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Review Article

Climate-smart forestry in a high-forest boreal production system: management trade-offs, peatland mitigation and implementation constraints in Finland

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A B S T R A C T

Finnish forests play a central role in national climate mitigation and adaptation, yet the climate value of forestry depends strongly on management choices and associated trade-offs. This scoping review synthesizes current knowledge on climate-smart forestry in Finland, with particular emphasis on carbon sequestration, drained peatlands, harvest intensity, and management-related trade-offs. We reviewed literature published between 2015 and 2026 and synthesized 30 core studies selected from 297 records identified across major academic search platforms. The evidence shows that management choices strongly modulate carbon outcomes and can in some cases outweigh the modeled effects of climate change, although increasing climate-driven disturbance and uncertainty remain central constraints. Continuous-cover forestry on drained peatlands has emerged as one of the most promising high-leverage pathways, with studies indicating the potential to strengthen Finland's forest carbon sink while reducing soil emissions relative to rotation forestry. Mitigation-oriented management can increase carbon stocks compared with business-as-usual scenarios, but typically at the cost of lower timber harvests, which highlights a persistent carbon–timber trade-off. Mixed-species stands, longer rotations, genetically improved regeneration material, and adaptive management approaches also show potential to support carbon sequestration and forest resilience under changing disturbance regimes. At the same time, regional variability, uncertainty in long-term projections, and the economics of private forest ownership complicate implementation. We interpret Finland as a high-forest boreal production system in which the main climate-smart forestry challenge is not forest expansion, but the redesign of management incentives, peatland practices and owner-level decision support within an already intensively managed forest estate. The strongest opportunities lie in peatland-sensitive management, harvest optimization and multifunctional approaches that integrate carbon, biodiversity, resilience and wood-use objectives. However, these pathways involve explicit trade-offs: higher in-forest carbon stocks and lower peatland emissions often require lower short-term harvest revenues, modified silvicultural systems or additional incentives for private forest owners. The Finnish case therefore provides transferable lessons for other high-forest production systems where carbon mitigation depends on aligning ecological potential, forest economics and practical implementation.

1. Introduction

1.1. Background on finnish forests

Finland is one of the most heavily forested countries in Europe, with forests covering approximately 74–86% of its land area, representing about 22–23 million hectares (Peltola, 2022). These boreal forests are dominated by Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and birch species (*Betula* spp.), with conifers forming the main commercial tree-species group. Finnish forests have historically played a dual role: serving as a cornerstone of the national economy through timber production and the forest industry, while simultaneously functioning as critical carbon sinks that contribute to climate change mitigation (Lipiäinen et al., 2022).

Yet, the significance of Finnish forests extends beyond their economic value. They provide a wide array of ecosystem services, including biodiversity conservation, water regulation, recreation, and cultural values. In the context of climate change, Finnish forests have gained

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increasing attention for their potential to sequester atmospheric carbon dioxide and store it in biomass and soil, thereby contributing to national and international climate goals (Forsius et al., 2023). However, the role of forests in climate mitigation is complex and multifaceted, involving not only carbon sequestration in standing biomass but also carbon storage in harvested wood products and the substitution of fossil-based materials and energy sources (Baul et al., 2017). Accelerating global biodiversity loss and climate change further underscore the need for forest management practices that enhance carbon sequestration while maintaining forest biodiversity (Peura et al., 2018).

1.2. Climate context and policy framework

Finland has committed to ambitious climate targets, including achieving carbon neutrality by 2035 and becoming carbon negative shortly thereafter. These goals are enshrined in national climate and energy strategies that recognize forests as a critical component of the solution (Forsius et al., 2023). The Finnish government has emphasized the need for climate-smart forestry practices that balance multiple objectives: maximizing carbon sequestration, maintaining timber production, enhancing forest resilience to climate change and disturbances, and preserving biodiversity (Peltola, 2022).

Climate change is already affecting Finnish forests through rising temperatures, altered precipitation patterns, and increased frequency and severity of disturbances such as storms, droughts, and pest outbreaks. These changes present both opportunities and challenges for forest management. For instance, while warmer temperatures may enhance tree growth in some regions, particularly in northern Finland, they also increase the risk of damage from bark beetles, wind, and other disturbances (Repo et al., 2024). Understanding how different management strategies can enhance forest resilience while maintaining or increasing carbon sequestration is, therefore, a critical research and policy priority.

The European Union's climate and forest policies also influence Finnish forestry. The EU has set targets for greenhouse gas emission reductions, emphasizing the role of forests in achieving these goals through initiatives such as the Land Use, Land Use Change and Forestry (LULUCF) regulation. A recent European region policy brief (Mäkipää et al., 2025) emphasizes that achieving climate targets will require stand-level guidelines that account for stand structure including tree size distribution and density and ensure the cost-effective allocation of management inputs. Climate-smart forestry, as promoted at the EU level, aims to reduce greenhouse gas emissions, adapt forests to climate change, and sustainably increase forest productivity (Nabuurs et al., 2017). However, integrating these objectives into coherent national and regional policies remains a challenge, particularly given the diverse ownership structure of Finnish forests, where approximately 60% are privately owned (Makkonen et al., 2015).

These policy and governance challenges also appear at the operational stand level. The timing and intensity of the first thinning are pivotal for shaping stand structure, promoting subsequent growth, and securing the future yield of high-quality saw logs (Niemistö et al., 2018). In Finland, the area of young forests in need of first thinning exceeded one million hectares in the early 2000s (Korhonen et al., 2017). In practice, many young stands reach the first-thinning stage later than recommended or remain untreated for longer than silvicultural guidelines would suggest, partly because early thinning often generates low revenues, requires pre-clearing and can be difficult to organize cost-effectively in dense young stands (Nuutinen et al., 2021). This illustrates a broader challenge for climate-smart forestry in Finland: the success of carbon-oriented management depends not only on policy objectives, but also on the economic and operational feasibility of stand-level interventions.

1.3. Objectives of the review

This scoping review aims to synthesize the current state of knowledge on forest carbon farming and climate-resilient forestry in Finland, focusing on the period from 2015 to 2026. The specific objectives are as follows:

- To identify and characterize current forest management practices and policies in Finland that are relevant to carbon sequestration and climate resilience.
- To evaluate the carbon sequestration potential of different forest management strategies, including continuous-cover forestry (CCF), rotation forestry, and various harvest intensities.
- To assess climate resilience strategies and their effectiveness in enhancing forest adaptation to climate change and disturbances.
- To examine the trade-offs between carbon sequestration, timber production, biodiversity conservation, and other ecosystem services.
- To identify key challenges and opportunities for implementing climate-smart forestry practices in Finland.
- To provide evidence-based recommendations for policymakers and forest managers to optimize Finnish forestry for climate mitigation and adaptation.

By addressing these objectives, this review seeks to provide a comprehensive and up-to-date synthesis of scientific literature to inform policy decisions and management practices in Finnish forestry.

1.4. Terminology and scope

To avoid ambiguity, we use "carbon outcomes" as an umbrella term for management-related changes in forest carbon stocks and fluxes, including live biomass, dead organic matter, soil carbon, harvested wood products and greenhouse-gas emissions where these were included in the reviewed studies. "Soil emissions" refers to greenhouse-gas emissions from forest soils, with particular relevance to drained peatlands where management and hydrology affect peat decomposition. "Mitigation-oriented management" refers to silvicultural or land-management choices explicitly designed to increase net climate benefits, such as reduced harvest intensity, modified rotation length, continuous-cover forestry, peatland-sensitive harvesting, species-mixture adjustment or carbon-oriented regeneration choices. "Longer rotations" refers to rotations extended relative to the business-as-usual or baseline regime used in the study under discussion, rather than a single fixed national threshold.

2. Methods

2.1. Review design

This study was conducted as a scoping review to synthesize recent evidence on climate-smart forestry, carbon sequestration, peatland management, and management-related trade-offs in Finland. The review followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) to improve transparency in study identification, screening, and synthesis (Peters et al., 2020; Tricco et al., 2018). The objective was not to perform a quantitative meta-analysis but to map and critically synthesize the main management pathways and ecological trade-offs discussed in the literature.

2.2. Search strategy and data sources

A structured literature search was conducted in January 2026 using three sources: SciSpace Deep Search, Google Scholar, and arXiv. The search covered publications from 2015 to 2026 and targeted combinations of keywords related to Finland, boreal forests, forest carbon,

carbon sequestration, climate-smart forestry, climate-resilient forestry, forest management, continuous-cover forestry, rotation forestry, peatlands, afforestation, and climate change mitigation.

The initial search identified 297 records in total, including 235 records from SciSpace Deep Search, 58 from Google Scholar, and 4 from arXiv. After deduplication, the remaining records were screened for relevance (see the screening and selection process below).

2.3. Eligibility criteria

Studies were included when they focused on Finland and addressed one or more of the following topics: (i) forest carbon sequestration or carbon balance, (ii) climate-smart or climate-resilient forestry, (iii) management system comparisons such as continuous-cover and rotation forestry, (iv) peatland forestry and soil emissions, (v) harvest intensity and forest carbon trade-offs, or (vi) biodiversity and ecosystem service implications of carbon-oriented forest management.

Peer-reviewed journal articles were prioritized, but dissertations, conference papers, and recent preprints were also considered where they contributed directly to the review objectives. Studies were excluded if they were not specific to Finland, did not address forest management implications, or focused on forestry topics without clear relevance to carbon sequestration, climate resilience, or associated trade-offs.

2.4. Screening and study selection

Study selection followed a multistage process. First, records were merged and deduplicated using title, author, and DOI information. Second, titles and abstracts were screened for relevance to the review objectives. Third, the remaining studies were assessed in greater detail at the full-text level.

AI-assisted prioritization was used only to rank the reading order of potentially relevant records; all eligibility decisions, interpretation, and synthesis were performed by the authors. Following screening, 67 highly relevant papers were identified, of which 30 core studies were selected for detailed synthesis. These 30 studies were treated as the core Finland-focused evidence base for detailed synthesis (Fig. 1). Additional policy, inventory and broader European sources were used only to contextualize the Finnish evidence and to assess transferability beyond the national case. The review should be interpreted as a focused scoping synthesis of core Finland-relevant literature rather than as an exhaustive meta-analysis of all European climate-smart forestry research. This design allows detailed analysis of management pathways and implementation constraints in a high-forest boreal production system, but limits statistical generalization across countries.

2.5. Data extraction

For each included study, the following information was extracted: bibliographic details, study design, geographical focus within Finland, forest type or management context, management interventions or scenarios examined, and key findings related to carbon sequestration, peatlands, climate resilience, biodiversity, or timber-production trade-offs. Where available, quantitative results such as changes in carbon stocks, emissions, timber removals, and/or mitigation potential were also extracted.

2.6. Synthesis approach

Given the heterogeneity of methods, datasets, and reported outcomes, the evidence was synthesized narratively rather than statistically. The synthesis focused on five thematic areas: (i) management levers and mechanisms, including harvest intensity, rotation length, continuous-cover forestry, peatland hydrology and species composition; (ii) reported climate effects, including biomass carbon, soil emissions, harvested wood products and biophysical effects where available; (iii) economic and operational feasibility, including harvest revenues, thinning costs, carbon payments and owner-level incentives; (iv) climate resilience and disturbance uncertainty; and (v) trade-offs and synergies among carbon, timber production, biodiversity and multifunctionality.

The aim of the synthesis was to identify converging patterns, highlight management-relevant ecological mechanisms, and clarify where the literature supports robust conclusions or where uncertainty remains.

3. Results

3.1. Overview of included studies

The 30 papers included in this review represent a diverse body of research spanning the period from 2015 to 2026. The studies employ a range of methodological approaches, including forest growth modeling and simulation, empirical analysis of forest inventory data, scenario analysis, economic optimization, and integrated assessment modeling. Geographically, the studies cover various regions of Finland, from southern to northern boreal zones, with some articles focusing on specific forest types, such as drained peatlands or Norway spruce stands.

The majority of studies (approximately 70%) focus on the trade-offs between carbon sequestration and timber production under different management scenarios. A significant subset (approximately 40%) explicitly addresses climate change impacts and adaptation strategies. Several studies (approximately 30%) examine the role of CCF as an alternative to traditional rotation forestry. Peatland forests, which are particularly important for carbon dynamics in Finland, are the focus of

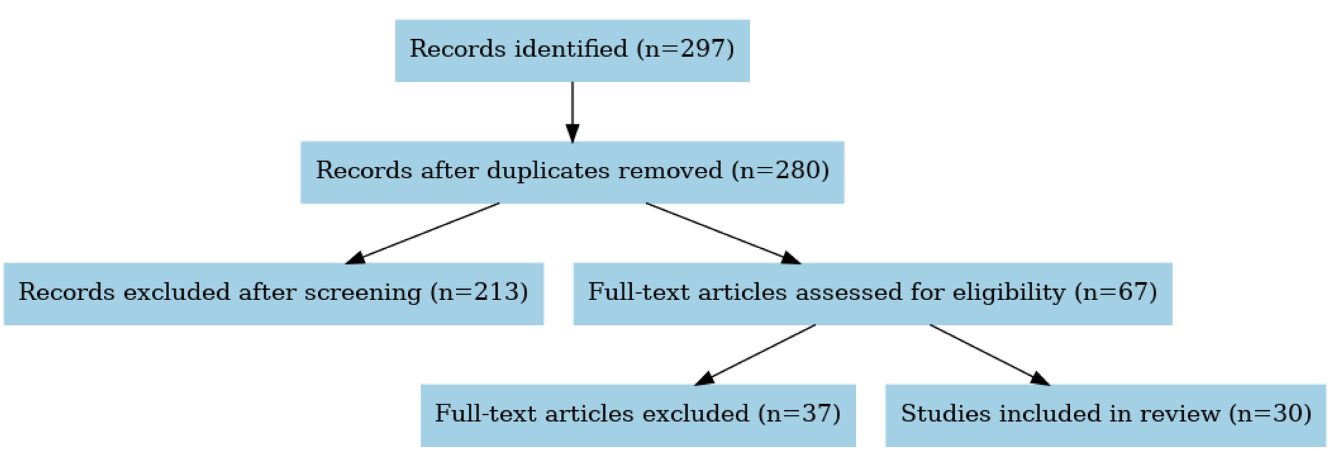

Fig. 1. PRISMA-ScR flow diagram illustrating the identification, screening, and inclusion of studies in the scoping review.

approximately 20% of the included studies.

3.2. Thematic organization of literature

The reviewed literature can be organized into six main themes that reflect the key dimensions of forest carbon farming and climate-resilient forestry in Finland. Table 1 presents the thematic organization of the literature, grouping papers by their primary focus areas.

The distribution of studies across these themes (Table 1) highlights that considerable research attention has been given to the carbon sequestration potential of various management strategies and to climate resilience and adaptation, while policy and economic considerations are increasingly being integrated into forest carbon research.

This thematic organization reveals several key patterns in the literature. First, there is substantial research on the carbon sequestration potential of different management strategies, reflecting the central importance of this issue for climate policy. Second, climate resilience and adaptation strategies have received increasing attention in recent years, particularly in response to growing concerns about disturbance risks. Third, policy and economic considerations are increasingly integrated into forest carbon research, recognizing that effective implementation requires appropriate incentive structures. The following subsections provide detailed findings for each theme.

3.3. Current practices and policies

Finnish forest management has traditionally been dominated by rotation forestry, characterized by clear-cutting followed by regeneration, typically with even-aged stands. However, recent policy developments and growing awareness of climate change have prompted a reevaluation of management practices and a search for alternatives that can better balance multiple objectives (Peltola, 2022).

Finland's climate-smart forestry strategy emphasizes three main pillars: increasing carbon sequestration from the atmosphere and storing it in forests, producing wood-based products for long-term carbon storage and substitution of greenhouse gas-intensive materials, and enhancing forest resilience to damage risks by promoting mixed-species stands instead of monocultures (Peltola, 2022). The strategy recognizes that, while maximizing carbon storage offers short-term climate-cooling benefits, it also carries the risk of forests becoming carbon sources due to natural disturbances. Therefore, a balanced approach that considers both mitigation and adaptation objectives is needed.

At the European level, climate-smart forestry has been promoted as a comprehensive strategy to unlock the mitigation potential of forests. For example, an EU-level study (Nabuurs et al., 2017) estimated that EU forests could achieve an additional combined mitigation impact of 441 Mt CO_2/year by 2050 through climate-smart forestry practices. However, they noted that European policy has not fully integrated forest potential into the EU climate policy framework, nor have climate objectives been firmly integrated into forest sector policies. This policy gap highlights the need for better coordination between climate and forest policies at both EU and national levels.

Table 1
Thematic organization of the literature on forest carbon farming and climate-resilient forestry in Finland.

Main Theme	Key Paper References
Current Practices and Policies	(Forsius et al., 2023; Kauppi et al., 2022; Lipiäinen et al., 2022; Makkonen et al., 2015; Nabuurs et al., 2017; Peltola, 2022)
Climate Resilience Strategies and Management	(ALRahahleh, 2018; Hohti et al., 2024; Pikkarainen et al., 2023; Repo et al., 2024; Triviño et al., 2022; Zubizarreta-Gerendiain et al., 2015)
Carbon Sequestration Potential and Rates	(Ahtikoski et al., 2022; Baul et al., 2017; Garcia-Gonzalo et al., 2017; Kalliokoski et al., 2020; Lehtonen et al., 2023b, 2024; Mäkelä et al., 2023; Sirkiä et al., 2023)
Challenges and Opportunities	(Ahtikoski et al., 2020; Forsius et al., 2023; Heinonen et al., 2018; Repo et al., 2024; Vauhkonen et al., 2019)
Afforestation and Reforestation Initiatives	(Ahtikoski et al., 2020; Forsius et al., 2023; Peltola, 2022)
Policy Frameworks and Economic Incentives	(Ahtikoski et al., 2020, 2022; Bianchi et al., 2023; Lipiäinen et al., 2022; Makkonen et al., 2015; Nabuurs et al., 2017; Pukkala at al., 2025)

The Finnish forest industry is also undergoing transformation in response to climate goals. Lipiäinen et al. (2022) examined the progress, tools, possibilities, and barriers of Finnish and Swedish forest industries in achieving deep decarbonization. They found that, while the forest industry recognizes the importance of carbon neutrality, significant challenges remain in terms of technology development, investment needs, and policy support. The transition to a carbon-neutral forest industry requires not only changes in forest management but also innovations in wood processing, product development, and energy systems.

Policy coherence is a critical challenge for implementing climate-smart forestry in Finland. Makkonen et al. (2015) analyzed policy coherence in climate change mitigation, taking an ecosystem service approach to forests as carbon sinks and bioenergy sources. They found that different policy objectives—such as maximizing carbon storage, increasing bioenergy production, and maintaining biodiversity—can sometimes conflict with each other, requiring careful balancing and trade-off analysis. Effective policy frameworks need to account for these trade-offs and provide clear guidance for forest managers.

Recent research has also emphasized the importance of better forest management in mitigating climate change. Kauppi et al. (2022) used detailed forest inventory data from Finland and Norway to demonstrate that managing existing forests can significantly increase forest carbon stocks. They argued that improved forest management, including adaptive silviculture practices, can enhance forest growth and carbon sequestration while also improving climate resilience. This finding underscores the potential for management interventions to make a substantial contribution to climate mitigation, even without expanding the forest area.

3.4. Climate resilience strategies and management approaches

Climate resilience has emerged as a central concern in Finnish forestry, driven by increasing recognition that climate change and its associated disturbances pose significant risks to forest ecosystems and the services they provide. Several studies have examined different management strategies for enhancing forest resilience while maintaining carbon sequestration and timber production.

Repo et al. (2024) conducted a comprehensive comparison of forest management strategies emphasizing either climate change mitigation or adaptation. Their simulations over an 80-year period revealed complex interactions between management choices, disturbance risks, and ecosystem outcomes. Mitigation-focused management resulted in 6–15% higher carbon stocks compared to business-as-usual scenarios, even when accounting for disturbances, but this came at the cost of halving annual harvests. Adaptation-focused management, which included measures such as increasing the proportion of deciduous trees and adjusting rotation lengths, had mixed effects on disturbance risks—reducing bark beetle outbreaks in some cases but sometimes increasing wind damage. These findings highlight the difficulty of optimizing for multiple objectives simultaneously and the need for context-specific management strategies.

A key insight from recent research is that management choices often have a greater impact on forest ecosystem services than climate change itself. Triviño et al. (2022) found that the future supply of boreal forest ecosystem services is driven more by management decisions than by climate change. This finding suggests that forest managers have considerable agency in shaping forest outcomes, even in the face of changing climate conditions. However, it also underscores the importance of making informed management choices that account for long-term climate trends and disturbance risks.

Regional differences in climate change impacts necessitate tailored management approaches. ALRahahleh (2018) showed that climate projections combined with different management regimes can yield divergent outcomes in timber production and carbon stocks between northern and southern Finland, indicating that region-specific strategies are warranted. Meanwhile, Hohti et al. (2024) explored boreal forest multifunctionality under varying harvesting intensities and priorities, emphasizing that strategies explicitly considering trade-offs and synergies among ecosystem services can improve overall outcomes.

3.5. Carbon sequestration potential and rates

Quantifying the carbon sequestration potential of Finnish forests under different management scenarios is central to informing climate policy and management decisions. The reviewed literature provides substantial evidence on carbon dynamics under various management approaches, with particular attention to the trade-offs between carbon storage and timber production.

One of the most significant findings concerns the potential of CCF on drained peatlands. Lehtonen et al. (2023a) demonstrated that CCF on nutrient-rich drained peatlands can increase Finland's carbon sink by approximately 1 Tg CO_2-eq annually compared to current forest management practices at equal harvest levels. This mitigation potential stems from maintaining higher biomass carbon stocks and reducing soil emissions by avoiding clear-cutting. Given that drained peatlands represent a significant portion of Finnish forest land and are substantial sources of greenhouse gas emissions, this finding has important policy implications.

The role of harvest intensity in determining carbon stocks and fluxes has been extensively studied. Mäkelä et al. (2023) found that harvest intensity is a key determinant of carbon stocks and fluxes at the national scale, regardless of specific management actions or moderate changes in the proportion of strictly protected forests. Their analysis of different harvest scenarios—ranging from no harvest to intensive harvest—showed that reducing harvest levels consistently increases carbon stocks, but at the cost of reduced timber production. This fundamental trade-off between carbon storage and timber yield is a recurring theme in the literature.

Kalliokoski et al. (2020) provided a comprehensive assessment of the mitigation impact of different harvest scenarios, accounting not only for carbon sequestration but also for biophysical factors such as albedo and aerosols. They found that decreasing harvests from baseline levels produced the largest cooling effect over a 50-year period, especially when considering the effects of biogenic secondary organic aerosols. Importantly, even when accounting for avoided emissions from increased wood use, the two lowest harvest scenarios had similar radiative forcing outcomes within uncertainty. This finding challenges the assumption that increased forest biomass utilization for short-lived products and bioenergy necessarily provides greater climate benefits than storing carbon in forests.

The potential for enhancing carbon sequestration through improved forest management practices has been demonstrated in several studies. Garcia-Gonzalo et al. (2017) found that maintaining higher stocking (growing stock volume) over the rotation, compared to Finnish baseline management, could simultaneously increase total timber production, economic profitability, and forest ecosystem carbon stocks. However, they also noted that timber production and carbon sequestration could not be maximized simultaneously, implying opportunity costs when prioritizing one objective over the other.

Baul et al. (2017) examined the climate change mitigation potential of boreal forests under different management scenarios and harvest intensities. They found that maintaining 20% higher stocking combined with earlier final felling and intensified biomass harvest (including logging residues, coarse roots, and stumps) increased both climate benefits and economic returns. However, the net climate benefit depended significantly on the displacement factors used for wood products and bioenergy, highlighting the importance of considering the full life cycle and substitution effects of harvested wood.

Economic considerations are crucial for the practical implementation of carbon-focused forest management. Ahtikoski et al. (2022) analyzed the cost of carbon abatement under CCF versus rotation forestry on both mineral soils and peatlands. They found that mineral soils were more cost-efficient for carbon sequestration, with an additional ton of CO_2 costing about €2 at the forest level (for private owners, given a carbon price of €25/tCO_2), compared to €30–39.5 per ton on peatlands. This cost differential has important implications for targeting carbon mitigation efforts and designing economic incentives.

The use of genetically improved regeneration material offers another avenue for enhancing carbon sequestration. Ahtikoski et al. (2020) examined the economic performance of genetically improved reforestation material in the joint production of timber and carbon sequestration. They found that including carbon pricing in the valuation of outcomes significantly improved the financial performance of using improved material compared to conventional stock, with the carbon benefit representing 27–42% of the absolute bare land value. This finding suggests that carbon pricing could provide strong economic incentives for adopting improved regeneration material and management practices that enhance carbon sequestration.

Uncertainty in carbon flux and stock projections is an important consideration for decision-making. Sirkiä et al. (2023) quantified forest carbon flux and stock uncertainties under climate change and examined their use in regionally explicit decision-making in Finland. They found that uncertainties increase with longer projection periods and vary by region, emphasizing the need for adaptive management approaches that can respond to new information and changing conditions.

Table 2 illustrates the scale of reported carbon effects across management scenarios, but these values should be interpreted relative to Finland's recent land-sector balance and the assumptions of each study. For example, the estimated +1 Tg CO_2-eq yr^{-1} sink increase from continuous-cover forestry on drained peatlands is not a marginal number: it is equivalent to roughly one-tenth of the preliminary 2024 net emission source reported for Finland's LULUCF sector. At the same time, national mitigation-focused scenarios that increase forest carbon stocks by 6–15% may require major reductions in harvest volumes, which makes their practical relevance dependent on compensation mechanisms, owner objectives and industry adjustment. Thus, the key question is not only the biophysical magnitude of each pathway, but whether the carbon benefit is large enough to justify the associated economic and operational trade-offs.

3.6. Challenges and opportunities

The implementation of climate-smart forestry in Finland faces several challenges but also presents significant opportunities for innovation and improvement in forest management practices.

One major challenge is the trade-off between carbon sequestration and timber production. As noted by multiple studies, maximizing carbon storage typically requires reducing harvest levels, which conflicts with the economic interests of forest owners and the timber industry (Mäkelä et al., 2023; Garcia-Gonzalo et al., 2017). Heinonen et al. (2018) examined the effects of forest management and harvesting intensity on timber supply from Finnish forests in a changing climate. They found that different management strategies and harvest intensities have significant implications for long-term timber supply, with more intensive harvesting potentially compromising future timber availability and carbon stocks.

The transition from even-aged management to less intensive forestry systems presents both opportunities and challenges. Vauhkonen et al. (2019) analyzed the impacts of shifting from even-aged management to less intensive forestry in varying proportions of forest land in Finland.

Table 2
Synthesized carbon sequestration impacts of forest management scenarios across scales.

Scenario / Management	Reported Carbon Sequestration Impact	Spatial Scale	Methodological Approach	Uncertainty / Limitations	Source
Continuous-cover forestry on drained peatlands	+1 Tg CO_2-eq yr^{-1} added to Finland's carbon sink	National (Finland)	Process-based modeling combined with forest inventory data	Sensitivity to peatland emission factors, hydrological assumptions, and management intensity	(Lehtonen et al., 2023a)
Mitigation-focused management vs. BAU	+6–15% increase in forest carbon stock (80-year horizon); ~50% reduction in harvest levels	National (Finland)	Scenario modeling (forest sector model with management optimization)	Trade-offs with timber supply; results depend on discount rates and management constraints	(Repo et al., 2024)
New biodiversity areas (afforestation + conservation by 2050)	426–452 Tg C total storage; 12–17.5 Tg CO_2-eq yr^{-1} sequestration	National / Regional (Finland)	Integrated land-use modeling combining conservation and afforestation scenarios	High uncertainty in land availability, species growth rates, and long-term policy implementation	(Forsius et al., 2023)
EU-wide climate-smart forestry by 2050	441 Mt CO_2 yr^{-1} additional mitigation potential	Pan-European (EU-wide)	Large-scale integrated assessment modeling (IAM) and forest sector modeling	Aggregated assumptions; regional heterogeneity and policy uptake variability	(Nabuurs et al., 2017)

They found that such shifts could increase carbon storage but would also affect harvest removals and harvesting costs. The economic viability of less intensive forestry depends on factors such as carbon pricing, timber prices, and the proportion of forest land converted to alternative management systems. Despite existing silvicultural recommendations, many Finnish forest owners postpone the first thinning due to high harvesting costs, low revenues, and the frequent need for pre-clearing dense undergrowth to enable mechanized operations (Nuutinen et al., 2021).

Disturbance risks pose a significant challenge to forest carbon management. As climate change increases the frequency and severity of disturbances such as storms, droughts, and pest outbreaks, the reliability of forests as carbon sinks becomes more uncertain (Repo et al., 2024). Management strategies that enhance forest resilience to disturbances are, therefore, critical for maintaining long-term carbon sequestration. However, as noted earlier, some adaptation measures may have unintended consequences, such as reducing one type of disturbance while increasing another.

Regional variability in forest conditions, climate change impacts, and socioeconomic contexts presents both a challenge and an opportunity. Forsius et al. (2023) modeled the regional potential for reaching carbon neutrality in Finland, considering sustainable forestry, energy use, and biodiversity protection. They found that potential new forested areas set aside for biodiversity protection could provide significant carbon storage (on the order of 426–452 Tg C accumulated) and an annual sequestration potential of 12 to 17.5 Tg CO_2-eq by 2050. This finding indicates complementarity between emission mitigation and conservation measures, suggesting that integrated approaches can achieve multiple objectives simultaneously.

The diversity of forest ownership in Finland, with approximately 60% of forests privately owned, also presents challenges for implementing coordinated management strategies. Private forest owners have diverse objectives—ranging from timber production to recreation and conservation—and may not prioritize carbon sequestration without appropriate economic incentives. Designing effective incentive mechanisms that align private interests with societal climate goals is, therefore, a critical policy challenge.

3.7. Stakeholder engagement and perspectives

Effective implementation of forest carbon farming and climate-resilient forestry in Finland requires the support and participation of a wide range of stakeholders, including private forest owners, government authorities, and the forest industry. Finland's forest ownership structure is diverse: about 60% of forests are privately owned, mostly by individual families, with the remainder managed by the state and companies (Makkonen et al., 2015). This diversity means that stakeholder attitudes and buy-in are crucial for translating climate-smart forestry strategies into practice. Recent studies indicate that Finnish forest owners have heterogeneous views regarding climate change and carbon-oriented forest management. Many owners exhibit uncertainty or skepticism toward pro-climate management changes, often adopting a "wait-and-see" approach and/or seeking clear guidance from authorities before altering traditional practices (Laakkonen et al., 2018). There is also evidence of a generally low willingness among forest owners to participate in new carbon offset or carbon credit schemes in the absence of strong financial incentives. For example, a survey carried out in Finland (Tzemi et al., 2025) found that compensatory carbon payments were the only attribute that consistently motivated Finnish private forest owners to consider joining carbon offset programs, and a large proportion preferred not to participate under current conditions. These findings underscore the importance of economic incentives and policy support in encouraging forest owners to adopt carbon farming practices.

This issue is especially important in Finland because private forest owners control a substantial share of the country's forest resources and annual increment, which makes their management choices highly consequential for national climate outcomes. In practice, the feasibility of carbon-oriented forestry therefore depends not only on technical or ecological potential, but also on whether private owners perceive alternative management pathways as economically credible, operationally feasible, and compatible with their ownership objectives.

Policymakers and local authorities in Finland appear to recognize the need to engage stakeholders when developing and implementing climate-resilient forestry initiatives. Still, as of the mid-2020s, there is active discussion but no comprehensive national policy yet for rewarding increased carbon sequestration on private forest lands (Tzemi et al., 2025).

4. Discussion

4.1. Management vs. climate as primary drivers

One of the most important insights from this review is that forest management choices often exert a greater influence on carbon sequestration and ecosystem services than climate change itself, at least over the time scales typically considered in forest planning (several decades to a century). This finding (Triviño et al., 2022) has profound implications for forest policy and management.

The primacy of management over climate as a driver of forest outcomes means that forest managers and policymakers have considerable agency in shaping the future of Finnish forests. Even in the face of significant climate change, appropriate management interventions can maintain or enhance carbon sequestration, timber production, and other ecosystem services. This is an empowering message that contrasts with narratives that emphasize the inevitability of climate impacts and the limited scope for human intervention.

However, this finding should not be interpreted as diminishing the importance of climate change or the need for adaptation. Rather, it highlights that management decisions determine how forests *respond* to climate change. Poorly designed management strategies can exacerbate climate impacts and increase vulnerability to disturbances, while well-designed strategies can enhance resilience and maintain ecosystem functions even under changing conditions (Repo et al., 2024).

The relative importance of management versus climate also varies by region and time scale. In northern Finland, where climate change is expected to have more positive effects on tree growth, the benefits of warmer temperatures may be more pronounced (ALRahahleh, 2018). Conversely, in southern Finland, where climate change may increase drought stress and disturbance risks, the need for adaptive management is more urgent. Over longer time scales (beyond a century), climate change effects on forests are likely to become more dominant, underscoring that proactive management can "buy time" and buffer impacts in the near term while global efforts to mitigate climate change continue.

4.2. Trade-offs between carbon and timber production

A central theme throughout the reviewed literature is the fundamental trade-off between maximizing carbon storage in forests and maintaining timber production. Forest management strategies that favor carbon sequestration—such as reduced harvesting intensity, longer rotations, or continuous-cover regimes—generally result in greater standing biomass and soil carbon stocks but at the expense of periodic timber yields. This trade-off is evident in modeling studies (Garcia-Gonzalo et al., 2017; Mäkelä et al., 2023) and long-term scenario analyses (Heinonen et al., 2018), and it reflects an inherent tension between using forests as a carbon sink and as a source of wood products.

The magnitude of this trade-off can be significant. Repo et al. (2024) demonstrated that a mitigation-focused management regime could increase carbon stocks by up to ~15% relative to business-as-usual scenarios, but this required roughly a 50% reduction in annual harvest volumes. Such a reduction in timber output has economic implications for forest owners, industry, and broader rural livelihoods. Conversely, intensive timber-oriented practices can erode the forest carbon sink, potentially undermining climate objectives. The challenge for Finland is to find an optimal balance that delivers climate mitigation benefits while sustaining an economically viable level of timber production.

Management interventions and innovations can partially mitigate this trade-off. For instance, the use of genetically improved tree stock can boost growth rates, potentially yielding more timber and carbon simultaneously (Ahtikoski et al., 2020). Diversifying species and age structures in forests may sustain productivity under stress and, thereby, reduce the severity of trade-offs over time. Additionally, when evaluating the carbon benefits of reduced harvesting, it is important to account for *substitution effects*: wood products can store carbon and substitute for fossil-intensive materials, offsetting some foregone in-forest carbon (Baul et al., 2017). Strategies that channel harvested wood into long-lived products or bioenergy can, thus, recuperate a portion of the climate benefit lost by harvesting. However, as Kalliokoski et al. (2020) and Baul et al. (2017) note, these substitution benefits have limits and uncertainties, and they do not fully negate the climate advantage of higher forest stocks.

CCF generally enhances carbon storage and maintains continuous forest cover (Table 3), which benefits biodiversity and resilience, but it yields lower timber volumes [often ~30–50% reduction in harvest compared to rotation forestry under similar conditions (Repo et al., 2024)]. Conventional rotation forestry maximizes periodic timber yield through clear-cut harvests, yet this comes at the cost of lower average carbon stocks and habitat disruption. Additionally, managing drained peatlands presents unique challenges and opportunities: under traditional rotation clear-cutting, peat soils can release significant carbon, whereas adopting CCF or partial harvest methods on peatland can avoid these emissions and turn peatland forests into a net carbon sink (Lehtonen et al., 2023a). Economically, CCF may require financial incentives (e.g., payments for carbon sequestration) to compensate landowners for reduced timber income (Ahtikoski et al., 2022), while rotation forestry benefits from established markets for timber but may incur future costs if carbon liabilities are assigned to land-use emissions. This comparison highlights that no single strategy optimizes all goals; instead, a mix of approaches is needed, tailored to site conditions and stakeholder priorities.

Ultimately, policy mechanisms will play a role in managing trade-offs. If climate policy assigns sufficient value to forest carbon (e.g., through carbon pricing or payments for ecosystem services), the economic calculus for forest owners could shift, making carbon-centric management more attractive (Ahtikoski et al., 2022). In the absence of such incentives, however, the traditional emphasis on timber revenues is likely to prevail. Thus, addressing the carbon–timber trade-off in practice may require policy intervention to reward landowners for the climate services their forests provide.

The economic dimension is not secondary to the ecological one. In privately owned forests, reduced harvest intensity, longer rotations or continuous-cover systems may increase carbon storage but can also delay or reduce cash flow. For many owners, accepting lower short-term revenue is unlikely without credible compensation, lower transaction costs or clear non-market benefits. In publicly owned forests, the issue is different but not simpler: using public resources to support lower-harvest or carbon-oriented strategies requires transparent justification

Table 3
Comparison of forest management strategies and their implications for carbon sequestration, timber production, climate resilience, biodiversity, and economics.

Aspect	Continuous-cover Forestry (CCF)	Rotation Forestry (Conventional)	Drained Peatland Management	Evidence Strength	Key Trade-Offs
Carbon sequestration potential	High: +6–15% increase in forest carbon stocks vs. BAU (long-term) (Repo et al., 2024); potential +1 Tg CO_2-eq yr^{-1} on peat soils (Lehtonen et al., 2024, 2023b)	Moderate: baseline carbon storage under standard rotation cycles	Variable: high emissions under clear-cutting; mitigation possible with CCF (~+1 Tg CO_2-eq yr^{-1}) (Lehtonen et al., 2023b)	High	Carbon vs. timber yield
Timber yield	Lower: ~50% reduction in harvest volumes (Repo et al., 2024)	High: maximized timber production under optimized rotations	Lower: reduced growth rates; operational constraints on wet soils	High	Timber revenue vs. carbon storage
Climate resilience	Higher: uneven-aged, mixed-species stands increase resistance to disturbances	Lower: even-aged monocultures vulnerable to pests and storms	Low–moderate: drainage increases drought and fire vulnerability; resilience improves with reduced disturbance	Medium	Stability vs. productivity
Biodiversity	Higher: continuous canopy and structural heterogeneity support habitat continuity	Lower: clear-cutting reduces habitat continuity and structural diversity	Sensitive: drainage degrades peatland ecosystems; partial harvesting reduces impacts	Medium	Biodiversity vs. management intensity
Economic performance	Lower private returns without incentives; requires carbon compensation mechanisms (Ahtikoski et al., 2022)	High: established markets and predictable revenues	High abatement costs (€30–39 tCO_2^{-1}) (Ahtikoski et al., 2022)	Medium	Profitability vs. climate mitigation

of climate, biodiversity and social benefits. This means that carbon-oriented management cannot be evaluated only by tonnes of CO_2-eq; it must also be evaluated by who bears the opportunity cost and how that cost is compensated.

In this context, decision-support tools capable of evaluating carbon revenues, timber trade-offs, operational costs, and site-specific constraints could play an important role in implementation. Such tools would help forest owners compare alternative management pathways under different assumptions regarding carbon pricing, discount rates, and future timber assortments, thereby reducing uncertainty around carbon-oriented silvicultural choices.

4.3. Role of peatlands in carbon mitigation

Drained peatland forests emerge from this review as both a priority and a challenge for climate-resilient forestry in Finland. Peatlands are significant because of their large soil carbon stocks and, when drained and managed for timber, their propensity to emit CO_2 due to peat decomposition. Finland has over 5 million hectares of peatland forests, many of which were drained in the 20th century to enhance tree growth. These areas now represent hotspots of greenhouse gas emissions within the forest sector, but they also offer outsized opportunities for mitigation if managed appropriately.

This evidence indicates that changing management on peatlands can yield substantial climate benefits. CCF on nutrient-rich drained peat soils can maintain a higher water table and continuous tree cover, thereby reducing peat oxidation and CO_2 emissions. Lehtonen et al. (2023a) quantified this effect, finding about a 1 Tg CO_2-eq per year increase in net sink capacity when peatland stands are managed with no clear-cuts (CCF), as opposed to rotation forestry. This is a remarkable contribution—equivalent to a significant fraction of Finland's annual land-use sector emissions—and it can be achieved on a relatively small portion of forest land if targeted to peat-rich sites.

However, implementing climate-smart practices on peatlands faces practical and economic hurdles. Peatland silviculture under continuous cover may require modified harvesting techniques (to minimize soil disturbance), potentially higher operational costs, and careful hydrological management (to prevent excessive waterlogging that could kill trees or excessive drying that could boost emissions). Ahtikoski et al. (2022) showed that the cost of carbon abatement on peatlands (in €/tCO_2) is an order of magnitude higher than on mineral soils. This suggests that, without policy support, private landowners have little financial incentive to adopt these practices on peatlands, especially since timber yields on peat soil can be lower and more variable.

There is also the option of peatland restoration or rewetting, which some studies advocate for severely degraded sites. Rewetting stops peat decomposition and can eventually reactivate peat accumulation (carbon sequestration in soils), but it means forgoing timber production entirely on that site. While outside the traditional scope of "forestry," such nature-based solutions could be part of Finland's strategy for difficult peatland areas where tree growth is poor and net emissions are high. The trade-offs are stark: restoration maximizes long-term carbon and biodiversity benefits but eliminates wood production in those areas.

Finland's climate and land-use policies are increasingly recognizing peatland forests in their strategies. The LULUCF sector accounting under EU rules provides incentives for maintaining or increasing the sink, and peatland management is a key lever. Adaptation considerations also come into play: drained peatlands are vulnerable to drought and fire under climate change (as seen in other boreal countries). Keeping them in a wetter state via continuous cover or rewetting can reduce these risks, aligning mitigation with adaptation.

In summary, peatland forests represent a critical frontier for climate-resilient forestry in Finland. By modifying management to reduce peat emissions—through CCF or selective rewetting—Finland can secure large carbon benefits. The success of such measures will depend on targeting the right sites (where carbon gains are maximized and timber losses are minimized), advancing harvesting technology for wet conditions, and implementing policy incentives to offset the economic costs. Given their disproportionate impact on the forest carbon balance, peatland forestry practices will likely be a focal point of Finnish climate-smart forestry efforts in the coming years.

4.4. Regional variability and uncertainty

Finland's longitudinal gradient and varied site productivity indicate that climate change and management impacts will not be uniform across the country. The literature highlights significant regional variability that must be acknowledged in both policy and management. For instance, climate models project stronger warming and lengthened growing seasons in northern Finland relative to the south. In principle, this could increase growth and carbon sequestration in the north (a potential climate benefit), whereas southern Finland might experience more drought stress, potentially slowing growth and increasing mortality in some stands (ALRahahleh, 2018). Management strategies should, therefore, be region-specific: in the north, taking advantage of longer rotations and perhaps slightly more intensive management might be feasible without jeopardizing the sink, whereas in the south, conservative harvest levels and emphasis on resilience (e.g., species mix, thinning to reduce drought stress) might be warranted.

Uncertainty is inherent in projections of forest carbon dynamics, especially over many decades. Sirkiä et al. (2023) demonstrate that uncertainties in carbon stock and flux estimates widen over time and differ by region. Factors such as future climate conditions, disturbance regimes, and socioeconomic developments (which influence management) are hard to predict. This suggests that an adaptive management approach is necessary. Policies and management plans should allow adjustments as new information emerges—for example, if evidence accumulates that a certain region is becoming a carbon source due to unexpected disturbances, managers might shift to more protective strategies there.

Regional considerations also extend to economic and social factors. The importance of forestry to local economies varies; in some eastern and northern municipalities, forestry is a dominant livelihood, whereas in others it is secondary. Acceptance of climate-oriented measures (like reduced harvesting or set-asides for carbon) may, therefore, face more resistance in areas where forestry is economically paramount. Engaging regional stakeholders (for example, using the Living Labs approach) can help tailor solutions that fit local contexts.

One strategy to address regional variability is to develop regionally differentiated forest policy. Forsius et al. (2023) provide support for this, showing that the potential to achieve carbon neutrality can differ by region based on the energy system and land-use options available. In high carbon-sequestration potential regions (e.g., with more land available for afforestation or protection), policies could push harder on climate mitigation through forestry, whereas other regions might focus on efficiency improvements in forest operations or wood utilization.

In conclusion, acknowledging and planning for regional differences improves the robustness of climate-smart forestry strategies. An optimal management solution in one part of Finland may not be optimal in another. Flexibility, continuous monitoring, and a region-specific knowledge base (e.g., localized growth models and climate impact studies) are crucial. By incorporating regional variability and uncertainty into management and policy, Finland can better ensure that its forest sector remains on track to contribute to climate goals under a range of future conditions.

4.5. Integration of biodiversity and carbon goals

A recurring theme in both the literature and policy discussions is the need to integrate biodiversity conservation with carbon sequestration objectives. Forests that are managed for carbon and timber in isolation could inadvertently neglect biodiversity values, whereas approaches that jointly consider multiple ecosystem services are more likely to achieve sustainable outcomes. The concept of multifunctionality has been suggested as a guiding principle—managing forests to provide a balanced suite of services, including carbon storage, timber, habitat for species, water regulation, and recreation.

Encouragingly, many climate-mitigation strategies in forests have co-benefits for biodiversity. For example, CCF typically maintains a more heterogeneous forest structure with multiple age classes and tree species, which generally benefits forest-dwelling species more than even-aged monocultures. Increasing rotation lengths or retaining larger tree and deadwood legacies in rotation forestry likewise enhances structural diversity and habitat availability. The promotion of mixed-species stands as a climate resilience strategy. Peltola (2022) not only buffers against disturbances but also provides a broader range of niches for biodiversity.

Regardless, there can be trade-offs. If maximizing carbon entails very dense stands or single-species stands of fast-growing trees (for carbon gain), this could conflict with species that require open habitats or certain forest compositions. In Finland, strictly protected forests are generally excluded from regular timber harvesting, and many older protected stands can maintain high carbon stocks while also supporting biodiversity. However, conservation-oriented management can still involve trade-offs at landscape scale if wood production is displaced elsewhere or if disturbance dynamics alter long-term carbon storage.

The reviewed studies provide examples of exploring these synergies and trade-offs. Mäkelä et al. (2023) considered both carbon sequestration and biodiversity in assessing national management choices, finding that some management regimes can deliver gains for both objectives. Forsius et al. (2023) indicated that establishing new conservation areas for biodiversity could substantially increase carbon storage, illustrating a situation in which conservation and climate goals align well. On the other hand, Pikkarainen et al. (2023), examined scenarios of increased conservation and found complex effects on timber, carbon, deadwood, and habitat areas—pointing out that the details of the conserved areas matter greatly, including which areas are conserved and how those areas are conserved.

From a policy perspective, integrating climate and biodiversity goals is increasingly seen as necessary. Finland's commitments under international frameworks include both climate agreements (e.g., Paris Agreement) and biodiversity conventions (e.g., CBD targets). Forestry strategies will likely need to satisfy both sets of targets. This may lead to initiatives like climate-friendly forest certification standards that incorporate biodiversity criteria, or incentive schemes that pay for carbon sequestration in ways that also reward biodiversity-friendly practices (such as preserving key habitats or keystone structures in managed forests).

In practice, a few guiding principles can help integration: maintaining and increasing structural complexity in managed forests, protecting a network of reserves and set-asides, and using landscape-level planning to ensure connectivity and representation of habitats. These measures can often be implemented while still pursuing carbon sequestration—for instance, leaving some patches within managed forests untouched for biodiversity barely diminishes carbon sequestration at the landscape level, and it may even enhance it through spillover old-growth carbon storage.

In summary, carbon farming and climate-resilient forestry need not be at odds with biodiversity conservation—in fact, they can reinforce each other when approaches are carefully chosen. The challenge is to avoid one-dimensional solutions. Finnish forestry, with its long tradition of multiobjective management, is well-positioned to develop models in which increasing the forest carbon sink is conducted in tandem with safeguarding biodiversity. The outcome should be **win–win** forests that are both carbon-rich and ecologically rich, contributing to climate mitigation, adaptation, and the preservation of Finland's forest natural heritage.

4.6. *Integration of biodiversity and carbon goals*

Although this review focuses primarily on management pathways in existing forests, the literature also suggests that where afforestation is pursued, implementation success depends on careful site selection, species choice, early management, and alignment with policy incentives. In the Finnish context, afforestation should therefore be treated as a complementary pathway rather than as the main framing of climate-smart forestry.

4.7. *Transferable lessons from the finnish case*

Although the evidence base is Finland-focused, the case has broader relevance for other high-forest boreal and temperate production systems. First, where forest cover and management intensity are already high, the main carbon-farming leverage often lies in modifying existing management rather than expanding forest area. Second, peatland and soil-related emissions can dominate the practical climate value of alternative silvicultural systems, making hydrology and site selection central to mitigation. Third, the carbon–timber trade-off cannot be solved by ecological optimization alone, because implementation depends on owner incentives, market conditions and institutional legitimacy. Fourth, MRV and decision-support tools should therefore quantify not only carbon stocks and flows, but also uncertainty, timber impacts, operational constraints and compensation needs. These lessons are not universal prescriptions, but they define a transferable problem structure for carbon-oriented forestry in managed northern landscapes.

5. Conclusion

This scoping review shows that climate-smart forestry in Finland is primarily a question of how existing forests are managed, rather than a question of forest expansion alone. Across the reviewed literature, management choices strongly shaped carbon outcomes over operational planning horizons, but their effectiveness remains conditional on the magnitude of climate change, disturbance regimes, regional variability and economic feasibility.

The strongest mitigation opportunities identified in the Finnish context are linked to management reform in existing boreal production forests, especially on drained peatlands. Continuous-cover forestry on nutrient-rich peatland sites appears to be one of the most promising high-leverage pathways, as it can maintain higher biomass stocks while reducing soil emissions relative to conventional rotation forestry. More broadly, mitigation-oriented management can increase forest carbon stocks, but these gains usually come with lower timber harvests, confirming that carbon–timber trade-offs remain a central challenge in Finnish forestry.

This review also indicates that climate-smart forestry cannot be reduced to carbon maximization alone. Mixed-species stands, structurally more diverse forests, peatland-sensitive management, and adaptive silviculture can improve resilience to disturbance while also supporting biodiversity and long-term ecosystem functioning. The most robust management strategies are therefore those that treat carbon sequestration, resilience, and multifunctionality as connected objectives rather than as separate policy targets.

From a practical perspective, implementation will depend on regionally differentiated approaches, better alignment between climate policy and forest economics, and stronger incentives for private forest owners, whose management decisions shape a substantial share of Finland's forest carbon dynamics. Transparent decision-support tools that help compare carbon benefits, timber trade-offs, and operational costs could further support implementation by reducing uncertainty at the owner level. Without such enabling conditions, the uptake of carbon-oriented management is likely to remain limited, especially where lower harvest intensity or alternative silvicultural systems reduce short-term economic returns.

Overall, Finnish forests can make a major contribution to climate mitigation and adaptation, but this contribution will depend on deliberate management choices and policy frameworks that explicitly recognize ecological trade-offs. Climate-smart forestry in Finland should therefore be understood as a long-term management reform agenda focused on optimizing the carbon sink, reducing peatland-related emissions, and maintaining resilience and biodiversity within multifunctional boreal forest landscapes.

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CRediT authorship contribution statement

Evgeny Lopatin: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Ville Hietalahti:** Writing – review & editing. **Lauri Sikanen:** Writing – review & editing. **Kari Väätäinen:** Methodology, Writing – review & editing. **Yrjö Nuutinen:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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