biodiversity, environmental

[2] Forests that on average produce more than 1 m^3 wood over bark/ha/yr.

[3] Forests that on average produce less than 1 m^3 wood over bark/ha/yr.

consideration, cultural heritage, recreation, reindeer husbandry, and game populations (Beland Lindahl *et al.* 2017). Since then, the number of goals has dramatically increased, in accordance with a “more of everything” rationale, or ecological modernisation discourse, which assumes that more can be extracted from the existing resources (Bäckstrand & Lövbrand 2006; Beland Lindahl *et al.* 2017; Mårald *et al.* 2017). A similar rationale shapes Finnish and European forest policies, and they have all been criticised for ignoring the multiple trade-offs associated with forest management, such as those between different ecosystem services and stakeholder groups (Beland Lindahl *et al.* 2017; Kröger & Raitio 2017; Mårald *et al.* 2017; Aggestam & Pülzl 2018; Elomina & Pülzl 2021; Pietarinen *et al.* 2023). Managing these trade-offs in collaboration with other stakeholders has become the responsibility of forest owners.

Under the current policies, forest owners are those with direct influence over forest management, while other stakeholders only have indirect influence through forest governance. Previous studies outline how non-forest-owning-stakeholders have argued for stronger forest regulations to increase their influence on forest management, while forest owners have argued for maintaining the current regulations (Sténs & Sandström 2013; Sandström *et al.* 2020). As current policies are focused on collaborative governance, under which forest owners and other rights holders and stakeholders should collaborate to fulfil joint policy goals, in 2013 the Swedish government initiated a National Forest Programme to develop shared pathways for Swedish forests (Johansson 2016). It was negotiated at the national level by a wide range of rights holders and stakeholders, even though it eventually favoured primarily wood production interests (Johansson 2016; Fischer *et al.* 2020), setting the vision that: “The forest, the green gold, must contribute to jobs and sustainable growth throughout the country as well as to the development of a growing bioeconomy” (translated from Swedish) (Näringsdepartementet 2018). The National Forest Programme have been followed by regional forest programmes, which aim to develop regional strategies and action plans linked to the national forest programme. These are still under development.

In parallel, forests are also governed by market-based certification schemes and voluntary agreements which, in some cases, are more demanding on forest owners than the current regulations are (Johansson 2013; Hallberg-Sramek *et al.* 2020; Lehtonen *et al.* 2021). Meanwhile, the national processes have been struggling with legitimacy issues, particularly relating to the inclusion and influence of environmental non-governmental organisations and reindeer herders (Johansson 2013), while also experiencing internal problems with distrust and polarisation (Elbakidze *et al.* 2022).

At present, there are several processes ongoing relating to forest-related land use rights. There has been a recent governmental investigation "Strengthened property rights, flexible forms of protection and nature conservation in the forest" (SOU 2020:73) which aimed to strengthen forest owners' property rights, while also addressing synergies and trade-offs between forestry and nature conservation, all in pursuit of a growing bioeconomy. The investigation was prompted by several court cases in which forest owners' property rights and rights to economic compensation for nature conservation had been tested, making it clear that the legal situation was ambiguous. Thus, there are now processes in place to clarify the extent of forests owners' land use rights. There is also an ongoing overhaul of the rights of the indigenous Sami people and the current Reindeer Herding Act, prompted by recent court cases in which international law on human rights and indigenous people's rights has been applied to strengthening the rights of specific reindeer herding communities (samebyar in Swedish), mainly focusing on their hunting and fishing rights (Allard & Brännström 2021; Allard 2022). Thus, there is now a parliamentary commission in place that will review and suggest changes to the Sami people's national legal rights. In recent years, there has also been increasing interest from Swedish forest stakeholders in European Union (EU) processes (Bjärstig 2013) and, following the new EU Forest Strategy for 2030 (European Commission 2021), among other recent EU policies, much of the national policy debate has centred around EU processes.

3.4 Rights holders and stakeholders

Compared to other European countries, Sweden stands out as having both strong public and private rights (Nichiforel et al. 2018), with a wide array of rights holders having layered land use rights: these include "public and private ownership, hunting rights, rights to public access, and the right of the Sami to practice their traditional way of life" (Sandström et al. 2016a). Forests in northern Sweden are typically owned by a mix of small scale forest owners, forest companies, and the state, while forests in southern Sweden are more often owned by small-scale forest owners (Table 1) (Nilsson et al. 2019).)(Nilsson et al. 2019). These forest owners are highly reliant on the provision of ecosystem services for their income (Winkel *et al.* 2022). In northern Sweden, the indigenous Sami people have exclusive usufructuary rights to reindeer herding, while also having rights to hunting, fishing, and extraction of timber for the structures and houses necessary for reindeer herding (Allard 2022). Reindeers (Rangifer tarandus L.) are domesticated free-ranging deer that move across the landscape in search of food and, during wintertime, feed on arboreal and ground lichens in the forest landscape (Sandström et al. 2016b). Wild deer species, particularly moose (*Alces alces* L.), are popular game for hunters and about 5% of the adult population in Sweden hunts (Boman et al. 2011). Hunting is both a recreational activity and a way in which people provide for themselves and it requires a hunting licence (Lindqvist et al. 2014; Dressel 2020). The right to hunt is directly tied to forest ownership, or reindeer herding, however it can also be leased (Sandström et al. 2011). Other recreational activities include camping, hiking, berry and mushroom picking, which are open to all people as part of the customary right to public access (Fredman *et al.* 2012; Sténs & Sandström 2014; Sténs *et al.* 2016). Nature-based tourism is another important activity taking place in forests, although this is currently concentrated in coastal and mountainous areas (Lundmark & Müller 2010). As long as these activities are performed within the realms of the right to public access, they do not require any permission from forest owners. However, the commercial use of the right to public access has been debated both in relation to berry harvesting and nature-based tourism (Sténs & Sandström 2013; Sténs & Sandström 2014; Sténs & Mårald 2020). ENGOs are also important stakeholders in the Swedish forest arena. They have no legal rights to forests, however in 2011 they successfully appealed a decision by the Swedish Forest Agency to allow harvesting of a privately owned forest area with high nature conservation values, by referring to the United Nations Aarhus Convention (Sténs & Mårald 2020).

4. Methods

This thesis includes four interdisciplinary studies (Papers I-IV), of which Paper I is based on a media analysis of forest conflicts in the Swedish daily press and Papers II-IV are based on two parallel collaborative co-production processes in Sweden involving the participation of local forest stakeholders. Both the media analysis and the co-production processes were used to understand the various competing expectations of forests and forest management in Sweden, and the co-production processes were also used to develop and evaluate locally tailored pathways for climate-smart forest management. In this chapter, I motivate and describe the methods used for the media analysis (Paper I) and the co-production processes (Papers II-IV).

4.1 Analysing competing expectations of forests in the media (Paper I)

To analyse the various competing expectations placed on forests in various parts of Sweden, I have analysed forest conflicts as reported in the Swedish daily media (Paper I). This project was conducted as part of the interdisciplinary research platform Future Forests, and it involved one sociologist, one historian of science and ideas, one political scientist, and one forest scientist (me). In this study we applied machine learning, specifically topic modelling, to analysing the vast volume of media material on forest conflicts, published in local, regional, and national newspapers in Sweden between January 2012 and May 2022.

4.1.1 Media analysis of forest conflicts

Forest conflicts are often portrayed in the Swedish daily media (Lisberg Jensen 2002; Westling 2012; Hallberg-Sramek *et al.* 2020; Sténs & Mårald

2020; Bjärstig *et al.* 2022). There is an interplay between the public and the media, in which the media influences which issues are considered by the public to be important and, at the same time, assigns more coverage to the issues that are important to the public (McCombs & Shaw 1972; Coleman *et al.* 2009; Crow & Lawlor 2016; Brants & van Praag 2017). Thus, the public's understanding of forest conflicts is shaped by how they are portrayed in the media, while the media's coverage of forest conflicts reflects which issues are of interest to the public. The daily newspaper media is an important agenda-setter in Sweden (Djerf-Pierre & Shehata 2017) with about 68% of the Swedish population relying on daily newspapers for their news consumption (Ohlsson 2021). The public also have higher levels of trust in the information provided by the daily media than that available through social media (Ekengren Oscarsson & Sjörén 2022). By studying how forest conflicts are reported on in the daily media we can better understand both how the media shapes the public's perceptions of those conflicts, and which forest conflicts are of particular interest to the public.

Previous studies of local and regional daily media have highlighted the geographies of particular forest conflicts, such as those around mining (Fjellborg *et al.* 2022), nature conservation (Hallberg-Sramek *et al.* 2020), wind power (Bjärstig *et al.* 2022), or land-related forest conflicts (Westling 2012). Paper I focuses on providing a more up-to-date overview and analysis of the broad range of forest conflicts, while also analysing their spatial, temporal, and relational dimensions.

4.1.2 Applying topic modelling in media analysis

A search of the online database Mediearkivet Retriever (https://app.retriever-info.com/) for local, regional and national daily newspaper media output shows that 53 600 editorial outputs, meaning reports, news articles and editorials, contained the words "forest" and "conflict" or other conflict-related words, over the period from January 2012 to May 2022. From an initial review of a random selection of these articles, it became clear that only a portion of them actually concerned forest-related conflicts. This is because in Swedish "forest" is quite commonly used in other contexts, for example in names of people and places, or as a figure of speech. We considered a range of alternative approaches for singling out the articles that actually related to forests, finally deciding to use machine learning, specifically topic modelling, to cluster all articles into “topics”, and then identify the topics of interest.

Topics represent the main themes in large collections of texts, and topic modelling was developed to organise and analyse such text-based datasets (Blei 2012). In the contexts of forest research, topic modelling has been used to analyse forest policies (Firebanks-Quevedo *et al.* 2022) and to review scientific literature (Clare & Hickey 2019; Nummelin *et al.* 2021), while this study is the first to apply it to media analysis. One of the most common topic models is LDA, which was developed in 2003 (Blei *et al.* 2003). Since then, there has been rapid development in the field, and we chose to use the recently released state-of-the-art BERTopic topic model (Grootendorst 2022). BERTopic uses a pre-trained language model which is able to 'read' texts taking into account the context in which words are used, in contrast to earlier models which scramble words into a 'bag of words'. Before applying the model, we downloaded and pre-processed all 53’600 articles. The articles were organised into collections called documents, each representing specific months and regions, to enable both temporal and spatial analysis. We then applied BERTopic (Grootendorst 2022) with the pretrained Swedish language model KB-SBERT (Rekathati 2021). This resulted in 916 unique topics, which I then filtered manually to include only topics relating to forest stakeholders, forests’ provision of ecosystem services, forest management, and forest governance, which resulted in 94 topics.

4.1.3 Data analysis

To allow for an overview and analysis of the topics, I inductively named and coded all topics, and then clustered and categorised them until I found that they formed cohesive categories, inspired by “grounded theory” and the “constant comparative method” (Glaser & Strauss 1967; Lindgren 2014b; Lindgren 2020). This yielded ten main topic categories, reflecting the main forest conflicts present in the material, which were: i. energy, ii. forest damages, IV. forestry, iv. hunting and fishing, v. international issues, vi. media and politics, vii. mining, viii. nature conservation, ix. recreation and tourism, and x. reindeer husbandry. We then analysed how these topic categories were distributed over time and different regional media, and how they related to each other using an “intertopic distance map” which clusters topics that are similarly framed (Grootendorst 2022). To illustrate the geographical distribution of forest conflicts, I created maps over the proportional topic category distribution in QGIS (https://www.qgis.org).

4.2 Tailoring forest management to local contexts (Papers II-IV)

To analyse the expectations placed on forest management by local stakeholders in Sweden, and to develop and evaluate locally tailored pathways for climate smart forestry, Papers II-IV are based on two co-production processes where local stakeholders and researchers collaborated to identify locally desirable and suitable forest management pathways. The co-production processes were part of a larger inter- and transdisciplinary research project on climate change called "Bring down the sky to the earth: how to use forests to open up for constructive climate change pathways in local contexts", which was a collaboration between one historian, two historians of science and ideas, two political scientists, three forest scientists (myself included), and local forest stakeholders. The project included two local co-production processes, one in northern Sweden and one in southern Sweden.

4.2.1 Co-production processes to tailor forest management to local stakeholders' situations and aspirations

To analyse and address local stakeholders' expectations on forest management, we can collaborate with them to develop locally tailored pathways for climate smart forestry. Local forest stakeholders have knowledge of the local conditions and the contexts in which forests are managed, while also having direct experience of the local use and management of forests. Thus, local stakeholders have local or "situated" knowledge that provides a gaze from somewhere (Haraway 1988; Fortmann & Ballard 2011; Nakashima 2015; Arora-Jonsson 2016), in contrast to scientists' knowledge which generally aims to provide a "gaze from nowhere" (Haraway 1988; Fortmann & Ballard 2011). Thus, by collaborating with local stakeholders, we can combine both scientific and local knowledge. Secondly, tackling the multiple, sometimes conflicting, expectations of forests require trade-offs, and it can be argued that these trade-offs should be made by those directly affected by them, i.e., local forest stakeholders. This is sometimes referred to as the normative contribution of stakeholder involvement, as it relates to the stakeholders' right to participate in the production of knowledge and pathways that will shape their futures (Arnstein 1969; Stirling 2006; Schmidt *et al.* 2020). Thirdly, by involving stakeholders in the development of forest management pathways, it is more likely that those pathways will be locally acceptable and legitimate, in turn increasing the likelihood of successful implementation (Stirling 2006; Reed 2008; Schmidt *et al.* 2020). Thus, by involving stakeholders in the development of locally tailored forest management, we can hopefully develop both knowledge and pathways that are locally suitable and desirable.

How can we engage forest stakeholders in developing locally tailored forest management? Co-production processes, in which stakeholders and researchers collaborate to develop locally relevant and desirable knowledge and pathways, have been used to address climate change and sustainability issues (van der Hel 2016; Lemos *et al.* 2018; Bremer *et al.* 2019; Wyborn *et al.* 2019; Norström *et al.* 2020; Chambers *et al.* 2021). While there are many types of stakeholder involvement, ranging from low to high levels of engagement (Arnstein 1969; Tress *et al.* 2005; Reed 2008; Mobjörk 2010), co-production processes typically entail a high level of stakeholder engagement as they are essentially iterative learning processes between scientists and stakeholders (Klenk *et al.* 2017; Norström *et al.* 2020; Turnhout *et al.* 2020). Their key characteristics include being: i., pluralistic, acknowledging and incorporating different ways of knowing and doing; ii., context-based, situating processes in specific places; iii., interactive, allowing for mutual learning and interactions; and iv., goal-oriented, developing shared goals and outlining preferred directions (Norström *et al.* 2020). Thus, co-production processes require a high level of engagement and are also quite time-consuming (Reed 2008; Lemos *et al.* 2018). Nonetheless, they have been framed as integral to tackling sustainability and climate change issues at the local level (Nakashima 2015; Nakashima *et al.* 2017; Norström *et al.* 2020; Gómez-Baggethun 2021). Mårald *et al.* (2017) have also argued that through stakeholder collaboration we can address "both overarching societal challenges and opportunities, and local people's situations and aspirations", while generating benefits at both levels, and that these kind of processes could be used to tailor forest management to local contexts (p. 136).

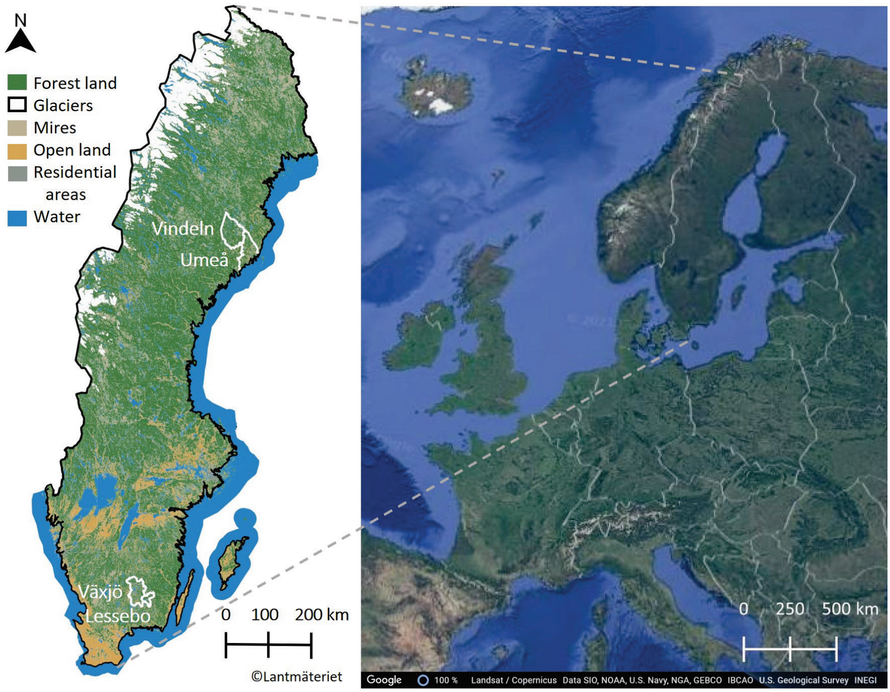


Figure 2. Map of Sweden and the study areas Umeå and Vindeln in northern Sweden, and Växjö and Lessebo in southern Sweden. Map on the left was produced in QGIS (https://www.qgis.org) with data from Lantmäteriet (the Swedish Land Survey). Map on the right was produced by Google Earth using a mix of sources named in the figure.

4.2.2 Study areas

The co-production processes took place in two study areas, one in northern Sweden, which included Umeå and Vindeln municipalities in Västerbotten region (Papers II-IV), and one in southern Sweden, which included Lessebo and Växjö municipalities in Kronoberg region (Papers II-III; Figure 2). Both study areas included one rural municipality and one urban, with the intention of capturing both rural and urban perspectives on forests and climate change. The population density is several times higher in the southern study area than in the northern study area, while both have a high proportion of forest land (Table 1). Both the northern and southern study areas have been shaped by forest industries and still have large sawmills and pulp mills that export forest products globally. Forests are also widely accessible to the public, and recreation, foraging, and hunting are common activities. Recently, there has also been increasing interest in nature-based tourism, which attracts both Swedish and international visitors. The northern study area is also an important winter-grazing area for domestic reindeer.

Ecologically, Sweden can be characterised as displaying a north-south gradient, with the north being less fertile with shorter growing seasons, and having a higher proportion of Scot's pine, while southern areas are more fertile with longer growing seasons and higher proportions of Norway spruce. These characteristics are reflected in our study areas (Table 1). Regular forest fires have been important historical drivers of the tree species distribution, and mainly favouring fire-tolerant or fire-prone tree species, while fire sensitive species have been disadvantaged (Molinari *et al.* 2020). As human land management has changed over recent centuries, from using fire as a tool to suppressing fires, the frequency of forest fires has substantially declined (Wallenius 2011; Molinari *et al.* 2020). The main forest damages are today caused by wildlife, wind, and snow, of which wildlife damages are common across the country, while damages from wind and snow are more common in northern Sweden (Nilsson *et al.* 2019). Generally, damage by pests, pathogens, and fires is less common (Nilsson *et al.* 2019). However, there have recently been some large wildfires in central Sweden, in 2014 and 2018, and problems related to pests and pathogens seem to be increasing in both northern and southern Sweden.

The tree species found in the northern study area are very cold-hardy, such as Scots pine, Norway spruce, Lodgepole pine, Birches, and Poplars (*Populus ssp.*) (Table 1). In the southern study area, the same cold-hardy species are present but more cold-sensitive broadleaved tree species, such as European beech (*Fagus sylvatica* L.), oaks (*Quercus robur* L. and *Quercus patraea* Matt.) and maples (*Acer platanoides* L. and *Acer pseudoplatanus* L.) are also found. Over recent decades, the proportion of Norway spruce has steadily increased in southern Sweden, due to it being less prone to browsing by ungulates. It has also been favoured in forest management due to being highly productive and easily managed (Lodin *et al.* 2017; Felton *et al.* 2020; Ara *et al.* 2021; Pfeffer 2021). This shift has disfavoured Scots pine and broadleaved tree species, as reflected in the current tree species distribution in the southern study area (Table 1). In contrast, Scots pine has generally been favoured in forest management in northern Sweden, and this is reflected in the tree species distribution found in the northern study area.

Table 1. Descriptive statistics of the regions in which the study areas are located, and for all of Sweden.

	Northern study area, Västerbotten Region	Southern study area, Kronoberg Region	All of Sweden
Population*	275 000 inhabitants	203 000 inhabitants	10 452 000 inhabitants
Forest area**	4 095 000 ha, 73% of land area (5 590 000 ha)	696 000 ha, 84% of land area (833 000 ha)	28 008 000 ha, 69% of land area (40 823 000 ha)
Productive[1] forest area**	3 285 000 ha	666 000 ha	23 550 000 ha
Protected and voluntary set aside forests (of productive forest area)*	Formally protected 6.1% Voluntary set-asides 5.1% Retention patches	Formally protected 2.3% Voluntary set-asides 5.7% Retention patches	Formally protected 5.8% Voluntary set-asides 5.6% Retention patches 2.1%
Forest ownership (proportion of productive forest area)**	Small scale forest owners 45 % Private forest companies 23% State and other public owners 32%	Small scale forest owners 77% Private forest companies 12% State and other public owners 19%	Small scale forest owners 52% Private forest companies 24% State and other public owners 24%
Tree species distribution (of standing volume)**	Scots pine 43% Lodgepole pine 4% Norway spruce 36% Birch 14% Oak 0% Other 2%	Scots pine 20% Lodgepole pine 0% Norway spruce 61% Birch 14% Oak 1% Other 4%	Scots pine 33% Lodgepole pine 2% Norway spruce 47% Birch 12% Oak 1% Other 6%
Soil productivity**	3.4 m^3 wood over bark/ha/yr.	9.2 m^3 wood over bark /ha/yr.	5.5 m^3 wood over bark /ha/yr.

*Statistics Sweden 2023

**Nilsson et al. 2019

4.2.3 Stakeholder recruitment

For the co-production process, we engaged forest stakeholders resident in our two study areas, including small-scale forest owners, forest companies, tourism enterprises, recreational organisations, environmental non-governmental organisations, local development representatives, educators, Sami reindeer herders, and hunters. The number of stakeholders participating in each workshop is displayed in Figure 3, and a detailed report on the characteristics of the stakeholders is provided in the papers. The scientists participating in the processes were one historian, two historians of science and ideas, two political scientists, and three forest scientists (myself included).

In recruiting the stakeholders we aimed for representation of a mix of different interests, ages, and genders, to bring in multiple perspectives on forests. We began the recruitment by identifying the forest-related organisations and sub-organisations active in our study areas. We then identified possible participants from these organisations, and invited them to participate in our project as members of the local community, rather than as representatives of their organisation. This approach resulted in more than 30 people participating in the project. The number of participants in each part of the project is shown in Figure 3, and the types of stakeholders are specified in each paper.

Informed consent was obtained from all stakeholders, and they were all interviewed prior to the co-production process. As it is harder for some stakeholder groups to participate in research in their salaried time (Frantzeskaki & Rok 2018), and to enable stakeholders to participate on terms that were comparable with ours as researchers (Turnhout *et al.* 2020), we financially compensated those who were not able to participate as part of their employed role. The interviews consisted of questions about the stakeholders' relationships to forests, climate change, and policy, as well as their expectations of the process. Thus, the interviews aimed both to prepare us researchers and the stakeholders for the process, while allowing them to make requests regarding the content of the process.

4.2.4 The co-production processes

During two parallel co-production processes, we co-produced knowledge and pathways with local forest stakeholders in our two study areas in northern and southern (Figure 3). The processes aimed to develop locally tailored climate action pathways for their communities (workshops 1-5), while also developing and evulating locally tailored climate-smart forest management pathways (workshop 3-5; Papers II-IV). As co-production processes often fail to deal with the social dynamics that they entail, including facilitation of power relations and enabling co-learning (Reed 2008; Mobjörk 2010; Voinov & Bousquet 2010; Davies *et al.* 2015; Turnhout *et al.* 2020), it was necessary to mitigate power relations between stakeholders, and between stakeholders and researchers. Thus, as suggested by Reed (2008), we recruited a professional facilitator to facilitate the processes. We also set up common ground rules with the stakeholders, which were reiterated throughout the processes. These mainly included being respectful of and listening to each other, while also being reflexive. Reflexivity refers to being aware of and reflecting on one's own perspective, in order to be able to think afresh or differently (Boström *et al.* 2017; Mårald

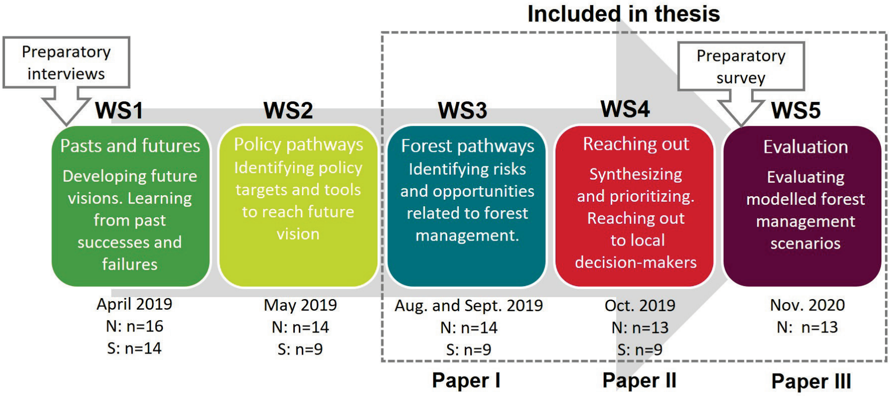


Figure 3. The co-production process consisting of four workshops in both locations and an additional fifth workshop in the northern study area.

et al. 2017; Pickering 2019). As researchers, we also emphasised that the workshops aimed to bring forward the stakeholders' knowledge and aspirations, while the researchers' presentations throughout the processes aimed to provide a shared knowledge-base and catalyse their discussions. All smaller group discussions were moderated by researchers, to make sure that all stakeholders were able to participate in the discussions, and to take notes. At the end of every workshop stakeholders were invited to document their individual anonymous written reflections, through which they could express their own (unfiltered) thoughts on the issues raised during the workshops, while also making suggestions for the following workshops.

As a key feature of co-production processes is the iterative interplay between scientists and stakeholders (Lemos & Morehouse 2005; Norström *et al.* 2020; Turnhout *et al.* 2020), thus we designed two iterative processes were the stakeholders participated in four whole-day workshops, and a fifth half-day workshop in the northern process (Figure 3). During the workshops, short researcher presentations prompted stakeholder discussions on a variety of themes related to local climate action and forest management. Between the workshops, the researchers processed the materials generated by the stakeholders and planned the subsequent steps in the process. The workshops were organised around the following themes: i. learning from the past and developing visions for the future, ii. developing policy pathways to reach those visions, iii. identifying forest management pathways (Paper II), and iv. synthesising their visions and pathways from previous workshops and reaching out to local decision-makers (Paper III). The northern process also included a fifth workshop, in which forest management scenarios were modelled based on the stakeholders' preferences, and then evaluated with the stakeholders (Paper IV). While the main steps of the processes were planned by us as researchers, the detailed design and content of each workshop was planned between workshops to allow for stakeholders' ideas to be incorporated into the design. As the workshops built on each other, I will describe the entire process (workshops 1 to 5), although the papers included in this thesis specifically build on workshops 3 to 5 (Papers II-IV, Figure 3)

Workshop 1 – Learning from the past and developing future visions

In the first pair of workshops (WS1), we focused on envisioning possible futures and learning from past successes and failures (Priebe *et al.* 2022). We first asked participants to develop visions for the future for their local community, "lokalsamhälle" in Swedish, while considering how they want to address climate change (Figure 4). To avoid risking "closing down" the future and reproducing already existing power relations (Stirling 2006; Klenk & Meehan 2015; Turnhout *et al.* 2020), participants developed multiple visions and, throughout the process, did not have to agree on their visions nor pathways. Participants were then invited to map examples of historical events or crises that have had significant impact at the local level, and to identify constructive ways in which the local community had managed these events. To conclude the workshop, we returned to the future visions, discussing potential changes and challenges to the local community and whether the constructive approaches identified in their history could be

Figure 4. Photograph of future vision collages from workshop 1 in the northern study area.

useful in meeting those future changes and challenges. Participants wrote individual reflections on the values and strategies that they thought, firstly, had facilitated transformative changes in their community in the past and, secondly, could facilitate transformative changes in their community in the future. The documentation from WS1 included: collages of future visions, including images and icons, illustrations, and written notes (Figure 4); researchers' notes from plenary sessions during the workshops; and participants' written, individual, anonymous reflections. The results of these workshops were published in Priebe *et al.* (2022), focusing on stakeholders' individual reflections on the values and strategies that can facilitate transformative change in their community.

Workshop 2 – Developing policy pathways.

In preparation for the second pair of workshops, the researchers compiled visions of preferred futures based on the material from workshop 1 and the "scenario families" described by van Vuuren *et al.* (2012). Departing from the categories of key assumptions identified by van Vuuren *et al.* (2012), we classified the visual elements and keywords from the future vision collages (Figure 4) and the values and strategies from the individual reflections (Priebe *et al.* 2022) across two dimensions: one addressing economic growth versus degrowth, and one focusing on local versus global governance (Figure 5) (Reimerson *et al.* Under review). We used the material in aggregated form to develop the scenarios, as one group's collage, or one individual's written reflection, could contain elements of several scenario archetypes. Our

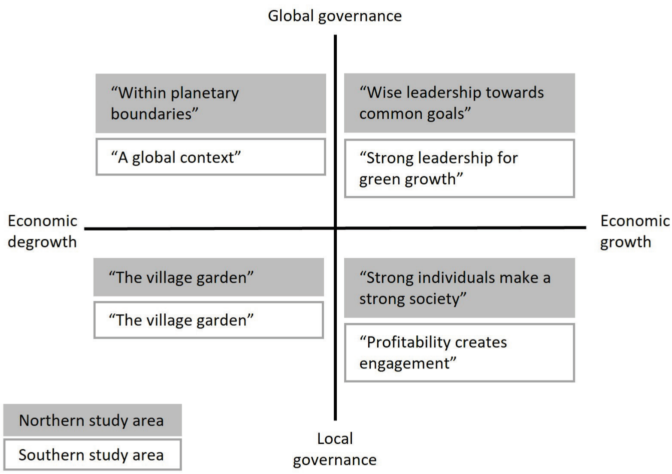


Figure 5. Co-produced future scenarios used in workshops 2 and 4.

ambition was to use the participants' illustrations and statements as the basis for different future scenarios – which could then facilitate the next step of the process: outlining pathways to achieve these different futures.

During workshop 2, the future scenarios (Figure 5) were used in a participatory backcasting process (Carlsson-Kanyama *et al.* 2008; de Bruin *et al.* 2017; Sandström *et al.* 2020; Toivonen *et al.* 2021) to outline the policy targets and tools needed to reach the future visons that were incorporated into the scenarios. Thus, during workshop 2, participants were invited to rank which of the scenarios they wished to develop pathways for, and then divided into groups based on those requests. In the northern study area, groups were formed for all four future scenarios (Figure 5). In the south, groups were formed for all but the economic growth - global governance scenario ("Strong leadership for green growth"). The groups were then asked to set intermediate targets to reach their selected future vision by the year 2100, sorted by time (present day to the year 2100) and scale (local to global), and to identify tools which may be useful in reaching those targets. To support the participants' identification of tools, researchers presented an overview of policy instrument types, i.e., regulatory, financial, or information-based (Vedung 1998), and a compilation of the historically constructive local approaches identified in workshop 1. Participants also wrote individual reflections on what policy targets and tools they thought were the most important for their local community to reach their preferred vision, and how they thought this related to forests and forest management. The results from these workshops were processed in preparation for subsequent workshops, mainly by clustering and categorising their preferred policy tools and targets (see section *Workshop 4 – Synthesis and prioritised pathways (Paper III)*). The results were also analysed in Reimerson *et al.* (Under review) with a focus on potential pathways for local climate action in Sweden.

Workshop 3 – Risks and opportunities of different forest management approaches (Paper II)

In the third pair of workshops (WS3, Paper II), which were planned under my lead, participants visited local experimental forests in Vindeln in the northern study area, and Asa in the southern study area (Swedish University of Agricultural Sciences 2020), to explore risks and opportunities of different forest management approaches, taking into consideration their local conditions, future visions, and climate change. The idea of being out in the forests was to provide participants with some common points of reference, while letting the environment prompt their discussions (Figure 6). The field visits included exploring five different sites representing five different types of forest management: i.) unmanaged forests, ii.) "non-clear-cut" forestry, IV.) even-aged forestry with clear-cuts iv.) short rotation forestry with intensive fertilisation, and v.) short rotation forestry with exotic tree species, reflecting a spectrum of management from low to high human influence (Figure 1). At each of the sites, I briefly introduced the site and management approach applied, while leaving the evaluation to the participants. They were then asked to discuss "What opportunities and risks do you see with this type of management, for your local community and the climate?". The participants first discussed the question in groups of two or three people, while exploring the site, and were then gathered into groups of four to five to discuss it further. This step was moderated and recorded by researchers. Finally, all participants were brought back together, and the researchers briefly reiterated what had been said in the groups, in the wording used by participants themselves, so that they had an opportunity to take part in, and comment on, the other discussions as well. These steps were repeated at each of the five sites.

After visiting all five sites, the stakeholders were reminded about the future visions and policy pathways developed during previous workshops. They then discussed and wrote individual reflections on: "What kind of forest management would you like to see more or less of in your local community? Explain why." and "Can forest management be tailored to suit your local community better? If yes, how?". Throughout the excursions, pictures were taken by a professional photographer to capture the

Figure 6. From the introduction to workshop 3 in the northern study location, Umeå/Vindeln. Photo: Andreas Palmén

management approaches at the sites visited. These pictures were used during the synthesis in workshop 4.

Workshop 4 – Synthesis and prioritised pathways (Paper III)

In preparation for workshop 4, the researchers processed the material produced during workshops 2 and 3. All policy targets were coded based on what process and scenario they originated from, what issues they related to, and which policy tools were suggested. Targets that were similar to each other were clustered and merged. Finally, cards were made for each of the targets to be used during workshop 4. We also made cards of the forest photographs taken during workshop 3, one card for each forest management approach at each of our study areas.

During workshop 4, participants synthesised the work they had done during the process and shared it with invited local decision-makers such as public officials and politicians (Paper III). The synthesis focused on what participants felt were the most urgent things to do here, now, and by us, and how they thought that forests should be managed to support their future visions. Each participant got to choose which scenarios they wanted to work with, which resulted in groups of between one and six people. There were four groups in the northern process and three in the southern process (no group for the "Strong leadership for green growth"-scenario). Participants used the cards prepared by the researchers to make collages of the policy targets and forest management methods that they had prioritised (Figure 7). They then had to prioritise just a few of the targets and describe in writing

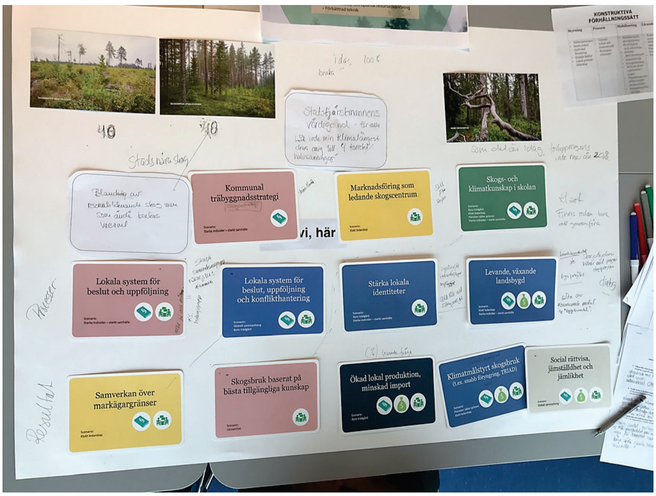


Figure 7. Photograph from one of the collages presented to local decision-makers in workshop 4.

how they thought these could be implemented, and by whom. They were also asked to explain their choice of forest management approaches in writing. These materials were gathered and used as a basis for the analysis. In the next step, the stakeholders presented their thoughts and ideas to local decision-makers and public officials.

Workshop 5 – Evaluating future forest management scenarios (Paper IV)

After the four parallel workshops, participants answered a survey about the process. For the northern stakeholder group, we also included questions about what forest management approaches and ecosystem services they felt were most important, considering their visions for their local community and climate change. Based on these results, and results from the previous workshops (mainly workshop 3, Paper II), we developed four forest management scenarios (Figure 8) which I modelled in Heureka, a forest decision-support system developed by the Swedish University of Agricultural Sciences (Wikström *et al.* 2011)(Paper IV). The scenarios were developed for the forest area that is currently available for wood production, thus excluding areas that are set aside from forestry. Data from the national forest inventories (Fridman *et al.* 2014) about the forest structure in our northern study areas was used as point of departure for the scenarios. For each of the scenarios, I developed a broad range of forest management strategies that could be applied. I then used the management optimisation tool in Heureka Planwise (Eggers & Öhman 2020) to optimise the use of forest management approaches to promote the stakeholders' preferred ecosystem services. This resulted in the following scenarios:

- Close-to-nature management (CTN), aiming to enhance biodiversity and climate change mitigation (including both carbon stocks and harvested wood products). This included no management, shelterwood systems, even-aged management with broadleaves and mixed species (prolonged rotation), and some selective felling. All management relied on natural regeneration, apart from a specific management strategy developed for areas with non-native Lodgepole pine. For those areas, Lodgepole pine would be replaced at maturity with planted native Scots pine.
- Classic management (CLA), aiming to enhance forest owners' livelihoods by maximising their Net Present Value from harvested wood products. This included mainly even-aged forestry with planted native species and a single application of

fertiliser (when ecologically and financially appropriate), with some selective felling, shelterwood systems, and even-aged forestry with naturally regenerated broadleaves, mixed species, or conifers.

- Intensified management (INT) aimed to enhance climate change mitigation by maximising harvested wood products while maintaining the level of carbon stocks in forests and soils. This mainly comprised short rotation forestry with planted native or non-native species and multiple applications of fertiliser (when ecologically appropriate). It also included some even-aged forestry with planted native species.
- Combined management (COM) aimed to enhance biodiversity, forest owner livelihoods, and climate change mitigation. While it initially included all types of forest management approaches developed for the other scenarios, it mainly applied management approaches from the CTN and INT scenarios, as a consequence of how the different goals were optimised. Thus, it mainly applied no management, short rotation forestry with planted native or non-native species and multiple applications of fertiliser (when ecologically appropriate), along with some selective felling, shelterwood systems, and even-aged forestry with planted native species.

When modelling the scenarios, I accounted for local ecological conditions in the study area (section 4.2.2) and for stakeholders' experiences of forest management in the study area (workshop 3, Paper II), which meant that I included clear-cutting to enable the regeneration of mixed species and

Figure 8. Co-produced forest management scenarios for the northern study area in workshop 5. Photos top left and bottom: Andreas Palmén. Photo top right: Jon Flobrant on Unsplash.

broadleaved tree species forests in the close-to-nature scenario, although clear-cutting is typically not included in close-to-nature forestry (chapter 2).

The results of the modelling were analysed with stakeholders during an online half-day workshop (workshop 5), that was designed under my lead. Prior to the workshop, participants received information on the scenarios, illustrations, descriptions, figures, and descriptive statistics. The workshop began with me presenting the modelled scenarios, specifically describing the management involved in the different scenarios and their provision of the following ecosystem services: climate change mitigation, biodiversity, reindeer husbandry, forest owner livelihoods, and recreation. The stakeholders then reacted and posed questions about the results from the modelling, and evaluated what they thought the consequences of these scenarios would be for their local community and for climate change. This was done in groups of three to four people, moderated by researchers, and the discussions were recorded for analysis.

4.2.5 Material and analysis

The material from workshops 3, 4 and 5 of the co-production process was analysed by me for Papers II-IV, and material from workshop 4 was also analysed jointly with Elsa Reimerson for Paper III. See Table 2 for an overview.

Table 2. An overview of the material and modes of analysis for Papers II-IV.

Paper	Material from	Type of material	Mode of analysis
Paper II	Workshop 3	Recorded focus group discussions and individual written reflections	Inductive, Deductive
Paper III	Workshop 4	Collages and written group motivations	Inductive
Paper IV	Workshop 5	Modelling data	Deductive
		Recorded focus group discussions	Inductive

My analysis of the material from the co-production process has been guided by my curiosity about and profound respect for the stakeholders' ideas, aspirations, and knowledge of forests, forest management, and climate change. Thus, my analysis of the materials has mainly been data-driven, starting with participants' statements and the general themes and ideas they reflect. The processing of the material has been inspired by grounded theory and the constant comparative method (Glaser & Strauss 1967; Lindgren 2014b; Bryman 2016; Thornberg & Forslund Frykedal 2019), and it included

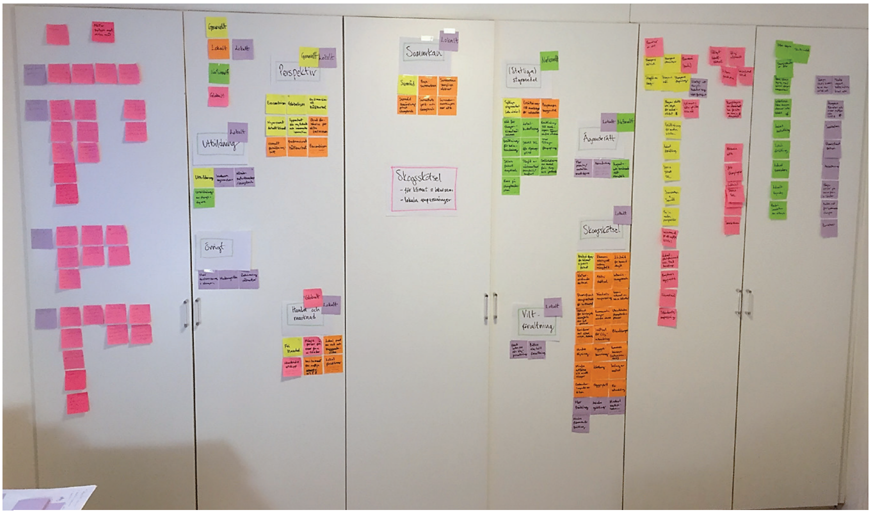


Figure 9. The "post-it-wall" from the analysis of the material from Paper II.

the following steps: i. transcription of the material; ii. coding of statements; iii. clustering and categorisation of similar statements; iv. identifying main themes; and v. iteration to the point of saturation, meaning that the process was repeated until the themes and categories formed coherent wholes. For Papers II and IV, this included first transcribing, coding, and clustering the material in Microsoft Excel, and then transferring it to a post-it-wall (Figure 9) to allow for an overview of the material, and to enable it to be iteratively processed. While I know of softwares that are specifically designed for the analysis of qualitative material, I found that the computer screen became too small to provide the overview that I was looking for, and the manual experience of working with the post-it wall gave me more flexibility in the placement and rearrangement of the material.

However, I have also applied a deductive (Bryman 2016; Johansson 2016), or theory-driven, approach in Papers II and IV. In Paper II, I was curious to discover what criteria and indicators for "sustainable forest management" and "climate-smart forestry" were present in the stakeholders' statements (Forest Europe 2015; Santopuoli *et al.* 2021; Bowditch *et al.* 2022). Thus, I screened the material for criteria and indicators, which resulted in 45 indicators, of which six novel ones based on our material. When analysing the modelling data from workshop 5, Paper IV, I used the indicators that the stakeholders had identified as important during the previous workshops, primarily workshop 3 (Paper IV), and the preparatory survey, while also using the literature to define new indicators that were not already present in the software, for example to estimate bilberry production.

In writing about the recorded group discussions from workshops 3 and 5 (Papers II and IV), I aimed to synthesise the stakeholders' statements so that they would be able to recognise themselves in the text, as far as possible. However, this is of course a challenge as the results were written in concise academic English, while the material was gathered in colloquial Swedish, over several days of workshops. In writing about the results, I initially included quotes from the discussions in the text. However, as the quotes were the products of longer focus group discussions (sometimes prompted by statements, questions, or comments from other stakeholders), I felt that this approach would lift quotes out of their context, and that there was not enough space to describe that context, which would be important when using such quotes (Lindgren 2014a). For this reason, I did not include any quotes. I also excluded any information that would make it possible to identify the stakeholders, and I have not made the transcripts or recordings publicly available, to safeguard the anonymity of the stakeholders (Bryman 2016).

5. Summary of papers

5.1 Paper I: Applying machine learning to media analysis improves our understanding of forest conflicts

Conflicts over the management and governance of forests are increasing. Previous media studies on forest conflicts have mainly focused on analysing the portrayal of specific conflicts. Paper I aimed to review the broad range of forest conflicts portrayed in the Swedish media by analysing their temporal, spatial, and relational dimensions. We used topic modelling, a machine learning approach, to analyse 53 600 articles published in the Swedish daily press between 2012 and 2022. Topic modelling identifies the main themes, or topics, of large text-based datasets. We identified 916 topics in the media articles, of which 94 were of interest for this study. The results revealed that the media coverage of forest conflicts is increasing and that the main conflicts related to hunting and fishing (35% of the total coverage), energy (24%), recreation and tourism (11%), nature conservation (8%), forest damages (6%), international issues (5%), forestry (5%), reindeer husbandry (4%), media and politics (2%), and mining (1%). Some of the conflicts, such as those around energy and nature conservation, were continuously reported on, while others, such as hunting and fishing or recreation and tourism, displayed more seasonal patterns, or were mainly reported on in relation to specific events, as was the case for forest damages and international issues. Four conflicts were mainly covered in specific regions or had regional tendencies: these included reindeer husbandry, nature conservation, forest damages, and mining. Others were covered across Sweden (Figure 10). Several of the conflicts related to each other, forming three clusters which focused either on industrial, cultural, or conservation conflicts. Table 3 provides an overview of the main results. The results emphasised the value of applying topic modelling to reviewing forest conflicts in the media, and highlighted the temporal, spatial, and relational dimensions of forest conflicts.

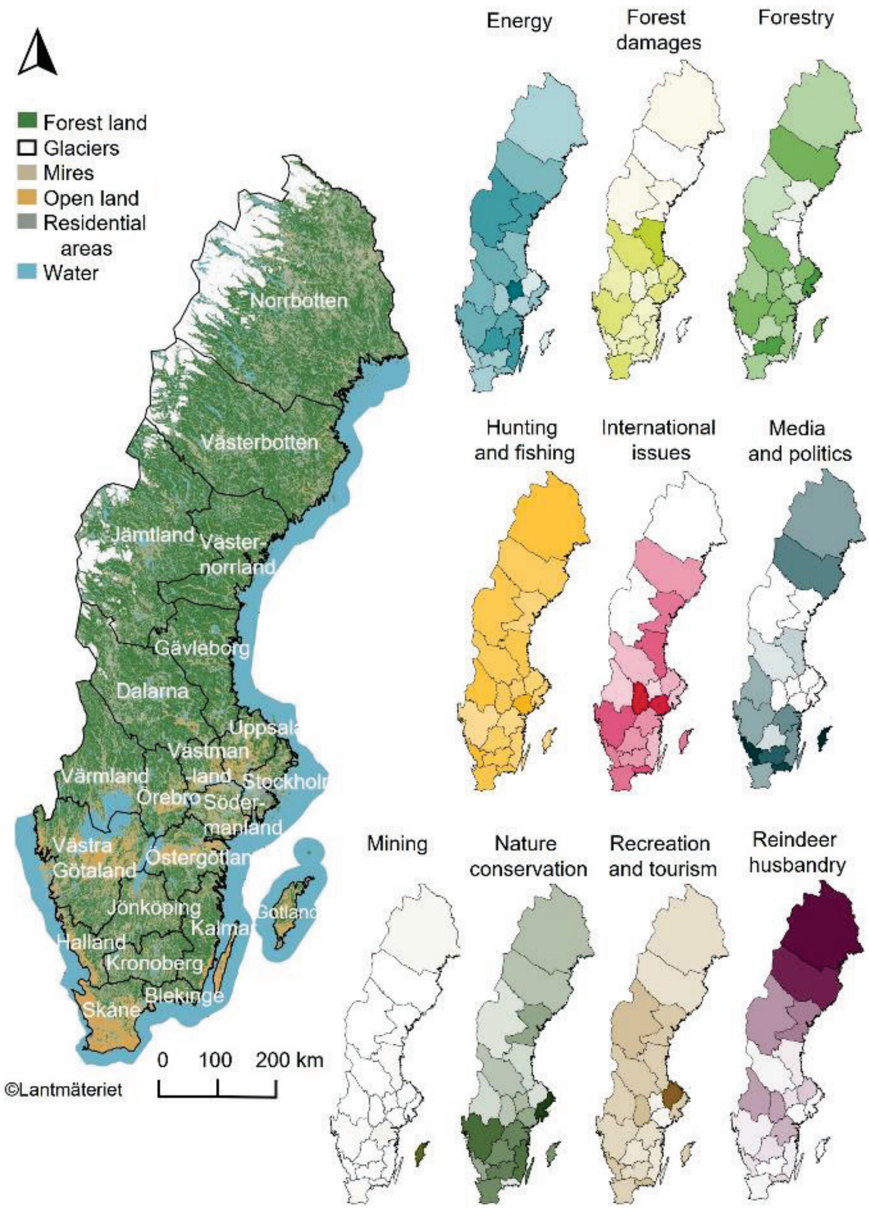


Figure 10. The geographic distribution of forest conflicts in Swedish media. The darker the colour, the higher the proportional coverage was of that conflict in that region. The large map was produced with data from Lantmäteriet (the Swedish Land Survey).

Table 3. An overview of the forest conflicts portrayed in the Swedish media 2012-2022.

Forest conflict	Document proportion	Main topics	Temporal pattern	Regional tendency	Closely related to
Energy	24,1%	Bioenergy and wind power	Continuous	None	None
Forest damages	5,9%	Storms, wildfires and herbivore browsing	Event-related	Southern and central Sweden	None
Forestry	4,9%	Swedish Forestry Model, gender equality, and climate change mitigation	Continuous	None	Mining, International issues
Hunting and fishing	34,6%	Hunting of wolves, wild boar, moose, and problems related to carnivore predation	Continuous, Seasonal	None	Reindeer husbandry
International issues	5,0%	Deforestation and biodiversity conservation	Event-related	None	Forestry
Media and politics	2,0%	Church election and government declaration	NA	None	None
Mining	0,7%	Limestone quarry in Ojnare forest	NA	Gotland	Forestry
Nature conservation	8,4%	Biodiversity conservation in woodland key habitats, nature reserves, residential areas	Continuous	Southern Sweden	Recreation, tourism
Recreation and tourism	10,8%	Berry and mushroom picking, bicycling, and the right to public access	Continuous, Seasonal	None	Nature conservation
Reindeer husbandry	3,7%	Reindeer husbandry and Sami rights	Event-related	Northern Sweden	Hunting and fishing

5.2 Paper II: Bringing “climate-smart forestry” down to the local level - identifying barriers, pathways and indicators for its implementation in practice

The theoretical concept of “climate-smart forestry” aims to integrate climate change mitigation and adaptation with maintaining and enhancing forests’ contributions to people and global agendas. We carried out two forest excursions with local stakeholders in northern and southern Sweden, aiming to translate climate-smart forestry to local contexts, while identifying barriers, pathways, and indicators for its implementation in practice. During the excursions, stakeholders described what characterises current forestry practices: primarily that it is streamlined towards either even-aged forestry or leaving forests unmanaged, while mainly using two native tree species. They then described what they thought would characterise climate-smart forestry: the key features of this were active management to promote multiple goals in various places, site-adapted management using a broader palette of tree species and management approaches and consideration of the landscape perspective. In moving from current practice to climate-smart forestry, they identified conditions that could act as barriers or pathways, depending on how they are managed, such as value chains for forest products and services; local knowledge and experiences of management alternatives; forest ownership structures and taxation policies; management of browsing ungulates; and collaborations and networks. Based on these results, 39 indicators for climate-smart forestry were identified, of which six were novel indicators adding to the existing literature. By bringing climate-smart forestry down to the local level, the theoretical concept of climate-smart forestry was translated into something that was locally desirable and actionable, thereby bringing it one step closer to local implementation. While the local articulations could very well fit within the theoretical concept in the literature, they could also contribute to improving that concept, through the interplay between science and practice (Figure 11).

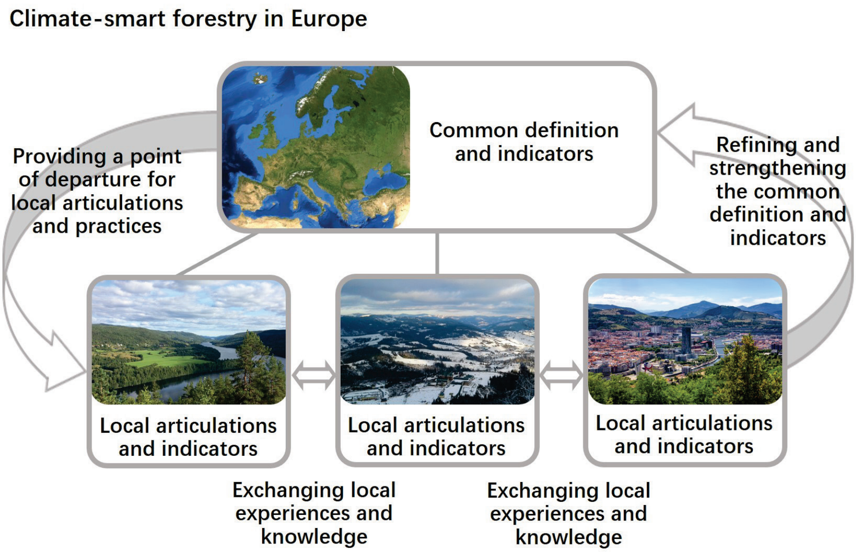


Figure 11. A conceptual figure for how "climate-smart forestry" could be improved in Europe. This involves linking the meta-level scientific discussion of the concept to local articulations and practices, thereby promoting an interplay between science and practice, while encouraging the exchange of knowledge between different local situations. Top satellite image from Wikimedia Commons: created by Koyos with NASAWorldWind. Bottom photos (from left to right): by Isabella Hallberg-Sramek, Tetiana Shyshkina, and Yves Alarie.

5.3 Paper III: "Here and now, by us": Co-production of climate action pathways in forest landscapes

Climate change requires solutions that are tailored to specific socio-ecological contexts. Thus, in Paper III, we aimed to co-produce climate action and forest management pathways with local stakeholders in Sweden. We conducted two parallel co-production processes to identify policy targets and tools for local climate action, which also included identifying how forest management can be used to support the local stakeholders' desired futures. We co-produced scenarios that focused on different governance levels and economic systems, i.e., local versus global governance, and economic degrowth versus growth (Figure 5), and the scenarios were used to catalyse discussions about policy targets, tools, and forest management. This resulted in eleven prioritised policy targets and 30 prioritised policy tools, which reflected three main pathways: "forest-based bioeconomy", "localism", and "global systemic change". The pathways differed in terms of targeted policy levels, from local to global; governance directions, either top-down or bottom-up; focus of change and assumed problems to be solved, such as fossil economy, globalisation or capitalism; and preferred economic system, economic growth or degrowth. However, regardless of which pathways or scenarios the stakeholder groups favoured, they all wanted to promote diverse forest management, involving a mix of no management, "non-clear-cut" forestry, even-aged forestry, and short rotation forestry with fertilisation, to enhance forests' provision of multiple contributions to people (Table 4). The ideological dimensions of stakeholders' preferred climate action pathways thus became less visible when considering the management of forests, a point which deserves further attention in future studies.

Table 4. Stakeholders’ preferences for forest management methods in relation to their preferred scenario. N and S reflect which process the group was part of, i.e., northern or southern. Photos: Jenny Svennås Gillner (even-aged forestry), Andreas Palmén (the rest).

Scenario group	Unmanaged	“Non-clear cut” forestry	Even-aged forestry	Short rotation forestry	
				fertilization	non-native
Global gov., Eco. degrowth, N	X	X	X	X	
Global gov., Eco. degrowth, S	X	X	X	X	
Global gov., Eco. Growth, N	X		X	X	
Local gov., Eco. degrowth, N	X	X	X	X	X
Local gov., Eco. degrowth, S	X	X	X		
Local gov., Eco. growth, N	X	X	X		
Local gov., Eco. growth, S	X	X	X	X	

5.4 Paper IV: Combining scientific and local knowledge improves evaluation of future scenarios of forest ecosystem services

Forest scenario analysis can help tackle sustainability issues by generating insight into the potential long-term effects of present-day management. In northern Sweden, forests provide important benefits including climate change mitigation, biodiversity conservation, reindeer husbandry, local livelihoods, and recreation. Informed by local stakeholders' knowledge on how forest management can contribute to the provision of these benefits, we created four forest management scenarios: the close-to-nature scenario (CTN), which emphasises biodiversity conservation and forest carbon stocks; the classic management scenario (CLA), optimising the forests' net present value; the intensified scenario (INT), maximising harvested wood from the forest; and the combined scenario (COM), applying a combination of measures from the CTN and INT. The scenarios were applied to the local forest landscape in Umeå and Vindeln municipalities (Figure 2), and modelled over a 100-year simulation period. The results of the modelling were then evaluated by a diverse group of stakeholders. The results revealed that, for most ecosystem services, there was a time lag of 10-50 years before noticeable effects and differences between the scenarios became evident, reflecting the time lags associated with forest management, while differences in the provision of harvested wood and forest owner livelihoods became evident from the start. This highlighted the need to consider both the short- and long-term effects of forest management. Evaluation by the stakeholders put the modelled results (Figure 12) into a local context, and emphasised the importance of considering more perspectives and indicators than those it is possible to model. They also raised additional considerations relating to wildlife and hunting, climate change risks, social acceptability, and conflict (Table 5), highlighting the value of evaluating the scenarios qualitatively as well as quantitatively. Overall, stakeholders thought that the CTN and CLA scenarios enabled more ecosystem services, posed fewer climate risks, and would create less conflict among stakeholders, while INT and COM scenarios had more negative impacts on ecosystem services and posed higher risks in relation to climate change and local conflicts. Our results illustrate the value of combining scientific and local knowledge when developing and evaluating future forest scenarios.

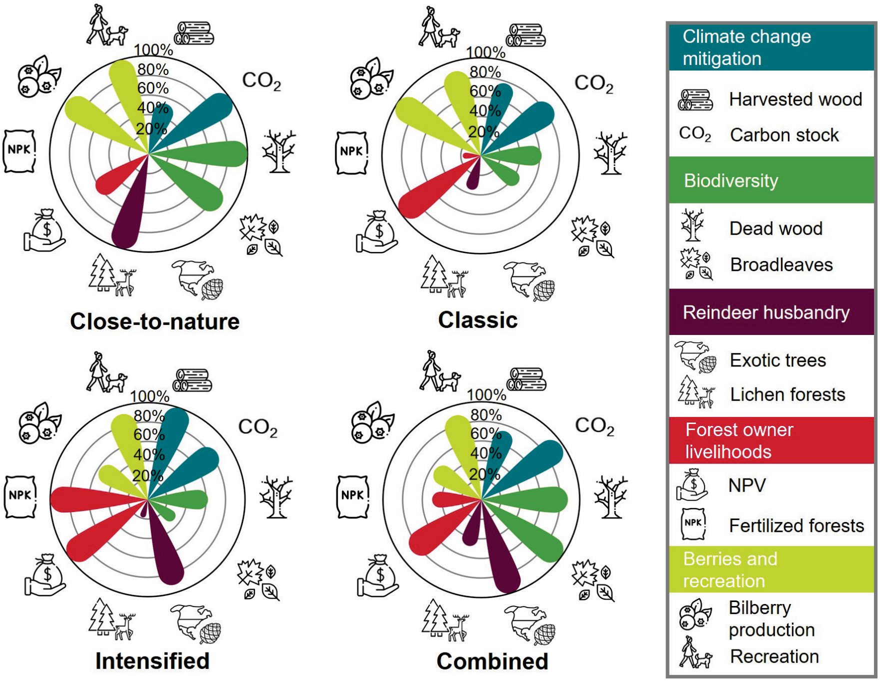


Figure 12. The modelled relative provision of ecosystem services by scenario, using the highest value for each indicator as a reference. Areas dominated by non-native trees negatively influence reindeer husbandry. Images: Flaticon.com

Table 5. Stakeholders' evaluation of the scenarios. Arrows indicate how they thought that ecosystem services and other consideration would be affected: favoured (↑), disfavoured (↓), or not mentioned (o). Ecosystem services and considerations in italics were added by the stakeholders to those that were modelled.

Ecosystem services and additional considerations	**Close-to-nature**	**Classic**	**Intensified**	**Combined**
Climate change mitigation *and adaptation*	↑ ↓	↑ ↓	↑ ↓	↑ ↓
Biodiversity conservation	↑	↑ ↓	↓	↑ ↓
Reindeer husbandry	↑	↑ ↓	↓	↑ ↓
Livelihoods	↑ ↓	↑	↑ ↓	o
Recreation	↑	↑	↓	↓
Hunting and wildlife	↑ ↓	↑ ↓	↓	↑ ↓
Social acceptance	↑ ↓	↑ ↓	↓	↓

6. Discussion and reflections

This thesis highlights the multiple expectations placed on forests and forest management in Sweden, and possible ways of addressing them locally. Forests and forest management are expected to provide a wide range of ecosystem services to address local and global expectations of forests, while also supporting the quality of life of people living in forested areas. The media analysis highlighted the competing expectations placed on forests in general across the country (Paper I), while the co-production processes highlighted the particular expectations placed on forest management in the two study areas in northern and southern Sweden (Paper II-IV). The inclusion of diverse stakeholders in the co-production processes brought to light multiple perspectives on, and local knowledge of, forests and forest management, providing a nuanced and pluralistic view on the strengths and weaknesses of different management approaches. The inclusion of local stakeholders also anchored the processes in local socio-ecological contexts, drawing to attention the local, national, and international conditions, processes, and structures that frame forest management options at the local level, thus highlighting also the opportunities and challenges for implementing climate-smart forest management in practice.

6.1 Competing expectations of forests

The media analysis and co-production processes highlighted the multiple, often competing, expectations placed on forests and forest management in Sweden. The co-production processes specifically highlighted the multiple expectations associated with forest management in the study areas: these included nature conservation, wood production, recreation, tourism, foraging for berries and mushrooms, reindeer husbandry, local livelihoods, hunting, and climate change mitigation and adaptation (Paper II-IV). Most of these expectations are widely reflected in the concepts of sustainable forest management (Innes 2016; Forest Europe 2022) and climate-smart forestry (Bowditch *et al.* 2020), and in national and European forest policies (Beland Lindahl *et al.* 2017; Mårald *et al.* 2017; Elomina & Pülzl 2021; Pietarinen *et al.* 2023), although reindeer husbandry is specific to the context of northern Sweden. Hunting and foraging for berries and mushrooms also seem to be more important at the local level than at other policy levels. The media analysis looked at forest conflicts in a broader perspective, considering also conflicts that are not commonly associated with forest management or forest policy, such as those relating to the presence of carnivores, wind power, and mining (Paper I). However, these issues do interact with issues that are directly related to forest management and policy: for example, the carnivore populations influence opportunities for hunting (Wikenros *et al.* 2015), and mining and wind power influence opportunities for nature conservation, reindeer husbandry, forestry, tourism, and recreation (Zachrisson & Beland Lindahl 2019; Jönsson *et al.* 2021; Bjärstig *et al.* 2022). While these issues were not addressed in the co-production processes, they may be worth addressing in future studies.

Analysing the competing expectations from a historical perspective, the expectations of forests have clearly increased since the beginning of science-based forest management in the 18th century, which initially was focused on the sustainable supply of wood (chapter 2), while forests today are expected to provide a variety of ecosystem services, while also being adapted to and mitigate climate change, as highlighted in Paper I-IV. These expectations are also connected to a variety of right holders and stakeholders, thus, current competing expectations relate to *why* and *for whom* forests should be managed, while the historical conflicts were more focused on *how* to manage forests (chapter 2 and section 3.1). In a previous study, forest stakeholders in Sweden have highlighted a shift in the public debate on forests, from being mainly focused on technical issues to being more political (Jakobsson *et al.* 2021). Which would agree with the results from the media analysis, were the media coverage of forest conflicts mainly focused on why and for whom forests should be managed (Paper I). However, the co-production processes included competing expectations also related to how forests should be managed, in addition to why and for whom, thus reflecting both past and current areas of conflicts (Paper II-IV). This may reflect an important difference between the media's, or the public's, expectations on forests and the local stakeholders', where the connection of the local stakeholders to the physical landscape also makes the issue of how important.

Interestingly, several of these expectations of forests had regional characteristics. The most obvious of these was reindeer husbandry, which was mostly covered by local and regional media in northern Sweden (Paper I), and only arose in the northern stakeholder process (Paper II-IV), reflecting the fact that this practice is only permitted and practiced in northern Sweden (Allard 2022). Other expectations showed less clear geographies: for example, nature conservation conflicts arose more in the media coverage from southern Sweden, but were covered in both northern and southern co-production processes, and other studies have identified north-western Sweden as a hotspot for such conflicts (Beland Lindahl 2008; Westling 2012; Bjärstig *et al.* 2019; Hallberg-Sramek *et al.* 2020; Bjärstig *et al.* 2022). Possibly, the higher proportion of media coverage of nature conservation conflicts in southern Sweden could relate to more forests being owned by small-scale forest owners in this region (Nilsson *et al.* 2019), a group which has felt particularly threatened by nature conservation measures (Hallberg-Sramek *et al.* 2020; Sténs & Mårald 2020; Jakobsson *et al.* 2021). However, the level of regional media coverage may also reflect the strength or absence of competing issues, as all issues covered by the media compete with others for limited space (Djerf-Pierre 2012). In the media study (Paper I), only one conflict was identified which was coded as a mining conflict. This arose in Gotland, an island in southern Sweden, where the local conflict soon escalated to a national conflict that continued for several years (Figure 10, Paper I) (Örestig & Lindgren 2017; Anshelm *et al.* 2018; Jönsson *et al.* 2021). Mining conflicts can actually be found all over Sweden (Zachrisson & Beland Lindahl 2019; Fjellborg *et al.* 2022), but they may not be generally associated with forests, which would explain why only the Gotland conflict was visible in the mining category in our analysis. In fact, another conflict which does relate to mining was identified in the media analysis, but it was coded as part of the reindeer husbandry category as it was primarily framed in words associated with this practice (Paper I). Thus, the media analysis highlighted how the conflicts primarily were framed, and only assigned each document to a particular conflict, while it would require another topic model or a deeper qualitative analysis to analyse the many facets, interrelations and nuances of these conflicts, which would provide an interesting avenue for future research.

One important result from the media analysis (Paper I) was that the relative and absolute coverage of forest conflicts in the Swedish media is increasing. This may reflect increasing levels of conflict in relation to forests, and an implementation deficit in current forest management relative to ambitious national multiple-use forest policies, as highlighted by previous studies (Beland Lindahl *et al.* 2017; Mårald *et al.* 2017). Indeed, stakeholders highlighted several problems with current forest management, and emphasised the need to diversify management practices to enable the provision of multiple ecosystem services (Paper II-III). This does suggest that current management is not living up to the ambitions of national multiple use policies.

Overall, the studies in this thesis have focused on analysing competing expectations on forests from more of a system perspective, to understand their implications for forest management, rather than connecting these competing expectations to specific stakeholder groups, as done in previous studies (Sandström *et al.* 2016a; Sténs *et al.* 2016; Mårald *et al.* 2017; Bjärstig *et al.* 2019; Hallberg-Sramek *et al.* 2020; Sandström *et al.* 2020; Bjärstig *et al.* 2022). Thus, while the participants in the co-production processes were recruited from different local stakeholder groups, they were invited to participate as part of the local community. This was important to enable a more nuanced and open discussion on forest management, as the stakeholders were not invited to represent a specific interest, but rather to engage with other community members to develop shared knowledge and pathways relating to forest management. Thus, it enabled collaborative learning and a more pluralistic and open process. At the same time, this did not mean that the stakeholders needed to agree with each other, and I have consistently highlighted areas where there were conflicting views, while not specifically addressing what type of stakeholders that had these conflicting views. Throughout the processes, the stakeholders also worked with different future scenarios, to enable different views and future aspirations. Surprisingly, all stakeholders wanted to favour a diverse forest management to enable multiple ecosystem services, which was quite surprising as the stakeholders had vastly different ideas about how they wanted their societies to be governed when considering climate change (Paper III). This may reflect that all stakeholders had various interests in relation to forests, while also having to co-exist and collaborate with each other locally, thus reflecting more entangled relations and interests related to forests at the local level. This may be what separates local stakeholders from stakeholders at other policy levels, and if so, maybe some forest conflicts could be dealt with by improving the collaborations, networks and collaborative learning at the local level, rather than trying to resolve the conflicts at other policy levels.

6.2 Locally tailored forest management

The iterative co-production processes (Paper II-IV) involved local stakeholders in developing and evaluating local pathways for climate smart forest management. This included identifying the risks and opportunities associated with different management practices, identifying principles and forest management approaches for climate-smart forestry, and evaluating different forest management scenarios. The processes highlighted the value of involving multiple stakeholders with different views, knowledge, and perspectives on forests, enabling collaborative learning to take place and a pluralistic perspective on the current and future management of forests to emerge. It also highlighted the complexity of forest management and the importance of addressing forest management in local contexts, as local situations differ even within one country.

The main differences between the study areas were forest ownership structures, land use, tree species composition, climate, land-use history, and forest disturbance regimes (Paper II). Given these differences, stakeholders in northern and southern Sweden sometimes expressed different ideas about the problems with current management practices and the challenges of changing them, although they shared similar views on what a more desirable future management would entail (Paper II and III).

The main problems the stakeholders' associated with the current management was that it is too streamlined into either applying even-aged forestry or no management, while mainly favouring Norway spruce and Scots pine (Paper II). Thus, it is not sufficiently adapted to specific site conditions and local use of the forests, and is also sensitive to forest disturbances, both biotic and abiotic. In northern Sweden, stakeholders felt that this streamlining partly related to the structure of forest ownership, with large proportions of non-resident and forest company owners (Nilsson *et al.* 2019; Swedish Forest Agency 2023) who, they argued, are not as personally engaged in their forests as resident small-scale forest owners. They also described it as a financial issue, because it is costly to harvest forests in northern Sweden, partly due to low wood volumes and large distances to industry, and thus it is more profitable to harvest larger areas at one time or not to harvest at all. This means that there are large differences in clear-cut size between northern and southern Sweden: 84% of clear-cuts in northern Sweden (Norra Norrland) are larger than 4 ha, and 55% are larger than 10 ha, while the corresponding numbers for southern Sweden (Götaland) are 49% and 15%, respectively (Swedish Forest Agency 2023)% (Swedish Forest Agency 2023). Stakeholders thought that some limitations in clear-cut size should be enforced, as they considered large clear-cuts (>c.10 ha) to be a problem. In southern Sweden, they particularly considered even-aged forestry with spruce as the dominant species to be a problem, as they have experienced significant outbreaks of Spruce bark beetles (*Ips typographus* L.). The high proportion of Norway spruce has arisen because forest managers prefer it over other species for being less prone to browsing damage, and more productive and easily managed, than other species (Lodin *et al.* 2017; Felton *et al.* 2020; Ara *et al.* 2021; Pfeffer 2021), which was also described by the stakeholders. However, they also pointed out that this preference had led to planting of Norway spruce on dry sites, making it more sensitive to drought and spruce bark beetles, hence their emphasis on the need for site-adapted tree species selection, and using a broader palette of tree species to diversify risks. Both the northern and southern stakeholders highlighted that forestry is the main income for forest owners in the study areas, which is characteristic of forest owners in north eastern Europe more generally (Winkel *et al.* 2022). Thus, making it possible to change management practices involves securing alternative incomes for forest owners, particularly bearing in mind that many of them need to pay mortgages on their forest properties.

By diversifying forest management, stakeholders thought that it could be better adapted to local conditions and forest uses, and spread climatic, financial, and environmental risks, while also promoting a mix of ecosystem services, such as climate change mitigation, biodiversity, health and recreation, hunting and wildlife, tourism, foraging, local livelihoods and employments, wood production (particularly of high quality wood), and reindeer husbandry (Papers II-III). Their preferred management approaches included no management, non-clear-cut forestry, even-aged forestry (with clear-cuts), and short rotation forestry with fertilisation, while some also wanted to include management with non-native tree species (Table 4, Paper III). Their motivations for opting for a mix of management approaches related to their knowledge of the local conditions for forest management, preferences for ecosystem services, and their view on risk management.

Stakeholders emphasised that all management approaches have strengths and weaknesses (Papers II-IV), which was particularly highlighted when they evaluated the management approaches in field (workshop 3, Paper II) and during the evaluation of the modelled scenarios (workshop 5, Paper IV). These strengths and weaknesses related to where they can be applied, what type of forest owner can apply them, what type of forests they create, and which ecosystem services they favour. Thus, to optimise the use of forest management approaches, they wanted to apply a mix of them at the landscape level (Papers II-III). This rationale is similar to that in the scientific literature on triad systems, in which a mix of management approaches ranging from no to high human influence (Figure 1) would be combined at the landscape level to provide a diverse and multifunctional landscape (Figure 13)(Betts *et al.* 2021; Himes *et al.* 2022; Larsen *et al.* 2022; Muys *et al.* 2022). In contrast, land sparing approaches simply combine no management with intensive management, which is very similar to how stakeholders described the current management (Paper II), or the combined scenario in the scenario modelling (Paper IV), while land sharing approaches apply extensive management everywhere (Figure 13). While the stakeholders were critical of land sparing approaches, a land sharing approach was not specifically discussed, but during workshop 3 (Paper II)

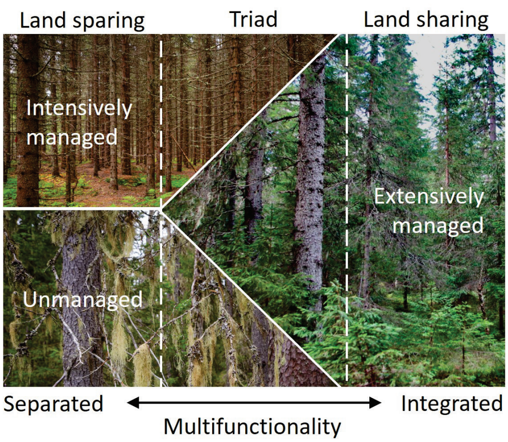


Figure 13. Different approaches to enabling multifunctional forests, including land sparing, land sharing, and triad systems. Photos: Andreas Palmén (photos on the left), and Lars Lundqvist (photos to the right).

the stakeholders argued that they wanted a diverse management approach which would be optimised towards different ecosystem services in different places, which does not agree with a land sharing rationale. Rather, it aligns with a triad system, and the proportion of different management approaches in a triad system must be adapted to the local landscape (Betts *et al.* 2021; Himes *et al.* 2022; Larsen *et al.* 2022; Muys *et al.* 2022). In this case, such proportions were not specified by stakeholders (although we prompted them to specify it in in workshop 4), and I would imagine that it would be very hard for them to agree on these, as they held sometimes quite different views on the strengths and weaknesses of different management approaches, while also having individual preferences for particular ecosystem services. It would be interesting, in a future study, to develop multiple triad scenarios, involving different proportions of management approaches, and to evaluate these with different stakeholders to see if, and how, their preferences differ.

When addressing the climate change impacts of forest management, the stakeholders highlighted the importance of learning from past local experiences and continuously improving forest management (Paper II), echoing the respondents in Andersson and Keskitalo (2018). This could be seen as a rather reactive approach in light of the IPCC (2019) definition of climate change adaptation which includes adapting to the current and future impacts of climate change. However, it is consistent with a sort of local common sense, or "bondeförnuft" (farmer's common sense), in which you do what works and learn from past experiences, and it aligns with the literature on adaptive management (Holling 1978; Innes *et al.* 2009; Puettmann *et al.* 2013; Rist *et al.* 2016). These findings also reflect the divide, described by Dessai and Hulme (2004), between the natural scientific, or technical, view on climate change, which focusses on modelling and adapting to short- and long-term changes; and a more social scientific view on climate change, which focusses on learning from the past and addressing challenges in the present: stakeholders' perspectives were more focused on the latter. Similar results were obtained by Lidskog and Sjödin (2014) in their analysis of analysing how forest owners addressed regeneration following hurricane Gudrun in 2005: the Swedish Forest Agency advised stakeholders to adapt to future risks by not replanting with Norway spruce, while forest owners chose instead to address the more immediate risks of failed regeneration due to high browsing pressure, and thus, against this advice, replanted Norway spruce. One of the forest owners involved in the southern co-production process had personal experience of this, as they had listened to the advice of the Forest Agency and planted maple, but the regeneration eventually failed and they had to replant again with Norway spruce. Thus, to successfully address climate change other risks also need to be considered and dealt with, and this is why I think that, in adapting to climate change locally, we cannot focus solely on adapting to current and projected climate change impacts but must also take into account other challenges and conditions that may by facing forest management at the local level.

With regards to climate change mitigation, stakeholders highlighted the importance of considering climate change mitigation not just in forests but also in society, and, at the same time, considering how it interacts with climate change adaptation (Papers II-IV). Forest management in northern Europe has contributed to simultaneous increases in carbon uptake, carbon storage in trees and soils, and harvested wood volumes since the 1960s (Kauppi *et al.* 2014; Iordan *et al.* 2018; Kauppi *et al.* 2022). It has thus made a significant contribution to mitigating climate change. However, the stakeholders did not argue for increasing forests' mitigation further, but rather focused on maintaining it. They highlighted the need to diversify management to better spread environmental, financial, and climatic risks, while also focusing more on producing high quality wood which could be turned into high quality products with a long lifespan in society. Thus, they were not in favour of using locally produced wood for bioenergy or single use products, although they recognised that those products also are important in society. Instead, they mainly wanted to favour wood for construction, high quality furniture, and other products with long lifespans, to store more carbon in society while replacing fossil and carbon-intensive materials, in line with other studies on climate change mitigation (Jandl *et al.* 2018; Verkerk *et al.* 2020). The scenario modelling and evaluation (Paper IV) also highlighted the various trade-offs between climate change mitigation, adaptation, and provision of ecosystem services by forests, and showed that these trade-offs can be lesser or greater depending on which indicators of climate change mitigation that are considered. Comparable results have been obtained in previous studies (Felton *et al.* 2016; Ferreira *et al.* 2018; Morán-Ordóñez *et al.* 2020). Thus, rather than focusing on particular indicators for climate change mitigation, such as increasing carbons stocks or harvested wood, there is a need to consider climate change mitigation from a more holistic perspective.

While the stakeholders had numerous ideas about how forest management could be improved, they also identified several conditions that could either favour or disfavour their implementation, depending on how they are handled. These include local value chains and markets for wood and non-wood products, local ownership and taxation (northern stakeholders), local experimentation and innovation, management of ungulate populations, and local collaboration and networks (Paper II). In Paper III, stakeholders also emphasised the importance of common networks, platforms, and locally-initiated forest programmes to catalyse local initiatives. Stakeholders argued that such enabling factors could unlock the potential of local forests to provide multiple contributions to local society, while being able to better adapt forest management to climate change. At the same time, some of these factors are in turn dependent on regional, national, or international conditions, processes, and structures. For example, the management of ungulate populations is governed at the regional level (Dressel 2020), taxation policies and ownership structures are governed at the national level, and new value chains and markets for wood and non-wood products need to compete in global markets. Thus, the space for local agency depends to an extent on other policy levels, in which there is a need to be responsive to bottom-up initiatives and aspirations, to support more diverse and climate-smart forest management.

The field excursions highlighted the local past experiences of different management practices, and potential risks and opportunities with their application today (Paper II). In contrast to discussing forest management in general, the field excursions prompted discussions on the specific management practices applied at the sites visited, their suitability to various socio-ecological conditions, while they also were contrasted with other management practices. This favoured pluralistic and nuanced discussions on forest management, where the physical environment also provided the stakeholders with shared references and promoted joint learning. While this is the first study, that I know of, that have used field excursions to prompt co-production processes, it has been used in individual forest owner interviews (Laakkonen *et al.* 2018), and I think it has a great potential in facilitating multi-stakeholder dialogues, collaborative learning and pluralistic evaluations of forest management practices.

In contrast, the stakeholder evaluation of the modelled forest management scenarios focused on the potential future consequences of different forest management practices, and it added several additional considerations to the evaluations, thereby also highlighting the strengths and weaknesses of forest modelling (Paper IV). This is especially important as forest management scenarios most often are quantitative and non-participatory (Hetemäki 2014; Hoogstra-Klein *et al.* 2017; Mårald *et al.* 2017), thereby often lacking the considerations brought forward by the stakeholders, such as the uncertainties related to modelling approaches, especially in relation to climate change impacts, and the need to broaden the evaluation to not only consider direct effects, but also indirect effects of different management scenarios. For example, the stakeholders highlighted the impacts on local forest-related conflicts or people's quality of life, especially as some scenarios may have great quantitative advantages, while they in practice would create environments where nobody would want to live, as the combined scenario in Paper IV. Thus, the stakeholders added important considerations, that are easily forgotten when not linking the modelling to the actual local situations in which forests are used and managed in practice. While the instinct of a modeller might be to try to incorporate the stakeholders' considerations into the modelling, I am not sure that it is possible or even preferable to model every aspect of forest management. Instead, I think that there is a need to evaluate what aspects of forest management that we can model, with fairly high confidence, and what aspects that are better left to other type of evaluations, such as through qualitative evaluations by stakeholders (Paper IV). While it can be hard to combine quantitative and qualitative research methods, and local and scientific knowledge, I think that paper IV have made important contribution to how it can be dealt with, and hopefully it can guide future evaluations.

While the socio-ecological contexts and forest management practices differ substantially across Europe (Section 2.2), I think that the approaches used in this thesis to study and address the multiple competing expectations placed on forests by various stakeholders could be applicable also in other settings. To enable similar processes in other places, I think the key principles of co-production processes, i.e., being pluralistic, context-based, interactive and goal-oriented, as identified by Norström *et al.* (2020) and described in section 4.2.1, will be important to facilitate open and locally rooted processes. At the same time, I also think it is important to recognize the historical context, both to understand why forests are managed the way they are today, but also to be able to critically and reflexively evaluate current and alternative management practices to better support aspirations for the future, which we aimed to do throughout the processes. Thereby linking the present to the future and the past and enabling transtemporal thinking and learning (Mårald *et al.* 2017), which I think is especially important when dealing with the vast time perspectives of forest management. Finally, I also want to highlight the importance of dealing with issues of power, as there are multiple power relations between different stakeholders and between stakeholders and researchers that need to be acknowledged and mitigated to enable equal participation in co-production processes (Klenk & Meehan 2015; Klenk *et al.* 2017; Turnhout *et al.* 2020). Dealing with these power relations becomes even more important when dealing with contested issues, such as forest management, which is why I also want to emphasise the need to not only invite various stakeholders, but also to set up the processes so that all can participate on the same terms, while also being prepared to handle potential conflicts. Hopefully, the descriptions on how these power relations were dealt with in our co-production processes can provide guidance for future studies (Chapter 4.2).

6.3 Reflections on the future of forest management

In reflecting on the future it is important to also reflect on the past, and I have learnt a great deal by reading about the history of forest science. Thus, in the following section, I reflect on some of the key challenges that I think face forest management today and in the future, with historical developments in mind.

Dealing with the multiple competing expectations of forests has become the mission of forest scientists and forest managers, because they are not dealt with through policy (chapter 1). I would argue that the cameral sciences, which have shaped forest management since its origin in the 18^{th} century (chapter 2), do not provide a wide enough toolbox for this because they are highly focused on the quantitative, ecological, and economic dimensions of forest management, which still are very important as emphasised in the co-production processes (mainly Papers II-IV), while it do not sufficiently address its qualitative and human dimensions, such as managing multiple expectations and conflicts, dealing with various rights holders and stakeholders, addressing ethical and moral considerations, and managing risks and uncertainties. These aspects have, however, been addressed in this thesis project, and should become part of future forest science, education, and practice in order to address stakeholders' competing expectations of forests in complex and inherently uncertain socio-ecological contexts. While this in part was already proposed by Bunnell (1976) almost 50 years ago, forest management is still struggling to deal with the human dimensions that it entails, and my hope is that this thesis will contribute to widening the toolbox.

To address the gaps between forest science, policy, and practice we need to reconnect scientific knowledge with local knowledge. Combining local and scientific knowledge about forest management was essential at the birth of forest science, as described in chapter 2 and 3. However, with time, it seems that the two have become disconnected, and forest science has become focused on providing knowledge that is applicable everywhere, rather than informing forest management somewhere, as argued also by Fortmann and Ballard (2011). Thus, to address forest management somewhere, we now need to reconnect forest science and practice to bring together scientific and local knowledge, and an important part of this will be learning from what is already being done locally. Several of the forest owners involved in the co-production processes were carrying out experiments on their own, for example by trying other management approaches or new or non-conventional tree species (Paper II). While we visited local experimental forests managed by the Swedish University of Agricultural Sciences (Swedish University of Agricultural Sciences 2020), during both the northern and southern co-production processes, these only cover the scientific forest experiments in the study areas. As current long-term experiments are dominated by clear-cutting experiments[4] (Goude 2022), and it takes a long time to set up and get results from new scientific forest experiments, we should get better at learning from the local experiments of forest practitioners, as Lawrence (2017) has already argued. This could then provide the local examples of different management approaches and tree species that stakeholders asked for (Paper II), supporting innovation in both forest management in the local area, and in forest management and science

[4] Only 3% (120) of all long-term field experiments in Sweden are non-clear-cut experiments: most of these have been initiated during the past 30 years, and are focused on either shelterwood systems with Norway spruce or Scots pine, or selective felling of European beech (Goude 2022).

more generally, by providing new ideas and examples of how forest management can be performed. An important part of this will be collaboration and networks between forest owners and stakeholders, through which knowledge and experiences can be exchanged and developed, both within and between different local contexts.

Finally, by including stakeholders in the development of climate-smart forestry, we can not only identify possible pathways, but also preferable and locally applicable pathways that will be relevant for practice. As demonstrated in this thesis, it can contribute to translating the rather abstract principles of climate smart forestry (Bowditch *et al.* 2020; Verkerk *et al.* 2020; Bowditch *et al.* 2022) into something tangible, while also making use of local stakeholders' various views, knowledges, and ways of doing things, complementing scientific knowledge and approaches, as highlighted in Papers II and IV. In the long-run I believe that this will strengthen both forest management science and practice, while also providing locally tailored solutions that recognise both the similarities and the particularities of specific places.

6.4 Conclusions

This thesis has contributed to improve our understanding of the competing expectations placed on forests and forest management in the 21st century and how they can be addressed at the local level by tailoring forest management to local socio-ecological contexts.

By departing from the 18th century, this thesis has shown that the expectations placed on scientific forest management have greatly increased since its origin in 18th century Europe. Initially, the focus was mainly on how to provide wood in particular places. However, it has now shifted to providing multifunctional forests everywhere, while dealing with climate change and various stakeholders. Although past forest-related conflicts have primarily focused on how forests should be managed, this thesis have shown through media analysis and local co-production processes that current conflicts also focus on why and for whom forests should be managed, thus including both technical and political dimensions. This makes forest management increasingly complex and highlights the need to widen the toolbox of forest management to address also its political dimensions.

This thesis has shown how co-production processes can address both the technical and political dimensions of forest management while tailoring it to local socio-ecological contexts. Despite the broad range of local stakeholders involved in the co-production processes, they all wanted to diversify forest management to enable more multifunctional and climate-smart forests. They also stressed several conditions that may enable or disable its implementation in practice, reflecting the local, national, and international structures that frame forest management at the local level. However, the stakeholders were hopeful that increased local collaborations could overcome some of these challenges.

Based on the results from the co-production processes, this thesis has also emphasised the importance of addressing climate change in local contexts. This is not only because the impacts of climate change will differ in various places, but also because there may be local conditions that can enable or disable climate change adaptation. Thus, highlighting the need for not only climate-adapted but also locally adaptive forest management. At the same time, the co-production processes have also stressed the need to consider climate change adaptation jointly with climate change mitigation and forests' provision of ecosystem services. This is because there are multiple trade-offs associated with promoting a more climate-smart forest management, some of which are not possible to model.

To tackle these trade-offs while making use of both local and scientific knowledge of forest management, this thesis has shown how co-production processes, where scientists and local stakeholders collaborate, can be used to develop and evaluate locally tailored and desirable pathways for a climate-smart forest management. Thus, leaving the trade-offs to be made by those directly affected by them, i.e., local forest stakeholders, while also combining the strengths of local and scientific knowledge. Although the processes were carried out in Sweden, the approaches used can offer guidance to similar processes in other parts of Europe.

Thus, by collaborating with local stakeholders when articulating what climate-smart forest management could mean in practice, we can reduce the gap between science and practice while developing locally and globally relevant knowledge on how forests can be managed to address both climate change and local stakeholders' expectations on forests.

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Popular science summary

Forests are expected to provide people with various types of ecosystem services, such as biodiversity, recreation, timber production, climate regulation, local income, and employment, while also being expected to adapt to the effects of climate change. By analysing forest conflicts in the media and co-producing knowledge with local forest stakeholders, this thesis aims to analyse the different expectations placed on forests in Sweden, as well as to develop and evaluate locally tailored forest management strategies together with local forest stakeholders. Machine learning, specifically topic modelling, was applied in the media analysis to analyse forest conflicts portrayed in Swedish daily media from 2012 to 2022. The media analysis highlighted several themes of forest conflicts, some directly related to forest management, such as biodiversity conservation, forestry, reindeer husbandry, and recreation, and some indirectly related to forest management, such as conflicts related to carnivore management, wind power, and mining. The conflicts were thus about the competing expectations of forests to provide people with a range of ecosystem services, while also highlighting conflicts related to competing land use rights, such as the right to public access, property rights, and reindeer herding rights. Hence, the conflicts concerned *why* and *for whom* forests should be managed. In the co-production processes, workshops, forest excursions, and forest modelling were used, and the results showed that forest conflicts and expectations on forests are about *how*, *why*, and *for whom* the forest should be managed. This creates new challenges to forest management, as forest management from a historical perspective has only needed to deal with technical issues related to how the forest should be managed, rather than political issues such as why and for whom. The strengths and weaknesses of different forest management methods were identified in the processes, including where and by whom they

can be used, as well as their effects. The effects were also evaluated through modelling in a forest decision support system called Heureka, where different forest management scenarios were evaluated in terms of their impact on forests' provision of various ecosystem services. The results from the modelling were also qualitatively analysed together with the local stakeholders. The findings highlighted the importance of evaluating forest management scenarios both quantitatively and qualitatively, as there are many effects of forest management that cannot be evaluated through modelling alone. For example, how risky the scenarios would be in relation to climate change, or whether they would be socially accepted at the local level. To manage the different expectations of forest management at the local level, the local stakeholders wanted to promote a diverse forest management approach that uses a mix of different management methods and tree species at the landscape level to promote a range of ecosystem services while mitigating climate-related, economic, and environmental risks. At the same time, the local stakeholders also highlighted several conditions that can either promote or hinder more diverse forest management, such as knowledge of alternative forest management methods and tree species, markets and value chains for different ecosystem services, management of wildlife populations, and local collaboration. To address the effects of climate change, the stakeholders stressed the importance of not only managing climate change but also other local challenges that can hinder or promote local climate change adaptation. Climate change adaptation, therefore, needs to be addressed from a broader perspective, and it can be helpful to learn from past local experiences of forest management and constantly work to improve forest management. The co-production processes also emphasized that to limit climate change, we need to both maintain forests' ability to mitigate climate change while also reducing our consumption, as forests' carbon uptake will not be able to compensate for current consumption levels. We also need to balance using the forest to limit climate change, produce a variety of ecosystem services, and adapt the forest to a changing climate. These trade-offs can be made through co-production processes, where those directly affected by the trade-offs, namely the local forest stakeholders, together with researchers develop locally tailored solutions. These processes can thus reduce the distance between forest science and practice while also addressing both climate change and local stakeholders' expectations of forests.

Populärvetenskaplig sammanfattning

Skogen förväntas förse oss med olika typer av ekosystemtjänster, såsom biologisk mångfald, rekreation, virkesproduktion, klimatreglering, lokala intäkter och sysselsättning, samtidigt som skogen också förväntas vara anpassad till klimatförändringarnas effekter. Genom att i. analysera skogliga konflikter i media och ii. samproducera kunskap med lokala skogliga intressenter syftar denna avhandling till att analysera de olika förväntningar som ställs på skogen i Sverige, samt att utveckla och utvärdera lokalt anpassade skogsskötselstrategier tillsammans med lokala intressenter. I medieanalysen användes maskininlärning, specifikt temamodeller, för att analysera skogliga konflikter porträtterade i svensk dagsmedia under 2012-2022. Medieanalysen lyfte fram flera teman av skogskonflikter, några direkt kopplade till skogsskötsel, som bevarande av biologisk mångfald, skogsbruk, renskötsel och rekreation, samt några som är indirekt kopplade till skogsskötsel, som konflikter relaterade till rovdjursförvaltning, vindkraft och gruvnäring. Konflikterna handlade alltså om de konkurrerande förväntningarna som finns på skogen att förse oss med en rad ekosystemtjänster, samtidigt som analysen också lyfte fram konflikter relaterade till konkurrerande markrättigheter, såsom allemansrätten, äganderätten, renskötselrätten. Konflikterna handlade alltså om varför och för vem skogen bör skötas. I samproduktionsprocesserna användes workshops, skogsexkursioner och skogsmodellering, och resultaten visade att skogliga konflikter och förväntningar på skogen handlar om hur, varför och för vem skogen bör skötas. Detta skapar nya utmaningar att hantera i skogsskötseln, eftersom skogsskötsel ur ett historiskt perspektiv endast har behövt hantera tekniska frågor relaterade till hur skogen bör skötas, snarare än politiska frågor såsom varför och för vem. I processen identifierades styrkor och svagheter för olika skogsskötselmetoder, inklusive var och av vem de kan användas, samt vilka effekter de ger. Effekterna utvärderades också genom modellering i ett skogligt beslutsstödsystem som kallas Heureka, där olika skogsskötselscenarier utvärderades med avseende på deras påverkan på skogens olika ekosystemtjänster. Modelleringsresultaten analyserades också kvalitativt tillsammans med de skogliga intressenterna, och resultatet framhöll värdet av att utvärdera skogsskötselscenarier både kvantitativt och kvalitativt, eftersom det finns många effekter av skogsskötsel som inte kan utvärderas genom modellering. Exempelvis hur riskfyllda scenarierna skulle vara i relation till klimatförändringarna, eller om de skulle accepteras socialt på lokal nivå. För att hantera de olika förväntningar som finns på skogsskötseln på lokal nivå, ville de lokala intressenterna främja en variationsrik skogsskötsel som på landskapsnivå använder en blandning av olika skogsskötselmetoder och trädslag för att främja en bredd av ekosystemtjänster och samtidigt mildra klimatrelaterade, ekonomiska och miljömässiga risker. Samtidigt belyste de lokala aktörerna också flera förutsättningar som antingen kan främja eller motverka en mer variationsrik skogsskötsel, till exempel kunskap om alternativa skogsskötselmetoder och trädslag, marknader och förädlingskedjor för olika ekosystemtjänster, hantering av viltstammar samt lokal samverkan. För att hantera klimatförändringarnas effekter lyftes det också fram betydelsen av att inte bara hantera klimatförändringar, utan också andra lokala utmaningar som kan hindra eller främja en lokal klimatanpassning. Klimatanpassning behöver alltså hanteras i ett bredare perspektiv, och här kan det hjälpa att lära av tidigare lokala erfarenheter av skogsskötsel samt att ständigt arbeta för att förbättra skogsskötseln. Samproduktionsprocesserna lyfte också fram att för att begränsa klimatförändringarna behöver vi både bibehålla skogens förmåga att bromsa klimatförändringarna, samtidigt som vi också behöver minska vår konsumtion, eftersom skogens koldioxidupptag inte kommer att kunna kompensera för nuvarande konsumtionsnivåer. Vi behöver också göra avvägningar mellan att använda skogen för att begränsa klimatförändringar, producera en variation av ekosystemtjänster, samt att anpassa skogen till ett förändrat klimat. Dessa avvägningar kan göras genom samproduktions-processer, där de som är direkt påverkade av avvägningarna, alltså de lokala skogliga intressenterna, tillsammans med forskare tar fram lokalt skräddarsydda lösningar. Dessa processer kan därmed minska avståndet mellan skoglig forskning och praktik, medan de också kan adressera både klimatförändringar och lokala intressenters förväntningar på skogen.

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II

forests

Article

Bringing "Climate-Smart Forestry" Down to the Local Level—Identifying Barriers, Pathways and Indicators for Its Implementation in Practice

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Abstract: The theoretical concept of "climate-smart forestry" aims to integrate climate change mitigation and adaptation to maintain and enhance forests' contributions to people and global agendas. We carried out two local transdisciplinary collaboration processes with the aim of developing local articulations of climate-smart forestry and to identify barriers, pathways and indicators to applying it in practice. During workshops in northern and southern Sweden, local stakeholders described how they would like forests to be managed, considering their past experiences, future visions and climate change. As a result, the stakeholders framed climate-smart forestry as active and diverse management towards multiple goals. They identified several conditions that could act both as barriers and pathways for its implementation in practice, such as value chains for forest products and services, local knowledge and experiences of different management alternatives, and the management of ungulates. Based on the workshop material, a total of 39 indicators for climate-smart forestry were identified, of which six were novel indicators adding to the existing literature. Our results emphasize the importance of understanding the local perspectives to promote climate-smart forestry practices across Europe. We also suggest how the concept of climate-smart forestry can be further developed, through the interplay between theory and practice.

Keywords: sustainable forest management; climate change; mitigation; adaptation; nature's contributions to people; stakeholder participation; interdisciplinary research; transdisciplinary collaboration; forest policy

1. Introduction

Forest management plays a key role in mitigating climate change and its potential negative impacts [1]. As a result of climate change, increasing forest disturbance can be expected, particularly in boreal and coniferous forests [2]. These disturbances can have both positive and negative impacts on forests' potential to mitigate climate change [3]. Hence, several papers have reviewed how forest management can be better adapted to the changing climate [4–9]. While climate change adaptation and mitigation can be seen as two sides of the same coin, they have usually been treated separately in science and policy [5,10,11]. However, several authors are now arguing for their integration to achieve "climate-smart forestry" [12–15].

Climate-smart forestry is a new forest management concept that has emerged in recent years in Europe. It aims to integrate both climate change adaptation and mitigation to protect and enhance nature's multiple contributions to people and increase forests' contributions to global agendas [12–15]. The concept builds on "sustainable forest management" criteria and indicators but is more focused on climate change action [12,14,15]. Bowditch et al. [12] and Verkerk et al. [15] proposed universal definitions and principles for climate-smart forestry, while stressing the need to adapt them to the local conditions and contexts in which forests are used and managed. Previous research has emphasized that involving local stakeholders in these kinds of processes is essential to developing locally adapted, relevant and preferred strategies, as it tailors them to the local conditions and contexts [5,16–19]. Bowditch et al. [12] identified this as the next step in the launch of the climate-smart forestry concept across Europe.

In terms of forest management, northern Europe stands out in the world as particularly production-oriented, with a long history of extensive forest management [20]. With still relatively many people employed in the forest sector and connected industries, one could assume that people in northern Europe would be especially concerned with the consequences of climate change. However, previous studies have shown the opposite. Forest owners in northern Europe are the least concerned about climate change among forest owners in Europe and have to a smaller degree changed their management to mitigate the effects [21,22]. Why is that? Is the management of forests already adapted to the changing climate? Are forest owners simply unaware of its effects? Or which other explanations could there be? Given this conundrum, we identified Sweden as an interesting case for studying what climate-smart forestry could translate to locally. To achieve some spatial and contextual variation, we identified one area in southern and one in northern Sweden as our study areas. While the tree species distribution are quite similar between the two, the local climate, forest productivity and forest ownership differ substantially [23,24]. Hence, they should provide two interesting cases of local articulations of climate-smart forestry that can help guide similar processes in other parts of Europe.

The aim of our study is to translate the theoretical concept of climate-smart forestry into something that is locally applicable, by bringing it down to the local level. Our assumption is that by engaging local stakeholders in two local collaboration processes in Sweden, we can better understand the local perspectives on climate-smart forestry, including barriers, pathways and indicators for its implementation in practice. At the end, we discuss our results in relation to the existing literature and expand on how the climate-smart forestry concept can be further developed in Europe.

2. Materials and Methods

To study local articulations of climate-smart forestry in Sweden, we used the ideas and principles of "reflexive forestry" [19] as our point of departure. In reflexive forestry, a shared understanding of forest management is fostered through collaborative processes including multiple stakeholders representing different ways of thinking, knowing about and working practices in the forest [19]. Reflexive forestry also emphasizes that we need both past experiences and future visions to scrutinize and deal with the challenges of today, that is, transtemporal thinking [19]. Prior to this study, the engaged stakeholders had been part of two workshops focusing on learning from the past and establishing visions [25] and pathways for the future [26], within the research project "Bring down the sky to earth", with the overarching aim of developing local pathways for forest land-use in support of climate action and local development [27], see Figure 1.

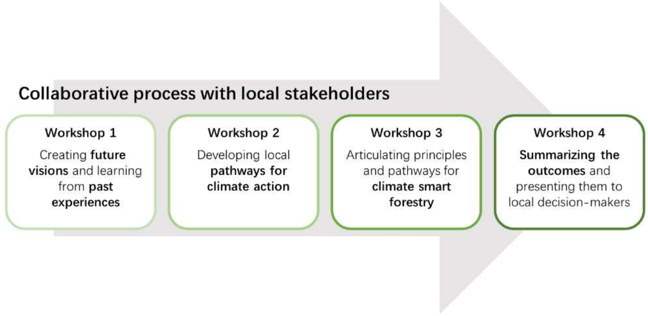

Figure 1. The set-up of the transdisciplinary collaborative process in the "Bring down the sky to earth" project, of which this study reports output from Workshop 3.

2.1. The Study Areas and Local Stakeholders

Our study areas were Vindeln and Umeå Municipalities, in Västerbotten County in northern Sweden, and Växjö and Lessebo Municipalities, in Kronoberg County in southern Sweden (Figure 2). They cover 495,000 ha and 208,000 ha of land, respectively, and are dominated by forests (forests cover 82% and 83% of the land area) [28]. A large proportion of the forest land in the northern study area is considered unproductive forests (30% of the forest land, compared to 12% in the southern area) [28], where the Swedish Forestry Act prohibits harvesting of wood. The productive forests in both the northern and southern study areas are dominated by Scots Pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* H. Karst) and Birch (a mix of *Betula pendula* Roth and *Betula pubescens* Ehrh.) [23]. There is a gradient across Sweden, with Scots pine being the most common species in the north (ranging from 48 to 30%) and Norway spruce in the south (29% to 51%) [23]. Birch is distributed evenly across the country, but in lower densities (about 10%–15%) [23]. The browsing of ungulates, namely moose (*Alces alces* L.), roe deer (*Capreolus* L.), red deer (*Cervus elaphus* L.) and fallow deer (*Dama dama* L.) are believed to be the main driver of the "sprucification" of southern Sweden, as a result of failing regenerations with Scots pine and broadleaved tree species [29–31].

Figure 2. The location of the study areas in northern and southern Sweden. Satellite image from Wikimedia Commons, created by Koyos with NASA WorldWind; and geographical distribution of our study areas visualized with data from Lantmäteriet.

Most productive forests in Kronoberg County are owned by family forest owners (78%), while the forests in Västerbotten County have a mixed ownership structure (40% is owned by family forest owners, 31% by the state and 23% by private forest companies) [23]. Of the family forest owners, about 80% in the southern study area are resident and own on average 30 hectares; while 72% of the forest owners in the northern area are resident and own on average 47 hectares [32]. Generally the state and private forest companies own forest properties larger than 1000 hectares [23,32]. The forests in our study areas are predominantly managed trough even-aged management with natural regeneration or planting. The average clear-cut size is about five hectares in the northern parts of the country, and two and a half hectares in the southern areas [32]. Shelterwood systems are also used, but to a low degree, and selective felling is uncommon. Some forests are left unmanaged (all unproductive forests, see numbers above; and 11% of the productive forests in Västerbotten County and 8% in Kronoberg County) to maintain and promote biodiversity [33].

In many ways, forests are a part of the way of life in both of our study areas, with the Swedish right to public access as an example of that. It allows the public to roam, camp and forage berries and mushrooms in any forest, without needing the forest owners' permission. Many Swedes enjoy an outdoor lifestyle, with forest walks and foraging as the most common activities [34,35]. Commercial berry-picking also occurs, mainly with foreign labor [36]. Another common interest is hunting, which over time has gone from being a way to supply the family with meat to being mainly an recreational activity [37]. In both areas, nature-based tourism is also a part of the forest use, although most nature-based tourism in Sweden is concentrated towards coasts and mountains [38]. In the northern study area, the land is also used by the Indigenous Sami to herd reindeer (*Rangifer tarandus* L.), which is a domestic deer that grazes freely in the area during wintertime. In addition, there are many forest industries in Sweden, which also owns large proportions of the forests, especially in the northern areas [23].

For the local collaborative processes, we engaged local stakeholders resident in our two study areas. The stakeholders were recruited to represent different interests related to forests, such as forest owners, forest industry representatives, people engaged in ENGOs, hunters, educators, local development representatives, tourism entrepreneurs and Sámi reindeer herders (Table 1). When recruiting stakeholders, we first identified forest-related organizations in our study areas, and then identified potential participants within these. Generally, the persons invited to participate were the chairperson of the organization or of the local unit of the organization (when approaching national or regional organizations). On some occasions, the invited persons redirected us to another person within their organization. In total, there were more than 30 stakeholders involved in the project, and while they were recruited from certain organizations, we asked them to act as members of the local community in the workshops. Twenty-three local stakeholders participated in workshop 3 (Table 1): fourteen stakeholders in northern Sweden and nine in southern Sweden. Both groups included a mix of men and women. Informed consent was obtained from all the stakeholders included in the study. In addition to the local stakeholders, eight researchers (one historian, two historians of science and ideas, two political scientists, and three forest scientists) were involved in planning and carrying out the workshops. To enable constructive dialogues, the process was guided by a professional facilitator [39].

Table 1. The stakeholders participating in workshop 3.

Interests	Southern Sweden			Northern Sweden		
	Men	Women	Total	Men	Women	Total
Education	0	0	0	1	1	2
Environmental organization	1	1	2	2	0	2
Forest industry	0	1	1	2	0	2
Family forest owner	3	1	4	3	1	4
Hunting	0	0	0	1	0	1
Local development	1	0	1	0	1	1
Reindeer herding	0	0	0	0	1	1
Tourism and recreation	1	0	1	0	1	1
Total	6	3	9	9	5	14

2.2. *The Design of Workshop 3*

The workshop was arranged as a visit in a forest, aiming to provide the stakeholders common references while also allowing the environment to catalyze and open up the discussions as inspired by the "forest walks" method developed by Laakkonen, et al. [40]. In contrast to the individual interviews carried out in Laakkonen, et al. [40], our study mainly used focus group discussions out in the forest (complemented with written individual reflections). Focus groups have been commonly used in, for example, sociology, psychology, marketing and, more recently, nature conservation research, mainly as they allow for debate and discussions between stakeholders [41]. In focus groups, the stakeholders' thoughts and views are challenged by the other participants. This allows for more, and often more nuanced and reflexive, aspects to be discussed than in individual interviews [42]. However, there is always a risk that some participants end up dominating the discussions, while others do not feel safe enough to express their opinions [42]. To address this risk, researchers served as moderators for all discussions. We also chose to complement the discussions with individual written reflections.

The workshops were held in the Vindeln and Asa experimental forests in northern and southern Sweden, respectively. They are both centers for experimental forest research in Sweden [43]. The purpose of situating the workshops within the research infrastructures was to allow the local stakeholders to experience different forest management systems, some of which are quite unconventional in the Swedish forest landscape. The aim was to broaden and challenge the participants' perceptions of how forests can be managed, and thus allow the environment to stimulate reflexive discussions, as reflexivity involves both 'self-confrontation' and 'reflection' to enable the 'rethinking' of current practices [19,44,45]. The workshops included visits to five different forests, managed in five different ways: one left unmanaged, one managed with continuous cover forestry, one with even-aged forestry, one with even-aged forestry including intensive fertilization and one with even-aged forestry including exotic tree species.

The workshops lasted one full day. They started with an introduction by the facilitator, consisting of a presentation of the workshop aim and program, a short summary of previous workshops, and establishment of rules for the day. At each of the five forest sites, the stakeholders were introduced to the site and management system by a forest scientist. This introduction included descriptions of the management system in general and descriptions of how it was applied at the specific sites. The stakeholders then had a couple of minutes to briefly experience and reflect on the site and management in groups of two to three people, before joining a larger group of four to five stakeholders and two researchers. In the group, they discussed risks and opportunities with each kind of management from their local perspective and when considering climate change. The groups were put together to include a mix of interests, ages and genders. The researchers mainly moderated, audio recorded and took notes on the discussions, while also answering the occasional science-based question posed to them. During this time, the facilitator kept track of the time and aided the moderating of the researchers when needed. Afterwards, all groups gathered, and the researchers repeated the main points of the discussions to the entire group, in the same language used by the stakeholders, to allow an exchange of ideas between the groups. After each presentation, the stakeholders could comment on each other's discussions, and this part was moderated by the facilitator. This four-step process, consisting of (i) the introduction by the forest scientist, (ii) pairwise reflections, (iii) small group discussions, and (iv) full group discussions, was repeated at each of the sites throughout the day.

At the end of the workshop, the stakeholders were taken indoors to conclude the discussions they had had during the day and relate these to the discussions they had had during previous workshops [25,26]. To relate to the previous discussions, the leaders of these workshops provided a short presentation of the main features and talking points of the workshops, which included the stakeholders' past experiences and future visions for their local society, as well as potential pathways to achieving those visons. This was followed by a short discussion with the entire group on which kind of forest management they would like to see, considering their past experiences, future visions and climate change. This discussion was moderated by the facilitator. Finally, the stakeholders wrote anonymous individual reflections on the same topic. The workshops in northern and southern Sweden were carried out during the autumn of 2019.

2.3. Analyzing the Material

The questions asked by the researchers to the stakeholders during the workshops were broad and open, hence, the material reflected a diversity of perspectives. To process the raw material into the summary provided in the results section, the recorded group discussions and the individual reflections were transcribed and analyzed by the main author. The analysis was based on "grounded theory" and "the constant comparative method", which is a common method for analyzing qualitative data [46,47] and material from focus group discussions [41] that involves coding, categorizing and thematizing the material. After the transcription of the material, the individual statements were extracted and grouped in different themes. For each theme, categories were identified and described. The categories and themes were later tested against the recorded and transcribed material and validated by the co-authors, and then rearranged until the categories and themes were judged to provide a reflection of the material, but in a condensed form. In this process, we considered it important to maintain the width of the material, to not exclude any of the stakeholders in the condensing process. A trade-off of this choice might be a loss of depth of the material, as some of the reasoning/arguments behind statements could not be included. Overall, the analysis involved an extensive iterative process, in line with Hjerm et al. [47] and Fejes and Thornberg [46]. In the end, the material was clustered into the following themes: (i) descriptions of current forestry practices and their consequences, (ii) articulations of climate-smart forestry practices and their potential benefits, and (iii) the barriers and pathways for implementing climate-smart forestry at a local level. These themes, in turn, included several categories and codes, presented in Table 2. The individual reflections mainly reflected the latter themes (theme ii. and iii. above), while the focus group discussions revolved around all themes identified in the material.

Whilst the first analysis of the material was inductive, or data-driven, the latter part was deductive, or theory-driven. In the latter part, the material gathered during the workshop on climate-smart forestry and how to achieve it was analyzed through the lens of sustainable forest management [48] and climate-smart forestry [12,14], focusing on criteria and indicators. In this process, we screened the material for criteria and indicators and identified several from previous frameworks and literature, but also some that were novel and specific for the case studies we investigated.

Table 2. The final themes, categories and codes derived from the material.

Themes	Categories	Codes	Derived from:
Current practices	Strengths and weaknesses with :Even-aged management; and Unmanaged forests	Climate change mitigation; climate change adaptation; biodiversity; local uses	Focus group discussions
What climate-smart-forestry would entail locally	General ideas that should guide the management: active management and multiple use; diverse management; landscape perspective.	Forest management principles, such as: Tree species; management systems; management aim; management scale.	Focus group discussions and individual reflections
Barriers and pathways for climate-smart forestry	Perceived barriers and pathways related to: socio-economic context, cultural context environmental conditions	Markets and value chains for wood products; use and promotion of non-wood products and services; forest ownership and taxation policies; forest policies; knowledge and experience; management of ungulates; collaboration and networks	Focus group discussions and individual reflections

3. Results

During our workshops, local stakeholders identified the strengths and weaknesses of the current forestry practices in our study areas (Section 3.1), articulated how they would frame climate-smart forestry locally (Section 3.2) and barriers and pathways for its implementation in practice (Section 3.3). Based on the workshop material, we have also identified indicators for climate-smart forestry (Section 3.4).

As the presented statements came from group discussions and anonymous individual reflections, we present the results without disclosing the identity of the individual stakeholders. This choice safeguards the anonymity of participating stakeholders. The material included both statements that the stakeholders agreed and disagreed on, which is why the results in some instances can be perceived as ambiguous. However, this ambiguity reflects the local multi-stakeholder settings in which the forests in our study areas are used and managed, which is why we have chosen to present both the general and diverging perspectives.

3.1. Current Forestry Practices and Their Consequences

Both the northern and the southern stakeholder groups stated that the local forests in their respective area were mainly managed through either even-aged forestry with native spruce (*Picea abies* H. Karst) or pine (*Pinus sylvestris* L.) or leaving forests unmanaged.

The main benefit identified for the practice of even-aged forestry was that it produced timber and pulpwood effectively. This was perceived by several stakeholders to be the main source of income for forest-related practices, whereas the income from non-wood products and services, for example, tourism and berry-picking, were considered less profitable. Some stakeholders also argued that due to the Swedish right to public access, which allows people to roam and forage freely in any forests, non-wood benefits from forests provided no income for the forest owners.

From a climate change mitigation perspective, all participating stakeholders agreed that forestry promoting timber and pulpwood production is important to the replacement of fossil-based materials and fuels with renewable ones. However, most of the stakeholders were concerned that societal demands would exceed the potential supply from the forest. This generated a discussion on the importance of reducing overall consumption. Moreover, some were concerned with the quality of the wood currently produced, as they identified high quality wood to be essential for producing long-lasting construction materials, which they thought were central to the sustainable use of these resources.

From a climate change adaptation perspective, multiple problems with even-aged forestry were mentioned, such as risks of large-scale infestations of pests and diseases, extensive wind throws, drought-stressed trees and lack of species diversity. This was particularly prominent in southern Sweden, where the stakeholders were currently experiencing such issues. They identified the causes of the problems to be the favoring of spruce in regeneration over the past decades, due to the species having a more rapid growth, in conjunction with major problems of browsing damage to pine from a growing ungulate population. Some stakeholders suggested that this, through a chain of events, had led to the current large-scale outbreaks of spruce bark beetles (*Ips typographus* L.). In northern Sweden, the trend has rather been to regenerate with pine; hence, the northern stakeholders were more concerned about browsing damage and pathogens on pine, while they were also concerned about the bark beetle situation in southern Sweden. Overall, many of the stakeholders from both northern and southern Sweden wanted to increase the proportion of deciduous trees and mixed species forests to spread risks and increase resilience, from both environmental and financial perspectives. In northern Sweden, some also wanted to use deciduous trees as fire barriers around their residential areas, as they identified them as more fire resistant.

The major problem of even-aged forestry highlighted by the stakeholders was its impact on biodiversity, where monocultures and short rotation periods were particularly perceived as having the most negative effects. In relation to forests' social values, the stakeholders identified the even-aged management system as advantageous for berry-picking, walks and outings, skiing, moose safari and hunting (specifically in northern Sweden). However, they emphasized that most of these opportunities were only present during a part of the rotation period, or during a certain season, and that the preferences differ greatly between different people. While some enjoy the openness of a clear-cut, others think it looks awful. However, most stakeholders agreed that they did not like very large clear-cuts (>10 ha), which were mainly considered a problem in northern Sweden by both stakeholder groups.

The main benefit of leaving forests unmanaged agreed upon by most of the stakeholders was that it contributed to biodiversity, recreation, tourism, and feed and habitat for wildlife. However, some of the stakeholders also identified problems with leaving forests totally unmanaged, mainly due to the ingrowth of spruce, which was considered a major concern by stakeholders in both northern and southern Sweden. From their perspective, ingrowth of spruce is a threat to other tree species, and therefore to biodiversity as such, but also to recreational values, as it creates a darker and less amicable forest. These stakeholders therefore concluded that many forests left unmanaged should benefit from some management, that is, at least work to remove some of the spruce. They also stressed the value of unmanaged forests for educational and cultural purposes.

The climate benefits of unmanaged forests were intensively debated. While some asserted that such forests hold large carbon stocks in both their soil and trees, others argued that the longevity of these stocks was uncertain, as spruce bark beetles and forest fires could release the carbon back to the atmosphere. A couple of the stakeholders held that some selective cutting should be allowed, as the timber produced in these forests would probably be of a very high quality, and thus be very long-lasting in constructions, such as has happened in century-old timber houses. At the same time, other stakeholders emphasized that deadwood remaining in the forest has a high value for biodiversity and that any harvest may decrease its availability. It was concluded that these forests offered multiple values and that any management intervention involved trade-offs.

In conclusion, the benefits of the current practices identified by the stakeholders as dominant in both the north and the south were mainly that even-aged forestry produced timber and pulpwood effectively, while leaving forests unmanaged preserved biodiversity. The main drawbacks were that these two practices were not appropriate everywhere, and that they may impact forests' other contributions to people negatively. Both stakeholder groups also described the management as mainly focused on the forest stand-level, while the forest landscape perspective was mostly neglected. Suggestions on how to achieve a landscape perspective in forest management included considering how the area is used by the local people, how the surrounding forests are managed and potential problems with pests and pathogens. One example often brought up was the risk of pest dispersal, specifically spruce bark beetles, from unmanaged forests to the surrounding areas, and the potential financial damage that might bring for the affected forest owners.

3.2. Local Articulations of Climate-Smart Forestry Practices

There are three major principles in the stakeholders' articulation of climate-smart forestry, that is, forestry that is adapted to their past experiences, future visions and climate change. These are:

- Active management to achieve various goals in different places;
- Diversified and site-specific management, mainly using a broader palette of methods and tree species adapted to the specific location and site conditions;
- Consideration of the landscape perspective.

3.2.1. Active Management to Achieve Various Goals in Different Places

Many of the local stakeholders portray climate-smart forestry as the application of diverse management measures where forests are actively managed to optimize forests' various contributions to people, including biodiversity. Active management refers to the process of actively tending to the forests to achieve a certain goal, in contrast to passive management, which allows the forests to develop in any direction. For example, when aiming to produce timber, there is an active and conscious effort to thin and manage the stand to produce high quality timber; instead of letting the stand to develop in its own direction. When aiming to preserve biodiversity, management should, in some cases, be applied to increase biodiversity in that area, that is, to remove ingrowth of spruce or promote regeneration of pioneer species. When aiming to increase recreational values, the forests, as well as the trails, signage, and camp sites should be managed to promote utility and accessibility. For the most part, the stakeholders thought that passive management leads to low goal fulfilment, while active management leads to the opposite. However, in the case of biodiversity conservation, they identified several trade-offs with active management (see previous section). In addition, while the stakeholders did agree that the forests should be managed to promote multiple values, they did not agree to what extent the different values should be favored—for example, the distribution between forests managed for biodiversity and forests managed for timber production or recreation.

3.2.2. Diversified and Site-Specific Management

From most of the stakeholders' perspectives, it was important to use a diverse set of methods and tree species in the forest landscape. When using a broader palette or toolbox, they thought that the most appropriate method and tree species for each specific site and location could be used, supporting forest health and utility. In line with this, they wanted to increase the proportion of broadleaves in the landscape overall, while also increasing the proportion of mixed species forests. By diversifying, they thought that they could spread both financial and environmental risks, so that "all eggs aren't put in the one basket". They also understood that other tree species have different properties to those used currently: for example, using birch as fire barriers around residential areas or using larch for its specific wood properties. More tree species and methods also mean higher biodiversity, which they thought was important for long-term sustainability.

While the stakeholders overall were in favor of the diversification of methods and species, there were different opinions of which methods and tree species to include and to what extent they should be used. For example, some of the stakeholders identified a potential in using exotic species, especially fast-growing species or using them in conditions where the native species would struggle. Others were completely opposed to exotic species overall, as they thought that they pose a threat to the native species and ecosystem. A similar division was apparent in relation to fertilization. Some stakeholders identified a potential in fertilizing more forests, especially at the end of the rotation period, to increase yield and carbon capture. Others argued strongly against fertilization because of its environmental impact. The stakeholders were also divided when it came to continuous cover forestry (described as forestry without clear-cuts). Some thought it could be better for biodiversity and forests' recreational values. Others were concerned that it would mainly favor spruce (because of its shade tolerance), that it would not be financially sustainable or that it would not capture the same amount of carbon as even-aged managed forests.

3.2.3. Consideration of the Landscape Perspective

The stakeholders also stressed that more consideration should be given to the landscape perspective, for example by creating corridors for wildlife and endangered species, creating fire barriers of deciduous trees around residential areas and removing sick trees to limit the dispersal of pests and pathogens. Most of them also thought that forests close to lakes, wetlands or urban areas should be given particular consideration. While the majority of stakeholders argued that the landscape perspective is important, they did not discuss further how, or on which scale, this should be implemented.

3.3. Barriers and Pathways for Implementing Climate-Smart Forestry Locally

The stakeholders identified several conditions and factors, environmental, socio-economic and cultural, that they thought enable current forestry practices and act as barriers to the climate-smart forestry practices. They also identified several pathways, mainly socio-economic and cultural, for overcoming these barriers and implementing climate-smart forestry locally. These are described alternately below as they often overlap, meaning that one condition or factor that currently acts as a barrier could also be managed differently and thereby become a pathway for climate-smart forestry.

3.3.1. Markets and Value Chains for Wood-Based Products

Several of the local stakeholders described the current markets for wood-based products as limited, due to low prices and few wood assortments. They thought that this steers the management towards either using large-scale machines with high productivity or doing nothing, as the potential revenue from the alternatives will not make a profit or break even. They also related this to the size of the clear-cuts. Several stakeholders thought that the high costs and low revenues steer the management towards harvesting larger areas at a time, while they would prefer a more specialized management with smaller machines. They also thought that the narrow markets leave little room for using other tree species in forestry. Hence, they identified a need to create local and more diverse value chains.

The benefits of local value chains were, from several of the stakeholders' perspectives, that they can generate local employment and investment, and a more diverse forest management. From their perspective, with local value chains, the jobs, taxes and investment remain in the local economy, which creates more opportunities for local development and positive feedback loops. They also thought that promotion of local processing industries focusing on wood assortments other than the common ones or even non-timber forest products, would create incentives for forest owners to undertake types of management other than business-as-usual. Consequently, they thought that this would create more diverse forest management, which would be better from a risk perspective in a changing climate and probably also create more opportunities for other uses of the forest.

3.3.2. Forests' Many Contributions to People

A large proportion of the stakeholders identified a potential in using more of the products and services produced in the forests, such as mushrooms, berries, and recreational experiences. By foraging and processing more of the mushrooms and berries produced in the local forests, less food would have to be imported to Sweden and more jobs could be created locally. However, it was also discussed whether this would be financially viable, as there are probably valid reasons for why this is not being done already.

Another aspect discussed was the many health-related advantages of being out in the forests, and that more people should take greater advantage of them. In this respect, they thought that more forests should be managed to promote their aesthetic and recreational values, while also maintaining trails, signs and camps to improve accessibility. To do this, they emphasized that there must be a way for the forest owner to receive compensation for doing this, especially as many forest owners have borrowed money to purchase the forest. This was also discussed in relation to carbon capture and storage, which were believed to be of value to the wider public. By compensating forest owners, forests' many contributions to people could be promoted and forest management diversified. However, it was not clear if the forests owners were to be compensated through market solutions or by the authorities. Moreover, several stakeholders emphasized that, regardless of how it was funded, it should be on a voluntary basis for the forest owner.

3.3.3. Forest Ownership and Taxation Policies

Some of the stakeholders in northern Sweden described how much of the profits, and employment that are created in the wood-based value chain do not stay locally, which hinders local development. They attributed the problem to the forest ownership structures and taxation policies, as a large proportion of the forests are owned by non-resident owners or large forest companies, which pay their taxes in a taxation area different to the one where the forest is located. Hence, in addition to creating local value chains, they also argued for more local ownership of forests.

Several of the northern stakeholders also believed that locally owned forests would lead to more responsible and diverse management of forests, as they thought that local owners would care for them more sustainably than non-resident owners. They argued that local forest owners show greater consideration to the local people and environment, as they also have a better understanding of the local context in which the forest is situated. They also thought increased local ownership would enable collaboration among landowners, which could help keep costs down while allowing for better management.

While local ownership was considered one option to return more of the taxes to the area from which they originated, local taxation of natural resources was another. Referencing the Norwegian system, some of the stakeholders in northern Sweden stressed that the tax revenue from natural resources should be returned to the area from which the natural resources were extracted. From the stakeholders' perspective, this would limit the problem of the resources leaving the rural areas, as at least some of the financial resources would return, benefitting local development and promoting a "living countryside" ("levande landsbygd" in Swedish).

3.3.4. Nature Conservation and Forests' Multiple Use

Several of the stakeholders described the governmental conservation of forests as too focused on leaving forests unmanaged. From their perspective, most protected areas were set aside and then not managed. The stakeholders considered this to be a problem, as many areas—especially areas with large ingrowth of spruce—would benefit from some management, both for biodiversity and for recreation. Some of the stakeholders also believed that more of the conserved forests have the potential to be used for other purposes, for example recreation and human health, grazing and browsing of livestock, and selective cutting of high-quality timber. They felt that by opening up for other uses, except for large-scale forestry, both ecological and cultural values could be maintained and developed jointly. At the same time, multiple stakeholders argued for the need to leave large areas entirely unmanaged, for biodiversity, but also to act as a reference for current and future generations. The desirable proportion between the managed and unmanaged areas was, however, not elaborated on.

3.3.5. Local Knowledge and Experiences

Regarding the knowledge of different management practices, the stakeholders thought that there was a lack of knowledge relating to practices other than even-aged forestry practices—specifically, what works when and where and how different methods can be used to achieve different goals. For example, they discussed how continuous cover forestry could probably be used more in recreational areas, on moist soils, and in areas with a high risk of spring frost. However, for this to be the case, there needs to be more local examples of when this has been done successfully. The same is true for the use of native (and exotic) tree species other than pine and spruce. To provide these local examples, several of the stakeholders in northern Sweden identified large-scale forest owners as potential frontrunners, as they have the resources to test different management options.

When discussing the potential of using exotic species, the large-scale planting of the north American lodgepole pine (*Pinus contorta* Dougl.) in northern Sweden was brought up as a discouraging example by several of the stakeholders in both northern and southern Sweden. They were especially concerned by the rapid and large-scale introduction of the species in the native landscape, which they perceived to have been done without sufficient knowledge about its properties. One example described was that lodgepole pine can regenerate without forest fires, which was not known during the introduction of the species in the past. Today, 50 years after its introduction, multiple problems have been identified with lodgepole pine relating to biodiversity, recreation, reindeer husbandry and wood quality. Several of the stakeholders therefore highlighted the need for long-term field experiments with exotic species before considering planting them in the native landscape, while others were completely opposed to the use of exotic species.

Another perspective that was mentioned was the loss of traditional knowledge, for example, of when and how to cut a tree to obtain the best timber, or how to saw a log to maintain the quality. Relating to this, several of the stakeholders referred to historical practices, such as selective and seasonal cutting. However, they did not specify how traditional knowledge could be “brought back”, but instead reflected on problems with it “being lost”.

3.3.6. Management of Ungulate Populations

Several stakeholders considered the high browsing pressure from ungulates, mainly moose, roe deer, red deer and fallow deer, to be a major barrier for diversifying the tree species use in forestry. This is especially true in southern Sweden, as several of the species that potentially could be used in forestry are targeted by the browsers. Fencing off regenerated areas and young stands to keep the animals away from the trees was not considered an option, as the stakeholders thought it was both costly and time-consuming to set up and manage. Instead, they wanted an improved management of the ungulate populations. However, they did not specify how the management could be improved.

3.3.7. Local Collaborations and Networks

Several of the stakeholders thought that more local collaborations and networks could lead to a greater understanding of other people’s interests and perspectives, and could promote knowledge exchange, cost-cutting, and diversification of forest management and utilization. They perceived the debate about how forests should be managed to be very polarized, partly due to people having little understanding of interests and perspectives other than their own. Through more collaboration, understanding of other interests could increase and the level of conflict decrease, which some of the stakeholders had also experienced from our project. They believed that new ways of utilizing and managing forests could emerge from collaboration and knowledge exchange. They also identified multiple opportunities for collaborations between both forest owners and other stakeholders, to keep costs down and create new projects. If collaboration could lead to new businesses or potential income from the forest, then they also thought that it could help diversify management.

3.4. Local Indicators for Climate-Smart Forestry

We have used Forest Europe's set of criteria and indicators for sustainable forest management [48] and the climate-smart forestry indicators from Bowditch et al. [12] to identify indicators present in the local stakeholders' articulations of climate-smart forestry. The results from the northern and southern study areas are here presented jointly (Table 3) and later compared to indicators for climate-smart forestry identified by Bowditch et al. [12] and Santopuoli et al. [14].

Table 3. Indicators for Climate-smart Forestry identified in our study, adapted from Forest Europe's Criteria and Indicators for Sustainable Forest Management (SFM) [48] with additions from Bowditch et al. [12] and our study.

Criteria	Indicator	Type	Present in Our Study	Comments
Sustainable Forest Management indicators by Forest Europe	1 National Forest Programs or equivalent	Qualitative		
	2 Institutional frameworks	Qualitative	X	
	3 Legal/regulatory framework: National (and/or sub-national) and International commitments	Qualitative	X	
	4 Financial and economic instruments	Qualitative	X	
	5 Information and communication	Qualitative	X	
	C.1 Policies, institutions and instruments to maintain and appropriately enhance forest resources and their contribution to global carbon cycles	Qualitative	X	
	1.1 Forest area	Quantitative		
	1.2 Growing Stock	Quantitative	X	
	1.3 Age structure and/or diameter distribution	Quantitative	X	
	1.4 Forest carbon	Quantitative	X	
	C.2 Policies, institutions and instruments to maintain forest ecosystem health and vitality	Qualitative	X	
	2.1 Deposition and concentration of air pollutants	Quantitative		
	2.2 Soil condition	Quantitative		
	2.3 Defoliation	Quantitative		
	2.4 Forest damage	Quantitative	X	
	2.5 Forest land degradation	Quantitative		
	C.3 Policies, institutions and instruments to maintain and encourage the productive functions of forests	Qualitative	X	
	3.1 Increment and fellings	Quantitative	X	
	3.2 Roundwood	Quantitative	X	Quality aspects should also be included
	3.3 Non-wood goods	Quantitative	X	
	3.4 Services	Quantitative	X	
	3.5 Forests under management plans	Quantitative	X	

Table 3. *Cont.*

Criteria	Indicator	Type	Present in Our Study	Comments
	C.4 Policies, institutions and instruments to maintain, conserve and appropriately enhance the biological diversity in forest ecosystems	Qualitative	X	
	4.1 Diversity of tree species	Quantitative	X	
	4.10 Common forest bird species	Quantitative		
	4.2 Regeneration	Quantitative	X	Size of individual clear-cuts should also be included; also related to C6
	4.3 Naturalness	Quantitative	X	
	4.4 Introduced tree species	Quantitative	X	
	4.5 Deadwood	Quantitative	X	
	4.6 Genetic resources	Quantitative		
	4.7 Forest fragmentation	Quantitative	X	
	4.8 Threatened forest species	Quantitative		
	4.9 Protected forests	Quantitative	X	
	C.5 Policies, institutions and instruments to maintain and appropriately enhance of the protective functions in forest management	Qualitative		
	5.1 Protective forests—soil, water and other ecosystem functions—infrastructure and managed natural resources	Quantitative		
	C.6 Policies, institutions and instruments to maintain other socio-economic functions and conditions	Qualitative	X	
	6.1 Forest holdings	Quantitative	X	Should also include the proportion of resident/non-resident forest owners
	6.10 Recreation in forests	Quantitative	X	
	6.2 Contribution of forest sector to GDP	Quantitative		
	6.3 Net revenue	Quantitative	X	
	6.4 Investments in forests and forestry	Quantitative	X	
	6.5 Forest sector workforce	Quantitative	X	Should include forest sector in a broad sense, such as people employed in forest-related businesses other than the timber and pulp industry.
	6.6 Occupational safety and health	Quantitative		

Table 3. *Cont.*

Criteria	Indicator	Type	Present in Our Study	Comments
	6.7 Wood consumption	Quantitative	X	Should include the longevity of the products consumed.
	6.8 Trade in wood	Quantitative		
	6.9 Wood energy	Quantitative	X	
Indicators added by Bowditch et al. (2020)	Forestry	Quantitative	X	
	Slenderness	Quantitative		
	Vertical crowns	Quantitative		
	Horizontal crowns	Quantitative		
Indicators added by our study	Active forest management	Qualitative/Quantitative	X	Active management practices to optimize the use of the forests.
	Collaborations and networks	Qualitative	X	Collaborations and networks to promote forests' multiple use.
	Knowledge and experiences	Qualitative	X	Local knowledge and experiences of different management alternatives.
	Local value chains	Qualitative	X	Local value chains for forest products and services.
	Management of ungulates	Qualitative/Quantitative	X	Management of ungulates to promote tree species diversity.
	Taxation policies	Qualitative	X	Taxation policies that feed back to the local area from which the wood was harvested.

The indicators for climate-smart forestry identified in our material cover a broad range of aspects, including descriptions of forest characteristics, forestry practices, forest use and forest ownership, of which most are related to how the local stakeholders articulated climate-smart forestry (Section 3.2) and pathways for implementation (Section 3.3). In total, we identified 39 indicators, of which 32 were from Forest Europe's set of indicators for sustainable forest management [48], one from Bowditch et al.'s added indicators for climate-smart forestry, and six novel indicators. For some of the indicators, we have added a comment on how the current definition of the indicator can be broadened to better capture the aspects that were important to the local stakeholders in our study areas. For example, related to the *forest sector workforce*, the stakeholders were also concerned with the employments created outside of the forest industry, such as people employed in nature-based tourism or the berry-picking industry. Related to *round wood* and *wood consumption*, they also found the quality of the wood produced and consumed to be important, in addition to the quantity. The novel indicators we identified (see descriptions in Table 3), mainly focused on the social context surrounding forest management in our study areas, such as *active forest management*, *local value chains* and *collaborations and networks*.

Compared to Bowditch et al. [12], who used a similar approach together with multinational forest experts from mountain regions of Europe, it is clear that the contexts and perspectives differ. In general, the indicators identified in Bowditch et al. [12] relate to environmental aspects and forest characteristics that in some cases were not pronounced in our study areas, such as indicators related to soils, deposition of air pollutants, defoliation and the shape of tree crowns (Table 3). Instead, the stakeholders in our study areas focused on social aspects of forests, such as forest uses and employments, which in turn were not present in Bowditch et al. [12]. When comparing both of these studies to Santopuoli et al. [14], who based their indicators for climate-smart forestry of a literature review, there are several similarities and differences to both of the studies. The comparison thus becomes more ambiguous. The most distinctive way in which our study differ is that our study also included qualitative indicators, while both Bowditch et al. and Santopuoli et al. focus exclusively on quantitative indicators for climate-smart forestry.

4. Discussion and Conclusions

Many studies have discussed how forest management in Europe can become climate-smart from a theoretical perspective [12–15,49,50]. However, our study provides novel insight to how this can be brought down to the local level, for it to be understandable and applicable in practice. We have together with local stakeholders developed local articulations of climate-smart forestry for two areas in Sweden, and identified potential barriers, pathways and indicators for its implementation in practice. The results reflected many similarities between our two areas and stakeholder groups, related to the shared national context, but also an exchange of knowledge and experiences between the two regional locations. While our local articulations and indicators will be specific to these locations, we do think they can provide valuable feedback to the previous definitions and indicators of climate-smart forestry, for example, [12,15], which we discuss in this chapter.

Conceptually, a scientific meta-level discussion aimed to define climate-smart forestry feeds into local articulations that in turn feeds back to the meta-level (Figure 3). In this feed-back loop, exchange between science and practice as well as between local level, national level and European level is promoted. This process could be supported by applying the ideas and principles of reflexive forestry, which promotes the inclusion of multiple stakeholders, with different views and knowledge of forests [19]. This allows multiple perspectives and favors the development of shared understandings of climate-smart forestry. As in our study, were both stakeholder groups framed climate smart forestry similarly, namely, active and diverse management towards multiple goals. While these local articulations could fit within the previously suggested definitions, mainly to integrate climate change adaptation and mitigation into forest management to enhance nature's contributions to people and global agendas [12,15], they do also provide a more practice-centered, perspective. Even though this distinction could be considered trivial, it might have great importance for the concept's implementation in practice, as it is then defined in a way that is easily understandable and relatable for the stakeholders. As argued by Klein and Juhola [16], "to many stakeholders adaptation concepts developed and applied by academics appear overly theoretical and irrelevant to their day-to-day reality". The same could be said about climate-smart forestry, which is why we need these local articulations of the concept for it to hold meaning, and make sense, on the local level, to thereafter feed back to the meta-level scientific discussion (Figure 3).

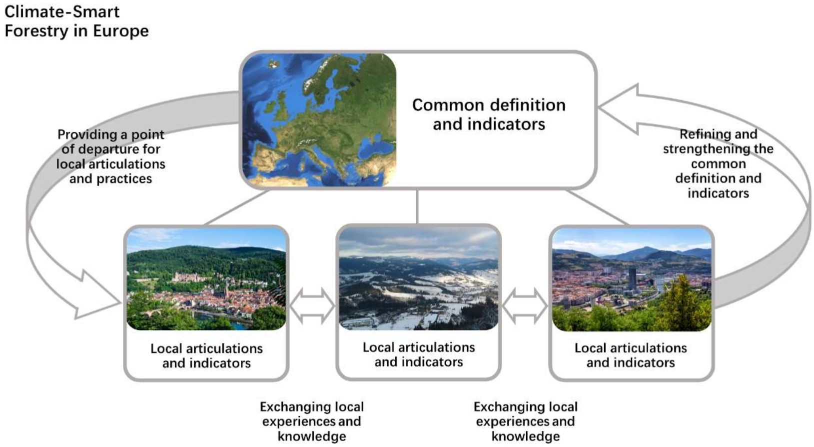

Figure 3. A conceptual figure for how the concept of climate-smart forestry could be used and developed in Europe. The message convened is that a meta-level scientific discussion on common indicators and definitions for climate-smart forestry needs to connect to local articulations and indicators to become applicable in practice and in turn can feed back to the meta-level. Top satellite image from Wikimedia Commons: created by Koyos with NASA WorldWind. Bottom photos from Unsplash (from left to right): by Matteo Krossler, Tetiana Shyshkina, and Yves Alarie.

When bringing climate-smart forestry down to the local level, our results reveal a variety of preferences among the local stakeholders, even though we had quite few participants. Especially when going beyond general principles. For example, while they often agreed on the overarching principles, such as diversifying the use of tree species in forestry, they disagreed about the details, for example, if this diversification should include exotic species or not. Even though the details of this discussion have been condensed in the results section, it very much resembles the scientific discussion on the same topic [51,52]. The same is true for several other issues, meaning that they did not achieve consensus on some of the how's. Here, we also identified a few differences between the northern and southern stakeholders, mainly relating to the different contexts and conditions. For example, some of the northern stakeholders identified the ownership structure to be a problem, while this was not mentioned by those from southern Sweden, relating to the fact that more forests in northern Sweden are owned by the state and forest industries [23]. This heterogeneity of preferences or opinions could be regarded as a problem in terms of policy making and steering, as it lacks clear direction. However, it could also be viewed as an opportunity in terms of forest management. With diverse preferences on how to manage forests, forest management could also be diverse [53].

An important aspect of climate-smart forestry is *climate change adaptation* [12,14,15]. In this regard, the local perspective in northern and southern Sweden differs from the perspective of previous authors. While Bowditch et al. [12] stated that climate change adaptation measures aim to "maintain or improve [forests'] ability to grow under current and projected climatic conditions and increase their resistance and resilience", the perspective of the local stakeholders were, rather, to actively tackle ongoing issues that risk becoming more severe in the future. Instead of *climate change adaptation* per se, this reflects an *adaptive forest management approach* [54]. This is similar to the results of Andersson and Keskitalo [55], and the main difference is if the management decision or issue tackled is perceived to be related to climate change or not. For example, are the outbreaks of spruce bark beetles in southern Sweden perceived to be a consequence of climate change, of forest management or of something else entirely? The actions aiming to limit the outbreaks would only be classified as climate change adaptation if it was perceived to be directly linked to climate change, while it could be regarded as adaptive management regardless of the perceived cause. Hence, the focus on climate change adaptation in the literature, could exclude important forest management considerations. This could perhaps also offer some explanation as to why forest owners in northern Europe do not seem to be adapting their forest management to climate change [21,22]—simply because they do not consider their management actions to be directly or solely related to climate change. When further developing the climate-smart forestry concept, it should be considered if climate change adaptation should be promoted together with or be replaced by adaptive forest management, to better fit local understandings and practices. This is something that local articulations of climate-smart forestry can contribute with to refine and strengthen a common definition of the concept (Figure 3).

Climate change mitigation is another key part of the climate-smart forestry concept. Previous authors have emphasized the need to increase carbon capture and storage, in both forests and products, and to achieve a climate-smart forestry by replacing fossil-based fuels and materials [12–15,49]. However, the stakeholders in our study presented a different perspective. While they agreed with the literature, most of them did not identify a significant potential in *increasing* the carbon sink or the amount of harvested wood in their local forests, in relation to what is already produced. Instead, they identified ways to improve the quality of the materials produced, to increase the longevity of the products, while also emphasizing the need to use resources sustainably, similarly to Jandl et al. [13]. Hence, when the stakeholders were presented with options to increase carbon capture and the supply of renewable materials, such as using exotic species and intensive fertilizing, they were not really interested. Especially as they thought that it would create even more risks, and thereby linking it to adaptation, while they also perceived it to be negative for forests' multiple contributions to people. This is in line with some of the previous research into stakeholder attitudes [56–58]. Looking at the history of Swedish forestry, the current practices have already increased the carbon stocks in forests (using standing wood volumes as a proxy) and forest products substantially over the last 60 years [59,60], with the consequence that other values have been set aside [61]. When climate change reopens the question of how and why we manage forests, the local stakeholders seem to want something different. This reflects the trade-offs between the different aspects of climate-smart forestry, which will be negotiated in relation to the stakeholders' future visions; their past experiences and practices; and climate change. Which is why transtemporal perspectives on forest management [19] are essential also for climate-smart forestry.

How, then, to achieve climate-smart forestry? While the stakeholders appear to have a positive attitude towards the idea of climate-smart forestry, they also emphasized that intent or attitude is not enough to implement it in practice. There are several external factors and conditions that influence the management as well, ranging from taxes and markets to knowledge and environmental conditions, see also [62–64]. While they, in some sense, were optimistic that these might be overcome, they also provided insight into why this haven't been done already, thereby reflecting both an optimism and a realism (or pessimism) when it comes to their implementation. While this realism may seem conservative, it does reflect the on-the-ground realities in which forests are currently being managed. It does not mean that this cannot change, or that the circumstances are the same everywhere. Given this line of argument, the potential for the implementation of climate-smart forestry practices can vary according to time and place. Moreover, it emphasizes the need to understand the barriers and pathways for climate-smart forestry from a wider perspective, as it goes beyond the mere natural scientific aspects of forest management. This is also reflected in the indicators for climate-smart forestry, where our local indicators included even more social aspects of forests than previous indicators [12,14,48]. Which is why also the indicators for climate-smart forestry could be informed by indicators developed locally (Figure 3).

There is also a need for exchange of knowledge and experiences between different places (Figure 3). In our study, we used two study areas to be able to compare local articulations of climate-smart forestry in two different settings. However, when analyzing the results, we found that there were more similarities than differences between the two groups of local stakeholders. One of the reasons for this, apart from the areas being located within the same country, is that they were clearly influenced by the settings and difficulties in the other study area. For example, the stakeholders in southern Sweden were worried about the use of exotic tree species, because they had heard about existing problems with exotic tree species in northern Sweden. The northern group was worried about the large pest outbreaks in southern Sweden, which they wanted to avoid. This reflects the interplay between different local areas, where there is a mutual exchange of knowledge and experiences, that we argue benefits the local articulations, and implementation, of climate-smart forestry in practice [17,65,66]. Hence, supporting and promoting these local exchanges should also be an integral part of developing climate-smart forestry across Europe Figure 3).

In conclusion, our results suggest that there is much to learn by bringing climate-smart forestry down to the local level. It reduces the gap between theory and practice, as the conceptual idea of climate-smart forestry becomes translated into something that is both apprehensible and applicable on the local level. At the same time, the local articulations and understandings of climate-smart forestry helps improve the concept and its indicators, while highlighting the potential barriers and pathways for its implementation in practice. This could also inform and be informed by similar articulations in other places, trough the exchange of local experiences and knowledge. Thus, based on our results and the following discussion, we believe that the concept of climate-smart forestry can be further developed through the interplay between theory and practice; and an exchange of knowledge and experiences between people in different places and contexts.

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Full Length Article

Combining scientific and local knowledge improves evaluating future scenarios of forest ecosystem services

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ABSTRACT

Forest scenario analysis can help tackle sustainability issues by generating insight into the potential long-term effects of present-day management. In northern Sweden, forests provide important benefits including climate change mitigation, biodiversity conservation, reindeer husbandry, local livelihoods, and recreation. Informed by local stakeholders' views on how forests can be enabled to deliver these benefits, we created four forest management scenarios: the close-to-nature scenario (CTN) which emphasises biodiversity conservation, the classic management scenario (CLA) optimising the forests' net present value, the intensified scenario (INT) maximising harvested wood from the forest, and the combined scenario (COM) applying a combination of measures from the CTN and INT. The scenarios were applied to the local forest landscape and modelled over a 100-year simulation period, and the results of the modelling were then evaluated by a diverse group of stakeholders. For most ecosystem services, there was a time lag of 10–50 years before noticeable effects and differences between the scenarios became evident, highlighting the need to consider both the short- and long-term effects of forest management. Evaluation by the stakeholders put the modelled results into a local context. They raised considerations relating to wildlife and hunting, climate change risks, social acceptability, and conflict, highlighting the value of evaluating the scenarios qualitatively as well as quantitatively. Overall, stakeholders thought that the CTN and CLA scenarios promoted more ecosystem services and posed fewer climate risks, while also creating less conflict among stakeholders. Our results emphasise the value of combining scientific and local knowledge when developing and evaluating future forest scenarios.

1. Introduction

The provision of ecosystem services in boreal forests today is greatly influenced by how past generations have managed them, as forest management deals with cross-generational time spans and substantial time lags (Fischer, 2018). Consequently, the management of forests today will influence their provision of ecosystem services to future generations. Ecosystem services refer to the "contribution[s] that ecosystems make to human well-being" and can include provisioning, cultural, regulating and maintaining contributions to people (Haines-Young and Potschin, 2018). However, current generations tend to focus on the needs of today rather than the needs of the future, creating what has been referred to as the "intergenerational sustainability dilemma" (Shahrier et al., 2017; Nakagawa et al., 2019). Tackling this dilemma has been at the heart of forest science and concerns about sustainability since its origin in the 18th century (Dargavel and Johann, 2013; Hölzl, 2010; Von Carlowitz, 1713). Different approaches to tackling this dilemma have been taken over time, as societal demands on forests have changed and evolved. Today, sustainable forest management in Europe is concerned with maintaining and enhancing the many ecosystem services that forests provide, such as biodiversity, harvested wood products, recreation, and local livelihoods, whilst also tackling climate change (Gauthier et al., 2015; Bowditch et al., 2020; Verkerk et al., 2020; Forest Europe, 2022).

Local knowledge, the "cumulative body of knowledge, practice and belief handed down through generations by cultural transmission"

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(Gómez-Baggethun, 2021), is increasingly acknowledged as valuable in sustainability and climate change issues (Nakashima, 2015; Balvanera et al., 2017; Nakashima et al., 2017; Gómez-Baggethun, 2021). As local knowledge can complement, triangulate and validate scientific knowledge, there is a growing interest in the co-production of knowledge between local stakeholders and researchers (Klenk and Meehan, 2015; van der Hel, 2016; Norström et al., 2020). In our study area in northern Sweden, a wide range of stakeholders shape the use and management of forests, both directly and indirectly. In this setting, local knowledge about the forests has been shaped by people-forest interactions since time immemorial. Combining this local knowledge with scientific knowledge offers interesting opportunities for improving sustainable forest management.

Typically, local stakeholders have not been involved in offering the cross-generational time perspectives that forest management research requires. Instead, according to several literature reviews (Hetemäki, 2014; Hoogstra-Klein et al., 2017; Mårald et al., 2017), most scenario studies have used quantitative modelling approaches to understand the consequences of different management and/or climate change scenarios on the provision of ecosystem services over time. These studies tend to focus on how ecological systems are managed, and have generally evaluated a broad range of ecosystem services including climate change mitigation, biodiversity conservation, harvested wood, and recreation (Biber et al., 2015; Langner et al., 2017; Pang et al., 2017; Gutsch et al., 2018; Zanchi and Brady, 2019; Blattert et al., 2020; Lundholm et al., 2020; Morán-Ordóñez et al., 2020). Models typically use quantitative indicators and proxies to evaluate the provision of ecosystem services, enabling quantitative comparison between scenarios and over time. However, this kind of comparison is limited to the kinds of indicators that are possible to model, thereby excluding qualitative aspects of ecosystem service provision, such as different scenarios' impacts on people's quality of life. In contrast, some studies have used qualitative participatory approaches to develop preferred forest futures with stakeholders (Bizikova et al., 2012; Sandström et al., 2016; de Bruin et al., 2017; Sandström et al., 2020; Toivonen et al., 2021). They have used backcasting approaches to develop desirable future visions and identify potential pathways to reach them, focusing primarily on the management of social systems. While these studies provide important insights into stakeholder preferences, they do not allow for a quantitative comparison between scenarios and are also not restricted by the limitations inherent to the ecological systems in question. Substantial benefits could possibly be gained by combining modelling approaches with stakeholder participation.

In this study, we aim to combine scenario modelling with participatory scenario analysis to develop future forest management scenarios based on stakeholder preferences regarding ecosystem services, and to model and evaluate these scenarios with the stakeholders. Our intention was to co-produce scientific and local knowledge with stakeholders, whilst rooting the study in our study area, situated in northern Sweden, where there is a long history of forest use and management.

These research questions guided our study:

- When modelling four local stakeholder-tailored forest management scenarios, what are the short- and long-term effects of the scenarios for the provision of ecosystem services?
- When evaluating the scenarios together with the stakeholders, what are the potential additional effects of the scenarios? Do the stakeholders agree with the modelled results?
- How does co-producing knowledge between scientists and local stakeholders improve the evaluation of scenarios?

2. Material and methods

We have used a mixed methods approach to develop and evaluate future forest management scenarios in the boreal forests of northern Sweden in collaboration with local stakeholders. Many participatory studies include stakeholders in the initial or final steps of the research process: that is, in either the development or the evaluation of scenarios (Alcamo and Henrichs, 2008; Mobjörk, 2010; Reed et al., 2013). In this study, stakeholders were involved both in the development of locally desirable scenarios and in the evaluation of those scenarios. Alongside this, quantitative modelling of the scenarios evaluated their effects on ecosystem service provision over time and the extent to which they were ecologically possible. The process involved three main steps: i.) scenario development based on stakeholder preferences regarding ecosystem services, ii.) scenario modelling using a forest decision support system and iii.) evaluation of the scenarios by stakeholders (Fig. 1).

2.1. Study area and forest stakeholders

Our study area was the municipalities of Umeå and Vindeln, which lie within the boreal forest of northern Sweden (Fig. 2). Umeå is an urban municipality with 232 000 ha of land and 130 000 inhabitants and neighbouring Vindeln is a rural municipality with 263 000 ha of land and 5 500 inhabitants in 2020 (Statistics Sweden, 2021, 2022). Most of the area is covered by forests (82 %; Fig. 2), of which two thirds are regarded as productive forests, meaning that they produce more than one m^3 wood over bark/ha/year. The remaining area is considered unproductive forest, in which forest management is prohibited according to the Swedish Forest Act. 40 % of the total forest area is owned by family forest owners, 31 % by the state and 23 % by private forest companies (Swedish University of Agricultural Sciences, 2019). The property sizes for the family forest owners are on average 47 ha, while the state and forest companies usually own thousands of hectares (Swedish University of Agricultural Sciences, 2019; The Swedish Forest Agency (SFA), 2020). There are also additional layers of land use rights, such as the right to public access, the rights of Indigenous communities, and hunting and fishing rights, that all shape the governance and management of forests (Sandström et al., 2016).

The study area has a long history of active forestry. Timber and pulpwood, as well as other forest-related products such as berries, fuelwood and game, have been important commodities since the middle of the 19th century (Bunte et al., 1982). The Indigenous Sámi people have since time immemorial used the land for reindeer herding (*Rangifer tarandus* L.), hunting, and fishing. Over the past century, forest management has consisted of selective cutting (mainly single tree selection with natural regeneration) and even-aged management (with seed trees and natural regeneration or clear-cuts and planting or seeding of native species), and the latter has been dominating since the 1950 s (Mårald and Westholm, 2016; Mårald et al., 2017). The North American species Lodgepole pine (*Pinus contorta* ssp. *latifolia* LP) was introduced in northern Sweden in the 1970 s (Jacobson and Hannerz, 2020), and now it constitutes about 2 % of the productive forests in our study area. Forest fertilization was a popular practice mainly between the end of 1960′s and the beginning of 1990′s, and it is today mainly practiced by forest companies (Lindkvist et al., 2011). Today, the forests are dominated by Scots pine (*Pinus sylvestris* L.; 51 %), Norway spruce (*Picea abies* H.Karst; 35 %) and birch (both *Betula pendula* Roth and *Betula pubescens* Ehrh.; 12 % combined). The area of young (0–40 years), middle-aged (41–80 years) and old forests (81 years or older) is fairly evenly distributed, both in terms of proportion and across the landscape. The productive forests in the area are slow-growing, growing on average 3.7 m^3 wood over bark/ha/yr. The mean annual temperature in the area is $\sim 3\ ^\circ C$, but it is expected to increase to 6–9 °C by the end of the century (RCP 4.5–8.5) (Berglöv et al., 2015).

To assess the scenarios from multiple perspectives, and to ensure that a broad range of knowledge, views and beliefs were represented in the process of evaluating the scenarios (Carlsson-Kanyama et al., 2008; Reed, 2008; Willis et al., 2018; Norström et al., 2020), we included 13 stakeholders with an array of interests and knowledge in relation to forests: four forest owners, one Sámi reindeer herder, two representatives of environmental organisations, one hunter, two forest industry

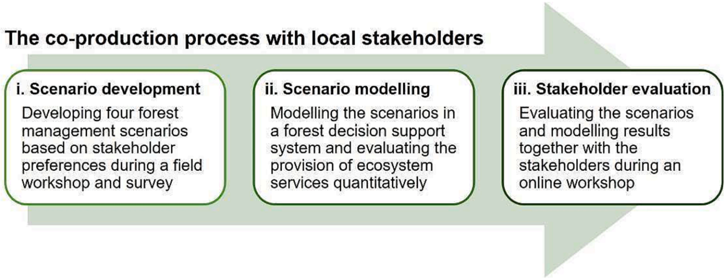

Fig. 1. An overview of the process of developing and evaluating future forest scenarios together with stakeholders.

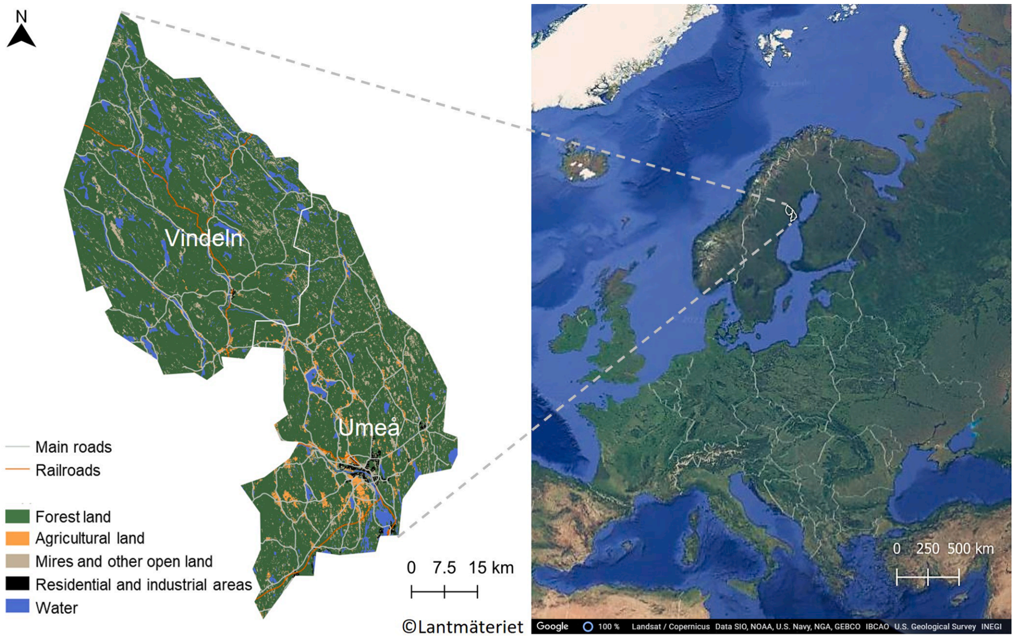

Fig. 2. The study area covering 354 000 ha of boreal forests located in Västerbotten County in northern Sweden.

representatives, one educator and two business entrepreneurs. We recruited these stakeholders from the participants in our collaborative research project "Bring down the sky to the earth", which aimed to co-produce local pathways to tackle climate change (Mårald, 2018; Hallberg-Sramek et al., 2022; Priebe et al., 2022; and forthcoming papers). The recruitment of participants to the research project was based on an analysis of the different kinds of stakeholder groups present in the area (including non-governmental organizations and businesses with interests in the local use and management of forests) and guided by previous studies in adjacent areas and on the Swedish national level (Beland Lindahl, 2008; Nordström et al., 2010; Sandström et al., 2016). Of 30 participants in the research project, 13 accepted the invitation to participate in this study. During the project and prior to this study, the stakeholders had participated in four full day workshops, including a forest excursion, to share and develop knowledge on forests and climate change. Thus, these 13 stakeholders were well versed in the issues in focus for this study, while also representing a broad variety of knowledge and interests in relation to forests. While focus group studies often involve more participants (Nyumba et al., 2018), we judged the number of participants to be sufficient for the purposes of this study.

2.2. Scenario development based on stakeholder preferences

We developed four forest management scenarios for the areas that today are managed for wood production, thereby excluding areas that are currently considered unproductive and/or that are set aside for nature conservation and/or recreation. The scenarios were based on the stakeholders' preferences of forest management approaches and ecosystem services. Prior to this study, they had participated in a field workshop to evaluate the risks and opportunities of different forest management approaches (Hallberg-Sramek et al., 2022). This was followed up by a survey, in which the stakeholders stated their preferences for ecosystem services and forest management approaches. The ecosystem services that received the overall highest scores (both means and medians) in the survey were climate change mitigation (including both harvested wood products and carbon storage in forests and soils), biodiversity conservation and forest owner livelihoods. While most stakeholders scored climate change mitigation high, some favoured livelihoods over biodiversity and others made an opposite prioritization. In terms of forest management, some were favouring more extensive approaches, some more intensive approaches, and some wanted a mix. Based on these results, we formulated three scenarios ranging from extensive management to intensive management, in line with the classification of Duncker et al. (2012), while also including a fourth scenario combining both extensive and intensive approaches (Fig. 3 and Table 1). We then added goal formulations to the scenarios, to tailor the scenarios also to the stakeholders' preferences for ecosystem services (Table 1). This resulted in the following scenarios:

- The close-to-nature management scenario (CTN) aimed to promote biodiversity conservation and climate change mitigation, by maximising the carbon stocks in forests and soils, while maintaining a minimum harvest level at the landscape level. The management strategies included unmanaged forests, selective felling, shelterwood systems, even-aged management with mixed species and pioneer broadleaved species, and clear-cutting of Lodgepole pine stands to replace with native Scots pine (Table 1). Thus, the management strategies reflected the passive, low and medium management intensity in Duncker et al. (2012).
- The classic management scenario (CLA) maximised forest owners' livelihoods by optimising the management in favour of the net present value from wood production (see motivation in Table 2). This scenario reflects more of a business-as-usual scenario in the study area, although management is typically more varied in practice. The management strategies included different variants of even-aged management including clear-cuts and shelterwood systems (Table 1), mainly reflecting the medium to high management intensity in Duncker et al. (2012).
- The intensified management scenario (INT) aimed to promote climate change mitigation by maximising the output of harvested wood from the forest without decreasing carbon stocks in forests and soils. The management approach included different variants of even-aged management including the use of forest fertilisers and planting of fast-growing non-native tree species (Table 1). This scenario includes a mix of the medium, high and intensive management approaches in Duncker et al. (2012).
- The combined management scenario (COM) maximised climate change mitigation and biodiversity conservation by applying a combination of management strategies from the CTN and INT (Table 1). This scenario included all management intensities in Duncker et al. (2012).

Fig. 3. Visualisations of the forest management scenarios modelled and evaluated in this study. These images were shown to the stakeholders during the workshop together with the scenario descriptions and Fig. 6. Photo top left: Jon Flobrant on Unsplash. Photos top right and bottom: Andreas Palmén.

Table 1
The main settings for the forest management scenarios in Heureka Planwise. Each period is five years, hence the 100-year simulation includes 20 periods.

Forest scenario	Management strategies	Goal formulation (objectives and constraints)
Close-to-nature	Unmanaged Selective felling, natural regeneration Shelterwood, natural regeneration Even-aged forestry with prolonged rotation, naturally regenerated mixed species Even-aged forestry with prolonged rotation, naturally regenerated broadleaves Even-aged forestry, species transition from non-native Lodgepole Pine to native Scots Pine	Objective: Maximizing the carbon stock in trees, stumps, roots and soil Constraints: Increasing carbon stock (non-declining stock between periods), Minimum timber harvest level, Evenness in harvests (max +/-20 % in periods compared to mean harvest level for all periods; max +/-20 % between periods)
Classic	Shelterwood, natural regeneration Even-aged forestry, natural regeneration of conifers Even-aged forestry, natural regeneration of broadleaves Even-aged forestry, planted native species Even-aged forestry, planted native mixed species Even-aged forestry, planted native species, single fertilization when appropriate*	Objective: Maximizing the net present value Constraints: Evenness in harvests (max +/- 20 % between periods), Increasing wood stock (non-declining harvests between periods), Evenness in harvests (harvests may not increase more than 60 % between periods), Tree species distribution (the standing stock should maintain at least 80 % of the initial spruce and broadleaves)
Intensified	Even-aged forestry, planted native species, single fertilization when appropriate* Even-aged forestry, planted native species, multiple fertilizations when appropriate* Even-aged forestry, planted non-native species, multiple fertilizations when appropriate*	Objective: Maximizing the harvested wood volumes Constraints:Increasing and even harvests (0 – 20 % increase between periods), Increasing standing wood stock (non-declining stock between periods), Maximum level of Lodgepole pine (max 33 % of total standing stock for all periods)
Combined	Unmanaged Selective felling, natural regeneration Even-aged forestry with prolonged rotation, naturally regenerated mixed species Even-aged forestry with prolonged rotation, naturally regenerated broadleaves Even-aged forestry, planted native species Even-aged forestry, planted native species, multiple fertilizations when appropriate* Even-aged forestry, planted non-native species, multiple fertilizations when appropriate*	Objective: Maximizing the carbon stock in trees, stumps, roots and soil Constraints: Evenness in harvests (max +/-20 % in periods compared to mean harvest level for all periods; max +/-20 % between periods), Minimum wood harvest level, Increasing carbon stock (non-declining stock between periods), Minimum level of broadleaves (min 20 % of total standing stock after period 10)

*There are several restrictions to when fertilizer can be applied to avoid nutrient leakage, such as ranges for number of stems, stand age, mean height, proportion of conifers and site index.

2.3. Scenario modelling in a forest decision support system

The scenarios were modelled and quantitatively analysed in Heureka Planwise, a forest decision support system developed by the Swedish University of Agricultural Sciences (for an overview, see Wikström et al., 2011). Heureka is broadly used in forest management research and practice in Sweden. It consists of a collection of sub-models, including models for tree growth and mortality, yield, silvicultural treatments, costs and revenues, formation of dead wood and carbon storage (Marklund, 1988; Fridman and Ståhl, 2001; Wikberg, 2004; Wikström et al., 2011; Fahlvik et al., 2014; Eggers and Öhman, 2020). These are described in detail on the Heureka Wiki (https://www.heurekaslu.se/wiki/Category:Model) and summarised in Table 2. While Heureka includes a climate change model which assumes that future growing conditions will generally increase tree growth, we excluded this due to the uncertainties that exist about the net impacts of climate change on tree growth and mortality, particularly under different forest management systems. Instead, the effects of climate change on the scenarios were assessed qualitatively by the stakeholders.

The modelling in Heureka PlanWise typically involves several steps (for an comprehensive overview of the process, see Eggers and Öhman, 2020), starting with importing data to describe the initial state of the forests in question. We imported data from the National Forest Inventories, gathered during 2008–2012 from 366 plots in our study area, representing 354 000 ha of productive forests (for an overview of the National Forest Inventory, see Fridman et al., 2014). Next, we defined a range of settings to reflect each of the management scenarios. We started by grouping the forests into subsections, referred to as forest domains, based on the currently-dominant tree species (Scots pine, Norway spruce, Lodgepole pine, broadleaves). When doing so, we could control the regeneration method based on the dominant tree species. Generally, Scots pine- or Lodgepole pine-dominated forests were regenerated with Scots Pine, Lodgepole Pine, broadleaves or a mix, while Norway spruce- or broadleaved-dominated forests were regenerated with Norway spruce, Siberian larch (*Larix sibirica* Ledeb.), broadleaves or a mix. The Lodgepole pine forests in the CTN scenario were regenerated with the native Scots pine. We then assigned several management strategies to each forest domain, which were further modified to fit the different management scenarios (see Table 1). Based on these settings, Heureka generated up to twenty treatment schedules per management strategy and treatment unit in every scenario. Treatment schedules are simulations of treatments and their timing over the next 100 years, divided into twenty-five-year periods, see examples in Eggers and Öhman (2020, pp.10–12). Heureka's optimisation tool was then used to select between the treatment schedules and associated management strategies based on the goal formulations set up for each of the scenarios (Table 1). When the strategies included a change of tree species, the already-present species were replaced with the preferred species in regeneration after final felling. Thus, the change of species did not take place all at once in the study area, but after final felling of the individual stands in question, which occurred at different points in time. The results of the modelling were scrutinised to match the scenario descriptions. In the end, the scenarios included a mix of management strategies designed to favour the stakeholder's preferred management and ecosystem services (Fig. 4).

The scenarios were presented in terms of their outputs of ecosystem services: climate change mitigation, biodiversity conservation, reindeer husbandry, forest owner livelihoods and recreation. These represent a mix of provisioning, regulating and maintaining, and cultural ecosystem services (Table 2, Haines-Young and Potschin, 2018). Each ecosystem service was, in turn, represented by two indicators that were chosen based on previous research, our experience from working with these stakeholders (e.g. Hallberg-Sramek et al., 2022), and the opportunities and limitations of the software (Table 2). The results were analysed and presented using visualisations and basic statistics (averages and sums).

Table 2
The ecosystem services and indicators used in the study, including motivations for their inclusion and a description of how they were modelled.

Ecosystem services	Indicator	Motivation and modelling
Climate change mitigation (regulating and maintaining)	Harvested wood: Volumes of harvested timber and pulpwood (m^3 under bark)	Harvested wood is an important source of renewable materials and energy that can replace the use of fossil ones. The indicator is a result of empirical models for regeneration and ingrowth of trees (Wikberg, 2004) and tree growth and yield - described and evaluated in Fahlvik et al. (2014). Recently, height development models for lodgepole pine have also been added (Liziniewicz et al., 2016).
	Carbon stock: Carbon stock in trees, stumps, roots, litter and soil (ton C/ha).	Carbon stocks in forests are important for mitigating global emissions. The indicator is based on a carbon model in Heureka that aggregates carbon in trees (Marklund, 1988), dead wood (Sandström et al., 2007), stumps and roots (Petersson and Ståhl, 2006), litter and soil (Ågren and Bosatta, 1998; Hyvönen et al., 2002; Callesen et al., 2003; Ågren and Hyvönen, 2003; Peltoniemi et al., 2004; Starr et al., 2005; Ågren et al., 2008) to provide an estimate of the total carbon stock.
Biodiversity conservation* (regulating and maintaining)	Dead wood: Volumes of standing and downed deadwood per hectare (m^3under bark/ha)	Dead wood provides important food and habitat for many species (Esseen et al., 1997; Siitonen, 2001; Rondeux and Sanchez, 2010). The indicator is based on an empirical model for tree mortality and dead wood decomposition developed by Elfving (2014).
	Broadleaved trees: Volume of broadleaved trees per ha (m^3 over bark/ha)	Broadleaved trees provide important food and habitat for many species in boreal forests (Esseen et al., 1997). The indicators are based on the same models for regeneration, ingrowth and growth as the indicator for harvested wood (see above). To simulate management strategies that relied solely on natural regeneration of birch, we set the programme to plant birch seedlings on clear-cuts while eliminating the cost of the planting, to mimic the abundant natural regeneration of birch in the area.
Reindeer husbandry (provisioning and cultural)	Forests dominated by non-native trees species: Area of Lodge pole pine dominated forests (ha)	Lodgepole pine has a negative impact on reindeer herding as it makes it harder to move the reindeer and dense lodgepole pine stands limit the production of ground lichens, which is important forage for reindeer. The indicator simply includes all forests that are dominated (≥50 % of

(continued on next page)

Table 2 (*continued*)

Ecosystem services	Indicator	Motivation and modelling
		all stems) by lodgepole pine (Eggers et al., 2019).
	Lichen forests: Area of forests with potential occurrence of arboreal lichens (ha).	Arboreal lichens provide important forage for reindeer. The abundance of arboreal lichens increases with increasing tree/stand age (Esseen et al., 1996; Esseen et al., 1997). Hence, the indicator is defined as forests with the mean age ≥ 100 years (Eggers et al., 2019).
Forest owner livelihoods (provisioning)	Net present value and net revenue from harvested wood: Net present value (SEK/ha) and net revenue (SEK).	The net present value is the current value of future costs and revenues from harvested wood products, which is the most important forest-based income for forest owners in the area today. The indicator is based on empirical models for costs and revenues for all management activities and an interest rate of 2 % was used to discount the values. When discounting, the costs and revenues occurring earlier in the time period have greater significance for the net present value than those occurring later (Arrow et al., 2013). The functions for the calculations can be found on Heureka Wiki (https://www.heurekaslu.se/wiki/Net_present_value).
	Fertilised forests: Area fertilised each five-year period (ha)	Fertilising is an additional financial investment in management that in most cases benefits net present value and wood production, and thereby also forest owner livelihoods. However, it is not commonly practiced among family forest owners in the study area. It was much debated during our previous studies with these stakeholders, both in terms of its impacts on forest owner livelihoods and its environmental impacts (e.g. Hallberg-Sramek et al., 2022), which is why we chose to include it in the study. The indicator is based on the area fertilised.
Recreation (cultural)	Bilberry production: Area with a high bilberry (*Vaccinium myrtillus* L.) production potential (ha)	Berry picking is carried out by local people as part of the "right to public access". There are also businesses related to bilberries (Sténs and Sandström, 2013). Previous research has identified stand conditions that favour bilberry production (Ihalainen et al., 2005; Miina et al., 2009). Based on these studies, the indicator was set to sum the area of spruce dominated forests with the mean age ≥ 30 years, soil fertility ≤ G28 and basal area ≤ 20 m^2; and pine dominated forests with the mean age ≥ 30 years and soil fertility ≥ T18, as these were assumed to have high bilberry production.
	Recreational values: Recreation index (RI)	Outdoor recreation is an important activity carried out as part of the Swedish right to public access. The indicator is based on the recreation model in Heureka, which calculates the recreation index (RI). The RI favours large trees, broadleaved trees and continuous forest cover, while it disfavours small trees, harvest residues and ground damage. A high value indicates high recreational value.

*Following Mace et al. (2012), we consider biodiversity as both the basis for all ecosystem services and an ecosystem service in itself. In this study, we have modelled it as an ecosystem service to highlight the impact of the scenarios on its provision.

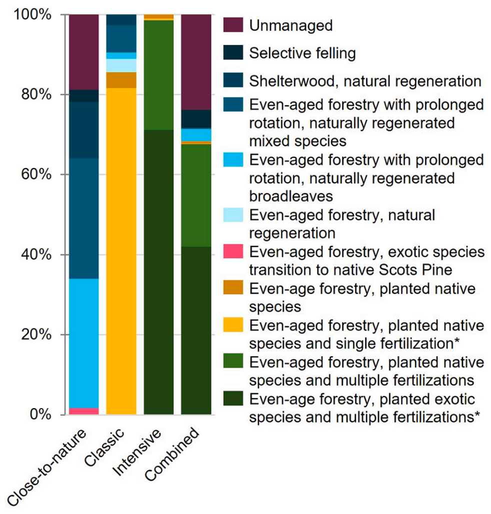

Fig. 4. The management strategies applied by the forest decision support system in the scenarios, described as the proportion of the total area. *There are several restrictions to when fertiliser can be applied to avoid nutrient leakage, such as ranges for number of stems, stand age, mean height, proportion of conifers and site index.

2.4. Scenario evaluation by the stakeholders

The scenarios were evaluated during an online workshop in November 2020 by the same stakeholders who had participated in the survey. Prior to the workshop, they were sent a document containing descriptions of, and data from, the modelled scenarios. The workshop began with participants agreeing on the aim, schedule and common ground rules for the workshop. The modelled scenarios were then presented using descriptions, pictures (Fig. 3) and data on the provision on ecosystems services (Fig. 6), and stakeholders were invited to ask questions. Following this, the stakeholders were placed in groups of four or five persons, with a mix of interests and genders in each group. The groups first discussed the main strengths and weaknesses of the four scenarios, to familiarise themselves with the scenarios and to give their initial assessment of them. Then, each of the groups was assigned a particular scenario to evaluate more in depth, in terms of the consequences of that scenario for their community and climate change. This was repeated with another scenario and, in the end, the groups were also given time to discuss the two remaining scenarios. The discussions were moderated by researchers, to ensure that all stakeholders were able to participate fully in the discussions (Reed, 2008; Willis et al., 2018). Between each of the discussions, the groups were gathered to exchange thoughts and ideas, and to ask questions. All workshop discussions were recorded, with participants' consent.

The workshop recordings were transcribed and analysed using the following questions i.) what ecosystem services and other considerations did the stakeholders discuss?, ii.) how did stakeholders expect these to be impacted by the scenarios? and iii.) concerning those ecosystem services that had been quantitatively modelled, did they agree or disagree with the modelling results? To structure the material, a matrix was created, with the ecosystem services and other considerations on one axis and the scenarios on the other axis. A highly condensed version of this matrix is provided in the results section (Table 3). When there were conflicting statements from the stakeholders, we included them both in the results description with a short explanation of the rationale behind the statements. However, as the workshop was set up as an opportunity to learn from each other, the stakeholders were mainly adding considerations or perspectives to each other's statements, rather than disputing them. The participants thus discussed potential strengths and weaknesses of the scenarios from multiple perspectives.

3. Results

In the modelling, the four management scenarios were tailored to the stakeholders' preferences of forest management approaches and ecosystem services. Having adopted a 100-year time horizon, the modelling showed that while some effects of forest management strategies on the delivery of ecosystem services occurred in the short-term (within 10 years), most had a lag phase of 10 – 50 years (Fig. 5). Stakeholders' responses to the modelled scenarios highlighted the complexity involved in interpreting quantifications of forest benefits over time and, at the same time, contributed qualitative perspectives on the likely consequences of the different scenarios. Stakeholders also brought into the evaluation additional ecosystem services and other considerations, beyond those modelled.

3.1. Modelling outputs of ecosystem services over time

For climate change mitigation, the indicators modelled were harvested wood and carbon stocks in forests and soils (Table 2). In the short term (the first 25 years), the CTN scenario produced about half the volume of harvested wood than that was produced under the other scenarios (Fig. 5). In the long term (75+ years), the CTN scenario produced about the same quantities of harvested wood as the CLA and COM scenarios, but the INT scenario produced almost double this amount (Fig. 5). A contrasting pattern emerged regarding carbon stocks in trees and soils, with stocks being approximately 40 % larger under the CTN and COM scenarios than the other scenarios at the end of the 100-year simulation period (Fig. 5). Regarding forests' delivery of the ecosystem service climate change mitigation, the results thus emphasise the trade-off between forest carbon stocks and harvested wood, as those scenarios offering the highest provision of harvested wood are also those offering the lowest carbon stocks, and vice versa. However, the trade-off is not linear, as demonstrated by the COM scenario which achieves equally high carbon stocks as the CTN scenario, while producing higher volumes of harvested wood (Fig. 5).

For biodiversity conservation, the amount of dead wood and abundance of broadleaved trees were simulated (Table 2). Both indicators were mainly favoured in the CTN and the COM scenarios (Fig. 5). Dead wood was especially favoured in the large areas of unmanaged forests in these scenarios (Fig. 3), because the unmanaged forests have a higher mortality rate than the managed forests. However, it took about 25 years for the mortality to start to differentiate between those scenarios that included unmanaged forests and those (INT and CLA) that only included managed forests. After 40 years, dead wood production levelled out in the INT and CLA scenarios, while it continuously increased in the CTN and COM scenarios. The volume of broadleaved trees decreased over time in the INT and CLA scenarios, which were optimised towards net present value and harvested wood, while it increased in the CTN and COM scenarios, which were developed to promote both climate change mitigation and biodiversity (Fig. 5). For biodiversity conservation, the differences between the scenarios were thus amplified over time for both indicators, and the CTN and COM scenarios anticipate substantially higher provision of the ecosystem services measured by these two indicators.

For reindeer husbandry, the simulation included forests with non-native tree species, which have a negative impact on reindeer husbandry, and forests with arboreal lichens, which have a positive impact (Table 2). The area of non-native tree species was very small in the CTN and CLA scenarios, as all regeneration under these scenarios was pursued using native species (Fig. 3) and any remaining areas of non-native trees were residuals left over from the situation at the start of the simulation period. In the COM and INT scenarios, non-native and fast-growing trees (i.e., lodgepole pine) were planted when regenerating forests, resulting in increasing areas of non-native tree species over the initial 75 years, levelling out at about 40 % of the forest landscape area in the longer term (Fig. 5). Forests with arboreal lichens were promoted in the CTN scenario, and steadily increased over time (Fig. 5). In the INT scenario, by contrast, such forests contracted over the first 50 years (Fig. 5). In the CLA scenario, most lichen-rich forests were harvested by the end of the study period. In the COM scenario, large areas of lichen-rich forests were first harvested but then, after 50 years, these forests increased again so that, by the end of the simulation period, the area of lichen-rich forests was about the same level as the start of the period (Fig. 5). Overall, the CTN scenario offered the most beneficial conditions for reindeer husbandry, while the INT scenario offered the least beneficial conditions.

Considering the scenarios' impact on forest owners' livelihoods, we modelled the net present value (NPV), the net revenue, and the area of fertilised forests (Table 2). The NPV of the forest was highest under the CLA and INT scenarios (both giving a NPV of 33 000 SEK/ha), followed by the COM scenario (29 000 SEK/ha). The CTN scenario generated a considerably lower value (21 000 SEK/ha). This is because the CTN scenario produced most of its net revenue late in the study period which, discounted to present day value, becomes less financially valuable than revenue produced early in the simulation period (Fig. 5). The INT scenario produced the largest area of fertilised forests, followed by the COM and the CLA. The CTN did not include any fertilised area (Fig. 5). The NPV in the COM scenario, which included large fertilised areas, was substantially higher than in the CTN scenario which, as noted, included none. The non-linear relation between NPV and fertilised area reflects the duality of fertilising forests: it increases wood production but is also an additional cost. Therefore, it can impact NPV both negatively and positively.

With regards to berries and recreation, we modelled bilberry production and the recreation index (Table 2). Bilberry production was highest under the CTN and CLA scenarios, and they maintained about the same level of bilberry production throughout the whole study period (Fig. 5). Bilberry production in the other scenarios (INT and COM) decreased over the first 50 years, and then levelled out as a result of the forests becoming denser. The recreation index was slightly higher under the CTN scenario than the other scenarios, but the differences were marginal (Fig. 5). Overall, forests' provision of berries and recreation were especially favoured under the CTN and CLA scenarios, while

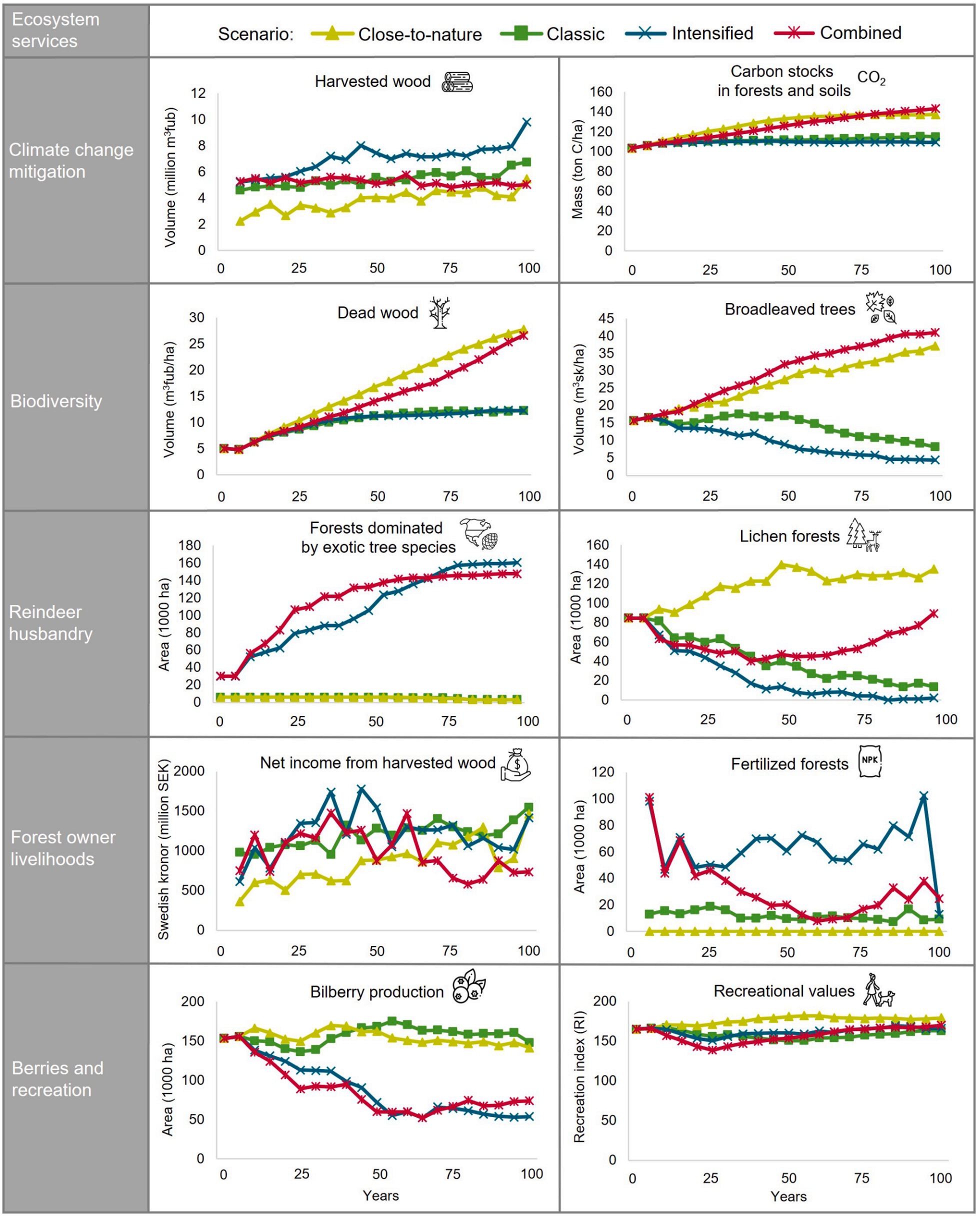

Fig. 5. The provision of ecosystems services over time across a forest landscape of 354 000 ha in Västerbotten county in northern Sweden. Each ecosystem service is represented by two indicators and the forest landscape was subjected to four different forest management scenarios: close-to-nature, classic, intensified and combined management, over a 100-year simulation period. Please note that areas dominated by non-native trees are influencing reindeer husbandry negatively.

provision was lower under the COM and INT scenarios.

3.2. Stakeholder evaluation of the scenarios and the modelling outputs

During their assessment of the modelled scenarios, stakeholders discussed the strengths, weaknesses and potential consequences of the scenarios, considering both climate change mitigation and adaptation of forests, and local uses of the forests. They used the modelled results, displayed as sums and averages (Fig. 6) to support the discussion, but they also included other ecosystem services and considerations that they felt were important. The ecosystem services that they added were high quality wood, employment opportunities, hunting and wildlife. They also discussed the implications of the scenarios for small scale forestry, climate change adaptation, social acceptance and conflicts. For many of the ecosystem services, the stakeholders identified both strengths and weaknesses with several of the scenarios (Table 3). This was related to the scenarios including a mix of management strategies, of which some were considered favourable and others disfavourable for that ecosystem service. In some cases, the ambiguous evaluation was related to the multiple indicators associated with that ecosystem service, of which some could be favoured in a scenario, while another was disfavoured. We present their evaluation and reasoning for each of the ecosystem services below.

Concerning climate change, stakeholders emphasised aspects of both mitigation and adaptation. Going beyond the modelled indicators (harvested wood and forest carbon stocks), they pointed out that forests' capacity to take up carbon is key to climate change mitigation, suggesting that the higher carbon stock modelled in the CTN scenario (Fig. 6) might be achieved at the expense of the carbon uptake rate, while the situation might be reversed under the INT scenario. Relating to harvested wood, they argued that wood quality was as important as wood volume, as high-quality wood has more potential to be used to

Table 3
An overview of the stakeholder evaluation of the scenarios. The arrows indicate how stakeholders thought the ecosystem services would be affected by the scenarios, either favoured (↑), disfavoured (↓), or not mentioned (o). The italicised ecosystem services and considerations were raised by the stakeholders, in addition to the modelled ones.

Ecosystem services and additional considerations	Close-to-nature	Classic	Intensified	Combined
Climate change mitigation *and adaptation*	↑ ↓	↑ ↓	↑ ↓	↑ ↓
Biodiversity conservation	↑	↑ ↓	↓	↑ ↓
Reindeer husbandry	↑	↑ ↓	↓	↑ ↓
Livelihoods	↑ ↓	↑	↑ ↓	o
Recreation	↑	↑	↓	↓
Hunting and wildlife	↑ ↓	↑ ↓	↓	↑ ↓
Social acceptance	↑ ↓	↑ ↓	↓	↓

make long-lived products, which may reduce consumption-related carbon emissions. However, it was also emphasised that large wood volumes may be needed to replace fossil materials and energy. Hence, it was considered that the non-native lodgepole pine and multiple fertilisations may produce large volumes of low-quality wood, while the CLA and CTN scenarios would probably produce higher quality wood at the expense of volume. The size of the unmanaged areas in the COM and CTN scenarios was also debated between the stakeholders, the inclusion of unmanaged forest areas substantially reduced harvested wood volumes overall, despite being important for biodiversity. Moreover, stakeholders argued that the INT and COM scenarios may be putting forests at high risk of pests and pathogens, storm damage, snow breakage and fire, due to the use of coniferous monocultures,

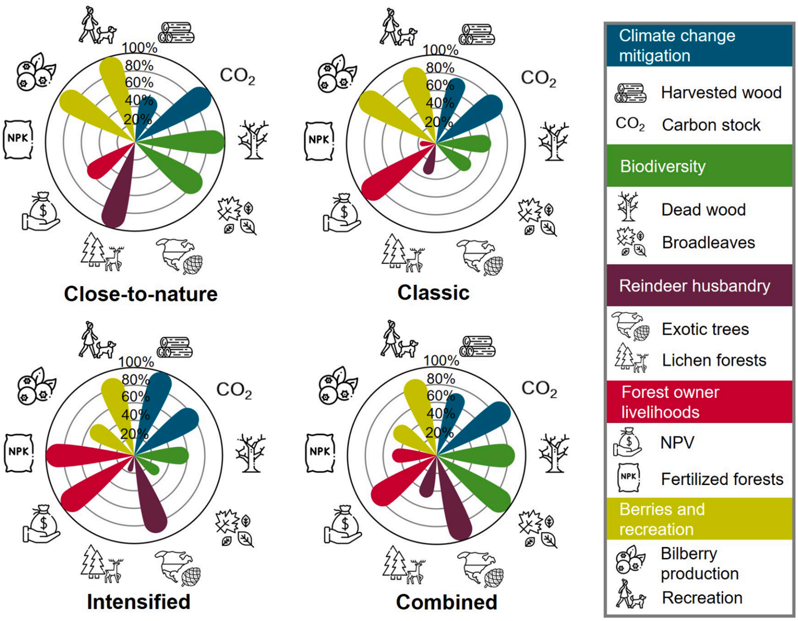

Fig. 6. The scenarios relative provision of ecosystems services, using the highest value for each indicator as a reference. Please note that areas dominated by non-native trees are influencing reindeer husbandry negatively. Images: Flaticon.com.

fertilisation and non-native tree species. It was therefore suggested that the modelled carbon stocks and harvested wood volumes could be overestimated in these scenarios. In contrast, it was brought up that the use of non-native tree species may be a way to reduce risks in relation to pests and pathogens, as they would promote an overall higher tree species biodiversity in the landscape. Stakeholders generally associated management strategies involving the use of site-adapted native species, mixed species forests and broadleaved forests with low risk. Thus, they associated the COM and INT scenarios with high risks, CLA scenario with intermediate risks and the CTN scenario with low risks. However, it was also argued that unmanaged forests (in CTN and COM) posed high risks, particularly of pests.

Regarding biodiversity conservation, stakeholders considered that negative management approaches for biodiversity include monocultures, fertilisation, and planting of non-native tree species (i.e., the INT and COM scenarios), while they viewed the use of native tree species, old-growth forests, dead wood, broadleaves and mixed species forests as positive for biodiversity (CTN and COM). INT was considered the worst scenario for biodiversity, while CTN was the most favourable. While comparing the CLA and COM scenarios, stakeholders' views were divided as to which would be more favourable, as the COM includes more of both negative and positive management practices for biodiversity, while the CLA scenario includes less of both. The discussion then revolved around the advantages and disadvantages of the different approaches. It was emphasised that if the CLA scenario were to include more broadleaved and mixed species forests, it would be considerably more favourable for biodiversity. Another option put forward was to decrease the area of non-native tree species in the COM scenario, while increasing the area of native species, to make it more favourable for biodiversity.

Stakeholders concluded that the opportunities for reindeer husbandry would be low in the INT and COM scenarios, because these scenarios tend towards dense forests with shorter rotations, which disfavours arboreal and ground lichens which are important winter forage for reindeer. The unmanaged forests in the COM scenario were considered positive for arboreal lichens, but several stakeholders emphasised that there would probably not be enough unmanaged forest in this scenario to compensate for the loss of forage in the more intensively managed parts. The high proportion of lodgepole pine also makes it harder to herd the reindeer in the INT and COM scenarios, as their dense nature makes them hard to navigate for both the reindeer and their herders. The CTN and CLA scenarios were considered more favourable for reindeer husbandry. The main drawback with the CLA scenario was the low proportion of old-growth forests, while the CTN scenario was considered to be generally favourable. An additional comment that applied to all scenarios was that more careful and precise soil scarification could make it easier for reindeer to move through and forage on the clear-cuts.

In terms of livelihoods, stakeholders discussed both incomes generated from forestry, employment opportunities created in the forest sector and opportunities for small scale forestry. The income and employment opportunities were believed to be highest under the CLA and INT scenarios, in line with the results of the modelling. However, there were discussions and disagreements about the income generated in the CTN scenario. Some thought that the income generated would be low, as modelled, and that it would have negative impacts on local employment. Others thought that the modelled income was underestimated, as a higher focus on wood quality rather than wood quantity would generate income on a par with the CLA scenario – especially if the unmanaged area were to be somewhat reduced. At the same time, stakeholders thought that the use of intensive fertilisation and non-native tree species, as in the INT and COM scenarios, would mainly benefit large forest owners such as forest companies. This is because it involves higher risks, is more labour-intensive and requires larger financial investments in forest management. If the same net income could be achieved using less intensive methods, several stakeholders argued that there would be no reason for a private forest owner to fertilise, especially when doing so also involves more trade-offs with other ecosystem services. They perceived CTN or CLA management to be more in line with what small-scale forest owners are already doing.

Stakeholders associated recreation value not just to the size and condition of the trees, but also canopy closure and light availability. In contrast to dark and dense stands, open and light stands promote ground vegetation, which creates a more interesting and aesthetically pleasing forest. The stakeholders therefore disagreed with the high provision of recreation modelled in the INT and COM scenarios, as they felt that the use of fertilisers and non-native tree species would create very dense and dark forests. It was also stated that no one would like to live in the area if the forests were managed this way. Instead, stakeholders felt that the CTN and CLA scenarios would provide better opportunities for recreation. However, there were also split views about the recreational opportunities created in unmanaged forests. Some thought that they provide the most exciting environment to explore, with a diversity of structures and species, while others thought that unmanaged forests look messy and are hard to access. It was also emphasised that the management of trails, signs and camps are just as important, possibly even more important, as the management of the trees in determining forests' recreational value. Overall, the stakeholders related the recreational value of forests with quality of life.

Stakeholders considered that opportunities to forage berries and mushrooms were an important aspect of recreation. While they agreed with the modelled results relating to bilberry production, they also discussed the opportunities for foraging lingonberries (also called cowberries, *Vaccinium vitis-idaea* L.) and mushrooms (unspecified). As lingonberries thrive in even poorer soils and lighter conditions than bilberries, they thought that these would be even more negatively impacted by the dense, dark and fertilised forests under the INT and COM scenarios. Those scenarios were also believed to disfavour mushrooms, while the CLA and CTN scenarios would create about the same opportunities for foraging as the current management approach.

In addition to several of the modelled ecosystem services, the stakeholders also discussed how the four scenarios would affect opportunities for hunting and wildlife, as this is an important factor for the local culture and tourism. On this theme, the key topic discussed was the supply of forage for wildlife. Stakeholders considered that forage would be easier to find in the CLA and CTN scenarios, as these would allow for rich ground vegetation. Some stakeholders also put forward the CLA scenario as the best, as it involves more clear-cuts which provide an abundance of herbs for large herbivores to feed on. Others argued that the CTN scenario was best, as it included more broadleaved trees which provide a more herbaceous and grassy ground vegetation, while the trees themselves also provide important forage and habitat for both herbivores and birds. The INT and COM scenarios would mainly provide forage during the initial stages after a clear-cut; thus, they were not felt to be as good for hunting and wildlife as the other scenarios. However, it was noted that the unmanaged forests in the COM scenario could provide shelter.

Social acceptance and conflicts were topics that the stakeholders returned to throughout their discussions. They thought that some scenarios would be more socially acceptable and would contribute to fewer conflicts between stakeholders, while other scenarios would do the opposite. Specifically, they argued that the INT and COM scenarios would spark more conflicts, as they negatively impact many ecosystem services (Table 3), pose high risks in relation to climate change, and include practices that are not considered acceptable locally, such as using non-native tree species and intensive fertilisation. In contrast, the CTN and CLA scenarios had more strengths in relation to the provision of ecosystem services (Table 3) and involve less risk and are based on less intensive practices. The stakeholders argued that CTN and CLA would be more in line with the local use of forests, create fewer conflicts and be more socially acceptable. However, there was no consensus on which scenario that would be best. Some stated that they, personally, could see benefits from incorporating aspects of the INT and COM scenarios into current management practices, but recognised that their views are quite controversial.

4. Discussion

In this study, we combined scenario modelling with participatory scenario analysis to perform a multifaceted evaluation of the future provision of ecosystem services from local forests. The modelling results highlighted the short- and long-term effects of forest management on the provision of ecosystem services which are key to supporting the needs of both current and future generations. Meanwhile, the stakeholder evaluation contributed by putting the results of the modelling into context, adding nuance to them, and identifying further important considerations such as assessing the risk and social acceptability of the different scenarios.

Given the urgency of climate change, society is asking for rapid solutions. However, forest management is a long-term endeavour that requires us to consider both the short- and long-term effects of management. The results of the scenario modelling emphasise these effects on a wide range of ecosystem services. While some indicators and ecosystem services were more directly impacted by management, primarily harvested wood and livelihoods, others involved substantial time lags of 10–50 years. These time lags, from change of management to impact on ecosystem service provision, make attempts to manage forests sustainably rather challenging (Fischer, 2018). This challenge is heightened because current generations tend to favour the needs of the present over the needs of future generations (Shahrier et al., 2017; Nakagawa et al., 2019), meaning that ecosystem services with a short delivery time risk being favoured over those which are longer-term. At the same time, forest management can have immense, sometimes irreversible, long-term effects – but it may not be possible to evaluate these effects for several human generations. For example, according to the modelling, the short-term impacts on biodiversity and reindeer husbandry were generally small. However, the CLA, INT and COM scenarios generated severe negative long-term impacts for some of the relevant indicators. While mitigating climate change has been argued to be the most pressing issue that forest management should tackle (Nunes et al., 2020; Skytt et al., 2021), our results emphasise that, depending on which indicator for climate change mitigation you focus on, there will be substantial impacts on forests' provision of other ecosystem services. Thus, as highlighted by other studies (Felton et al., 2016; Ferreira et al., 2018; Morán-Ordóñez et al., 2020; Hallberg-Sramek et al., 2022), simply focusing on climate change mitigation when modelling and managing forests risks having serious effects on their provision of multiple ecosystem services in the long-term. There is therefore a need to evaluate the overall effects of management, with consideration to which ecosystem services will be important for both current and future generations.

Due to the long time-perspectives of forest management, dealing with uncertainties and risks has become central to both science and practice (Lidskog and Sjödin, 2014; Lidskog and Löfmarck, 2015; Keskitalo et al., 2016; Lidskog and Sjödin, 2016; Mårald and Westholm, 2016; Uggla and Lidskog, 2016; St-Laurent et al., 2018; Brunette et al., 2020; Venäläinen et al., 2020). In this study, we did not model risk. Instead, the stakeholders included it in their evaluation of the scenarios. They were particularly concerned about the risks posed by the INT and COM scenarios in relation to natural and climate-related disturbances such as pests and pathogens, storm damage, snow breakage and fire. These scenarios used more intensive management methods, such as intensive fertilisation and introduction of non-native tree species, which stakeholders thought made the forests more susceptible to damage. This made them question the modelled results for these scenarios, as the high risks may mean that the ecosystem services and indicators modelled have been over- and/or under-estimated. While there are studies modelling the risk of storm damage in boreal forests (Reyer et al., 2017; Chen et al., 2018; Subramanian et al., 2019; Hahn et al., 2021), it is not currently possible to get an overall risk estimate from these models due to the complexity of the relationships between forest disturbances, human management and climate change (Seidl et al., 2017). However, recent reviews have highlighted Norway Spruce as especially sensitive to climate change impacts such as storm damages, drought, pests and pathogens (Keskitalo et al., 2016; Venäläinen et al., 2020). With a similar risk assessment, the Swedish Forest Agency is recommending site adapted management with a greater diversity of tree species (Swedish Forest Agency, 2020), which also is in line with the stakeholder evaluation. The stakeholders also argued that monocultures and fertilization increase risks, while they identified both opportunities and risks with non-native tree species. Jasanoff (2007) argues that we should treat this kind of uncertainties with humility towards the opportunities and limitations of science. This means that we need to be transparent about what we can and cannot know through modelling, and to accept when we need to leave the judgement of risks to those directly impacted by them, for example, local stakeholders – which is what we did in this case.

As local knowledge can be used to validate and complement scientific knowledge (Klenk and Meehan, 2015; van der Hel, 2016; Norström et al., 2020), we were interested in finding out whether or not the stakeholders would agree with the modelled results, and if they had anything to add to them. In most instances, they agreed with the modelled results, while also bringing additional ecosystem services and considerations into the evaluation, complementing the modelling. Some of these additional ecosystem services, such as the quality of harvested wood and forage for wildlife, could potentially be quantified and incorporated into the modelling. Some of the other considerations would be harder to incorporate, including the stakeholders' assessment of management-imposed uncertainties and risks, and their evaluation of how socially acceptable different management approaches would be locally. With regards to the recreational value of forests, the stakeholders disagreed with the modelling. They thought that the management under the CLA and CTN scenarios would be much more beneficial to the recreational values of forests than the management in the INT and COM scenarios, mainly due to higher light availability and richer ground vegetation. To better reflect the experience of stakeholders, the model could be adjusted to include stem density parameter as used in Finnish studies (Pukkala et al., 1988; Silvennoinen et al., 2001). However, as both scientific knowledge and local knowledge could include biases, the new model would need to be tested, preferably in field together with the stakeholders.

The stakeholders also nuanced some of the modelled results and drew attention to them from their local perspectives. When evaluating the climate change mitigation potential of the scenarios, they emphasised the need to include more aspects than just carbon stocks and harvested wood volumes, for example, carbon capture and the quality of harvested wood, while also considering how well-adapted the management approach is to climate change impacts. They thereby underscored that climate change mitigation and adaptation are tightly linked, as has already been highlighted in the academic literature (Locatelli et al., 2011; Keenan, 2015; Kongsager, 2018; Bowditch et al., 2020; Verkerk et al., 2020; Hallberg-Sramek et al., 2022). Mitigation is needed to slow down climate change and thereby reduce the need for adaptation. Adaptation is needed to make that mitigation sustainable, while also adapting to already-ongoing changes. At the same time, it is important to consider why we want to mitigate and adapt to climate change in the first place. In this case, the stakeholders wanted to promote forests' multiple ecosystem services, including a mix of provisioning; regulating and maintaining; and cultural ecosystem services (Haines-Young and Potschin, 2018).

The fourth scenario, COM, aimed to combine extensive and intensive management strategies to promote multifunctional forests. This could be classified as a "land sparing" approach, where functional zoning of forests could provide important habitat for biodiversity while also allowing substantial wood harvests (Ranius and Roberge, 2011; Blattert et al., 2018; Betts et al., 2021; Himes et al., 2022; Muys et al., 2022). This was confirmed by our modelling results, were the COM scenario had high provision of biodiversity, forest owner livelihoods and climate change mitigation, all ecosystem services that were highly valued in the initial stakeholder survey. However, when the stakeholders evaluated the scenario during the workshop, they thought that the COM scenario would pose high risks, be negative for forests' cultural ecosystem services, and involve management practices that would not be socially acceptable in the relevant locality. Instead, the stakeholders identified greater benefits from the CLA and CTN scenarios, which would promote forests multiple ecosystem services more broadly while also involving less intensive and risky, management methods. These results emphasize the importance of bringing stakeholders in, as their local knowledge can complement, nuance, and challenge the results of modelling, while also providing insight into local preferences regarding the management practices and ecosystem services involved in tackling climate change.

5. Conclusions

To evaluate forest management scenarios' impacts on the provision of ecosystem services, scenario modelling can be an important tool for extending time frames and evaluating both short- and long-term effects of forest management. Scenario modelling can also highlight the time lags associated with forest management, which can have severe effects on the future provision of ecosystem services. At the same time, quantitative modelling is only one way of acquiring knowledge about the effects of forest management. The knowledge of local stakeholders can provide vital information about forests through people's long-term relationships with them, rooted in particular places. This study demonstrates that local knowledge may add to and nuance the evaluation of scenarios, for example, by bringing up additional indicators for ecosystem services or aspects of risks and uncertainty. Local knowledge may also introduce social considerations, such as local acceptability and desirability of different management strategies. Bringing scientific and local knowledge traditions together can provide broader, more informed, and nuanced support to forest management decisions, while also indicating which forest management scenarios would be accepted locally.

CRediT authorship contribution statement

Isabella Hallberg-Sramek: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Visualization, Project administration, Software, Writing – original draft, Writing – review & editing. **Eva-Maria Nordström:** Conceptualization, Methodology, Validation, Investigation, Investigation, Resources, Supervision, Writing – review & editing. **Janina Priebe:** Investigation, Writing – review & editing. **Elsa Reimerson:** Investigation, Writing – review & editing. **Erland Mårald:** Investigation, Funding acquisition, Writing – review & editing. **Annika Nordin:** Conceptualization, Methodology, Validation, Investigation, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: A. N. reports a relationship with Stora Enso AB that includes employment. A.N. reports a previous relationship with Sveaskog AB that included board membership.

Data availability

The data from the scenario modelling is available in the supplementary material. The data from the stakeholder evaluation are available on request from the corresponding author.

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Data Availability Statement: The data from the scenario modelling is available in the supplementary material. The data from the stakeholder evaluation are available on request from the corresponding author. It is not publicly available to safeguard the anonymity and privacy of the stakeholders.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2023.101512.

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Forests are expected to provide multiple ecosystem services and contribute to climate change mitigation, while also being adapted to the impacts of climate change. This thesis highlights the various competing expectations placed on forests in Sweden and how they can be addressed by tailoring forest management to local socio-ecological contexts in collaboration with local forest stakeholders, thereby reducing the gap between forest science and practice.

Isabella Hallberg-Sramek received her doctoral education in forest management at the Department of Forest Genetics and Plant Physiology at the Swedish University of Agricultural Sciences (SLU). She received her Degree of Master of Science in Forestry from SLU in 2019.

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