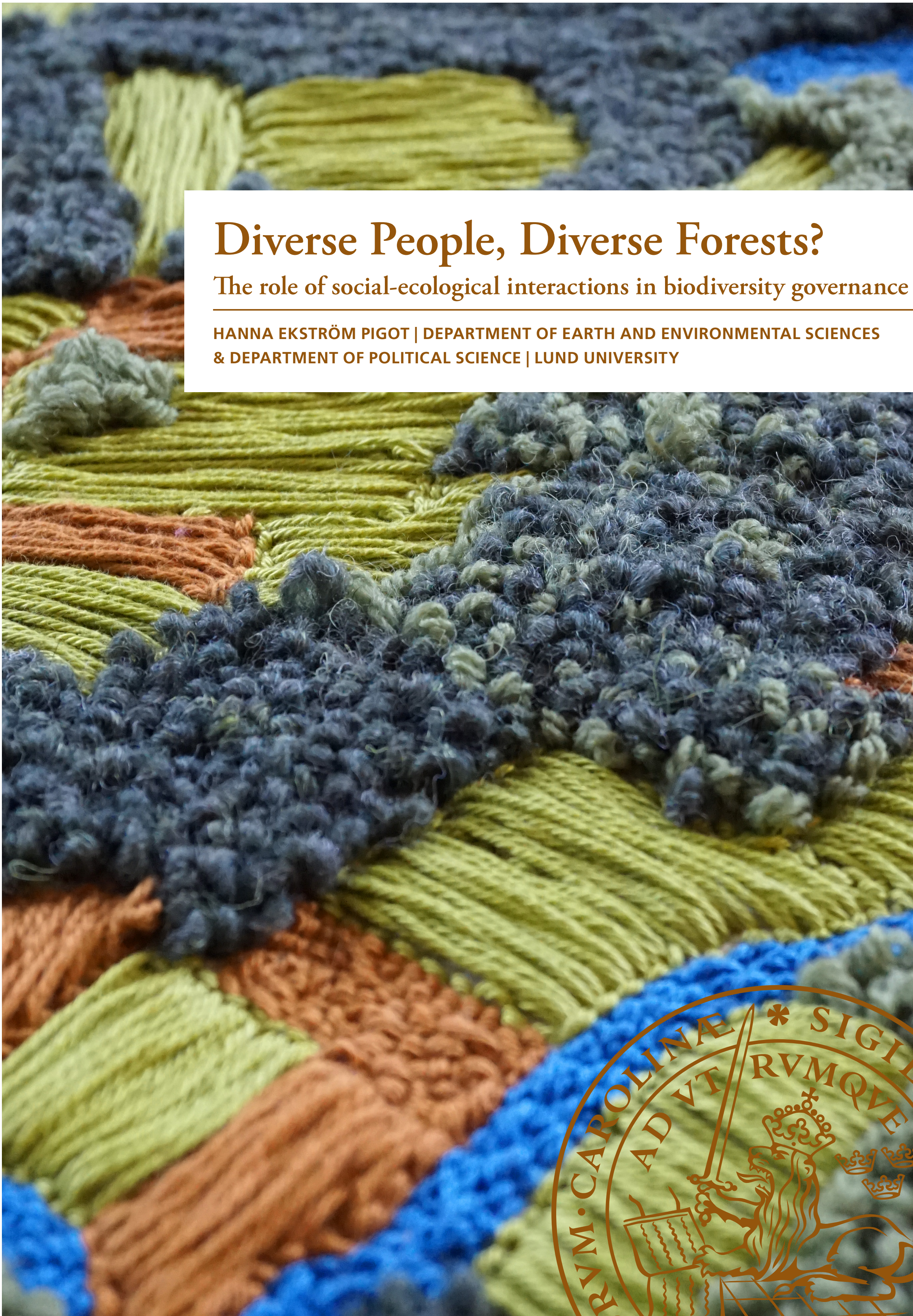
Diverse People, Diverse Forests?

The role of social-ecological interactions in biodiversity governance

Ekström Pigot, Hanna



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HANNA EKSTRÖM PIGOT | DEPARTMENT OF EARTH AND ENVIRONMENTAL SCIENCES & DEPARTMENT OF POLITICAL SCIENCE | LUND UNIVERSITY

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Hanna Ekström Pigot

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Abstract:

Despite decades of claimed ambitions to increase environmental consideration in forest policy, biodiversity loss in boreal forests continues. As the pressure on forest biodiversity intensifies, due to land use competition, shifting societal demands, and climate change, it is crucial to address the shortfall of biodiversity policies in reaching their intended outcomes. Voluntary policy instruments are increasingly suggested as conservation strategies in managed forests, but we lack understanding of the joint influence of social processes, like diverse landowner values, and ecological processes, like diverse forest conditions, on policy outcomes. The aim of this thesis is to understand I) how different methodological approaches capture social-ecological interactions, and II) how social-ecological interactions influence the implementation and outcomes of biodiversity policies in managed forests. Four subprojects focus on case studies in Sweden and Finland, and combine methods of walking interviews, agent-based modelling, cluster analysis, and literature reviews. The results demonstrate that i) forest agent-based models are promising for combining social and ecological data, but few models explicitly model their interactions, and ii) choice of method influence which forest owner characteristics that are highlighted in forest owner typologies. These insights emphasise the need for methodological reflexivity in research on forest policy, particularly when findings inform policy design. The thesis contributes with two main insights on the role of social-ecological interactions for biodiversity policy implementation: iii) For interactions on a local and individual level, forest owners may hold strong emotional or cultural connections to their forest, yet still make management choices that conflict with conservation objectives, expanding perspectives on the relational values-concept, iv) On a national and landscape level, spatially targeted voluntary policy instruments can enhance the quantity of protected areas, ecological quality, and landscape connectivity, providing support for policy making. In summary, the thesis shows how a social-ecological system-lens helps in understanding factors that hinders or enables biodiversity protection, from individual values to national policies. By combining empirical analysis with methodological reflection, the thesis contributes to developing more nuanced, ecologically effective, and context-aware approaches to forest biodiversity policy.

Key words: social-ecological systems, private forest owners, voluntary policy, relational values, forest biodiversity, connectivity

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Abstract

Despite decades of claimed ambitions to increase environmental consideration in forest policy, biodiversity loss in boreal forests continues. As the pressure on forest biodiversity intensifies, due to land use competition, shifting societal demands, and climate change, it is crucial to address the shortfall of biodiversity policies in reaching their intended outcomes. Voluntary policy instruments are increasingly suggested as conservation strategies in managed forests, but we lack understanding of the joint influence of social processes, like diverse landowner values, and ecological processes, like diverse forest conditions, on policy outcomes. The aim of this thesis is to understand I) how different methodological approaches capture social-ecological interactions, and II) how social-ecological interactions influence the implementation and outcomes of biodiversity policies in managed forests. Four subprojects focus on case studies in Sweden and Finland, and combine methods of walking interviews, agent-based modelling, cluster analysis, and literature reviews. The results demonstrate that i) forest agent-based models are promising for combining social and ecological data, but few models explicitly model their interactions, and ii) choice of method influence which forest owner characteristics that are highlighted in forest owner typologies. These insights emphasise the need for methodological reflexivity in research on forest policy, particularly when findings inform policy design. The thesis contributes with two main insights on the role of social-ecological interactions for biodiversity policy implementation: iii) For interactions on a local and individual level, forest owners may hold strong emotional or cultural connections to their forest, yet still make management choices that conflict with conservation objectives, expanding perspectives on the relational values-concept, iv) On a national and landscape level, spatially targeted voluntary policy instruments can enhance the quantity of protected areas, ecological quality, and landscape connectivity, providing support for policy making. In summary, the thesis shows how a social-ecological system-lens helps in understanding factors that hinders or enables biodiversity protection, from individual values to national policies. By combining empirical analysis with methodological reflection, the thesis contributes to developing more nuanced, ecologically effective, and context-aware approaches to forest biodiversity policy.

Populärvetenskaplig sammanfattning

Trots att miljö- och produktionsmål formellt varit jämställda i skogspolitiken under de senaste decennierna, är förlust av biologisk mångfald ett fortsatt problem. Inom skogspolitiken i Sverige och Finland har strategier för ökat skydd av biologisk mångfald framhållit frivillighet, som certifiering av skogsbruk och frivilliga avsättningar mot kompensation. Det saknas dock kunskap om hur resultaten av dessa strategier påverkas av samspelet mellan privata skogsägares olika mål och varierande ekologiska förutsättningar. För att kunna bidra till politiska åtgärder som leder till effektivt skydd av biologisk mångfald men också tar hänsyn till lokala förutsättningar behövs en bättre förståelse av samspelen mellan skogsägares mål och värderingar, politiska åtgärder och variationer i skogslandskapet.

Denna avhandling syftar till att sätta själva samspelen mellan skogsägare, politik och skogen i fokus. Det görs dels genom att undersöka hur verktyg inom forskningen tar dessa samspel i beaktande, och dels genom att utöka förståelsen för hur dessa samspel påverkar implementeringen av skydd för biologisk mångfald. Avhandlingen bygger på tidigare forskning inom skogspolitik, skogsbruk, landskapsekologi och socioekologiska system. Genom fyra delstudier och ett tvärvetenskapligt angreppssätt inkluderar avhandlingen intervjuer, agentbaserad modellering, statistisk klusteranalys och litteraturöversikt.

Genom att undersöka metoder som skogsmodellering och kategorisering av skogsägares attityder och värden, visar resultaten att metodval kan spela en stor roll för hur samspelen mellan sociala och ekologiska processer representeras och förstås. I jämförelsen av metoder för att gruppera skogsägares attityder, ses metodval ge effekter både för vilka attityder som anges som typiska, och för hur skogsägare fördelas mellan grupperna. Vidare pekar resultaten på att agentbaserad modellering är en lämplig metod för att kombinera sociala och ekologiska data, men att få modeller uttryckligen simulerar samspelen mellan dessa. Dessa insikter visar vikten av att forskare reflekterar över metodval, särskilt när deras resultat används som stöd för att utforma politiska åtgärder.

På en lokal nivå uttrycker de intervjuade skogsägarna i södra Sverige starka känslomässiga och kulturella kopplingar till skogen. I vissa fall ligger dessa kopplingar till grund för beslut som gynnar den biologiska mångfalden, medan liknande underliggande värden i andra fall kan stödja beslut som leder till minskad mångfald. Insikterna bidrar till bättre förståelse av vad som på lokal nivå hindrar och möjliggör skydd av biologisk mångfald. Det bidrar också till att utveckla den vetenskapliga diskussionen om hur relationen till naturen påverkar beslutsfattande och agerande. På en nationell nivå visar analysen av det finska programmet för frivillig avsättning, METSO, att politiska mål som endast är baserade på areal av skyddad skog riskerar att missa områden med höga skyddsvärden. Genom att i utformningen av politiska åtgärder ge ökad vikt till rumslig prioritering av lämpliga områden kan både antalet skyddade områden, deras kvalitet och deras grad av sammankoppling förbättras.

Sammantaget bidrar avhandlingen till att lyfta sociala och relationella aspekter av skogsägande och till ökad förståelse av hur sociala och ekologiska aspekter samspelar inom frivilligt skydd av biologisk mångfald. Detta stödjer utvecklingen av åtgärder för skydd av biologisk mångfald inom skogspolitiken som är mer nyanserade, effektiva, och anpassade efter lokala förutsättningar.

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As I tried to step outside one academic box though, I soon realized that I ended up in another. In that I am forever grateful to Åsa Knaggård, for helping me navigate the expectations from different departments and research traditions. Thank you for reading and providing feedback, spreading kindness, and for your engagement in the PhD community.

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List of papers

Paper I

Ekström, H., Droste, N., & Brady, M. (2024). Modelling forests as social-ecological systems: A systematic comparison of agent-based approaches. Environmental Modelling & Software, 175, 105998.

Paper II

Ekström, H., Danley, B., Clough, Y., & Droste, N. (2024). Barking up the wrong tree? - A guide to forest owner typology methods. Forest Policy and Economics, 163, 103208.

Paper III

Ekström Pigot, H.(*in review*) Both heritage and resource – a relational approach to forest owners' decisionmaking. *Submitted to* People and Nature.

Paper IV

Ekström Pigot, H., Byari, M., Brady, M.V., Clough,Y., Brown,C., Rounsevell,M., & Droste., N. How policy design shapes connectivity – Modelling biodiversity protection in managed forests. *Manuscript.*

Author contributions

I. Hanna conceptualised the study with input from Nils and Mark VB. **Hanna** performed the literature review and analysis, visualised the results and wrote the initial draft. All co-authors contributed to writing, reviewing and editing.

II. Hanna conceptualised the study with input from all co-authors. **Hanna** performed data curation, developed the methodology, and performed analysis with input on R-scripts from Brian and Nils. **Hanna** prepared the initial draft, and all co-authors contributed to reviewing and editing the final manuscript.

III. As single author, **Hanna** conceptualised and performed the study.

IV. Hanna conceptualised the study, with contributions from Mohamed and Nils. **Hanna** prepared the data and developed the model CRAFTY-Finland using the framework and user interface developed by Mohamed, Calum, and Mark R. Mohamed supported with necessary code development. **Hanna** performed model calibration with support from Mohamed, Mark VB, Calum, Yann, and Nils. **Hanna** analysed and visualised the results, with input from all co-authors, and wrote the initial draft. All co-authors contributed to reviewing and editing the final manuscript.

Authors: Hanna Ekström Pigot, Calum Brown, Mohamed Byari, Mark V. Brady, Yann Clough, Brian Danley, Nils Droste, and Mark Rounsevell

Additional papers not included in the thesis

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Sánchez-García, P. A., Jónás, K., Pellowe, K. E., Ekström, H., Scheuermann, M., & Loft, L. (2025). Toward an intersectional equity approach in social–ecological transformations. Global Sustainability, 8, e2.

Droste, N., Brownell, H., D'amato, D., Ekström, H., Fridén, A., Harrinkari, T.,Iliev, B., May, W., Nebasifu, A., & Thomsen, M. (2025). Evaluating transformative policies in complex land-use systems. Ecological Economics, 238, 108734.

Nebasifu, A. A., D'Amato, D., Ekström, H., Pietarinen, N., Fridén, A., Harrinkari, T., Iliev,B., Brownell, H., May, W., Brockhaus, M., Thomsen, M., & Droste, N. (2025). Comparing Nordic forest governance: Key informant perspectives. Forest Policy and Economics, 170, 103368.

Nebasifu, A., Ekström, H., Iliev, B., Pihlainen, S., Linser, S., Polo-Villanueva, F. D., Viljanen,A., Charlier,M., Rauhanur Rahman, Md., Kuhlman., J, Assmuth,A., Garfield,D., D'Amato, D., & Droste, N. (2025). Avoiding Nightmare Forests: Insights From a Co-Creative Workshop. Futures & Foresight Science, 7(2), e70010.

Fridén, A., D'Amato, D., Ekström, H., Iliev, B., Nebasifu, A., May, W.,Thomsen,M., & Droste, N. (2024). Mapping two centuries of forest governance in Nordic countries: An open access database. Forest Policy and Economics, 160, 103142.

Nebasifu, A. A., Pietarinen, N., Fridén, A., Ekström, H., Harrinkari, T., D'Amato, D., & Droste, N. (2024). Forest policy in Nordic countries: Expert opinions on future needs, uncertainties, and recommendations. Trees, forests and people, 16, 100582.

Nebasifu, A., Fridén, A., Ekström, H., Pietarinen, N., Harrinkari, T., D'Amato, D., & Droste, N. (2024). An outlook on modalities in Nordic forest governance. Forests Monitor, 1(1), 16-38.

Introduction

The year is 1826. The month of May is drier than usual, and a farmer is about to split a big block of stone to plough his field. The usual procedure is to heat the stone followed by a shock of cold water to crack it. But a spark from the fire catches the wind and settles in the dry brush. Soon, smoke rises over the treetops. We fast-forward two hundred years to May 2026. The trained eye can spot the traces left by the fire: crooked tree trunks growing around burned scars. If you are lucky, the coal-flake lichen has finally established its tightly sitting, roof-tile-like scales along the rough bark. This lichen grows on pine trees once burned to the core.[1] *The coal-flake lichen requires forest structures that are rarely found in current intensive forest management systems. It starts to grow in open forests of mixed coniferous trees 100–300 years after a severe fire. The lichen is considered close to threatened in Sweden and threatened in Finland (Eide et al., 2020; Hyvärinen et al., 2019). Many species in boreal forest ecosystems depend on long, uninterrupted ecological processes. At the same time, forests are used in other ways and for other reasons compared to 200 years ago. The rarity of the lichen is thus not only a consequence of slow ecological processes but the outcome of social choices, including policies, economic priorities, and governance systems. To protect biodiversity, we need to understand how forests are shaped by the interaction of people and the environment, over time and place.*

On a global level, boreal forests are a biodiversity hotspot providing important refuge for many species, though their status as such is not as visible as for tropical forests (UNECE, 2024). In 2022, the Kunming-Montreal Global Biodiversity Framework was adopted as the most ambitious international agreement to date on biodiversity protection. The agreement aims to establish 30% of Earth's land as networks of well-connected protected areas by 2030. It was followed by a report that highlighted the role of forests to reach the targets (Secretariat of the Convention on Biological Diversity,

[1] The story about the fire and the lichen is fictional, but inspired by the events of the severe forest fire which started on the 16th of August year 1868, in Småland, Sweden (Kalmar, 1868).

2022, 2024). As the pressure on forest biodiversity intensifies, due to land use competition, shifting societal demands, and climate change, attention to biodiversity protection in forest governance has increased. However, forest biodiversity is still in decline, with biodiversity protection unevenly distributed across landscapes (Swedish Forest Agency, 2022). The "worthless lands" thesis argues that the uneven distribution occurs because protection for nature's own sake has been secondary to interests of agricultural and forestry use (Runte, 1977). This leads to a higher degree of protected areas in low productivity landscapes and lower degree of protected areas on productive lands (Angelstam & Andersson, 2001; Nilsson & Götmark, 1992; Pressey, 1994).

In the boreal region, Sweden and Finland are known for large forestry sectors and historically ambitious environmental goals. In both countries, forests are the most species-rich landscape types and a major group of endangered species are connected to forests (Eide et al., 2020; Hyvärinen et al., 2019). Forest management is dominated by the practices of rotation forestry, where even-aged stands are harvested and regenerated in regular cycles (Brukas & Weber, 2009). In the beginning of the 1990s, forest policy in both Sweden and Finland changed from largely regulatory frameworks to a larger emphasis on voluntary measures, advisory services, and forest sector responsibility (Appelstrand, 2012; Fridén et al., 2024). The general policy direction has been to promote voluntary policies like certification schemes, centring the role of private forest owners in biodiversity policy implementation.

Forest owners' attitudes, values, and management goals can influence their responses to policy incentives, but management decisions also depend on site specific conditions. At the same time, varying ecological conditions and landscape structures can amplify or constrain policy outcomes, but are not always integrated into policy design. How social and ecological aspects jointly influence biodiversity outcomes are still not well understood.

To better understand the role of social-ecological interactions in biodiversity governance, we need tools that take these interactions into account. Research related to forest policy implementation is undertaken through methods from qualitative analysis and statistical classification to field work, and modelling. Each method captures specific aspects of forest systems but also comes with assumptions and limitations that influence what researchers observe. The methodological choices are not neutral; they actively shape our understanding of social-ecological interactions and the policy recommendations that follow.

As an overarching problem, this thesis is motivated by a continued decline of biodiversity in managed forests and unevenly distributed conservation measures. To develop more effective and context-sensitive biodiversity policies requires both a better understanding of how interactions between landowners, policies, and forests impact biodiversity policy implementation, as well as a critical examination of the methodological approaches used to study these interactions.

Aim and research question

Although the drivers of land use change and biodiversity loss are usually a combination of social, political, environmental and economic factors, these factors are often considered to belong to different disciplines (Filotas et al., 2014), which hinders our ability to understand how they interact. Understanding their interactions is key to explaining why biodiversity policies succeed in some contexts and fail in others. This thesis helps to bridge this gap by disentangling the social-ecological interactions in forest policy and management.

I approach this using a social-ecological systems lens, which highlights the interplay between the two processes for system outcomes. It is beyond the scope of this thesis to conduct an analysis that considers all aspects of forests as social-ecological systems. However, to improve our understanding of the outcomes of voluntary biodiversity policies, I focus on the social-ecological interactions between forest owners, institutions and forests. The policy process literature shows that the development and negotiation of a policy is important for understanding how it is implemented. However, this project focuses on processes that occur after a policy has been approved. Throughout the work, I use *social dimensions* when referring to forest owners and institutions, in local and national contexts. My focus lies on forest owners' decision-making, and on the interactions between forest owners and policy. By *interactions with ecological processes,* I refer to how people and policy interact with ecological processes like spatial variability in the landscape, and ecosystem processes like nutrient cycling and forest growth.

The aim of this thesis is twofold, first to understand how methodological choices influence how social-ecological interactions are represented and interpreted, and secondly, how the process of biodiversity policy implementation is influenced by social-ecological interactions. The thesis is guided by the following overarching research questions:

I) How do different analytical and modelling approaches capture social-ecological interactions, and how do methodological choices influence the insights we gain from them?

II) How do social-ecological interactions influence the implementation and ecological outcomes of biodiversity policy in managed forests?

Contributions to environmental science

Using concepts and approaches from different disciplines, this thesis is a mixed-methods study grounded in environmental science. Environmental science treats "the many ways that we affect our environment and the many ways that we can address these issues"(Chiras, 2009, p. 5). It offers various perspectives and tools to understand human-nature interactions. In contrast to some of the disciplines in which the field has its roots in, environmental science highlights the interactions and feedbacks within and between social and environmental systems as important and perhaps the foremost object of analysis (Chiras, 2009).

Environmental science is inherently interdisciplinary, which may be pursued with different goals, for example the four outlined by Öberg (2011): i) pragmatic; to solve a practical problem, ii) conceptual; to contribute to new or emerging fields, c) epistemological; to understand in what way disciplinary structures cause problems, and/or d) ontological; to understand in what way societal perceptions of the issue cause problems. This project departs from a pragmatic approach, for which combining knowledge from different fields is necessary to understand and contribute to sustainable forest governance. Borrowing ideas across disciplines has proven to be the most influential information transfer method in forestry (Steele & Stier, 2000). In addition, throughout the thesis I pay attention to the conceptual and epistemological aspects of interdisciplinarity, to contribute to strengthening attention to these aspects in environmental science analysis (Persson et al., 2018).

Empirically, this thesis contributes to environmental science by showing how the attention to social-ecological interactions supports understanding what hinders and enables biodiversity protection, from the local to national level. Methodologically, the results contribute insights about how social-ecological interactions can be recognised when studying environmental challenges in forestry. Conceptually, the project expands the perspective of landowner behaviour through a lens of relational thinking. This broadens the traditionally common perspective of landowners as foremost rational economic optimisers to an understanding that emphasises a diversity of values, and that the connection between landowner values and behaviour is mediated by the context in which management decisions are taken.

Literature review

Forest policy and forest management are usually studied in separate bodies of literature (Wallin, 2017). The interaction between the policy level and management actions on the ground is a key aspect of biodiversity policy implementation. In the following, I outline the contributions from each field to the issue of biodiversity policy implementation, together with a landscape ecological perspective on biodiversity protection, and insights on policy implementation from a social-ecological system perspective.

Forest policy

Implementing biodiversity conservation in forest policy has raised several challenges addressed by researchers in forest policy analysis: how it leads to new modes of governance, a changing role of the state, policy integration across multilevel governance within the EU, and dynamics between actors in policy processes (Arts, 2014; Bjärstig et al., 2024; Imran et al., 2025; Johansson, 2012; Pülzl et al., 2018). These insights have been generated from multiple methods and theories, reflecting the range of disciplines that inspire current forest policy analysis[2]. Initially, the field of forest policy analysis was considered a sub-discipline of forest science. The studies were often aimed at directly benefiting practitioners, and the use of policy process theories was limited (Arts, 2012; Wiersum et al., 2013). Over time, policy theories entered the field of forestry education. Moving from prescriptive to analytical focus, key scholars of the field argued for the so-called empirical-analytical approach (Krott, 2005). This approach is often said to be a paradigm shift, aimed at analysing policy processes without normative judgments. The approach has continued to inform forest policy analysis and the field has been largely influenced by positivism, which postulates an objective reality and generalizable laws (Ladyman, 2002). However, analysis paying

[2] This introduction to forest policy analysis comes from a Northern and European perspective, which reflects the context of the study, but which is also a dominating narrative. For the field to contributing to diversifying perspectives and contribute to social justice, this aspect that could need more discussion (Koch & Tetley, 2023).

attention to how knowledge and power structure what is considered true, has gradually taken a larger role in the field. These studies have placed more emphasis on aspects of power, norms, and justice and showed the role of these aspects for the legitimacy and uptake of biodiversity policies (Arts, 2012; Koch & Tetley, 2023; Lenzi et al., 2023). In this strand of literature, recent studies have investigated the importance of understanding social dynamics like interactions in social networks to spread norms of importance for biodiversity protection among forest actors (Loch et al., 2025).

New modes of governance

New modes of governance that complement or replace the traditional role of the state have been a topical research issue in forest policy analysis for over a decade (Arts, 2014). Examples include forest certification schemes (Giessen et al., 2016; Johansson, 2012; Schlyter et al., 2009), public-private partnerships (Appelstrand, 2012; Hayter & Clapp, 2020; Widman, 2016), payment for ecosystem services (PES) (Batpurev et al., 2025; Kangas & Ollikainen, 2022; Wunder et al., 2020) as well as other types of voluntary agreements (Miljand et al., 2021; Nebasifu et al., 2024).

Scholars in public administration have highlighted how these new modes of forest governance impact public-private interactions. These interactions have led to a change of public administration from having a traditional role of steering toward a new role of serving and facilitating collaboration between stakeholders (Appelstrand, 2012; Bjärstig et al., 2024).

Multilevel governance

Another body of policy analysis literature focuses on aspects of multilevel governance. In a European context, this often means questions of policy integration at the EU level. In contrast to the agricultural sector regulated by the Common Agricultural Policy (Giuliani & Baron, 2025), forest policy is considered a competence of the EU Member States. Many have argued that forest policy in the EU is fragmented, with a variety of policies in different sectors (Pülzl et al., 2018; Sotirov & Arts, 2018; Winkel et al., 2013). This causes policy overlaps and conflicts between different policies' objectives (Aggestam & Pülzl, 2018; Winkel & Sotirov, 2016). In the EU Biodiversity Strategy for 2030, forests are emphasised as being crucial for biodiversity protection (EC, 2020), while the European Climate law (EU, 2021) and the Circular Economy Action Plan (EC, 2021) stress a more production-oriented role of forests for carbon removal and as basis for the biobased sector (Hermoso et al., 2022). Research on the EU level indicates that biodiversity protection is a recurrent theme in recent policy developments (Bottaro et al., 2024). On a national level, implementation has been slower due to discourses of delayed action (Pietarinen et al., 2025). This highlights the importance of understanding the interactions between different institutional levels as well as the dynamics of policy processes.

Policy processes, implementation and inclusion

In both Sweden and Finland, processes of policymaking have often been interpreted as being developed under the influence of strong coalitions emphasising production or environmental conservation (Harrinkari et al., 2016; Hysing & Olsson, 2008; Imran et al., 2025; Piiroinen et al., 2025), sometimes identifying a third coalition focusing on social or administrative values (Harrinkari et al., 2016; Piiroinen et al., 2025). Research on policy processes has thereby contributed insights about how interactions among different actors and institutions shape over time , and what core values these different groups of actors hold(Fleckenstein et al., 2025; Johansson, 2016).

Studies on the effectiveness of forest policy instruments have often focused on acceptance among forest owners, indicating the importance of specific spatial and temporal dynamics in affecting policy outcomes (Hertog & Brogaard, 2021; Schlyter et al., 2009). While policy instruments have developed, many of the historical obstacles continue to be reflected in current studies. Conflicting goals, lack of legal procurement, lack of technical instruments, and inadequate environmental knowledge were identified as affecting environmental performance negatively during the implementation (Eckerberg, 1987). Reviewing policies and programs of forest conservation, Börner et al., (2020) concluded that the effectiveness, measured as normalised effect size, was moderate on average. The authors refrain from recommending any best choice for policymakers, but state that PES schemes and protection of indigenous lands were considered the most effective policy instruments among those evaluated (Börner et al., 2020). However, the policy design and the local context matter for the implementation of different conservation policies (Wunder et al., 2020).

Studies of how indigenous Sámi actors, forestry, and environmental non-governmental organisations perceive the legitimacy and conflicts of forest certification (Johansson, 2014; Ott, 2025), the consultation processes aimed at addressing conflicting goals between reindeer husbandry and forestry (Roos et al., 2022), and mobilisation for political change (Harnesk et al., 2023) highlight the existing power asymmetries between actors, and the difficulties in current governance processes of managing these asymmetries. These studies highlight the importance of connecting policy implementation with experiences on the ground.

Forest owners and management

In Sweden and Finland, around half of the productive forest land is owned by small-scale private forest owners. In a comparison by Nichiforel et al.,(2018) of property rights in forestry across European countries, the degrees of decision-making freedom in Sweden, Finland, and Norway were relatively high. The authors judged one delimiting factor to be the rule of "everyman's right", which assures public access to privately owned forests and the public right to harvest non-timber forest products like berries and mushrooms (Nichiforel et al., 2018). The Swedish Forestry Model is guided by the principle "freedom under responsibility", emphasising the role of the private forest sector to balance production and environmental goals. Combined with strong property rights and policies based on voluntary principles, much of the literature has focused on understanding the connection between private forest owners' attitudes and behaviour (Butler et al., 2023; Danley et al., 2021; Fischer et al., 2010).

This has, however, not always been the case. The term non-industrial private forest owner was coined at a time when the greatest concern in the field was that small-scale private forest owners did not produce enough timber, according to the industrial commodity production model (Fischer et al., 2010). A common assumption among forestry professionals was that small-scale forest owners held values closer to the forest industry than to the general public (Bliss, 2000). In recent decades it has become widely accepted that private forest owners manage for multiple objectives (Bengston et al., 2011; Koskela & Karppinen, 2024; Weiss et al., 2019).

Forest owner typologies

Consequently, a large part of the forest owner and management literature has since then been concerned with understanding the diversity of owners' values, beliefs, attitudes and their management decisions. A common approach has been to create forest owner typologies (Boon et al., 2004; Danley, 2019b; Ingemarson et al., 2006; Kuuluvainen et al., 1996; Urquhart et al., 2012; Van Herzele & Van Gossum, 2008). Typologies are often motivated by the aim of providing a better understanding of the diversity among forest owners. Comparing typologies of European forest owners, typologies were commonly created quantitatively, based on k-means clustering (Ficko et al., 2019). Despite typology formation being a common practice to study forest ownership, little is known about how approaches to typology formation compare and few typologies are revisited, which calls for taking a deeper look at methods for typology creation.

In the Finnish context, a typology based on national surveys has been used in several cases, for example, to study the connection between different types of forest owners and timber harvests (Favada et al., 2009) and the degree to which demographic differences can explain timber supply (Kuuluvainen et al., 1996, 2014). These studies indicated differences in management between groups, for example that multiobjective and self-employed owners harvested about 2m^3/ha/year more than recreationists and indifferent owners. Although the literature contains more examples of these indications of connection between objectives and management behaviour, a recurrent criticism toward typology studies has been that few studies directly address the link between values and behaviour (Ní Dhubháin et al., 2007; Novais & Canadas, 2010; Stanislovaitis et al., 2015).

The value-action gap

The value-action, or attitude-behaviour, gap has been addressed in a large body of literature within and beyond forest management (M. Andersson, 2012; Blennow, 2012; Götze & Naderer, 2019; Hengst-Ehrhart, 2019). The value-action gap refers to the difference between what people say and what they do, defined as the discrepancy between an individual's stated values and their actions. Within the forest management literature, attempts to explain the gap have been made by drawing attention to how forest owners' decisions are affected by structural factors like public policies, environmental issues, and markets (Deuffic et al., 2018), and by highlighting value misalignment between landowners and forestry and conservation experts (Caputo et al., 2026). Suggestions have also been made to bridge the gap, for example, by strengthening education and information to forest owners (Uliczka et al., 2004). Despite this widespread recognition of the value-action gap, it is a recurring assumption that management behaviour can be proxied through stated values and attitudes. There is thus a need to understand to what extent values translate into actions in practical decision-making.

In a study focusing on the diversity within the commonly identified category of passive forest owners, Matilainen and Lähdesmäki (2023) highlighted how the participating Finnish forest owners, who had been categorised as passive forest owners in earlier studies, expressed a variety of management goals. They conclude that the label of passive may lead to false assumptions about forest owner behaviour. As an example, some were passive when it came to timber sales, but passionate and active in management activities. The study emphasises the emotional role in management decisions (see also Lähdesmäki & Matilainen, 2014) and calls for complementary qualitative and in-depth studies of forest owners' decision-making.

Some studies have suggested that policies should be adjusted to target different forest owner types with different strategies, for example, by targeting some groups with a production logic and others through their interest in environmental values (Boon & Meilby, 2007). Others have seen weak relationships between ownership objectives and willingness to take part in forest certification, thereby implying a limited appeal of targeting policy instruments to different owner types (Danley, 2019b; Serbruyns & Luyssaert, 2006). Additionally, come studies indicate that biodiversity-enhancing measures may be taken based on other motivations than environmental concern. In a mixed-methods study of certified forests in Sweden, the motivations were almost equally based on environmental as economic reasons, and the last proportion of owners said they based their decision to certify the forest on their forest owner association's recommendation (Johansson & Lidestav, 2011). To summarise, the forest owner and management literature contributes with insights relevant for biodiversity policy implementation about the practical possibilities and limitations.

Biodiversity- A landscape perspective

A reason why forestry is identified as an industry with high impact on biodiversity is that naturally growing mixed-age, mixed-species-forest ecosystems have been replaced with planted even-aged monocultures (Eide et al., 2020). The system is effective in wood production and profitable for the industry, and in Sweden, the standing wood volume has more than doubled since the 1920s (Jacobsson et al., 2025). However, the effective rotation-forestry system has led to forest stands that support few forest specialist species (Savilaakso et al., 2021), simplified landscapes with habitat fragmentation and loss of natural structures that had evolved over thousands of years (Fahrig, 2003). To balance the critical need of strengthened conservation strategies and the ability to use wood as a renewable resource, biodiversity policies target both biodiversity-enhancing measures in production forests, as well as enhanced strategies for protected areas.

Research within biodiversity conservation has long stressed the importance of addressing both loss of habitats, and the degradation of habitat quality (Normander et al., 2012; ten Brink, 2000). Efforts have been made to create indicators that take both ecosystem quantity and quality into account when measuring changes in biodiversity. Quantity would often be measured as the habitat area, and quality, for example, as a combination of species abundances (Normander et al., 2012; ten Brink, 2000). A broad range of indicators have been suggested to assess forest biodiversity in Europe, both structural indicators like the volume of deadwood, and species indicators like types of beetles, birds, or lichens (Gao et al., 2015). In addition to measuring quantity and quality, the issue of habitat fragmentation (Bailey, 2007; Fahrig, 2003) has highlighted the importance of landscape connectivity. Connectivity between habitats is necessary for the survival of many species, as well as to sustain important ecological functions (Brodie et al., 2025; Tucker et al., 2018). Through the Kunming-Montreal Global Biodiversity Framework, strengthening the connectivity between protected areas was raised to an international policy level.

A key issue is how to define and scientifically ground the concept of a "well-connected" network of protected areas in a way that is meaningful both ecologically and socially across landscapes and scales (Brodie et al., 2025). While it is critically important to establish new protected areas to make sure, for example, that remaining old-growth forest ecosystems are conserved (R. Andersson & Östlund, 2004; Jönsson et al., 2009), researchers have pointed to the importance of addressing the areas in between protected areas. This area is often referred to as the landscape matrix (Fletcher et al., 2024), and human activities like urban sprawl, road construction, and forestry operations in the landscape matrix hinder the flow of species and ecological processes (Zeller et al., 2012). When habitat fragmentation occurs, key species may become isolated, community structures are affected, and ecological processes like nutrient cycling, seed dispersal, and pollination may change (Bailey, 2007; Jacquemyn et al., 2001).

The complexity of biodiversity is difficult to capture in measurable indicators that are valid across scales and varying landscape contexts (Gao et al., 2015). Nevertheless, from a policy perspective, it is important to find approaches to assess biodiversity changes on a landscape level. This provides an opportunity for research to contribute with approaches that take all three aspects of biodiversity change on a landscape level into account: habitat quantity, ecological quality, and landscape connectivity (Hodgson et al., 2009).

Social-ecological interactions

From social-ecological systems (SES) literature, policy outcomes are understood as emerging from the interactions between social and ecological processes. Forests are often brought up as a classic example of an SES. In studying forest systems as shared and governed by multiple actors, SES has been a common approach to understand complex dynamics of ownership and responsibility (Davenport et al., 2016; Oberlack et al., 2015; Schlager & Ostrom, 1992). Examples of SES studies applied to Nordic forestry have focused on multi-stakeholder collaborations (Elbakidze et al., 2010), multi-use of forests (Moen & Keskitalo, 2010), evaluating management strategies for climate change mitigation (Blanco, Brown, et al., 2017; Klapwijk et al., 2018), and conflicts around Swedish moose management (Sandström et al., 2013). However, the insights from SES literature of cross-scale interactions, time lags in human-nature interactions, and the importance of understanding heterogeneous actors, as important factors for understanding forest dynamics, have so far not had a breakthrough in forest modelling communities (Filotas et al., 2014; Fischer, 2018; Messier et al., 2015; Nocentini et al., 2017; Sotirov et al., 2019).

Researchers studying natural resource governance from a social-ecological systems perspective often highlight an understanding based on complex systems. The studied system is imagined as consisting of diverse subsystems, time lags, resilience, interactions, and feedback loops (Messier et al., 2015; Preiser et al., 2018). The actions performed on the microlevel by individual agents in the system are contributing to emerging patterns on the macrolevel. This conceptual background has supported studies of cascading ecological effects, interactions between multiple governance institutions and system resilience (An et al., 2020; Bourceret et al., 2021; Schouten et al., 2013).

Agent-based modelling (ABM) has been a common method for modelling such complex, evolving systems, where ecological and social data are combined to study the emerging patterns in resource governance (Janssen & Ostrom, 2006; Schulze et al., 2017). ABMs have often been used as a conceptual modelling tool to explore issues within natural resource governance, like risk-mitigation strategies among land managers (Tilman et al., 2018), the impact of formal rules versus informal norms on forest-related outcomes(Adhikari & Agrawal, 2013), and management strategies in fire-prone landscapes (Spies et al., 2018). In recent years, there has been a surge in the research community for developing ABMs that can be used for informing policy. As a consequence, researchers have raised the needs for better integration between empirical data and modelling (Schlüter et al., 2023), challenges associated with empirical calibration of an ABM (Elsawah et al., 2020; Polhill et al., 2019), and ABMs at scales beyond local (Lippe et al., 2019).

Research gaps and major contributions

Previous research has shown that the implementation of biodiversity policy is an issue of multilevel governance. Institutional aspects of multilevel governance have been relatively well studied, showing that new modes of governance require an increased focus on the interactions between private owners and public institutions. This is one example of the importance of understanding the interactions involved in the implementation of biodiversity policies. Connecting literature on forest policy, forest owner and management, landscape ecology, and social-ecological systems in resource governance, I see opportunities for research contributions in four main areas related to the social-ecological interactions of biodiversity policy implementation:

1. Capturing social-ecological interactions in forest modelling. Modelling has a strong position in forest research, with important contributions for understanding forest growth, nutrient cycling, and the effects of different management techniques. Literature on resource governance in social-ecological systems has highlighted the importance of recognising how social dimensions like diverse values among forest owners, individual and collective learning, and dynamic governance structures affect changes in forest systems, aspects rarely recognised in forest modelling. I contribute to bridging this gap by reviewing and comparing existing agent-based models in their ability to represent forests as social-ecological systems (Paper I). Based on the comparison, I develop an agent-based model that represents Finnish forests as social-ecological systems. The model is used to understand how social-ecological interactions influence the outcomes of voluntary biodiversity protection (Paper IV).

2. The methodological impacts for understanding forest owner characteristics. Despite typology formation being a common practice to study private forest owner behaviour, little is known about how approaches to typology formation compare and few typologies are revisited, which calls for taking a deeper look at methods for typology formation. Through the project, I address this gap by comparing five different approaches to typology formation. The comparison is used as a basis for creating a guide to typology formation (Paper II).

3. Values and action in forest management. Common theories in the forest management literature assume a link between values and action, however empirical data often shows a value-action gap. This calls for more attention to how values link to management decisions. In addition, to understand the dynamics of diverse values and biodiversity-enhancing measures, there is a need within the forest owner literature to include a broader focus on aspects of landownership, like connection to and care for the forest. I contribute to this gap conceptually and empirically by using a relational framework and walking interviews as a novel approach in the forest owner literature to understand local needs and values related to biodiversity protection (Paper III).

4. Policy impact on quantity, quality, and connectivity of protected areas. Landscape ecologists have emphasised that landscape-level assessments of changes in biodiversity need to take both habitat quantity, quality, and connectivity into account. We lack understanding about how interactions between social dimensions, like diverse landowner values, and ecological processes, like diverse ecological conditions, influence ecological outcomes of voluntary conservation measures. The development of an agent-based model contributes to addressing this gap by evaluating how social-ecological interactions impact the quality, quantity, and connectivity of habitat within a protected area network based on voluntary participation (Paper IV).

Conceptual background

> "Environmental scientists (natural and social) study complex, particular, deeply interconnected systems, and their knowledge claims are correspondingly specific and partial" (Lave et al., 2018, p. 12)

Environmental sciences draw on research from multiple disciplines with the aim of studying and supporting solutions to environmental problems caused by humans (Boersema & Reijnders, 2009). However, although research interests often, if not always, involve human activities and both ecological and social processes, integration of foundational theories from both social and biophysical sciences continues to be a challenge (Moran, 2011). Different theoretical perspectives influence both how we approach problems, and what kind of solutions we suggest.

Throughout the thesis, I engage with different theoretical perspectives, each offering a distinct interpretation of reality. One such perspective is rationalism, which is common in traditional forest management and silviculture. Based on objectivism, the rationalist approach views individuals as autonomous, rational decision-makers who base their choices on anticipated outcomes and the calculation of personal costs and benefits. According to this perspective, change can be achieved by offering strategic incentives that influence how people behave (Arts et al., 2014).

The second, institutionalist, approach forms the basis of social-ecological systems thinking. Institutions are here not seen as steering but influencing behaviour through rules or norms. As people are social beings, change is best achieved by institutions changing regulations (Arts et al., 2014; Ostrom, 1990).

The third approach is the practice-based model, underlying the thesis's parts of relational thinking. The practice-based approach is grounded in interpretivism, emphasising how individuals constantly interpret and shape rules and regulations (de Koning, 2014). As outcomes are considered to depend on the situation, context becomes important for understanding human behaviour and social change (Arts et al., 2014).

If we were to look at a forest map through the eyes of each theoretical perspective, they would most likely highlight different dimensions. The rationalist would see cells of varying biodiversity priority. The institutionalist would focus on the mix of different property regimes, and the one with a practice-based approach, would highlight the family that has farmed the area for generations. Although there are inevitable tensions between these perspectives in how they understand human behaviour, they also provide different lenses to look at the issue of biodiversity protection in managed forests. Throughout the thesis, I move between these perspectives. Below, I outline key concepts used in the different papers from research in social-ecological systems, environmental behaviour, landscape-scale conservation, and modelling.

Modelling the forest

One reason for the difficulties in integrating different perspectives is that the tools used to create knowledge about complex systems are often based on specific assumptions. Inspired by scholars in political ecology, critical physical geography, and science and technology studies (Jasanoff, 2004; King & Kraemer, 1993; Tadaki et al., 2015) I think of models not as neutral tools for analysing the world, but as ways of producing knowledge based on certain assumptions. It is commonly recognised that models need to represent specific processes and exclude others to handle complexity. This affects what kind of questions a model can answer and leads to models being developed for certain purposes. The broader implications of that are, however, less often discussed, as we come to certain conclusions based on what we have decided to include in our models. If we assume that human-nature interactions can be generally described through economic optimisation, we also exclude the possibility of drawing conclusions based on other social-ecological interactions. To contribute in this regard, the model used in the current study recognises forest owners' diverse motivations and simulates the societal importance of non-market ecosystem services, like biodiversity, recreation, and carbon sequestration, in addition to timber.

When economic liberalism entered forestry, the purpose of forest management became oriented toward maximum yield (Puettmann et al., 2009). German foresters developed the concept of *normalwald*, an ideal for a forest with evenly distributed age classes. Yield tables and models like the Faustmann formula were developed as a basis for taxation and planning, and to estimate optimal machinery capacity for harvesting. These also laid the ground for the first forest models (Pretzsch et al., 2008; Puettmann et al., 2009).

Early forest models were focused on statistical or empirical patterns of growth and yield, where regression models predicted future yield as a function of the current stand conditions (Shifley et al., 2017). They were followed by forest dynamics models to describe stand growth over time. In the 1960's, the biocentric view that management needed to be sustainable in terms of carbon and nutrient balance inspired the development of eco-physiological models (Pretzsch et al., 2008), and the technological development in the coming decades allowed for models based on detailed inventory plot data. When the societal and academic debate emphasised landscape interactions, forest landscape models were developed to simulate stand dynamics together with processes on the landscape scale at a spatially explicit framework. Other types of forest models common today are process-based models that simulate biogeochemical cycling, either dynamic vegetation models or so-called forest landscape models, for example LANDIS, LINKAGES, and LPJ-GUESS(Dijak et al., 2017; Lindeskog et al., 2021; Mladenoff, 2004). This very short explanation might give the impression of a linear development, but as Pretzsch et al.,(2008) write, these developments have happened in parallel, and the different types of models are used today for different purposes:

> "The history of forest growth models is not simply characterized by the development of continuously improved models replacing former, inferior ones. Instead, different model types with diverse objectives and conceptions were developed simultaneously. The objectives and structure of a model reflect the state of the art of the respective research area at its time, and document the contemporary approach to forest growth prediction. The history of growth modelling thus documents also the extended knowledge about forest functioning and structure." (Pretzsch et al., 2008, p. 1067)

Researchers who are studying the process of Integrated Assessment Models (IAMs) have emphasised the political nature of modelling, and the power that the modelling communities have in choosing what type of scenarios are modelled (van Beek et al., 2020). Modellers know that this is the nature of modelling, and are well aware of the uncertainties and limitations of their findings. Users tend, however, to interpret the results with much more certainty (MacKenzie, 1990). Together with a common understanding of a linear relationship between science and policy, there risks being little discussion in policy making about the underlying assumptions involved in scientific research. As the modellers Meadows et al.,(1982) wrote about modelling: "the most important forces shaping the future are social and political, and these forces are the least well represented in the models" (Meadows et al., 1982, p. 280).

But if we as environmental scientists want to contribute to solving concrete environmental problems, what to do with these critical perspectives on the tools used? Maybe these perspectives can be a reminder that methodological decisions have implications, and perhaps we can use the insights to structuring and focus our analyses and contributions. It is also an important reminder to clarify assumptions when communicating results. Models are developed for specific purposes, and the study's objective guides the choices for what to include and not include in the model design. In a review of IAMs, Gambhir et al.,(2019) observed three prominent perspectives in the critique of models used for future scenario explorations: those who argue for a) discarding the models, 2) improving the models, and 3) complementing models with other tools. This thesis is intended as a contribution to improving and complementing forest models. By 'improving and complementing', I mean incorporating social aspects and adopting a broader view of human-environmental relations in forest modelling (see for example Pereira et al., 2021). This does not guarantee improvement in the sense of more precise results; in fact, adding more variables and complexity most likely leads to greater uncertainty (Harremoës & Madsen, 1999). However, including a broader diversity of landowner values and ecosystem services improves the representation of different perspectives in models, in turn contributing to more inclusive policy support. This leads me to argue for the need to represent forests as social-ecological systems.

Forests as social-ecological systems

A social-ecological system (SES) understanding emphasises how social and environmental processes are intertwined. The concept was developed by researchers studying common-pool resource governance. In contrast to the Tragedy of the commons theory (Hardin, 1968) where Garrett Hardin concluded that common resources without rules for access would be overexploited, Elinor Ostrom and others showed how communities self-organised to build sustainable resource governance (Berkes & Folke, 1998; Folke et al., 2005; Ostrom, 1990, 2009a). These insights formed the basis for the concept of social-ecological systems, highlighting the interactions between institutions, resource users, and ecosystems (Ostrom, 2009a).

Based on years of empirical research on governing of the commons (Armitage, 2007; Epstein et al., 2020; Herrmann-Pillath, 2023; Holmgren et al., 2010; Ostrom, 1990), the social-ecological systems framework was developed as an approach to identify and diagnose problems in resource governance and to facilitate ecosystem-based management (Anderies & Janssen, 2013; Werdiningtyas et al., 2020). The framework provides a list of variables that affect outcomes of SES, and conceptualises the interaction between these variables (Partelow, 2018). As a basis for studying policy implementation in SES, policies are perceived and influenced by the implementing actors in each community and in a specific ecological system (Carr Kelman et al., 2023). Enacting a policy in a SES affects the interaction between humans and the environment and could therefore be thought of as adding a feedback loop in the system (Anderies & Janssen, 2013).

According to the Ostrom SES framework, the system is structured after variables in two different layers: first-tier and second-tier variables (Ostrom, 2007, 2009a). The first-tier variables are: resource units, resource system, resource actors, governance system, interactions, outcomes, and the social, economic and political settings, see adaptation to a managed forest in Figure 1. The second-tier variables further elaborate aspects of the first-tier variables. In a managed forest, resource units could, for example, be trees, berries, and herbs, while the resource system describes other parts of the system, like biodiversity, and processes of nutrient cycling and plant growth. Resource actors, here called forest actors, could, depending on the analysis, be thought of as households, landowners, hunters, or the local communities. The second-tier variables are used to further specify the different actors' past experiences, norms, and dependence on the resource. The governance system could be the local government, forest owner associations, regional boards, and policies. Between these are important interactions and outcomes, in activities like information exchange, conflicts, harvesting, and lobbying (McGinnis & Ostrom, 2014).

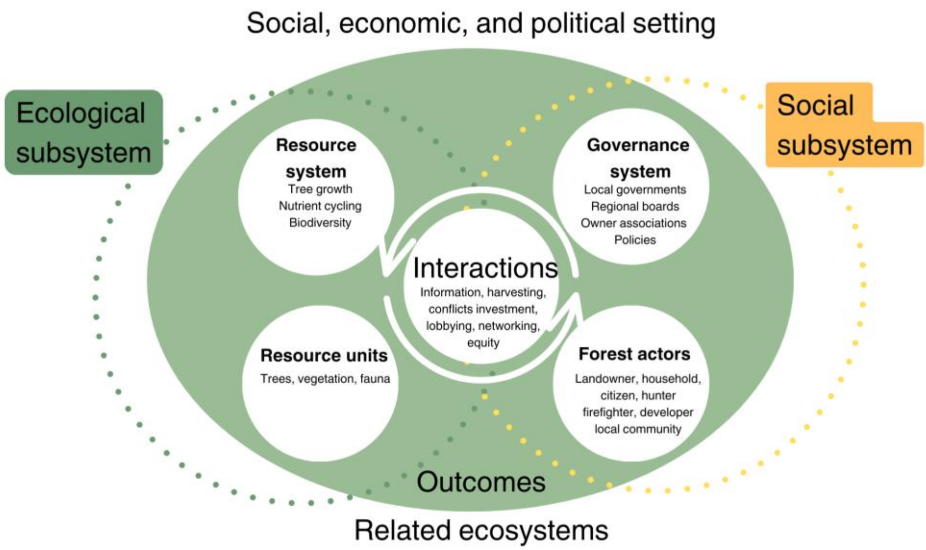

Figure 1.
Suggested conceptualisation of managed forests as social-ecological systems. Figure adjusted based on McGinnis and Ostrom (2014), and adapted from Paper I.

Policies and ecological processes

The question of how institutions and ecological processes interact has been studied through the so-called problem of fit (Galaz et al., 2008). Studies have investigated causes of misfits, i.e. the failure of an institution to take the dynamics of the specific ecological system it influences into account (Ekstrom & Young, 2009). The aim has been to understand under what circumstances social-ecological systems are governed in a way that does, or does not, lead to the deterioration of ecosystems. Institutions developed in long-lasting SES of fisheries, water, and forest resources have often been based on where, when and how to harvest rather than limiting the volume of harvest (Ostrom, 2009b; Wilson et al., 1994). To fit institutions with ecology, it thus becomes important to take the spatial and temporal dynamics of a resource into account.

As the introduction shows, the SES framework could be used to study, diagnose and theorise a range of different questions related to forests and forest management. In this thesis, the SES framework is used as a point of departure to highlight two key aspects of the implementation of biodiversity policies in forest dynamics: a) social and ecological processes are intertwined and need to be studied as such, and b) interactions between people and the forest within and across scales lead to emergent outcomes. To better understand aspects of these interactions, I turn to the concepts within research on environmental behaviour.

From values to practice

Human actions and motivations are an important aspect of social-ecological systems. In the following, I first present the theory of planned behaviour, which is commonly used in forest management literature, before introducing relational values as a novel entry point for understanding decision-making in forestry.

The theory of planned behaviour (Ajzen, 1985, 1991) is probably one of the most influential social-psychological theories for explaining behaviour. It is commonly applied in studies of private forest owners' motivations for biodiversity conservation (Koskela & Karppinen, 2024; Thompson & Hansen, 2013). The theory assumes that motivation and ability guide behaviour. A person is more likely to take environmental action if they see it as positive (attitude), believe that significant others want them to do it (subjective norm), and feel that they have the ability to do it (perceived behavioural control). Attitudes are directed at specific objects or situations. Attitudes are, in turn, shaped by values, which are understood as more general guiding principles in people's lives (Schwartz, 1994). The subjective norm could be thought of as the perceived social pressure on acting or not. Perceived behavioural control includes both one's perception of the likelihood of obstacles to the behaviour and one's perception of the strength of these obstacles (Ajzen, 1991).

The theory of planned behaviour, sometimes used in combination with Schwartz's value theory and the value-belief-norm-theory (Schwartz, 1994; Stern et al., 1999), provides a foundation for understanding forest owners' behaviour by studying their objectives, attitudes, and underlying values. The theory is well-grounded empirically for explaining specific behaviours (Chao, 2012). However, the theory's focus on cognitive aspects of behaviour has, in the forest owner literature, supported a main attention to individual aspects of forest owners' decision-making. To better understand the gap between values and action, it is important to account for broader aspects impacting forest management. With this project, I suggest social-ecological interactions as a starting point for understanding management behaviour, to add to the insights gained from a psychological perspective.

The concept of relational values originates from environmental sustainability-related research. In contrast to the above-mentioned focus on values in psychological terms, relational values refer to the values of nature. Defined as "preferences, principles and virtues about human-nature relationships, both interpersonal and as articulated by policies and social norms" (Chan et al., 2016, p. 1462), the concept was suggested as an addition to the traditional understanding of nature's value as coming from either nature's worth for people (instrumental values) or nature's worth for its own sake (intrinsic values) (Chan et al., 2016).

Relational values centre the relationships between humans and nature, aspects that have often been overlooked in conservation discourses (Pratson et al., 2023). The concept has gained much attention in recent landowner literature (Arias-Arévalo et al., 2025; Chapman et al., 2019; Chapman & Deplazes-Zemp, 2023; Githinji et al., 2023), and been suggested as a helpful analytical concept in interdisciplinary settings (Stålhammar & Thorén, 2019). Yet, researchers have also questioned whether relational values should be thought of as a separate category and not just an integral part of intrinsic and instrumental values of nature (Luque-Lora, 2023; Norton & Sanbeg, 2021). I agree with Himes and Dues (2024) about the potential of relational thinking for forest management and policy, but identify a need to further clarify what distinguishes relational values and to what extent they support pro-environmental behaviour.

Although the original definition of relational values is open to include all types of relations between humans and nature, much of the work so far has focused on relational values as environmentally beneficial (Hoelle et al., 2023). Foundational work on relational values has often studied values of stewardship, care, and place connection as motivation for sustainable resource management (Norton & Sanbeg, 2021). Recent literature has called for a broader conceptualisation of relational values, to also see how it affects behaviours that are not necessarily "beneficial", but taking place in production landscapes (Chapman & Deplazes-Zemp, 2023; Hoelle et al., 2023). Together with the longstanding question of the value-action gap, this gives a conceptual point of departure for studying forest owners' connection to, and care for the forest, and how these aspects impact management decisions, see Table 1.

Table 1:
Summary of the two main theoretical foundations for how the different parts of the thesis engage with discussions on environmental behaviour.

Theory/concept	Definition	Suggestions for environmental behaviour	Paper of relevance
Theory of Planned Behaviour (Ajzen, 1985)	Behaviour is shaped by attitudes, norms, and perceived behavioural control	Pro-environmental attitudes, norms, and the perception that it can be acted upon guides behaviour	II, III
Relational values (Chan et al., 2016)	Relational values are preferences, principles and virtues about human-nature relationships	Valuing human-nature relations supports environmental behaviour	III

Biodiversity in forests – key concepts

As mentioned in the literature review above, landscape-scale conservation could be perceived through three key dimensions: habitat quantity, habitat quality, and ecological connectivity (Hodgson et al., 2009). In the following, I describe how these concepts are defined in the thesis.

Habitat quantity refers to the habitat area and the number of habitats. An obvious effect of changes in habitat quantity could be when the area is simply too small to sustain a population over time. In fact, for a long time, the principles of island biogeography stating species occurrence as a function of habitat size and degree of isolation were thought to be the main explanation for how habitat area affected populations (Fletcher, Jr. et al., 2007). But landscape ecologists now stress the role of edges, meaning boundaries between different habitat types. These areas often have a great importance ecologically (Koelemeijer et al., 2023; Prugh et al., 2008; Willmer et al., 2022). The insights about edge effects have contributed to an attention to spatial patterns of protected areas. In a simple form, these insights imply that a protected area network with many, but small habitat patches may have a very different effect on biodiversity compared to a network with relatively larger but fewer patches, even though the two networks have the same total protected area.

Habitat quality could be defined as the capacity of an environment to sustain life. Many aspects that determine habitat quality are species-specific, but some aspects have similar effects on several species. Logging, drainage of wetlands and elimination of fire are examples of actions that have played a role in habitat degradation with severe effects on densities of species populations (Hodgson et al., 2011). In addition to the attention of habitat quality of protected areas, both theoretical and empirical studies have highlighted the importance of the quality of the surrounding landscape, the so-called landscape matrix, for conservation of forest species (Häkkilä et al., 2018; Lovejoy, 2006).

Ecological connectivity is defined as the unconstrained movement of organisms and natural processes across land- and seascapes (Brodie et al., 2025). Connectivity could be divided into two types: structural connectivity, which refers to the continuity between ecosystems, and functional connectivity, which refers to the movement of species and processes. Both structural and functional connectivity need to exist to prevent habitat fragmentation (Brodie et al., 2025). Habitat fragmentation is described as a landscape-scale process that involves both the breaking apart of habitat and habitat loss (Fahrig, 2003). The breaking apart of habitats leads over time to smaller patches of habitat isolated from each other. Habitat fragmentation affects the ability of organisms to disperse and colonise, meaning to spread and establish in a new area. It also affects, for example, the availability of food resources, the ability to reach microhabitats, and can lead to altered ecosystem dynamics between species (Robinson & Wilcove, 1994).

Research design

The conceptual background described above is referred to in different parts of the thesis. The SES framework is explicitly used in the analysis of Paper I. Papers II and III both relate to the discussions on the connection between values and behaviour in forest management. Paper III focuses more directly on interactions between forest owners and the forest, through the concept of relational values. Finally, Paper IV focuses on policy implementation on a national level and could therefore be thought of as going deeper into the processes, dynamics, and interactions of the overall social-ecological system, including the concepts of ecological connectivity, quantity and quality of biodiversity protection, see Figure 2. In the following, I go more into depth about the research design.

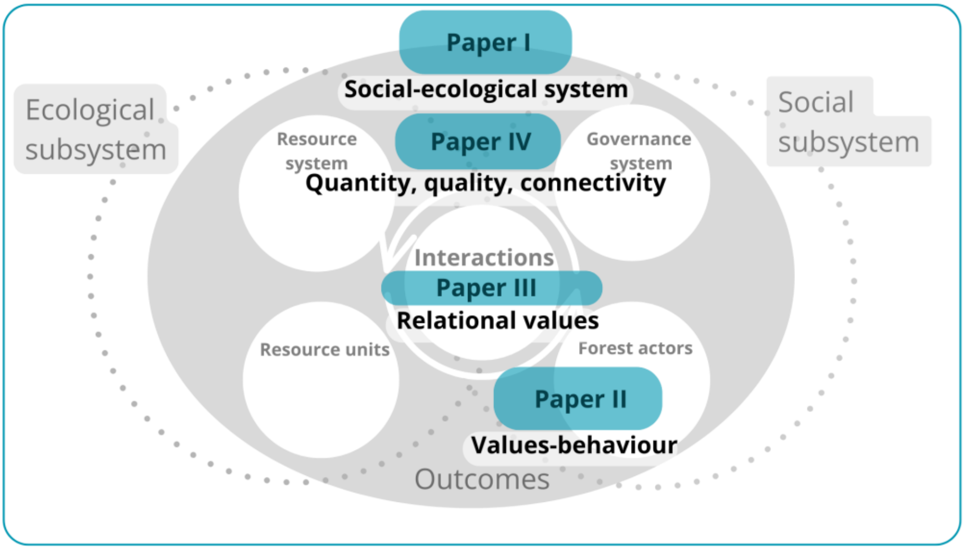

Figure 2:
Overview for how the conceptual background is referred to in the different papers of the thesis, and what aspects within social-ecological systems the concepts relate to.

Study area

After a history of state-based forest governance, both Finland and Sweden changed in the 1990s forest policy direction toward interactive modes of governance (Nebasifu et al., 2024). With Sweden as the third and Finland the fifth largest exporters of sawnwood globally in 2024 (FAOSTAT, 2025), the two countries are considered important actors in the global wood industry and provide interesting cases for studying the social and ecological factors that impact biodiversity policy implementation, among various stakeholders in intensively managed forest systems. Figure 3 shows the spatial scale of the cases studied in papers II-IV.

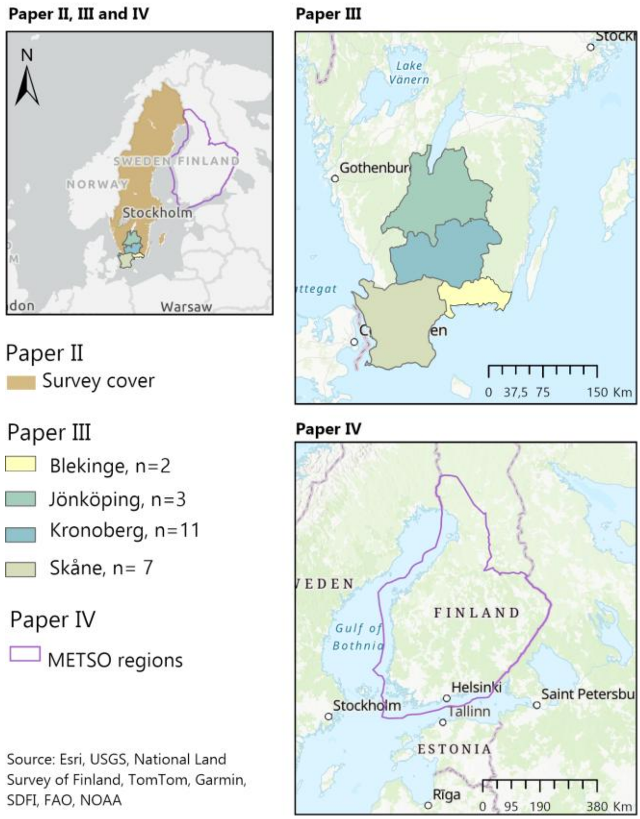

Figure 3.
Maps of the study areas in focus for the different studies. Paper I is a literature review of agent-based models, with applications across the globe and is therefore not mapped out. Paper II is based on a survey that was sent out to 3000 forest owners in Sweden. Paper III is based on walking interviews with private forest owners in southern Sweden. The number of interviews in each county is shown in the legend. Paper IV is a study of the Biodiversity programme for Southern Finland, METSO.

Forests in Sweden and Finland have a long history of being under human influence, and of debates about private and public interests in forests (Aakala et al., 2023; Östlund et al., 1997; Siiskonen, 2013). In northern Sweden in the 1800's, the state rented large forest areas to individual owners or communities who received the right to collect hay, hunt, fish, and restrict access from other users. By the mid-1800s, the government started to define the boundaries of the state-owned forests, and by the end of the century, private companies bought a large proportion of land from farmers. The introduction of market-oriented logging brought about changes in forest ownership as well as in wider social structures (Östlund et al., 1997).

The natural vegetation in the two countries is a mix of boreal and hemi-boreal forests, with coniferous species mixed with mosaics of birch and aspen, and in hemi-boreal areas additionally with maple and beech (Van Cleve & Dyrness, 1983). The temperate forests in southern Sweden may contain coniferous trees or be completely dominated by deciduous trees (Frelich et al., 2024; Gauthier et al., 2015). However, forest management has largely changed these natural vegetation patterns. Current Finnish and Swedish management regimes are based on the German model of scientific forest management, followed by a focus on monitoring and controlling forest growth and yield, and managing for maximum harvest. The Faustman formula became influential in Scandinavia, as a way to estimate optimal rotation lengths (Brukas & Weber, 2009; Puettmann et al., 2009). The ideas about rotation forestry started to be implemented on state forests in the 1800's, and the role of private ownership and public interests were largely debated around the turn of the century (Enander, 2000; Kotilainen & Rytteri, 2011; Östlund & Zackrisson, 2000; Siiskonen, 2013). Forests were in the public debate seen as being deforested and degraded. The new method of rotation forestry, with even-aged stands planted and harvested in regular cycles, was argued to be an approach for ensuring long-term economically sustainable yield. Forests started to be seen as a source of income for the state, and traditional rural practices like swidden agriculture were now considered a driver of forest degradation (Dove, 2015; Kotilainen & Rytteri, 2011). The Finnish Forest Act of 1886 and the Swedish Forest Act of 1903 were placed in force with a focus on afforestation (Nylund, 2009; Siiskonen, 2007).

After World War II, forestry practices were intensified with larger machines and clear-cut areas to serve the wood and pulp industries (Järvinen et al., 2012; Mönkkönen, 1999). With environmental issues being raised during the 1960s and 1970s, environmental protection of Nordic forests started to be discussed. In the mid-1990s, both Finland and Sweden had stated environmental goals in their national forest acts, but at the same time, timber and pulp production continued to be the focus in policy and practice (Sandström & Sténs, 2015). Today, rotation forestry with even-aged monocultures is the dominating management regime in both countries.

The ownership structure of Swedish and Finnish forests is a mix between private landowners, the state, the church, and corporate owners (Häyrinen et al., 2014; Statistics Sweden, 2021). Finland has about 574 000 non-industrial private forest owners who own at least 0.5 ha of forestland, in total 60% of the productive forest land (Metsäkeskus, 2022). In Sweden, around half of the productive forest area is owned by non-industrial private forest owners, some 308 565 individuals (The Swedish Forest Agency, 2025). In both countries, non-industrial private forest owners own a larger share of the forest area in the south, whereas companies and the government are the main landowners in the north, see Table 2.

Table 2:
Comparison of key figures regarding forestry in Finland and Sweden. *= The contribution from the forest sector to the Gross Domestic Product depends on if calculating based on the value of the raw material or including contributions from the whole value chain, including e.g. paper and pulp, which are a large part of both Finnish and Swedish forest industries. Sources: forest cover (FAO, 2025a; Statistics Sweden, 2026), ecological zones (FAO, 2025b), ownership distribution (FAO, 2025a), size of forest properties (Metsäkeskus, 2022; The Swedish Forest Agency, 2025), protected area (Natural Resources Institute Finland, LUKE, 2025; Statistics Sweden, 2024), contribution to GDP (Eurostat, 2024; Luke, 2025; The Swedish Association of Industrial Employers, 2025).

	Sweden	**Finland**
Proportion of forest cover	68%	74 %
Main ecological zone	Boreal coniferous, temperate continental	Boreal coniferous
Ownership distribution	State & public 25% Private companies 24% Individuals 47% Local communities 3%	State & public 31% Private companies 10% Individuals 59% Local communities 0%
Average size of private forest properties	34 ha	32 ha
Protected area	9.2%	12.9%
Forest sector contribution to GDP (2022)	Raw material, ca 0.85%* Value chain, ca 3%*	Raw material, 1.9%* Value chain, ca 4%*

Material and methods

To understand key social-ecological dynamics of policy implementation at different levels, I use a mixed-methods approach including literature reviews (Papers I and II), agent-based modelling (Papers I and IV), cluster analysis (Paper II), and walking interviews (Paper III). An overview of the material, the different methods and how they support in answering the research questions is given below.

Literature review-Papers I,II

A literature review was used as a method in paper I for giving an overview of methods used in forest owner typology literature, and in paper II, for giving an overview of existing agent-based model applications of forest management and for comparing their ability to represent forests as social-ecological systems. The purposes of creating landowner typologies vary from understanding reasons for uptake of management practices, to theory testing and modelling (Bartkowski et al., 2022). Despite it being a very common approach and being used for a broad range of purposes, the methods used for creating forest owner types have not received much attention. The aim of the literature overview in paper I is therefore to determine which methods have been used for creating forest owner typologies, and for which purposes these typologies are being used. The reviewed studies consisted of the 30 reviewed forest owner typologies from 1985 to 2015 in Ficko et al., (2019) combined with an additional search for recent publications in Web of Science. The search contained peer-reviewed articles published in year 2016-2023 with “forest owner” and “typology” or “type*” in the article title, abstract or keywords. The search was not meant to be exhaustive, but to provide an overview of existing forest owner typology purposes and methods.

For paper II, the literature review was the main method. The literature search was divided into six steps: 1) developing a search string, 2) making searches in Scopus and Web of Science to explore alternatives for narrowing down the list of results, resulting in title only plus abstract for the method, 3) compiling the list of results in Excel, 4) selecting the articles describing model applications of forest management and filtering out review papers as well as applications of purely ecological models, 5) filtering out replicates and papers describing the same model application, and 6) complementing the final result list with 5 models that were referenced to in the already selected list of articles, see Figure 4.

Figure 4:
Overview of the search process for scientific articles describing agent-based models applied to forest management. Figure adapted from Paper II.

The final collection of 31 model applications was compared both in terms of common model applications' differences and through a social-ecological systems framework. The first part of the comparison focused on differences in spatial units, model time step, scope of the model world, validation approach, open-source license, framework used, and integration to other types of models. As a second step, I compared the model applications' ability to represent interactions and dynamic processes, both social and ecological, as these are key aspects of a social-ecological system.

Cluster analysis, owner typologies – Paper II

An important part of understanding the dynamics of policy implementation in Sweden and Finland are the actions taken by private forest owners. In paper II, together with co-authors, I focus on Swedish forest owners and use the responses from a survey collected between December 2014 and the first quarter of 2015, from the research project Future Forests (Danley, 2019b, 2019a). The survey was developed to explore owners' perceptions, values, and actions related to biodiversity conservation in Swedish forestry, and contained 1279 survey responses. We used a subset of the variables as empirical material for exploring different approaches to creating forest owner typologies.

Following earlier research, we strived to take a broad view of forest ownership (Weiss et al., 2019) and included 25 variables representing dimensions of forest ownership. The variables were divided into three subcategories: ownership objectives, attitudes and beliefs, and decision aspects. The 9 variables describing forest owner objectives are the same as in Danley (Danley, 2019b) combined with aspects of decision-making (n=4), and attitudes toward environmental politics (n=10). All variables were ranked on Likert scales from 1 (totally agree) to 4 (do not agree), and additionally 5 (No opinion).

The survey responses were used as a basis for comparing five methods for forming typologies to see the extent to which the methods resulted in similar forest owner groups. Three of the compared methods – Principal Component Analysis (PCA), k-means clustering, and hierarchical clustering – were chosen as they were seen to be among the most used quantitative methods within forest owner typology literature. In addition, we studied Latent Profile Analysis (LPA) and Archetypal analysis (AA) as more novel approaches within the forest owner typology literature.

The first approach combined PCA for reduction of dimensionality, and k-means clustering, which is one of the most commonly used methods for creating forest owner types (Danley, 2019b; Favada et al., 2009; Hujala et al., 2007; Jennings & van Putten, 2006; Serbruyns & Luyssaert, 2006; Urquhart & Courtney, 2011; Van Herzele & Van Gossum, 2008).

In the second approach, we avoided the first step of dimensionality reduction and performed k-means clustering directly on the 25 original variables, similar to the forest owner typology by Mizaraite and Mizaras (2005). The third approach was done using hierarchical clustering, like Ingemarsson et al (2006) and Boon et al (2004). In contrast to k-means clustering, hierarchical clustering is not dependent on the researcher choosing the number of clusters prior to the analysis. However, to be able to compare, we used the same number of clusters for all methods. In the fourth approach, we used LPA, which is similar to Latent Class Analysis used by Boon and Meilby (2007). Through the method, a model is used to determine how many groups the data is suitable to be divided into, and how these groups differ in mean characteristics.

The final approach differs from the other ones in not being a clustering analysis per se, but an unsupervised learning method for multidimensional data. Through Archetypal Analysis (Cutler & Breiman, 1994), one can explore the extreme values in the data, and conceptually it could then be used as building blocks for describing forest owners in different degrees.

From the five methods, we created five forest owner typologies of three types in each. These typologies were then compared across methods to understand similarities and differences in key characteristics of the resulting forest owner groups as well as the distribution of forest owners between groups.

Agent-based modelling – Papers I,IV

Agent-based modelling is a bottom-up approach to modelling, which means that the model is based on micro-scale interactions and the emergence of large-scale patterns (An, 2012; Matthews et al., 2007). This gives the possibility of representing actors with different motivations and values, and how actors' interactions with each other and with the environment create effects in the landscape. This is one reason why ABMs have become popular in modelling of social-ecological systems (Rounsevell et al., 2012). Another reason is the possibility of combining quantitative and qualitative data both inductively and deductively (Axelrod, 1997).

Paper I provides an introduction and overview of agent-based models applied to forest management. In paper IV, modelling is used to study landscape patterns of policy implementation. The chosen modelling framework, Competition of Resources among Agent Functional Types, CRAFTY (Blanco, Holzhauer, et al., 2017) was chosen as a result of the model comparison in paper I. CRAFTY represents both social and ecological processes dynamically, is one of the few large-scale agent-based models, and provides flexibility for adjustments to a broad range of land use and forest issues (Murray-Rust et al., 2014).

The basis for CRAFTY-Finland is a land cover raster, where each cell represents a 1x1 km area of Finland. The land in a cell can be managed by an agent, in this case one of the five different forest owner types. In CRAFTY-Finland, other types of land covers, like urban, agriculture, and water, are not actively managed or changed, but this could be changed depending on the research focus. Each agent type is characterised by guiding motivations and corresponding management behaviour, determining, for example, how different owners value timber production compared to recreation. Agents strive to produce ecosystem services to reach societal demands of biodiversity, timber, carbon, and recreation. How much an agent type can produce of each ecosystem service is determined partly by the resources (called capitals) available on their land, and partly by each owner type's sensitivity to that resource. The agents in CRAFTY-Finland could be thought of as acting under bounded rationality. Their decisions are driven by utility maximisation, but they have incomplete knowledge about all decision options. They perceive and react to the environment, and their decision-making possibilities are impacted by their surroundings as outlined below through the Modelling Human Behaviour framework (Schlüter et al., 2017), see Figure 5.

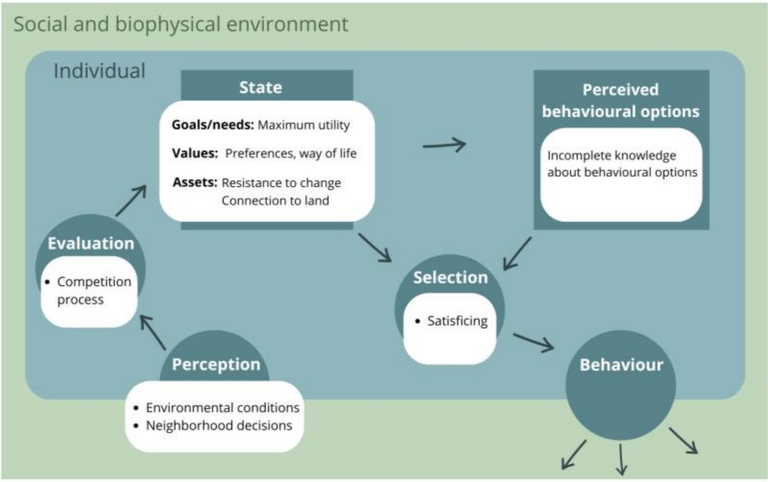

Figure 5:

Description of the conditions of agents' behaviour and decision-making in CRAFTY-Finland, structured according to the Modelling Human Behaviour, MuHoB, framework (Schlüter et al., 2017). From the social and biophysical environment, agents perceive available resources and the decisions taken in their surroundings. The decisions are evaluated against other agents' decisions when entering the competition process. The overarching driving behavioural assumption is utility maximisation, but the degree of optimisation varies depending on agents' preferences, way of life, resistance to change and connection to land. Figure adapted from Paper IV.

To create the initial land use map and cell-based resources, data from the Finnish National Forest Inventory, the European Environmental Agency, and CORINE land cover data were used (Copernicus Land Monitoring Service, 2020; Luke, 2006, 2009). The map was classified into different forest types, to which agents were assigned ownership of different cells. The agent types and their behaviour were based on a typology repeatedly used for Finnish family forest owners (Favada et al., 2009; Karppinen, 1998; Kuuluvainen et al., 1996; Leppänen, 2010). A simple growth and yield model, ProdMod (Ekö, 1985) was used to prepare maximum production of timber and carbon given the different management strategies of the forest owner types (Blanco, Holzhauer, et al., 2017). The degree to which areas are preferred for recreation in Scandinavia depends, to a large extent, on the development phase of the forest, the management practices, and accessibility (Edwards et al., 2012). For forest biodiversity, we base estimations on tree diversity and management practices(Duncker, Barreiro, et al., 2012; Duncker, Raulund-Rasmussen, et al., 2012; Gamfeldt et al., 2013; Marchetti, 2004). Agents' contribution to providing biodiversity and recreation was based on equations that take the above-mentioned aspects into account. The resulting ”production” numbers of biodiversity and recreation reflect variation among agents' management strategies. The METSO policy was simulated so that forest owners who sign a contract become one of the two types of METSO agents: either one representing permanent and 20-year contracts, or one for temporary 10-year contracts. State-owned land and already protected areas were masked out, and only METSO agents could produce additional protected areas.

The model was run from 2003, five years before the start of the METSO policy, until the year 2020. For calibration, we used empirical data on policy uptake over time(Luke, 2025a, 2025b). In contrast to ABMs that focus on internal consistency, here we parameterise the model based on values that reproduce the observed patterns in year 2008-2020, similar to the approach by Millington et al.,(2021). The calibrated baseline scenario was then compared to three scenarios representing changes to i) a centralised policy implementation, ii) increased decentralised implementation, and iii) optimisation in the spatial planning process. The outcomes were compared against metrics of the quantity, quality, and connectivity of the resulting network of protected areas.

Walking interviews – Paper III

To understand forest owners' relations to forests, and their reasoning around management decisions, in paper IV, I use walking interviews as a method that allows for engaging with the context where management decisions are taken. Walking interviews, or narrative walks, go-alongs, or commented walks, are methods taking inspiration from explorative field walks and transect sampling. By walking with smallholder farmers in their local area during a semi-structured interview about land use change and agricultural practices, Jerneck and Olsson (2013) saw the abilities of the method to compensate for the otherwise often asymmetric roles in an interview. When walking in places that participants know well, respondents become the "knower", and objects and places in the field make it possible to connect to memories, site-specific knowledge and feelings of pride, fear, or attachment to the place. Walking interviews with forest owners have the potential to enrich and ground the understanding of landowners' everyday actions and how these connect to policy responses (Laakkonen et al., 2018).

The semi-structured interviews were conducted in April-December 2024 in southern Sweden (Skåne, Blekinge and Småland). Participants were selected using purposive sampling, which builds on the assumption that specific groups of people may have important and different views on the topic (Palinkas et al., 2015). Here, I focused on obtaining a diverse representation of forest owners owning at least 5 ha of land, and with different ownership purposes, degrees of active management, and representing different age groups. Each interview started with a few general questions about their reasons for ownership, their objectives with the management, and how often they were out in the forest. We then went for a walk in their forest, letting the participants choose where to go. The walks lasted between 1 and 2 hours. The interviews were documented using audio recording combined with photographs of places in the forest that participants pointed out as important, either as places for visits or for decision-making. The method and procedure were granted ethical approval (nr. 2024-00475-01, the Swedish Ethical Review Authority).

The transcription was done using OpenAI's Whisper (Open AI, 2024) on an offline computer that was restored and encrypted after each use. The transcripts were then checked to correct mistakes and made anonymous by deleting any mentions of people or places. The analysis was done in a deductive way using the analytical framework of relational values in Nvivo (Lumivero, 2023).

Transdisciplinarity

The close connection to societal issues, a transdisciplinary ambition, is often highlighted in environmental and forest science (Oberg, 2011; Thorén & Breian, 2016). In the work with this thesis, I have strived to engage with and make the work relevant for forest owners and forest owner associations, and NGOs. After the walking interviews, I shared preliminary results with the participating forest owners. I presented and held discussions about the work at two local NGOs, and developed a workshop for forest owners as environmental representatives in Södra, the forest owner association in southern Sweden. These discussions encouraged me to revisit the material and notice other nuances from different perspectives and thereby fed into the final results.

Summary

The literature review of Paper I supports the choice of model framework used in Paper IV. The comparison of methods of typology formation in Paper II contributes with important insights for the modelling based on forest owner types in Paper IV. The discussion on values and actions, an important aspect of the forest owner typology literature, serves as a point of departure for going deeper into the relationship between values and actions through the walking interviews with forest owners in Paper III. The qualitative insights from the interviews could, in future research, be used to inform modelling, expanded on in the section on Future research, see Table 3.

Table 3:
Overview of the research design of the four papers in the thesis, for each study outlining the social and ecological levels analysed, material, methods and main contribution with respect to the overarching research questions.

Paper	Social level		Ecological level	Material	Methods	Contribution
	Actors	Institution				
I	Individual, Group	Local - National	Landscape	Peer reviewed literature	Literature review	SES interactions are recognized in few models. Calibration is still a major challenge. (RQ I)
II	Group	National, Sweden	Stand, landscape	Survey of Swedish forest owners, 2014-2015	Five types of cluster analysis	Clustering methods influence which owner characteristics are highlighted (RQ I)
III	Individual	Local, Sweden	Stand	Interview material	Walking interviews	Relational values do not necessarily lead to decisions beneficial for biodiversity (RQ II)
IV	Group	National, Finland	Landscape	Copernicus land cover, national forest inventory, METSO statistics	Agent-based modelling	Emphasised spatial targeting in the policy design can further improve landscape connectivity (RQ II)

Main findings

The outcomes of the four subprojects demonstrate the impact of social-ecological interactions on the implementation and outcomes of biodiversity policies, how these interactions are recognised methodologically, and the effect of methodological choices on the representation and interpretation of interactions. The main insights about social-ecological interactions in forest modelling and forest owners' decision-making are summarised below. Each section provides answers to the two research questions, see Table 4.

Table 4.
Summary of how the main findings are grouped thematically, and to which research question the results contribute to answering.

Social-ecological interactions…	RQ I) How interactions are recognised in methods	RQ II) How interactions impact policy implementation and outcomes
…in forest modelling	Paper I	Paper IV
…through forest owners' decision-making	Paper II	Paper III

Social-ecological interactions in forest modelling

Although drivers of biodiversity degradation in forests have been emphasised as being a combination of social and ecological factors (Filotas et al., 2014; Nocentini et al., 2017), their interactions are seldom recognised in forest modelling.

Recognising interactions, RQ I

Paper I provides an overview of 31 agent-based model applications of forest management. Based on the SES framework, we systematically compare their ability to represent forests as social-ecological systems. The results contribute to the first research question by showing how agent-based modelling as method enables recognising forests as SES. However, few existing model applications represent SES interactions.

Many of the reviewed models are relatively specific in purpose and are thus weighted toward representing the complexity of either social or ecological systems, see Figure 6. For example, the models with the most complex ecological subsystem, representing variation in species and processes like nutrient cycling, are often constructed as an ABM coupled with an ecological model, like a dynamic vegetation model. The models that are most complex in social dynamics include agents that learn over time, have social networks, take emotional aspects into account in decision-making, or have dynamic governance structures.

Of those models that were spatially explicit, most were applied to local scale, which is common for agent-based models. A handful were designed to study interactions at regional or landscape scale, and one, CRAFTY-Sweden, was explicitly designed for national scale (Blanco, Holzhauer, et al., 2017). When it comes to temporal aspects of dynamics, most models employ a yearly timestep, reflecting the relevant period for forest management decisions.

The results of Paper I show the ability of agent-based models to represent important social processes of policy implementation in forests. However, few applications include a holistic representation of forests as social-ecological systems, like the direct interactions between people and the environment. The paper contributes to the literature with an overview to approaches that can be used to integrate social and ecological data. We conclude by highlighting dynamics that need more attention in modelling forests as SES, particularly adaptive governance, social learning, and coupling between social and environmental processes. For agent-based models to be used as a tool in policy development, calibration and validation is a research frontier.

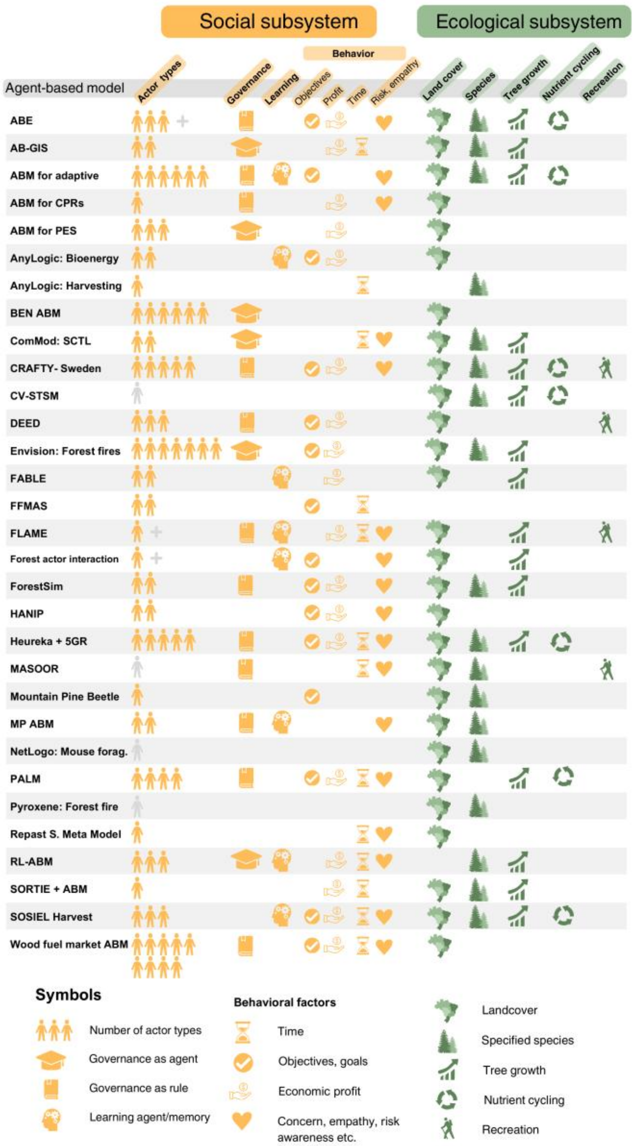

Figure 6:
Overview of the 31 reviewed agent-based models and their ability to represent key aspects of forests as a social-ecological system. From left to right, the figure describes: Social subsystem a) number of actor types, b) government system representation as agent or legislation, c) learning agents and d) types of factors determining agent's behaviour and for the ecological subsystem e) land cover, f) functional types/species, g) tree growth, h) nutrient cycling and i) recreational features explicitly modeled in the landscape. Greyed actor symbols indicate that actors are indirectly represented, through e.g., a forest management decision. A grey plus indicates that actor types are not pre-defined, but resulting from a pool of actor characteristics.Figure adapted from Paper I.

Interactions and policy outcomes, RQ II

In **Paper IV** I develop the model CRAFTY-Finland to analyse the Finnish biodiversity program METSO. The model is based on the CRAFTY framework, identified in Paper I as one of the few model frameworks incorporating key interactions between social and ecological processes. The framework is also one of few that is designed for agent-based modelling at national and international scale, which could support in bridging between scales important for policymaking (national and international) to those of ecological relevance (local and landscape), a key issue in SES research.

CRAFTY-Finland is calibrated based on empirical data of policy uptake from 2008 to 2020 and validated against the spatial distribution of the observed network of protected areas. We did not expect the calibrated model to match policy uptake on a yearly basis or strict spatial overlap of protected areas, since the model does not recognise variation in resources for implementation and the location depends largely on where agents are located initially. However, the model should produce the overall observed temporal and spatial patterns. After calibration, the model matches the total protected area by year 2020 and represents the main differences in temporal uptake between temporary and permanent contracts. Based on Ripley's K, we see that the model outcomes follow similar patterns of spatial distribution as the empirical data. For habitat quality, the modelled network contains a larger proportion of cells with mid-range values. This is likely due to the model currently overestimating the trade-off between carbon sequestration and biodiversity protection. Since the trade-off was consistent throughout the calibration, we accept it as a known limitation when proceeding with scenario comparison.

The calibrated scenario was compared to three scenarios representing completely centralised policy implementation, increased decentralised implementation, and increased spatial planning optimisation. The comparison shows that the *spatial optimisation* scenario leads to improvement on both the number of protected areas, the proportion of high-quality areas, and the connectivity within the protected area network. When it comes to the total protected area, the spatial optimisation scenario does not provide improvement compared to the baseline scenario, see Table 5.

Table 5:

Summary of metrics that describe the quantity, quality, and connectivity of the protected area network resulting from the calibrated baseline and the three different modelled scenarios. Colours in the table indicate the performance for each scenario for a single metric in comparison to the baseline scenario (grey). Poorer performance than the calibrated baseline scenarios is shown in light to dark purple (poorest performance), and improved performance compared to the baseline scenario is shown in light to dark green (highest performance). Table adapted from Paper IV.

Modelled scenario	No of PAs	Tot. protected area (km2)	Proportion of Zonation score >0.8	LNK	IIC
	Quantity		Quality	Connectivity	
0. Baseline	4461	1256	0.15	282	2.71E-07
1. National focus	5640	1590	0.13	403	3.54E-07
2. Local focus	2879	790	0.14	107	1.15E-07
3. Spatial optimisation	5913	1218	0.18	1555	2.17E-06

For the spatial patterns, both the *local focus* and *spatial optimisation* scenarios lead to more clustered patterns compared to the baseline. The *national focus* scenario leads to improvement on all aspects expect the quality, whereas the *local focus scenario* leads to a substantial decrease on all dimensions, see Figure 7.

Social-ecological interactions through forest owners' decision-making

Papers II and **III** focus on understanding how social-ecological interactions influence forest owners' decision-making about biodiversity protection, and methods used to study them.

Representing interactions, RQ I

As a result of the increasing interest in private forest owners' heterogeneity, it has been a common approach to create forest owner typologies (Ficko et al., 2019). A majority of typologies are created based on quantitative studies using clustering analysis.

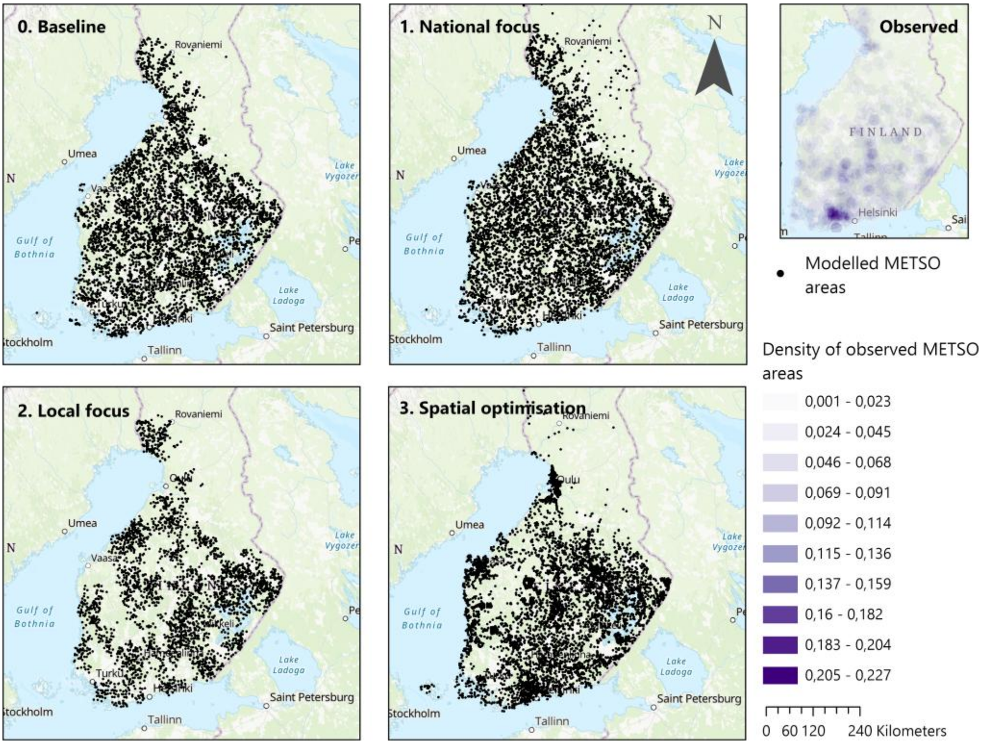

Figure 7:
Spatial distribution of protected areas in the different scenarios as black points. The point distribution of observed protected areas (with area density units in square kilometres) allows visual comparison of co-location in the data. The *local focus* and *spatial optimisation* scenarios both lead to more clustered distributions compared to the baseline scenario, whereas the *national focus* scenario leads to less clustering compared to the baseline scenario.Figure adapted from Paper IV.

In Paper II, we analyse survey data of Swedish forest owners from 2014-2015 (Danley, 2019b). We cluster survey responses using five different methods and compare the resulting typologies. The results show that different methods yield different insights about forest owner types' characteristics, see Figure 8.

The methods also result in varying number of owners being allocated to the different types. This means that even methods that create similar types of forest owners, the different methods lead to different answers about which forest owner type is most commonly occurring.

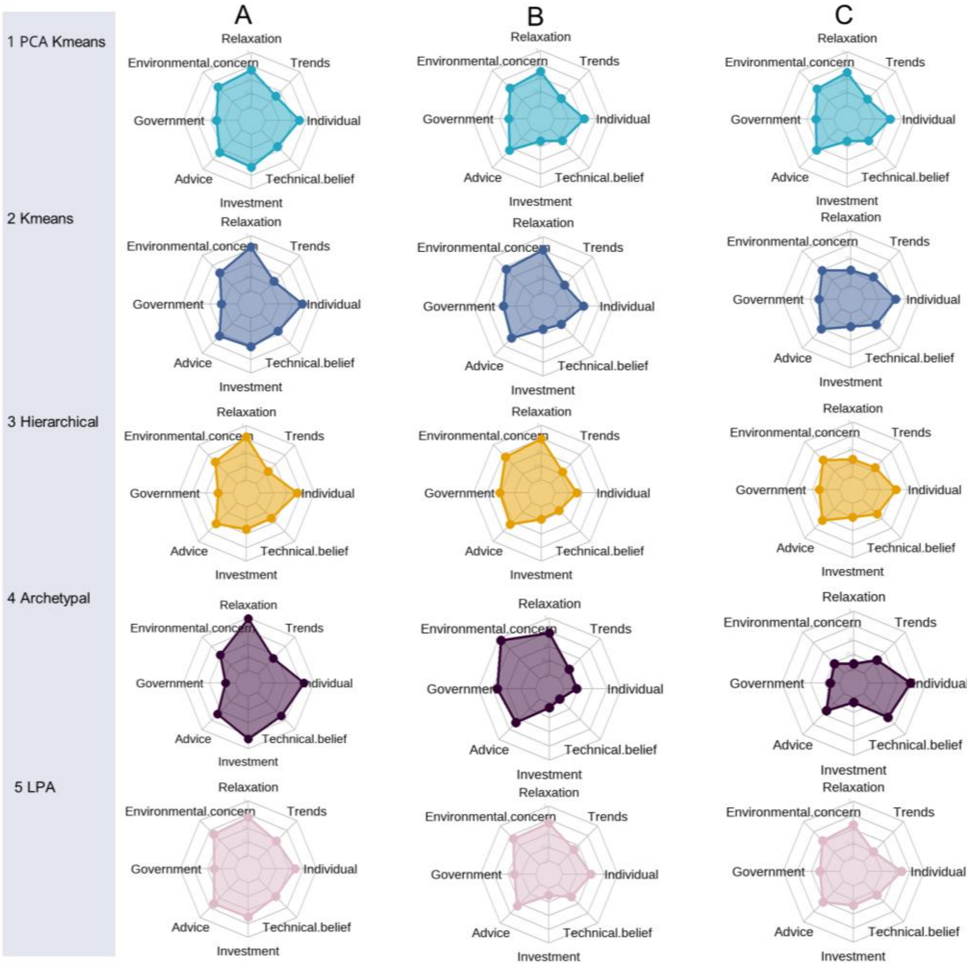

Figure 8:
Radar charts for each of the forest owner types as resulting from the five different methods, from top to bottom: Kmeans clustering based on PCs, Kmeans clustering based on original variable values, Hierarchical clustering, Archetypal analysis and Latent Profile Analysis (LPA).

Taken together, the outcomes of Paper II highlight that methods may be differently suited for different purposes of typology formation, in turn emphasising the importance of methodological reflection when analysing forest owners' attitudes and values. We conclude the paper by suggesting a guide to choose a method based on the overarching purpose of grouping forest owners, see Figure 9.

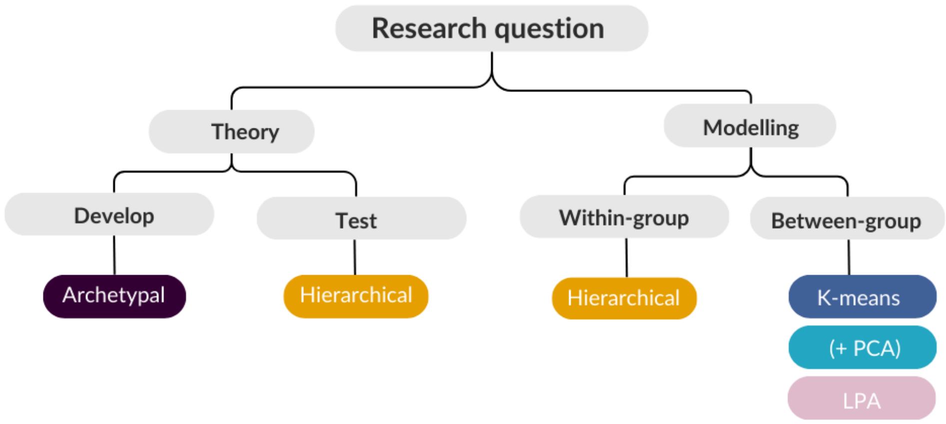

Figure 9:
The scheme is meant as a guide for choosing method for creating typologies. It is based on the outcomes of Paper II, suggesting that methods should be chosen based on the purpose of the study. Figure adapted from Paper II.

Interactions and management decisions, RQ II

Studies on forest owner typologies are often done under the assumption that forest owners' values, attitudes, and objectives are linked to actions. There have been recurring calls to address this link more directly. In addition, the forest owner literature has so far paid relatively little attention to relational and emotional aspects involved in the decision-making by private forest owners. **Paper III** addresses these two overarching aspects and contributes conceptually by using relational values to understand forest owner decision-making.

Through walking interviews in southern Sweden, 23 forest owners shared their views on reasons to own forests, what they appreciate about the forest, and if and how these aspects of appreciation impact management decisions. The interviewees were on average 61 years old. A majority lived closed to their forest, while 2 participants were non-resident owners. For biodiversity protection, 8 of the interviewees had formal protection on their property, and 12 owners mentioned being certified by PEFC or FSC. A majority of the forest owners practiced rotation forestry on all or parts of their property, but two forest owners only managed using selective cutting, and 9 of the interviewed used some form of alternative forestry methods in parts of their forest. Based on a framework of different types of relational values, the analysis highlights that relational values play an important role in the interviewed forest owners' decision-making.

The most mentioned aspect was that of family connection. Eight of the interviewees had inherited the forest property, and several owners had received an interest in forests from their childhood. Spending time in the forest with family members was considered a way of sharing knowledge about species and management techniques.

> “I've cleared this whole area, from here and downwards, of small spruce trees and even some larger spruce trees and such (…). In the old days, the cattle used to graze here all the way down to the river. Now my daughter and I are going to take that side, because she's coming with me to look for small spruce trees” (In12, retired/ self-employed, man)

Another common theme was that of stewardship, which the interviewees gave different meaning to. Some expressed it through how they thought about their own role as a steward for a limited time, seeing themselves in a chain of generations. Others highlighted the role of humans in the ecosystem, and several interviewees expressed frustration with how current conservation policies left them feeling limited in their feelings of autonomy and stewardship.

> “If this had been a nature reserve, there would be spruce forest here, not beech forest. So, it is human intervention that has created many of these natural values. Then the authorities come and say: I've seen that you have fantastic high values in your forest. We want to take care of that now. We're basically declaring you incompetent, saying that you probably won't be able to safeguard this in the future, so now we're going to take care of it instead.” (In9, forest entrepreneur, man)

The relation to the forest as a basis for decision-making can lead to actions that are beneficial for biodiversity, like formally or informally protected areas, as well as a maintained focus on production to sustain a rural livelihood. Forest owners may hold strong emotional or cultural connections to their land, yet still make management choices that conflict with conservation objectives. While the literature on relational values has so far paid more attention to when relational values lead to pro-environmental behaviour, the study shows how relational values to nature, like familial ties, place connection, and identity, lead to both pro-environmental behaviour as well as sustained production-oriented actions and contributes thereby conceptually to the discussion about the role of relational values in environmental governance. Empirically and methodologically, **Paper III** contributes to walking interviews as a novel approach in the context of understanding forest owners’ decision-making and gives insights about what kind of effects social-ecological interactions at the local scale have on forest biodiversity.

Discussion

This thesis was set out to contribute to better understanding of how social-ecological interactions are recognised in different methodological approaches, how methodological choices influence the representation of such interactions, and how social-ecological interactions influence the outcomes of biodiversity policy in managed forests. In the following I discuss themes across the four subprojects, reflections on the research approach, and directions for future research.

Social-ecological interactions in biodiversity governance

Through the thesis, interactions between humans and forests have been studied at different levels. From the local and individual perspective of the interviewed forest owners in paper III, to forest owners on the group level and the national context in papers II and IV. The relational values framework allowed for analysing how everyday interactions between forest owners and the forest influence management decisions. One important insight is that an interest in biodiversity protection is not always the stated objective for why a forest owner decides to formally or informally protect an area. The decision may be grounded in a feeling of interest and care to protect an area for other reasons, like family history, recreational values, or an interest in the cultural value of an area. This goes in line with how much of the literature has discussed relational values, where valuing the relation to nature is connected to a care for well-functioning ecosystems (Jax et al., 2018; Pratson et al., 2023; Yuliani et al., 2023). However, the interviews show how care can be expressed in different ways, for example by managing a forest so that it looks neat and tidy. Similar to how Burton (2012) described farmers aesthetic preferences for tidy agricultural landscapes as a way of reading the landscape for signs of skilled farming, the analysis in paper III indicates that the presence of relational values does not per se lead to decisions that are beneficial for biodiversity. Apart from economic incentives, current management decisions may be well-rooted in family traditions and feelings of stewardship, which from a landowner perspective adds further resistance for changing management strategies. These are important insights about how local social-ecological interactions influence biodiversity policy implementation and outcomes.

The interviews also highlight the importance and effects of interactions between individual forest owners and institutions over time. The interviewees commonly perceived a drastic shift from the promotion of herbicides for removal of birches in the 1970's, to current incentives for specifically preserving broadleaved trees. These major shifts in regulations participants often described through a notion of frustration, in turn contributing to mistrust of institutions and current guidelines. Research on public administration in forest governance highlights the importance of trust for successful policy outcomes (Bjärstig et al., 2024). Focusing on the local and place-based social-ecological interactions thus supports in understanding what acts as hinders and enablers in biodiversity policy implementation.

In Paper II, I focus on forest owner typologies as an approach for categorising and understanding social-ecological interactions on group level, between forest owners and their forest. When introduced, this approach contributed to a paradigm shift in the forest management literature; from a focus on private forest owners as foremost economic optimisers toward a more multifaceted understanding of management goals in privately owned forests (Fischer et al., 2010). Previous research has focused on how variable selection influence the resulting types, arguing that variable selection is more important than classification method (Kostrowicki, 1977). The results from Paper II shows however that methodological choice influence which forest owner characteristics that are highlighted. None of the compared methods for typology formation comes without drawbacks. These include, for example, limitations when it comes to representing diversity within groups, providing information about variable importance, or a lack of information for deciding an appropriate number of groups. However, with attention given to how typology formation is done and for what purpose, the results also indicate how landowner typologies can be a helpful approach for understanding patterns among landowner attitudes, objectives, and values. Such insights can form the basis for analysing key aspects of forest SES: interactions between forest owners, forests, and institutions(Fischer, 2018).

The analysis of the Finnish PES scheme METSO further emphasises the role of interactions between private forest owners, ecological processes, and institutions through the policy implementation process. Spatial ecological variability is recognised in the policy design through a ranking of suitable areas for biodiversity protection (Mikkonen et al., 2023). The results of paper IV show the importance of the ranking system for guiding contract approval. It illustrates that by strengthening spatial prioritisation in the policy design, ecological quality and connectivity can be further improved. Spatial targeting has been emphasised as key for ensuring that PES schemes result in protection of the areas with highest biodiversity values (Fooks et al., 2016; Wunder et al., 2020; Wünscher et al., 2008). Although distance to already protected areas could be part of the spatial targeting (Wünscher et al., 2008), spatial targeting has been less often discussed as in the current study, an instrument for supporting emerging connectivity in a voluntary protected area network.

Adopting a social-ecological systems approach helps to recognise the interactions between forest owners' behaviour and spatial ecological variability. These insights are important not only in the Finnish context, but also when voluntary policies such as the METSO programme are used as instructive examples for achieving international biodiversity protection goals.

Forest owners' decision-making

Forest owner decision-making is a theme that recurs across the four papers of the thesis. In Paper I, it is compared across agent-based modelling approaches. The outcomes show differences in how the models recognise for example agents' ability to learn over time, their social network, and cognitive abilities. The motivation for why specific aspects of agent behaviour have been included or excluded is seldom discussed. This insight aligns with previous research which has highlighted that agent-based models often fail to outline the behavioural theories behind agents' decision-making processes (Schlüter et al., 2017).

Although in a different field of application, migration studies, Klabunde and Willekens (2016) separated six different groups of agent-based models when it comes to using decision theory. The first type of models makes no or little use of behavioural theories. The second type of models is based on microeconomic expected utility maximisation to explain people's choices. The third type of models uses theories of action drawing on social psychology, while a fourth type is based on heuristics. The fifth and sixth types are, to a small or large extent, based on direct observations (Klabunde & Willekens, 2016). CRAFTY-Finland belongs to the second group where agents' decisions are based on utility maximisation theory, and the survey that is the basis of the different agents' behaviour is grounded in the theory of planned behaviour (Ajzen, 1991). As mentioned above, the theory states that attitudes, subjective norms, and the perceived control of being able to perform an action are the factors that impact behaviour.

How do these behavioural assumptions impact model outcomes? The competition between resources as a main driving logic in the CRAFTY framework has shown potential to replicate empirical patterns of land use change in agriculture in Brazil (Millington et al., 2021), and for studying the role of forest owner decision-making, climate change, and societal demands in Sweden (Blanco, Holzhauer, et al., 2017). The behavioural assumptions in the CRAFTY framework have been developed to explore the role of diverse actors in large-scale land use patterns. Compared to other ABMs focused on local scale or specific decision-processes, agents in CRAFTY-Finland do not remember or learn over time. Mechanisms of feedbacks are important aspects of SES (Filotas et al., 2014; Fischer, 2018) and the interviews with forest owners in paper III highlight how past experiences are important when taking decisions. In the case of the METSO program, a follow-up study evaluated contract renewal of temporary contracts and showed that renewal was influenced by changes in the program's habitat criterium and of management strategies (Hänninen et al., 2021). To simulate policy outcomes over a longer period, it would therefore be important to develop agent memory and learning.

Like the modelling approach for understanding variation in forest owners' decisions, Paper II contributes to the tradition of understanding decision-making through categorisation of forest owner types. Based on survey data of Swedish forest owners in 2014-2015, the outcomes show that the forest owners differed more when it came to ownership objectives and were more similar in their stated values. Based on values alone it would therefore be difficult to differentiate between different motivations for decision-making. Recent literature has highlighted the context for decision-making, like social/cultural norms, personal and social identities, and dynamics within households (Andabaka et al., 2021; Caputo et al., 2019, 2026). Similarly, the insights from the interviews in Paper III, illustrate that similar values can be followed by different actions, and that the context in which decisions are taken is important to understand. In addition to studying forest owner decision-making through typologies to see overarching patterns, it is important to develop approaches that focus on better understanding the context of decision-making.

Relational thinking for forest biodiversity

The thesis contributes to emerging literature on the use of relational values and relational thinking in forest management (Halla et al., 2023; Himes & Dues, 2024), and more broadly to attention to the role of social and emotional aspects in forest owner literature (Bjarstig & Kvastegard, 2016; Bjärstig & Sténs, 2018; Buijs & Lawrence, 2013; Johnsson & Beery, 2023; Olofsson & Jakobsson, 2023). The relational value framework serves in the current study as a lens to analyse broader aspects of forest owner behaviour, and the outcomes show a nuanced picture of management decisions among the group of small scale and active private forest owners in Southern Sweden.

By focusing on relations between forest owner and the forest, the results highlight the private forest owners' strong connection to the land across different ownership objectives. Within the landowner literature, the role of connections to land for management decisions have been frequently discussed in relation to the concept of stewardship. In line with how the interviewed forest owners express diverse understandings of stewardship, Enqvist et al.,(2018) argue that tensions between different understandings can be used for making richer analysis. In the current study, several interviewees saw themselves as stewards. For some, this meant a notion that the forest was only theirs to manage for a limited period, for others, the feeling of stewardship was connected to autonomy and control. Understanding how these different views on human responsibility in relation to forests is crucial for better understanding of what hinders and enables biodiversity protection in different contexts (Mathevet et al., 2018). Stewardship is about caring for what we value (Berry, 2006), and Paper III contributes with insights to better understand, not if, but what forest owner values, and how they care.

A key contribution from Paper III to the overall project is the insight that similar values depending on context can lead to different management decisions. One example is the familial value attributed to the relation to the forest, which was present in all interviews to some extent. A forest owner who expressed a strong connection to their forest and saw forest management as spreading environmental knowledge, to share family history, and to have valuable days in nature with family and friends, could express it as a reason for wanting to avoid harvesting specific areas and therefore explore alternative management approaches. If wood production was stressed as what enabled a rural livelihood, the same underlying emphasis on familial and community importance could be a reason for expansion of production-oriented management.

These insights have implications for the field of relational values beyond those in forest management. Although the definition of relational values in principle is open for relations to be both beneficial and non-beneficial for pro-environmental behaviour, many empirical studies have so far focused on relational values as supporting pro-environmental behaviour (Hoelle et al., 2023). In addition to the empirical contributions for the role of relational values in forest management, the thesis makes a conceptual contribution to the literature on relational values, showing how relational values may contribute to both pro-environmental management and sustained forest utilisation.

Previous literature has shown the potential of relation thinking for supporting understandings of points of alignment between landowner values and voluntary incentive programs for biodiversity protection (Arias-Arévalo et al., 2025; Messick & Serenari, 2023). Building on this work, an interesting venue for future work would be to integrate relational thinking into modelling of voluntary biodiversity protection (see e.g. Klein et al., 2024; Schlüter et al., 2025).

Agent-based models as tools for knowledge production

Forest models have commonly been focused on analysing resource dynamics and optimal management decisions. This project emphasises the role of social dimensions, intending to incorporate social science perspectives in forest modelling. This was done with the intention to support inclusive decision-making (Pereira et al., 2021; Schlüter et al., 2023). However, the increasing complexity of models per se does not lead to more inclusive policies or more precise results. In fact, rather the opposite, as models including more parameters also include more factors of uncertainty (Harremoës & Madsen, 1999). To address this, it is, on the one hand, important to discuss reflexivity as a modeller. This means to reflect on how the researcher's assumptions impact model behaviour. For agent-based modelling, frameworks like the ODD-protocol for model documentation (Grimm et al., 2020) and the Modelling Human Behaviour framework for mapping behavioural assumptions (Schlüter et al., 2017) can be a support in this regard. For the current study, I have also aimed at visualising the impact of modelling choices through the process of calibration. However, although clarifying assumptions is an important first step, the real impact of reflexivity happens when insights become integrated into the modelling process. A continuation on the current project would be to integrate empirical insights from the relational framework analysis to better capture different consequences of agents' connections to land.

Apart from generating more transparent modelling processes for decision-making, a second aspect to be discussed is the role of models in decision support. Model results have contributed substantially and weighed heavily in international policy-making related to forests, like IPCC and IPBES (Lövbrand, 2011; van Beek et al., 2022), and studies have aimed at broadening the scope of decision tools by integrating social and ecological knowledge in national conservation planning (Paloniemi et al., 2018). While the integration of broader aspects into modelling and decision tools, which this thesis contributes to, is an important aspect of diversifying knowledge integration, a modelling approach does not answer all questions of importance for understanding current and future challenges in land management. To really diversify knowledge integration, the balance between how models and other research practices are contributing to policy forums must also be addressed.

To summarise, agent-based modelling offers a possibility of visualising important aspects of forest dynamics that historically have been invisible in forest modelling, like the role of diverse human behaviour, social networks, and institutional dynamics. The field of agent-based modelling has gone from conceptual and scenario testing toward developing tools to be used as policy decision-making. This makes it a crucial point for future research to focus on reflexive modelling practices, to understand how model assumptions about individual decision-making, social interactions, and interactions between people and institutions, impact model outcomes.

Reflections about the research approach

This project contributes with an interdisciplinary and mixed-methods approach to biodiversity implementation and outcomes. Together with an empirical focus that ranges from individual forest owner decision-making to policy outcomes on the national level, the thesis provides a broad perspective for understanding human-environment relations in biodiversity governance. However, the focus on multiple perspectives limits the ability to engage more in-depth with each approach. It also includes tensions between perspectives coming from different epistemological and ontological traditions, a common feature of interdisciplinary forest research as highlighted by Persson et al., (2018). In the following, I reflect on limitations in the different papers and tensions within the overall research approach.

The research focus on implementation and outcomes of voluntary forest policies led me to focus on private forest owners. However, a social-ecological understanding of forests highlight the diversity of actors and interests involved. This thesis thus contributes with a piece of the puzzle for understanding social-ecological interactions in forests. For the interviews in Paper III, I aimed to understand how forest owners with an active engagement with their forest related to it, and how that relation impacted management decisions. I defined active engagement broadly, in terms of engaging in decision-making and management, and regularly visiting the forest. Aware that the active forest owner could be active in different ways and for different reasons, I used purposive sampling to reach forest owners with different goals, living at different distances from their property, and owning properties of different sizes. Forest owners who own properties up to 200 ha make up 67% of the privately owned productive forest area (The Swedish Forest Agency, 2025). The group of participating forest owners represent the diversity within a larger proportion of private forest owners. However, private forest owners who have little interest in visiting their forest, or who own very large land areas, were not represented in the material. To understand management decisions by owners of larger properties would be important, not least if bringing in attention to how power impacts biodiversity governance.

The CRAFTY agent-based modelling framework allowed for representing dynamics in both social and ecological processes, as well as their interactions. The framework was developed to work on a large scale, which was an important criterion for studying the effects of a national policy. Although not incorporated in the current study, ongoing work to couple CRAFTY to a dynamic vegetation model, and to incorporate agents' cognitive and social aspects to a larger extent, also played a role in the decision for the framework. However, building on a model framework developed for land use change, the model offers fewer possibilities for explicitly representing the temporal dynamics of forest management. I expect this to have an impact on how different management strategies influence carbon sequestration over time. This limitation would be important to address if the model is to be used in the future to understand synergies and trade-offs between carbon and biodiversity.

Modelling social dimensions like heterogeneous actors and institutional dynamics is one approach for analysing social-ecological interactions in forests. The process of model development and calibration can serve to better understand key mechanisms of change. But it requires some form of simplification of social dimensions, which stands in contrast to the context dependence and richness indicated by the interviews. Combining these methods highlights tensions about how we understand truth, ontological tensions, and how we see knowledge can be generated, epistemological tensions.

As briefly touched on in the conceptual background, through the thesis I move between rationalist, institutionalist, and practice-based perspectives on forests and forest management. This has on the one hand, practical implications for the approaches used to study human behaviour and policy change. On the other hand, these perspectives also influence what kind of policy suggestions we make. With a simplified example, a strict rationalist would focus on incentives for efficient policies, an institutionalist would highlight the importance of clarifying rules, and a practice-based approach would lead to saying that policy outcomes are difficult to steer and predict (Arts et al., 2014). The policy suggestions in the different papers are also a result of the perspectives and research traditions that they are part of.

To properly engage with the tensions brought up here would require a deeper discussion about the philosophy of science. Through this project, I have, however aimed at bringing different approaches and traditions in dialogue with each other. Through that, I hope to contribute to environmental science that to a greater extent acknowledges and engages with these tensions between world views. I think such recognition both contributes to stronger and more fruitful interdisciplinary collaborations and is necessary to avoid suggesting policy solutions that neglect how social context, like values, power, and attitudes, impact policy outcomes.

Future research

Based on the thesis project, I see an opportunity for three possible future directions.

- **Recognising diverse human behaviour when modelling key challenges in biodiversity governance.** As a spatially explicit model that recognises diverse human behaviours in the governance and management of a diversity of ecosystem services, CRAFTY-Finland has the potential to contribute insights for key challenges in biodiversity governance. Future focus could be to study spatial synergies and trade-offs between carbon sequestration, biodiversity protection, and recreation. Developed with the same resolution as the overarching CRAFTY framework, it would also be possible to scale the modelling and do comparative studies of biodiversity policy implementation in countries with different conditions within a European context.
- **Framework for integrating relational values in modelling.**
  The current project departed from an ambition of contributing to more inclusive models when it comes to social-ecological interactions of forest dynamics. The results have shown the potential contributions that agent-based modelling can bring to forest policy analysis by recognising a broader representation of human behaviour compared to traditional approaches to forest modelling. However, as agent-based models are increasingly being developed with the aim of being tools for policy making, it is a crucial time for studying the assumptions of human behaviour in these models and how these assumptions impact scenario development and policy suggestions. Through reflexive modelling practices, a potential for future research could be to integrate qualitative insights about human-forest relations, contributing conceptually to recent suggestions of situated modelling (Klein et al., 2024).
- **Walking interviews and relational thinking to understand local needs and conditions.** The project shows the potential for using walking interviews as an approach for understanding forest owners' decision-making, and more broadly, local responses to policy ambitions. The importance of recognising local needs and conditions is increasingly stressed by international policy organisations and in national implementation plans for biodiversity restoration and energy transition. A fruitful direction for future research could be to use walking interviews with a broader group of forest users to gain other local perspectives on biodiversity protection.

Conclusion

Motivated by the critical need for more diverse boreal forests to sustain a variety of functions, habitat, and structures, this thesis was set out to answer two overarching questions: i) how different methodological approaches used to study forest policy implementation take social-ecological interactions into account, and how methodological choices influence the representation of interactions, and ii) how social-ecological interactions influence biodiversity implementation and outcomes.

Based on previous literature in forest policy, forest management, social-ecological systems, and landscape ecology, I identified four opportunities for further research: the ability of modelling forests as social-ecological systems, the methodological impacts on understandings of forest owner behaviour, a broader perspective on the value-action gap, and an attention to the quantity, quality, and connectivity of voluntary biodiversity policies.

Taken together, the outcomes emphasise the social and ecological dynamics involved in implementing biodiversity policy in managed forests in Sweden and Finland. In response to the first research gap identified, the thesis provides an overview of, and comparison between, agent-based models used to study forests as socio-ecological systems (SES). The results demonstrate the potential of agent-based models in combining social and ecological processes in forest research. However, the ability of existing models to recognise SES interactions varies, interactions that are crucial to represent for better understanding the governance of forest biodiversity.

A common approach to studying the dynamics between forest owners on a national and group level, and their responses to forest policy, has been through forest owner typologies. While the analysis highlights important dynamics in the heterogeneity among owners of attitudes toward biodiversity-enhancing measures, the results' main contribution consists of how methods impact the final typologies. This speaks to the second research gap and the first research question, suggesting that researchers interested in forest owner attitudes and behaviour need to pay attention to the methods used to study these dynamics.

For understanding social-ecological interactions on a local and individual level, the thesis contributes by using walking interviews as a novel approach for studying forest owner decision-making. Contributing to responding to the second research question and the third research gap, the outcomes show that relational values play an important role in private forest owners' decision-making. Aspects that give importance to the relationship with the forest, like place connection, family, and care, impact the decisions on, for example, which areas to formally or informally protect. The direction is not simply beneficial for biodiversity, and sometimes relational values like community identity can support a sustained focus on production and extraction.

On a national and landscape level, the analysis of the case of the Finnish METSO program, a payment for ecosystem services policy that aims at voluntary protection of forest habitats in southern Finland, highlights how social dynamics like regional policy implementation structures, and ecological dynamics like the weight given to habitat prioritisation, impact the quantity, quality, and connectivity of the resulting network of protected areas.

Beyond the project's outcomes, I have, through a mixed-methods and interdisciplinary approach, strived to emphasise that it matters *how* we come to the outcomes. By encouraging reflection on assumptions we make, methods we use, and our role as researchers in producing knowledge this thesis aims to open pathways for more inclusive decision-making about future forest landscapes.

Declarations

Declaration of Generative AI

During the preparation of this work, I have used Deep L and Grammarly for aid with grammar and spelling, Gemini and Chat GPT for programming feedback, and Open AIs Whisper for transcribing interviews. Transcription was carried out locally on an offline, secure computer that was restored and encrypted after each run. After using these services, I have reviewed and edited as needed and take full responsibility for the content of the work.

Statement on inclusion

Paper III was made possible through the participation of private forest owners in southern Sweden. In reaching out to presumptive interviewees, I explicitly attempted to get a broad representation of forest owners across age, gender, residence, ownership experience, and management goals. In writing the manuscript I aimed to give justice to the nuances in different interviewees' responses.

Data availability statement

For Paper I, all reviewed articles are shared within the manuscript.

For Paper II, we do not have permission to share the data, but code for replicating the analysis can be found at 10.5281/zenodo.10854181

For Paper III, the interview material cannot be made publicly available, to protect participant confidentiality and to comply with the ethical approval under which the research was conducted.

For Paper IV, the CRAFTY framework is fully open-source and available at https://github.com/CRAFTY-ABM

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THE PRESSURE ON FOREST BIODIVERSITY is intensifying due to land use competition, shifting societal demands, and climate change. Voluntary policy instruments are increasingly suggested as conservation strategies in managed forests, but we lack understanding of how social processes, like diverse landowner values, and ecological processes, like varying forest conditions, jointly influence policy outcomes.

In this thesis I take an interdisciplinary approach combining walking interviews, geographic information, and agent-based social simulation to examine the interplay between landowners, policy, and ecology, in shaping biodiversity protection.

HANNA EKSTRÖM PIGOT has a background in Geography with an interest in social and natural science approaches to understanding society's use of natural resources, land use change, and urban and rural dynamics.

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