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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 ~ 3 °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

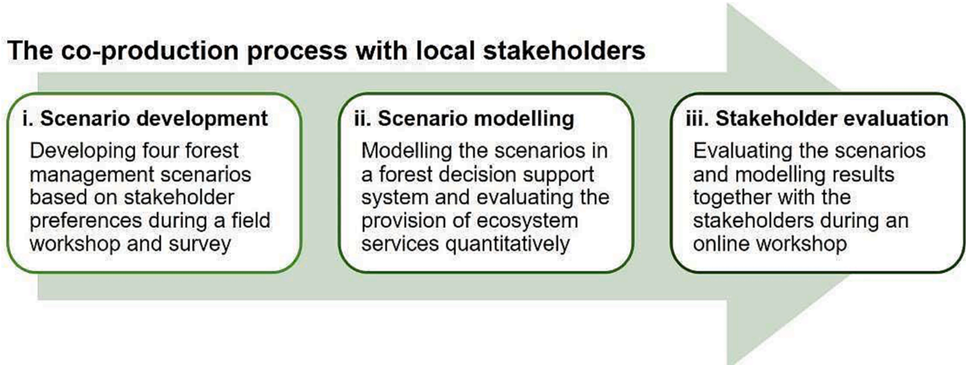

Fig. 1. An overview of the process of developing and evaluating future forest scenarios together with stakeholders.

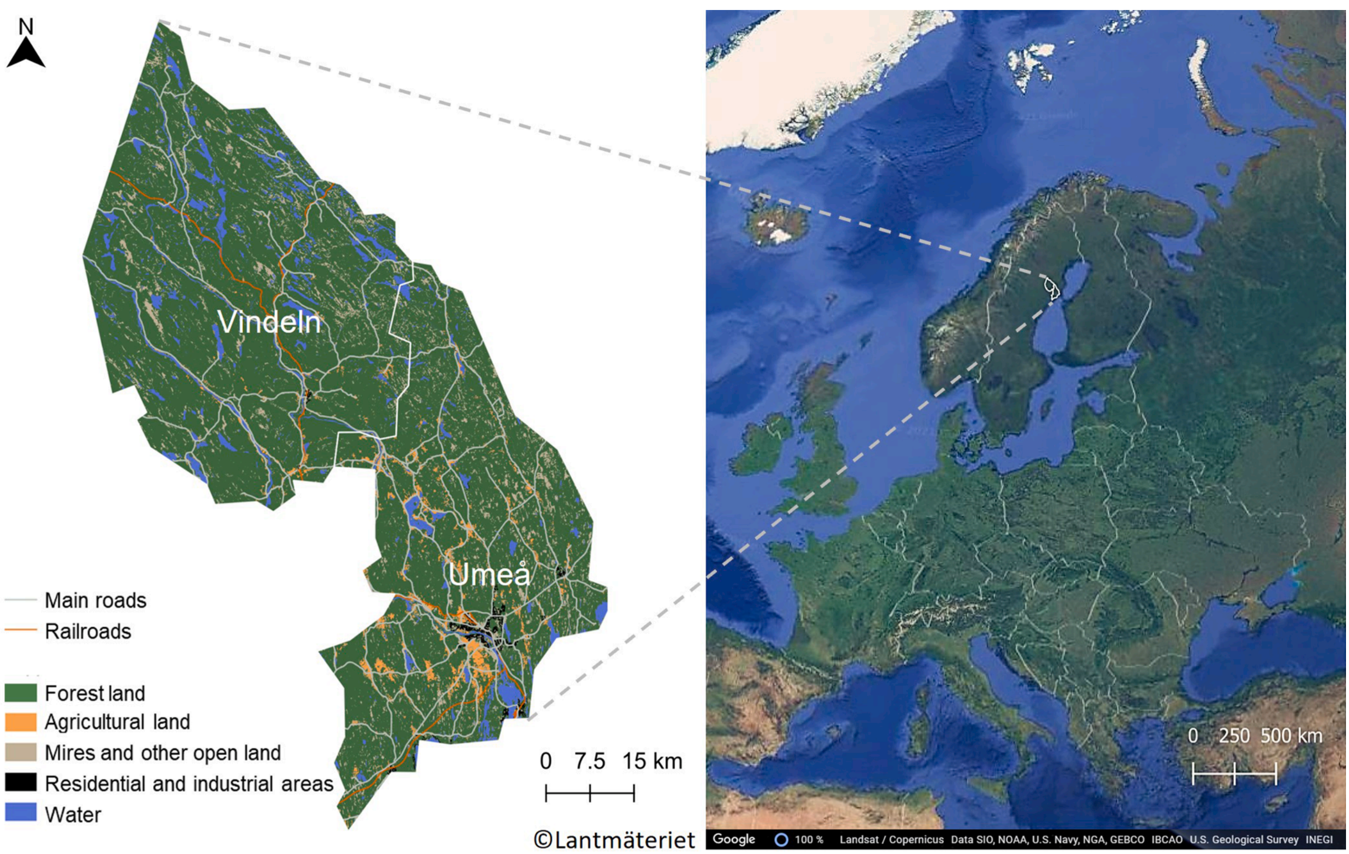

Fig. 2. The study area covering 354 000 ha of boreal forests located in Västerbotten County in northern Sweden.

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.

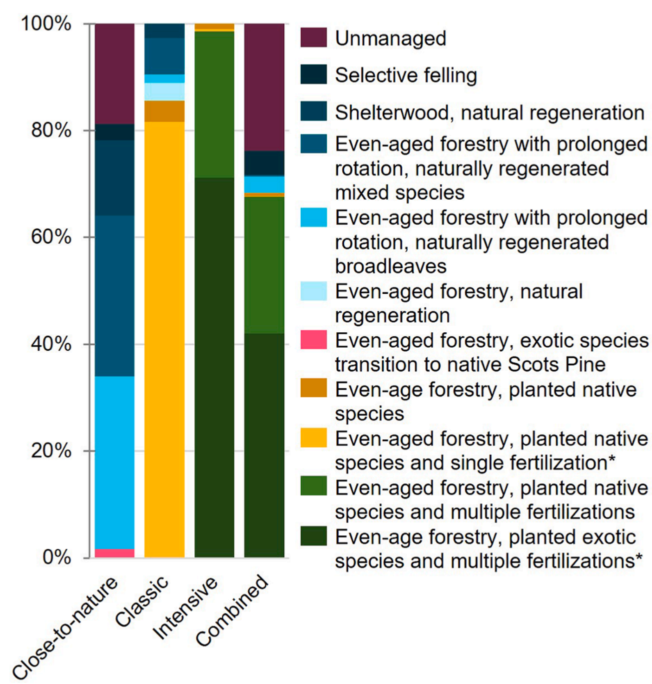

Fig. 4. The management strategies applied by the forest decision support system in the scenarios, described as the proportion of the total area. *There are several restrictions to when fertiliser can be applied to avoid nutrient leakage, such as ranges for number of stems, stand age, mean height, proportion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

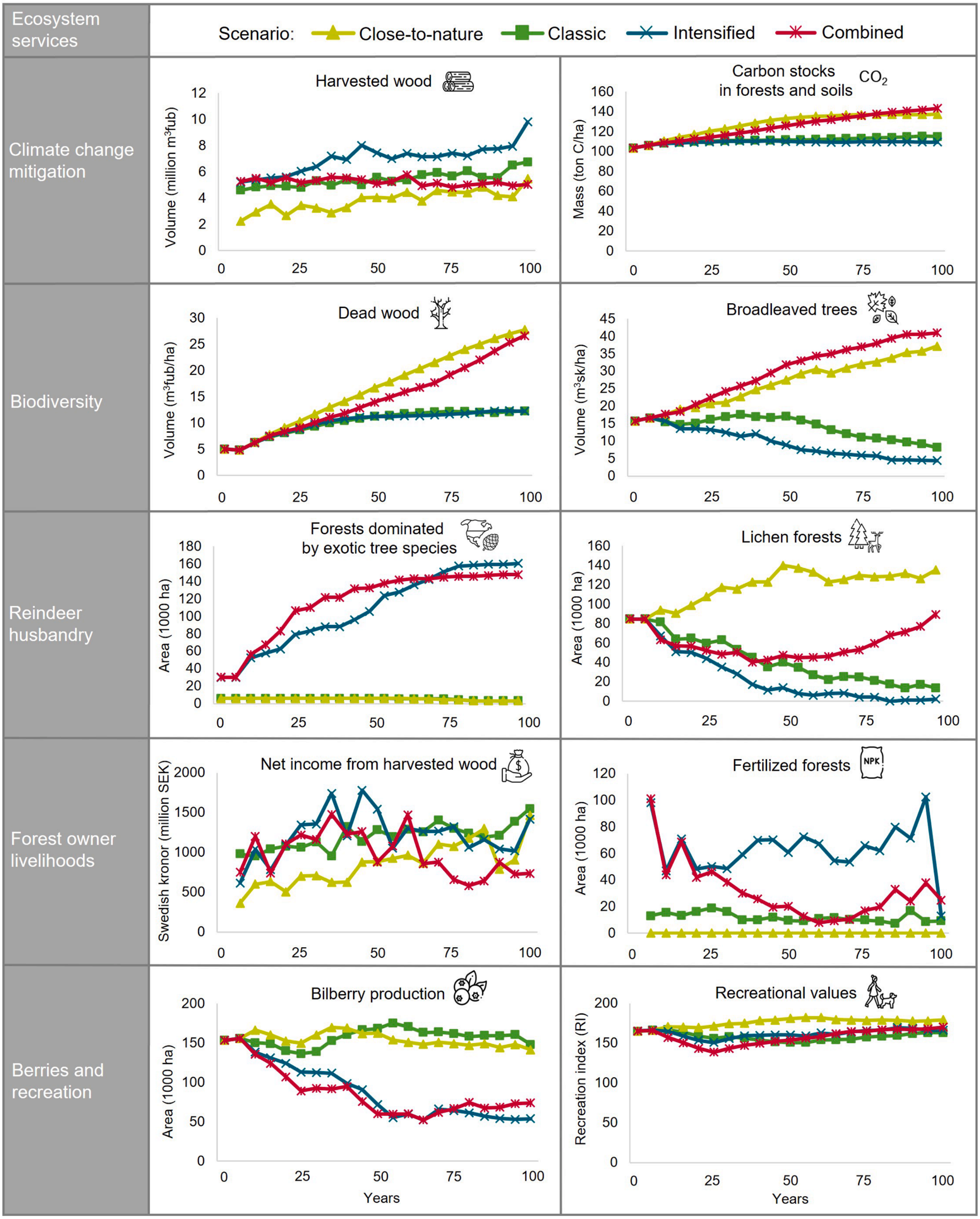

Fig. 5. The provision of ecosystems services over time across a forest landscape of 354 000 ha in Västerbotten county in northern Sweden. Each ecosystem service is represented by two indicators and the forest landscape was subjected to four different forest management scenarios: close-to-nature, classic, 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,

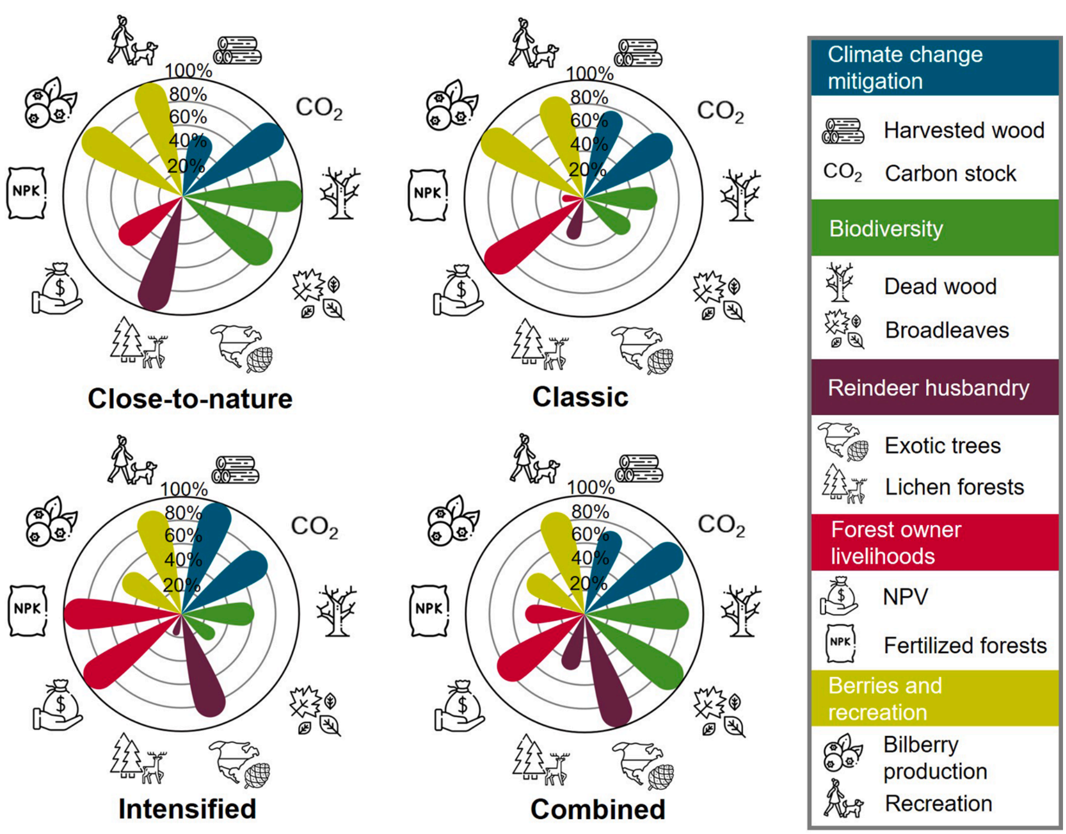

Fig. 6. The scenarios relative provision of ecosystems services, using the highest value for each indicator as a reference. Please note that areas dominated by non-native trees are influencing reindeer husbandry negatively. Images: Flaticon.com.

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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