Between theory and practice: Multifunctionality as a key concept for sustainable forest management?

A systematic literature review of multifunctional forest management in Germany, Sweden, and Finland.

Niklas Bruns

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A thesis submitted in partial fulfillment of the requirements of Lund University International Master's Programme in Environmental Studies and Sustainability Science (30hp/credits)

LUCSUS
Lund University Centre for Sustainability Studies

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Abstract

The intensification of forest management over the recent decades, in combination with the effects of a warming climate, leaves forestry and forest management with the challenging task of maintaining forest ecosystems' further abilities to provide ecosystem services. By systematically reviewing peer-reviewed academic literature this study analyzes the concept of multifunctionality and its application in current forest management in Germany, Sweden, and Finland, its role in climate adaptation strategies and its usage in policy documents. The findings show a discrepancy between the theoretical concept of multifunctionality and its practical implementation. Further it shows that climate change adaptation is not a main concern for multifunctional management as of now. There is an urgent need to bridge the gap between theory and practice and place an increasing emphasis on climate adaptation for future research on forest ecosystems and their management.

Keywords: multifunctionality, forest ecosystems, ecosystem services, ecosystem functions, multifunctional forest management, climate change adaptation

Word Count: 11,992

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1 Introduction

Forest ecosystems are representing the most important values of natural assets (Kornatowska & Sienkiewicz, 2018) and are a key ecosystem for provisioning services, with forestry being a major human land use (Rist & Moen, 2013). But the intensification of forest management over the recent decades to increase production of only a small subset of ecosystem services as food supply, timber products, and bioenergy, has left forest ecosystems in numerous locations with substantial declines of biodiversity (Felipe-Lucia et al., 2018; Pohjanmies et al., 2021; Rist & Moen, 2013). Ecosystem services provided by forests are of great importance to human welfare and livelihoods (Acharya et al., 2019; Jonsson et al., 2019). But the current intensive management of forest ecosystems, leading to their homogenization and simplification of forest structures, which finally results in loss of biodiversity and a decreasing provision in ecosystem services, is further threatening their capacity to do so in the future (Jonsson et al., 2019; Kramer et al., 2022; Pohjanmies et al., 2021). On top of that, these challenges must be faced considering the increasingly unfolding climate crisis. That leaves forestry and forest management with a challenging task if forest ecosystems as well as their capacity to provide crucial services and goods are at least supposed to be maintained in the future (Rist & Moen, 2013; Sandström et al., 2017).

Forest ecosystems supply a wide array of essential ecosystem services (Seidl et al., 2016). Some examples are the provision of timber products and non-timber products, for example, wild berries and mushrooms. Additionally, forests clean the air, filter water supplies as well as sequester and store carbon. Further they contribute to flood regulation, protect the soil from erosion, sustain biodiversity and provide realms for recreational opportunities, education and culture (Balloffet et al., 2012; Pohjanmies et al., 2021; Simons et al., 2021). Ecosystem services can be local, regional, or global in their scale. For example, while the provision of clean water is commonly a regional service, mostly defined by the watershed's boundaries, climate regulatory services instead are commonly local or global. On the one hand, ecosystems regulate the climate on a global scale by removing and releasing, for example, carbon dioxide. On the other hand, forest ecosystems affect local micro-climates as they regulate variables such as temperature and precipitation. Therefore, land-use changes, forest degradation and biodiversity loss, through their impacts on forest ecosystems, can affect local climates (Balloffet et al., 2012; Staal et al., 2020). Forest ecosystem services are especially important for the support of impoverished and vulnerable people. Around 80% of the world's poor live in rural areas and are directly depend on forest ecosystems for providing services as, for example, food, clean water, energy, shelter, medicine, and cash income (Kramer et al., 2022).

Forests are experiencing a drastic increase and intensification of pressures from global changes (Seidl et al., 2016). As Kramer et al. put it, forests and their ability to supply ecosystem services are “increasingly under pressure from a ‘perfect storm’ of ‘wicked problems’” (Kramer et al., 2022, p. 25). Among other things, the decline in ecosystem services is largely driven by changes in land use and forest management approaches resulting in forest fragmentation, deforestation and degradation (Kramer et al., 2022; Seidl et al., 2016; Taubert et al., 2018). Further, a “primary concern is the growing mismatch in temporal scales between anthropogenic alterations of the environment and ecological mechanisms of adaptation” (Seidl et al., 2016, p. 121). Meaning the biotic world experiences increasing adaptation problems as drastic changes in the climate system are unwinding at a high rate. Especially forest ecosystems are endangered as changes are expected to evolve in just one tree generation, which is suggested to transcend adaptation capacities of many species through natural processes (Seidl et al., 2016). And climate change will not only influence forests solely through rising temperatures affecting tree growth and species adaptability (Reich et al., 2022), but also impact natural disturbance regimes (Seidl et al., 2016). By co-evolving with natural disturbances such as, for example, storms, pests, and wildfires forest ecosystems are highly suited and adapted to their impact on the biophysical environment. But forest disturbance regimes are tremendously sensitive to climate conditions and are already affected by current climate changes (Seidl et al., 2016). For example, beneficial conditions for insect population dynamics through increasing temperatures combined with an increased vulnerability of trees to insect attacks through more droughts, have already had severe negative impacts on forest ecosystems (Popkin, 2021; Seidl et al., 2016). This way global climate change does not only impact forest ecosystems directly, but additionally creates and increases further pressures by altering and intensifying other natural disturbances at a rate that forests cannot adapt to themselves.

Such challenges leave forestry with the difficult task of managing converging aspects of climate change, climate mitigation and adaptation, forestry, and forest management. The growing awareness of forests’ importance for global climate change mitigation leads to an increasing set of objectives that forests and forest management are expected to fulfill (Hernando et al., 2021; Ogden & Innes, 2007). These objectives include conserving biodiversity, maintaining the forest’s productive capacity, its health, and vital functions as, for example, conserving soil and water resources, maintaining the forest’s contribution to the global carbon cycle, as well as several more (Alarcón, 2015). This diversity of objectives that must be considered leads to diverging opinions between forest managers and practitioners about what sustainable forest management characterizes (Ogden & Innes, 2007; Popkin, 2021).

Today’s forests do not have a single productive use but are required and expected to provide countless ecosystem services (Hernando et al., 2021). At the same time, an increasing number of pressures are threatening the ecosystem’s health and with that its ability to satisfy the growing demand of important ecosystem services. Therefore, as a large majority of European forests are being actively managed (Korhonen & Stahl, 2020), it is up to these management practices to enable resilient multi-purpose forests now and in the future. Pursuing a multifunctional forest management approach can then help to harmonize ecological, economic, and socio-cultural values of forest ecosystems (Hernando et al., 2021).

In this thesis I will going to systematically review peer-reviewed academic literature to analyze how the concept of multifunctionality is framed and applied in the current status-quo of forest management practices. Further, I will examine the role of multifunctionality for climate change adaptation in current forest management practices. I selected Germany, Sweden, and Finland as the focus of this study as forestry constitutes an important economic sector in all three countries (Finnish Statistical Yearbook of Forestry, 2014; Hertog et al., 2022; Popkin, 2021), with the latter ones being the most densely forested countries in the European Union (eurostat, 2021). Further, all three countries experience increasing debates about forest management as past and current intensive forest management combined with warming temperatures negatively impact forest ecosystems in all three countries (Hertog et al., 2022; Kröger & Raitio, 2017; Popkin, 2021).

Additionally, I am going to analyze how forest management guidelines in federal policy documents address and apply the concept of multifunctionality. To examine this third sub-question I will solely focus on Germany as a result of its unique forest governance structure as well as the circumstance that most policy documents were published in the native language of their respective countries. This leads to the following research questions, which are investigated in the following paper:

1. How does the current forest management in Germany, Sweden, and Finland address multifunctionality in forest ecosystems?
2. What role does multifunctionality play for climate change adaptation in current forest management?
3. How do forest management guidelines of German Federal States address the concept of multifunctionality?

A core theme of sustainability science is sustainability pathways and strategies towards the attainment of sustainability goals (Jerneck et al., 2011). One pathway towards sustainable development is multifunctional forest management. By exploring these questions, I will assess the current reported state of forest managements' transformation towards multifunctional forest management and decrease uncertainties around the concept of multifunctionality. This study helps to strengthen the reliability of the concept and its application in future research, therefore, taking important steps on the path to sustainable forest management.

To answer these questions the thesis will continue with case background information on current debates around the usage of forest biomass, information on forest management practices discussed in this thesis, and general information about forestry in Germany, Sweden, and Finland. The next section provides an introduction of the concept of ecosystem services and clarifies the distinction between ecosystem functions and services. Further it introduces the concept of multifunctionality and the framework of ecosystem service and ecosystem function multifunctionality. The following method section describes the systematic literature review process. The subsequent sections are going to first present the results from the systematic review and then discuss its main findings. The section further includes a short discussion of potential limitations as well as implications for sustainable science before a conclusion is drawn in the last section.

2 Background

In this section I will begin with briefly discussing forests' unique and challenging position within debates around climate change politics, and how their usage is seen as part of the problem as well as part of the solution. Further, I will introduce the two forest management approaches that are mostly discussed in this study: rotational forestry and continuous cover forestry. Subsequently, this section continues with background information on forestry in Germany, Sweden, and Finland.

2.1 Forests and climate politics

"Climate change is bad, and it's poised to get worse" (Nicholas, 2021, p.22). Achieving the 1.5° goal of the Paris Agreement will require drastic action (Tollefson, 2018) and an increasing need for land-based mitigation. Additionally, the urgent need for the transition of global energy and transportation systems put forest resources in a contradictory position and creates a conflict of interests for forestry development (Alarcón, 2015; Dominković et al., 2018). On the one hand forests' ability to sequester and store great amounts of carbon makes them a cornerstone of global climate change mitigation schemes (Alarcón, 2015). On the other hand forest biomass is considered in parts to be an attractive substitute to decarbonize e.g., energy systems and transportation sectors, and deliver low carbon emissions instead (Sandström et al., 2017; Yan, 2018). But biomass' categorization as carbon neutral, the idea being that emissions from its combustion are being compensated through plant regrowth, is becoming strongly contested (Petersson et al., 2022; Vass & Elofsson, 2016; Yan, 2018). First, bioenergy can only be considered climate neutral on a larger time-scale, as there lies a significant amount of time between the combustion of biomass and the sequestration by plant regrowth (Norton et al., 2019; Vass & Elofsson, 2016), assuming functioning future forest ecosystems. And second, the biomass supply chain, including harvesting, transporting, and processing of biomass, is not carbon neutral, but is also emitting carbon into the atmosphere (Vass & Elofsson, 2016; Yan, 2018). Bioenergy's carbon neutrality is not only highly debatable, furthermore it is also not contributing to crucial emission reductions that are needed now. Nevertheless, Sweden highlights the usage of forest biomass-based solutions in their endeavors to reach net zero GHG emissions by 2045 and becoming a fossil-fuel free society (Petersson et al., 2022). Also the European Union continuous with its categorization of woody biomass as a renewable energy source in its revised Renewable Energy Directive, despite intensive efforts from environmentalists and forest advocates (Catanoso, 2022).

Therefore, forests are left in a contradictory position within climate change politics as their usage is seen as part of the problem as well as part of the solution to climate change (Alarcón, 2015; Petersson et al., 2022). This contradiction was already acknowledged by the Intergovernmental Panel on Climate Change back in 2007 when stating, that in "the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual yield of timber, fiber, or energy from the forest, will generate the largest sustained mitigation benefit" (IPCC, 2007, p. 543). Simultaneously it was recognized that the mitigation potentials past the year 2030 will be influenced by "the interrelationship of a complex set of environmental, socio-economic and political factors" (IPCC, 2007, p. 577).

2.2 Forest Management Strategies

The choice of a certain silvicultural system is an important step in forest planning and management. A silvicultural system is constituted by a coherent set of silvicultural operations that are applied to a certain forest (Duncker et al., 2012) and can be defined as "the process by which the crops constituting a forest are tended, removed, and replaced by new crops, resulting in the production of stands of distinctive form" (Matthews, 1991, p. 3). The silvicultural system can have great consequences for forest ecosystems' status, processes, and sustainability. Hence, management decisions will affect the goods and services that the forest is going to provide. Therefore, ecosystem service provision can be characterized as a driver as well as a consequence of forest management (Duncker et al., 2012).

Much of the forests in Europe have been and still are managed through rotational forest management, which includes silvicultural systems such as clear-cutting, seed tree and uniform or strip shelterwood. This results in forests that are arranged in a series of age classes, which are dominated by just a few productive tree species (Mason et al., 2021). Rotational forest management approaches are usually applied to maximise timber production and harvest, with other ecosystem services being mostly just by-products rather than management objectives. This concentration on a just small subset of services, mainly timber production, has received increasing criticism over the last years and decades, as it can produce harmful circumstances for the provision of other ecosystem services (Felipe-Lucia et al., 2018; Mason et al., 2021; Rist & Moen, 2013). Additionally, the economical superiority of rotational forest management in comparison to alternative approaches has been recently up for debate and is becoming increasingly contested (Mason et al., 2021).

An alternative management approach that is mainly discussed in this study is continuous cover forestry, which is sometimes also referred to as close-to-nature forestry. These approaches are based on five silvicultural principles that include "partial harvesting rather than clear-felling; preferential use of natural regeneration; developing structural diversity and spatial variability within forests; fostering mixed species stands and avoidance of intensive site management practices such as soil cultivation, herbicide application and fertilizer input" (Mason et al., 2021, p. 2). They are relying on less intensive silvicultural systems such as single stem and group selection. But, as of now there is no exact and widely accepted definition of continuous cover forestry (Hertog et al., 2022).

2.3 Forestry in Germany

Germany is renowned as the country that invented 'scientific' forestry more than three centuries ago (Popkin, 2021). In the early 1700s Hans Carl von Carlowitz proposed a sustainable management of forests as demands from mining and smelting caused disastrous timber shortages. His proposal intended to limit wood harvests to the amount that the land could produce with regularly replanted trees to insure future supply. As the German forests started to recover, the approach of planting fast growing species in precise rows became increasingly popular and was internationally adopted (Popkin, 2021).

Today Germany has around 11.4 million hectares of forests, covering nearly a third of its land cover with a slight increase over the past decade (Bundesministerium für Ernährung und Landwirtschaft, 2022; eurostat, 2021; Popkin, 2021). The German forest products sector generates around €170 million annually and employs more than 1.1 million employees (Popkin, 2021). Forest ownership splits up in four categories of owners. Almost half the forest (48%) is managed by private forest owners, with most private forests being 50 hectares or smaller. The second group of owners are forest corporations, owning 19% of forests. The remaining forests are public forests, with 29% being owned by federal states and 4% by the Federal Republic of Germany (Bundesministerium für Ernährung und Landwirtschaft, 2022). The great majority of German forests must be considered as fully managed forests, which have been framed in an entirely economic context and intensively managed for an extended period of time (Häusler & Scherer-Lorenzen, 2002). Approximately 70% of managed forests are managed with rotation forestry management systems, while 30% are managed by continuous cover forestry systems (Mason et al., 2021).

But intense debates about the future of forest management in Germany have been on the rise. Since 2018 more than 300,000 hectares of forest, accounting for more than 2.5% of Germany's total forested area, have died because of droughts and beetles fueled by a changing climate system (Popkin, 2021). While there is a great understanding that change is needed, specific developments towards new approaches are harshly disputed, splitting the forest community in two camps. Some advocate for a stop of the widespread promoting and planting of commercially valuable species as Norway spruce and instead encourage natural regeneration of forests. It is argued that natural regrown forests are more resilient to future disruptions (Popkin, 2021). As Peter Wohlleben, a prominent face within the German forest debate, frames it: "I don't know any place on Earth where a planted forest is better than a native forest" (Popkin, 2021, p. 1187). The other side is alarmed by this approach, arguing that the climate changes at a rate that many native species will not survive without human intervention. Instead, further planting of more resilient and barely known species is said to be necessary, to meet economic, environmental and climate goals (Popkin, 2021). An agreement should be reached soon, a change in management is urgently needed as a lot is at stake, environmentally as well as economically.

2.4 Forestry in Sweden

Sweden has the largest absolute forest cover in the European Union and is with more than 60% forest cover also one of the most densely forested countries (eurostat, 2021; Hertog et al., 2022; Nordström et al., 2016). Swedish forests account for 28 million hectares of forested land with 23.6 million hectares (84%) being productive forests (Hertog et al., 2022). It is further a major global producer of sawn wood, pulp, paper, and paperboard (Hertog et al., 2022; Nordström et al., 2016), although contributing less than 1% to global forest area (Nordström et al., 2016). Forest products related exports represent approximately 10% of the country's export value (Hertog et al., 2022; Keskitalo et al., 2016), making it a major employer and cornerstone of Sweden's economy (Ulmanen et al., 2015). For decades Swedish forests were mainly managed towards the maximization of wood production, using intensive forest management approaches including tree plantations and clear-cutting (Hertog et al., 2022). The vast majority of managed forests are managed through rotation forestry systems (Mason et al., 2021), with approximately 187,000 hectares being clear-cut annually (Hertog et al., 2022). It is estimated that at best only a few percentages are managed through continuous cover forestry practices (Hertog et al., 2022; Mason et al., 2021). Sweden's forestry has created, through its long-lasting forest intensification, young and homogenous forest stands with very limited capacities to support biodiversity. Recently, the narrative of climate mitigation has been used by the industry to justify further intensive management as a strategy to increase wood production and carbon uptake (Hertog et al., 2022).

Despite the Swedish Forestry Act from 1993 and more recent efforts to put equal emphasis on economic, ecological, and social objectives within forestry practices, only little has changed in actual practices within the forestry sector. Hence, increasing concerns and critics are voiced opposing current management practices leaving Swedish forests with predominantly even-aged monocultures of pine and spruce (Hertog et al., 2022). Critics are especially pointing out the increasing susceptibility of forests to droughts, storms, and forest fires that are becoming more likely and severe through a warming climate system and their decreasing abilities to foster biodiversity. (Hertog et al., 2022; Keskitalo et al., 2016). Additionally, intensive forestry practices in Sweden are negatively affecting traditional practices of Sami reindeer herding (Hertog et al., 2022; Parkatti & Tahvonen, 2021; Strengbom et al., 2017). Therefore, forest management in Sweden must also overcome great challenges in combining economic, ecological, and social management objectives.

2.5 Forestry in Finland

Due to its close economic and cultural ties with forests, Finland has been called the 'forest nation' of Europe (Donner-Amnell, 2004; Kröger & Raitio, 2017). Forests cover more than 75% of Finland's land area, with a total stock volume of 2.5 billion cubic metres and an annual growth rate of 103,5 million cubic metres (Järvinen, n.d.). 91% of the productive forest land is commercially used (Finnish Statistical Yearbook of Forestry, 2014). Therefore, the forest sector plays an important role in Finnish policy, economy, and society. The economic importance of the Finnish forestry sector is significant, as it makes up for 20% of the exported goods and approximately 4% of the Gross National Product in 2012. However, in absolute terms, the importance of forestry for the Finnish economy has decreased throughout the last decades (Finnish Statistical Yearbook of Forestry, 2014). In total, 160.000 people are employed in the forestry sector (Kröger & Raitio, 2017), which is approximately 3% of the Finnish population.

Finland is proportional to its size the most forested country in Europe, with 20.3 million hectares available for wood production, and a total drain of approximately 92 million cubic metres in 2021. Hence, Finland's wood resources are the fifth largest in Europe, following Russia, France, Sweden, and Germany (Järvinen, n.d.). The majority (61%) of wood producing forests is privately owned by 685.000 landholders that are mostly families (Järvinen, n.d.; Kröger & Raitio, 2017). 24% of the productive forests are owned by the state and 9% by forest companies (Finnish Statistical Yearbook of Forestry, 2014).

Around 97% of the Finnish forests are managed by rotation forest management practices, as it was the legally required management system up until 2014 (Eyvindson et al., 2021; Pohjanmies et al., 2021). Only 3% of the forests are managed by continuous cover forestry practices, which has only become popular in the last decade (Mason et al., 2021; Nevalainen, 2017). Practices of intensive rotation forest management have homogenised forests in Finland, where the majority of forests were transformed into uniform even-aged stands with plantation characteristics (Mason et al., 2021).

With 12,6% under protection or restricted use, Finland has the highest share of protected forest area in Europe (Järvinen, n.d.). Traditionally, the forest policy of Finland focussed on the economic sustainability of timber production and harvesting (Kotilainen & Rytteri, 2011). However, biodiversity and climate change concerns are becoming increasingly relevant for citizens (Kröger & Raitio, 2017; Valkeapää & Karppinen, 2013). This leads to persisting conflicts over forest policy priorities, navigating between timber production interests of the forest industry, conservation efforts of environmentalists and forest use and needs of the indigenous Sámi people (Kröger & Raitio, 2017; Raitio, 2013; Saarikoski & Raitio, 2013).

Particularly in face of the biodiversity crisis, resentments against current forest management regimes are mounting, as forestry has become the dominant driver of habitat and species diversity loss (Kröger & Raitio, 2017; Pykälä, 2007). Additionally, already existing abiotic (wind damage, snow damage, forest fires and droughts) and biotic (insect pest damages, forest pathogens, mammal herbivores) risks to forests are exacerbated by climate change (Venäläinen et al., 2020). This results in complex policy challenges for the Finnish forest management, aiming to ensure competitiveness of the forest industry, while reaching biodiversity and climate targets at the same time (Kröger & Raitio, 2017).

3 Theoretical framework

3.1 The concepts of ecosystem services and multifunctionality

Although in recent years research examining ecosystem's abilities to provide multiple ecosystem functions and services simultaneously has become increasingly abundant, the concept of multifunctionality is so far only broadly defined with a single accepted definition still missing (Manning et al., 2018). Current efforts in defining the concept are therefore characterizing multifunctionality as, for example, "the simultaneous provision of multiple functions" (Byrnes et al., 2014, p. 112) or "the potential of landscapes to supply multiple benefits to society" (Mastrangelo et al., 2014, p. 345). And while these definitions appear to be simple and straightforward, there are complex issues concerning the concept's conceptualization and its measurement that have yet to be resolved as well as uncertainties towards its overall practical utility (Garland et al., 2020; Manning et al., 2018).

The recent research on multifunctionality has been mainly part of two separated fields of research. The first is concerned with the ways that ecological communities' biotic properties, especially biodiversity, are related to the general functioning of the ecosystem, so-called biodiversity–ecosystem functioning research. The second research field studies as to how landscapes can be managed to maximize the delivery of alternative land-use objectives, so-called land management research (Manning et al., 2018). As both fields define and measure multifunctionality in varying ways Manning et al. (2018) propose the clear distinction between measures of multifunctionality that just include ecosystem functions and measures that just include ecosystem services. Therefore, they coin the concepts of ecosystem function multifunctionality (EF-multifunctionality) and ecosystem service multifunctionality (ES-multifunctionality).

Before these concepts can be further discussed it is important to distinguish between ecosystem functions and processes and ecosystem services. Ecosystem functions and processes play an important part for ecosystem services, nevertheless, these two terms cannot be used synonymously. Instead, ecosystem functions and processes represent biophysical relationships and properties which exist irrelative to human demands or benefits (Costanza et al., 2017). So, ecosystem functions

> relate to the structural components of an ecosystem (e.g., vegetation, water, soil, atmosphere, and biota) and how they interact with each other, within an ecosystem and across ecosystems. Primarily, these are exchanges of energy and nutrients in the food chain which are vital to the sustenance of plant and animal life on the planet as well as the decomposition of organic matter and production of biomass made possible by photosynthesis (Trivedi et al., 2018, p. 2).

Then, EF-multifunctionality describes a metric to judge the overall performance of an ecosystem. It is an attempt to represent the general ecosystem functioning objectively, unbiased, and without any value judgment regarding anticipated kinds of functions or desired level of functioning (Manning et al., 2018).Nevertheless, there are several barriers that pose obstacles in creating standardized and comparable measures of EF-multifunctionality. First, there is little agreement on what defines ecosystem functioning with already long-lasting ecological debates, for example, if states, rates, and processes all should be characterized as functions, as well as the question of what should be regarded as a high level of functioning. Second, it must be assessed which variables constitute distinct properties of ecosystem functioning. According to Manning et al. (2018) recent multifunctionality metrics have the tendency to generate a representation of ecosystem functioning by trying to include a maximum number of different functions. Therefore, with functions being interrelated through sets of interactions and similar drivers, these metrics run the risk of becoming biased towards certain types of functions by overweighting them. As researchers might differ vastly in their definitions of different sets of ecosystems functioning properties, these should be defined as objectively as possible to avoid running into such risks (Manning et al., 2018). And third, to date there is no single agreed on method of measuring multifunctionality. While the main methods used for quantifying EF-multifunctionality within biodiversity–ecosystem functioning research are the 'averaging' approach and the 'threshold' approach, there is little knowledge about the relevance of these approaches to other ecological research fields or 'real world' management objectives(Manning et al., 2018).

Ecosystem services are of great importance to human well-being, to economic development and sustaining livelihoods (Acharya et al., 2019). The concept first emerged in the 1970s as 'environmental services', was later changed into 'ecosystem services' and began to gain traction from 1997 onwards (Lele et al., 2013). Today the concept works as a basis for a great and further expanding body of literature, which seeks to measure, assess as well as value properties of human dependence on nature (Lele et al., 2013). The concept's most used current definition characterizes ecosystem services as "the ecological characteristics, functions, or processes that *directly or indirectly* contribute to human wellbeing: that is, the benefits that people derive from functioning ecosystems" (Costanza et al., 2017, p. 3).

Different types of ecosystem services can be distinguished in four categories: Provisioning, Regulating, Cultural, and Supporting/Habitat (Costanza et al., 2017; Houballah et al., 2020; Malinga et al., 2015). Provisioning services include the supply of food (e.g., crops, livestock, and wildlife products), materials (e.g., fiber, cork, and timber) as well as energy (e.g., hydropower, fuel wood, and biofuel). Regulating services describe besides other the regulation of air quality, of biological pests and of the climate, with climate regulatory services being, for example, the sequestration and storage of carbon in below as well as in aboveground biomass. Further services are the regulation of water quality and quantity. The third category includes aesthetics and inspirational services, which comes down to, for example, scenic beauty, services that provide educational and research opportunities, recreation and tourism and religious and spiritual ones. Lastly, the fourth category describes a set of services encompassing primary production (e.g., carbon fixation and oxygen supply), habitat and supporting biodiversity (e.g., biodiversity, biodiversity maintenance and genetic storage) (Costanza et al., 2017; Malinga et al., 2015).

Interactions between different ecosystem services can be complex and at times non-linear. Therefore, to achieve and sustain multiple services at once, it is crucial to understand relationships between ecosystem services in order to minimize trade-offs and avoid ecological surprises (Qiu et al., 2018). Main types of ecosystem services include trade-offs, in which the increased usage or supply of one service decreases another, and synergies, where a multitude of services benefit each other and are enhanced at once. Further, recent studies have suggested the possibility of constraining effects, meaning that one ecosystem service is setting an upper limit for another (Qiu et al., 2018).

A major difference between EF-multifunctionality and ES-multifunctionality is that the second measure "represents the supply of ecosystem services relative to human demand" (Manning et al., 2018, p. 429) (Figure 1). When trying to quantify ES-multifunctionality a first step often includes the identification of desired ecosystem services. Said services and the level and scale on which their provision is wanted

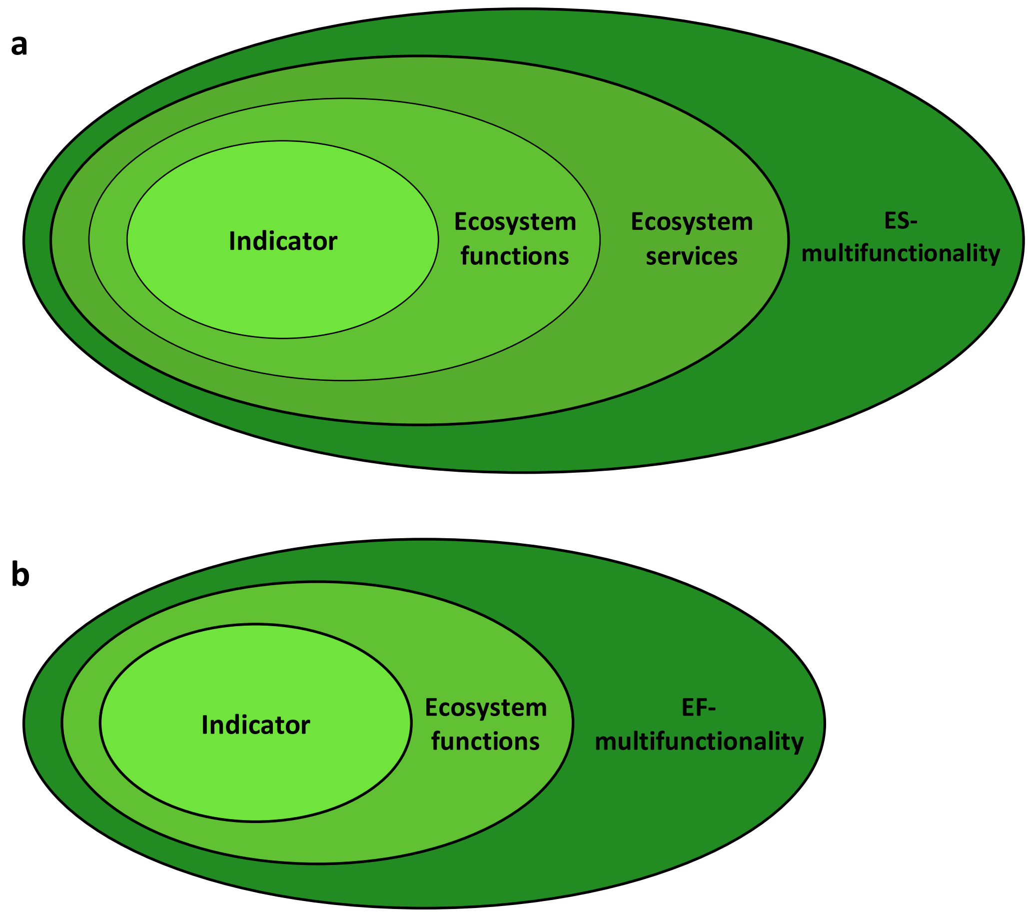

Figure 1. Conceptual diagram of the multifunctionality framework, showing the difference between ecosystem service multifunctionality (a) and ecosystem function multifunctionality (b). (Adapted from Garland et al., 2020).

requires the consultation of stakeholders. Meaning, as the demanded services together with their valuation differs depending on the stakeholders' interests, as well as their identities, local ecological conditions, and socio-economic backgrounds, a single ES-multifunctionality metric would not be representative on a global scale. Therefore, ES-multifunctionality measures need to be based on local stakeholder's demands and valuation of ecosystem services.

4 Methodology

To answer the first and the second sub-question, which read as follows: *How does the current forest management in Germany, Sweden, and Finland address multifunctionality in forest ecosystems?* and *What role does multifunctionality play for climate change adaptation in current forest management?* this study presents a systematic literature review of peer-reviewed research concerning multifunctional forestry and forest management. Therefore, the review process follows the five step structure of Woroniecki et al. (2019). First, to identify relevant, recent literature a search of the Scopus database was conducted in February or 2022 by using the following replicable search query: (TITLE ("multi purpose" OR multifunctional* OR "multi use" AND forest*) AND TITLE-ABS-KEY (afforestation OR forest* OR "climate change" OR adaptation OR "forest management" OR multifunctional* OR "ecosystem services") OR TITLE-ABS-KEY (germany OR finland OR sweden OR norway)) AND PUBYEAR > 2009. The search resulted in 153 entries. As first considerations included Norway as a further study area the search query includes it as another search criterion. Due to no significant search results that included a spatial or thematic focus on Norway it was eventually disregarded in the final study area of the thesis.

The collection of the data was followed by screening and cleaning of the data. Therefore, the relevance of all found entries was checked by reading the abstracts and comparing them against a set of inclusion and exclusion criteria. When at least one of the responses towards the following criteria was "no" the paper was excluded from the systematic review (see decision tree in appendix figure A1):

- Is the paper a case study or conceptual paper?
- Does the paper thematically focus on the management of forest ecosystems?
- Does the paper predominantly focus on the concept of multifunctionality and/or climate change?
- Does the paper cover at least parts of the focus area of this study?

The screening of all entries resulted in 46 papers potentially relevant for this study. After reading the full texts the number of papers was finally reduced to 31 relevant entries (see appendix table A1). During the full text review the content of each relevant paper was analysed according to 39 prior defined review categories. The categories included descriptive characteristics relevant to the managing of forests towards multifunctionality as, for example, the applied definition of the concept of multifunctionality, characteristics of current silviculture practices as well as proposed changes and adaptations. The gathered dataset for the analysis contained numbers, words, and partly text excerpts.

To answer the third sub-question, which reads as follows: *How do forest management guidelines of German Federal States address the concept of multifunctionality?* I reviewed 11 policy documents published by various responsible federal ministries. In total, publications of 7 different Federal States were reviewed that generally address the topic of forest management. In doing so, I accounted for various document types, such as forest management guidelines, status reports, strategies, position papers, action plans and visions. The selection of Federal States was guided by two principles: Geographical distribution and availability. Geographical distribution was selected as a criterion to ensure that Federal States of all parts of Germany are represented in the case study. Availability was chosen for practical reasons, as it was required that policy documents on forest management were published online. A list of all reviewed documents can be found in appendix table A2.

All statistical analyses as well as all graphic displays of results were performed and created in Excel (Version 16.58) and Matlab (Version R2022a).

Table 1. Review process following the approach for a systematic literature review as described by Woroniecki et al. (2019)

Steps	Procedure	Results
1. Data gathering	Search in Scopus	Identification of 153 papers potentially relevant for systematic review
2. Data screening and cleaning	The abstract of all 153 papers were checked according to the following decision criteria (see decision tree in appendix figure A1): - Is the paper a case study or conceptual paper? - Does the paper thematically focus on the management of forest ecosystems? - Does the paper predominantly focus on the concept of multifunctionality and/or climate change? - Does the paper cover at least parts of the focus area of this study?	46 potentially relevant papers
3. Paper review	Full text review of all 46 potentially relevant papers according to 39 prior defined review criteria, further irrelevant papers were excluded after content analysis	Dataset with *N* = 31 articles (see appendix table A1)
4. Statistical analysis	Statistical analysis in Matlab and Excel	Various statistical results

5 Results

5.1 Characteristics of the analysed literature

The first results I present are meant to generate an initial overview as well as a characterisation of the concept of multifunctionality as it appears and is used within the reviewed literature. Out of the 153 potential articles, 31 were identified as relevant for the systematic review. The review shows a general upwards trend for publications on forest management research in recent years (Figure 2). Within those 31 articles that were analysed, Sweden was the country being most often examined (13 articles), followed by Finland (12 articles), and Germany (nine articles). While six articles specifically analysed two or more countries, three articles did not focus on any country included in the focus area in detail.

Within the total number of articles analysed, 24 articles (77%) applied multifunctionality according to the concept of ecosystem service multifunctionality, whereas only one article (3%) applied it according to the concept of ecosystem function multifunctionality. Additionally, four articles (13%) included both concepts of multifunctionality in their analyses. Although the thematic focus on multifunctionality was an inclusion criterion for the systematic review, the majority of articles did not define the concept. Out of the 31 reviewed articles, only 14 articles (45%) clearly defined the concept of multifunctionality, while 17 articles (55%) did not provide any further definition. But interestingly, articles that provided a clear definition were not cited more often than papers which did not (Figure 3a). Instead, articles

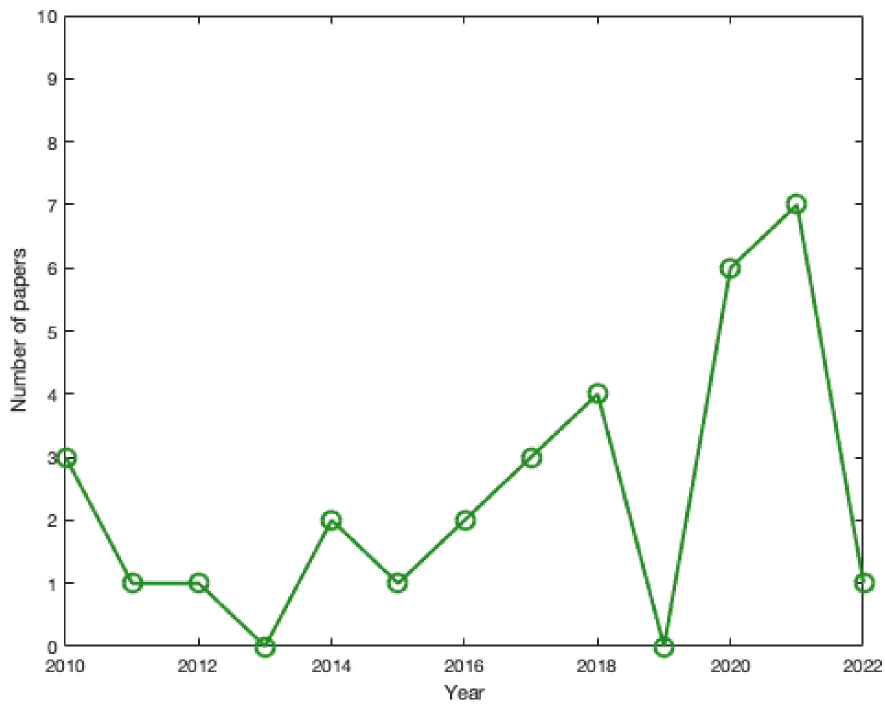

Figure 2. Development of published articles studying multifunctional forest management between 2010 and 2022. A general increase in publications on multifunctional forest management can be observed. The data point for the year 2022 can be characterised as not entirely representative, as the literature search was conducted in February of 2022.

which did not provide a definition were cited up to 82 times with an outlier of 555. In comparison, articles which did provide a clear definition received just up to 71 citations, with two outliers of 136 and 143. But articles that defined multifunctionality appeared in journals with cite scores up to 23.2 whereas articles that did not appeared in journals with cite scores just up to 11.7 (Figure 3b).

When a clear definition was provided, multifunctionality was most defined as the simultaneous provision of multiple ecosystem services (nine times). Other definitions included characterisations as, for example, the provisioning of additional ecosystem services besides timber production (two times), as the state where all ecosystem services and biodiversity features are as close to their potential maximal levels (two times), and as the ability of an ecosystem to maintain high levels of multiple ecosystem functions (two times) (Figure 4). For defining the concept, the reviewed articles referred to 29 different sources of literature with no clear baseline articles emerging. Out of these, five authors (first author only) were cited more than once with Gamfeldt and Hector being the most abundant with three citations each (Gamfeldt et al., 2008, 2013; Hector & Bagchi, 2007). The framework of multifunctionality applied in this thesis was proposed by Manning et al. (2018) and aims to define a standard definition for ecosystem service and ecosystem function multifunctionality. The framework was only cited twice and is therefore relevant in just 11% of the articles since its publication. Altogether, the 31 articles included 27 different ecosystem services and functions when characterising properties of multifunctional ecosystems. Most mentioned categories of ecosystem services and functions are the production of timber (17 times), provision of non-timber products as, for example, wild berries and mushrooms (15 times), climate mitigation services as, for example, carbon

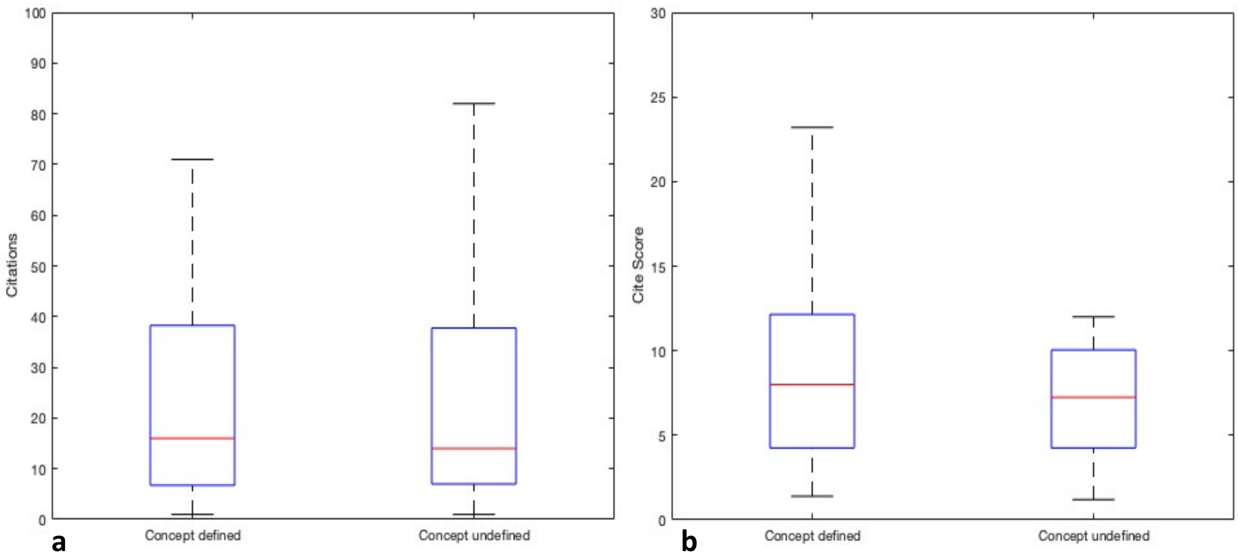

Figure 3. How defining the concept influences citations and Cite Score. a) Citations for articles defining the concept of multifunctionality and articles that did not define the concept (two outliers of articles defining the concept at 136 and 143 and one outlier of articles not defining the concept at 555). b) Cite Scores according to Scopus for journals that publish articles that did define and did not define the concept of multifunctionality.

sequestration and storage (15 times), biodiversity features (15 times), recreational and cultural usage (13 times) and regulatory services and functions as, for example, water and climate regulation (12 times).

5.2 Characteristics of multifunctional forest management

The reviewed literature showed that the necessity for changing forest management practices is widely recognized. Nevertheless, there is still a great discrepancy between the theoretical concept of multifunctionality and its recognition as an overall desired management objective, as well as its practical implementation within forestry practices.

Out of all reviewed articles, nine (29%) argued that forest practitioners are currently applying forest management practices that account for and actively manage towards multifunctional forest ecosystems. 19 articles (61%) argued that this is currently not the case. The remaining three articles (10%) did not supply enough information to answer the question unambiguously. Within the review process the read articles were distinguished in different categories. The first category included articles that focused on management practices that are already being implemented, while the second contained articles that instead focused on potential multifunctional practices or on giving clear recommendations for solutions. Articles in the third category focused on both examining existing multifunctional forestry practices as well as on producing further action recommendations. This

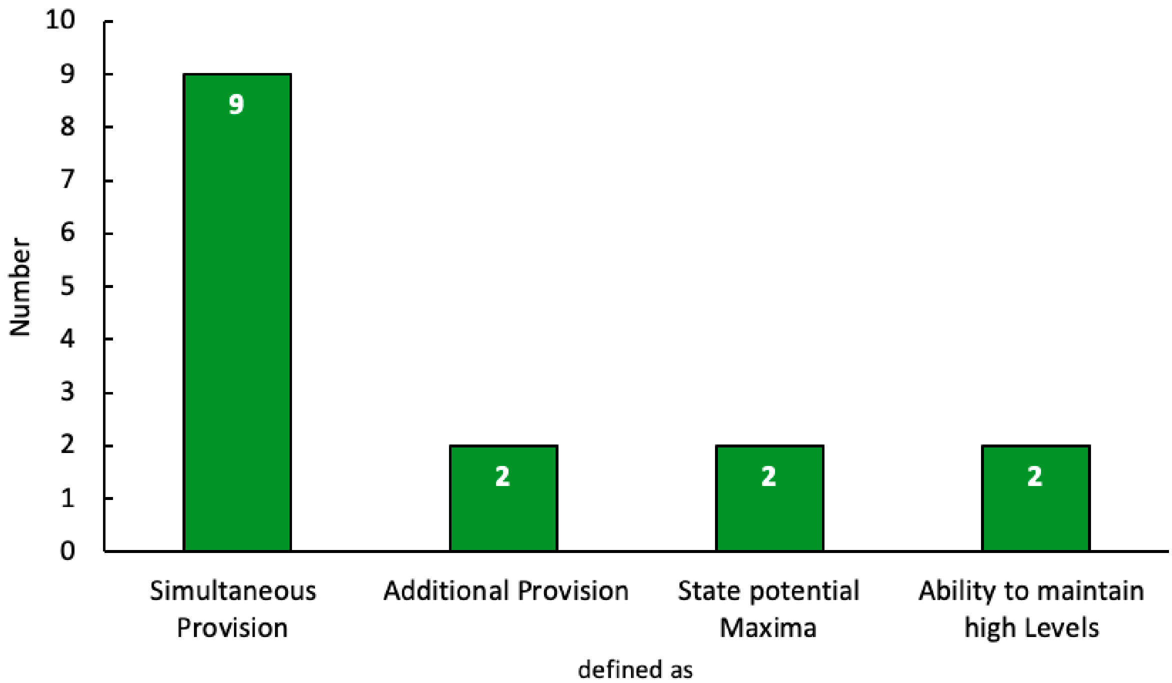

Figure 4. Abundance of different definitions of multifunctionality. Number of articles that defined the concept of multifunctionality as the simultaneous provision of multiple ecosystem services (9 times), as the provisioning of additional ecosystem services besides timber production (two times), as the state where all ecosystem services and biodiversity features are as close to their potential maximal levels (two times), and as the ability of an ecosystem to maintain high levels of multiple ecosystem functions (two times).

classification shows that the great majority of the reviewed literature, in total a share of 19 articles (61%), concentrates on studying potential beneficial management plans rather than current practices. Further, five articles (16%) deal with existing and recently implemented practices and four (13%) focus on both, existing as well as proposed practices. Three articles (10%) do neither discuss existing, nor potential management options to achieve multifunctional forests.

A closer examination of the subsample of nine articles (29%) focusing on implemented practices that account for forest ecosystem multifunctionality displays a discrepancy between the theoretical concept of multifunctionality and practical implementation. According to the reviewed articles, a short array of applied practices for multifunctional management emerges, with no form of management being predominant. This includes a multiscale conservation approach to create, and especially maintain a continuous and heterogenous ecosystem structure as well as its functions (three times). Further a retention forestry approach (two times), a continuous cover forestry approach (two times), and the waiving of clear-cut harvesting (three times) are applied. Instead, it is acknowledged that even with the consideration of multifunctionality, management of forests is still mainly designed for commercial usage and economic profits. This resonates within the rest of the reviewed literature, with intensive even-aged forestry (11 times) and short-rotation forestry (five times) being the most abundant silviculture systems, accompanied by clear-cut harvesting (seven times) and thinning (five times) being the most mentioned management practices.

The analysis of the reviewed literature shows that 19 out of 31 articles argued that current forest management approaches do not account for multifunctionality. Further, even in the pool of studies that examine forest management with practices accounting for multifunctionality a notable share of articles concluded it to be of low significance compared to other management aims (*N* = three, 33%). Nevertheless, out of all the reviewed literature 19 articles presented clear recommendations for possible solutions. Two of the most common recommendations were the recurrence to heterogenic forest structures (nine times) and a shift away from the currently predominant silvicultural systems (seven times).

To generate heterogenic forests, an increasing mix of tree species was deemed to be necessary (six times) (e.g., Eyvindson et al., 2021; Simons et al., 2021), together with the promotion of forest types that provide complementary sets of ecosystem services (three times) (e.g., Díaz-Yáñez et al., 2019; Simons et al., 2021). The most common recommended alternative management approaches were continuous cover forestry (five times) (e.g., Parkatti & Tahvonen, 2021; Pohjanmies et al., 2021), with studies suggesting it to have high economic competitiveness compared to rotation forestry, even outcompeting it in certain scenarios, and uneven aged forestry (two times) (e.g., Parkatti & Tahvonen, 2021). It was even more often recommended to combine different approaches and generate diverse and flexible management strategies (nine times) (e.g., Díaz-Yáñez et al., 2019; Pohjanmies et al., 2021), with a combination of continuous cover and rotation forestry being the most popular suggestion (four times) (e.g., Eyvindson et al., 2021; Peura et al., 2018).

Further, six articles explicitly pointed out the importance of developing a more holistic approach and recognise the landscape level as key scale for successful planning and functional stewardship of forest ecosystems (e.g., Angelstam et al., 2022; Friedrich et al., 2021). Therefore, another common recommendation was to follow a zonation approach (seven times) (e.g., Angelstam et al., 2022; Friedrich et al., 2021), where forests are managed for just a subset of ecosystem services on stand level, creating a multifunctional ecosystem at landscape level. This solution was seen especially fitting for areas consisting of mostly small-scale private forests. Additionally, it was often pointed out that there is no 'one size fits all' solution, but approaches should be chosen site and goal specific (seven times) (e.g., Lagergren & Jönsson, 2017; Messier et al., 2021).

Moreover, already existing trade-offs and synergies must be considered in order to set realistic management goals (six times) (e.g., Strengbom et al., 2017; Tebenkova et al., 2020). More recommendations included the demand for increasing areas of set aside forests (five times) (e.g., Díaz-Yáñez et al., 2019; Jonsson et al., 2019) and the development of economic incentives (four times) (e.g., Friedrich et al., 2021; Simons et al., 2021), such as payments for ecosystem service schemes that provide other services besides timber production, or funding for restoration efforts. Furthermore, the prolongment of rotation periods (four times) (e.g., Pukkala et al., 2011; Triviño et al., 2017), as well as the waiving of intensive management practices as clear-cut harvesting and thinning of stands (four times) (e.g., Ekström et al., 2021; Eyvindson et al., 2021) was recommended. Further but less abundant recommendations were investments in forest education at universities and universities of applied science (one time) (Benz et al., 2020) and the necessity of the market to adapt to the forest rather than the forest adapting to the market (one time) (Messier et al., 2021). Meaning the mixture of tree species should not be driven by market demand. Instead, the market and wood re-processing industries should adapt to the wood that can be supplied sustainably by forests. And lastly it was recommended to implement at least temporary forest protection schemes as it is argued that just a modification of management approaches will not be enough (one time) (Pohjanmies et al., 2021).

Looking at existing practices, as well as at the long array of proposed and recommended management adaptations, an overlap between both categories becomes evident. Therefore, it can be argued that current implemented practices are generally causing developments towards less intensive forest management practices. But it is still strongly emphasised that forest management which strengthens and prioritises multifunctional ecosystem properties must be adopted more widespread and multifunctionality itself needs to gain significantly more importance as a management goal. As most studies attest the forest to be in a critical condition, change is said to be needed sooner rather than later, and preferably now.

5.3 Multifunctionality and climate change adaptation

Reviewing the literature identified climate change adaptation's minor role as a desired objective within current forest management. Nevertheless, multifunctional management practices showed great potential for adaptation and increasing resilience of forest ecosystems to climate change.

Out of all the reviewed literature, 22 articles (71%) mentioned the term 'climate change' at least once, while 9 articles (29%) did not mention it at all. Within the subsample of 22 articles, climate change was a thematic focus in 13 (59%), while the other nine (41%) did not discuss climate change in the context of multifunctional forest management any further. Additionally, within these nine articles, seven (77%) mentioned the term just three times or less. Therefore, out of the total number of articles, only 13 (42%) put a greater emphasis on both multifunctional forest management and climate change.

Examining the relation of climate change and multifunctional forest management in this subsample of articles shows that nine (69%) characterise climate change adaptation as an important service provided by multifunctional forests, or as a positive side effect of multifunctional management practices. For example, Díaz-Yáñez et al. (2019) concludes that a more diverse structure in age and tree species composition may help to adapt forests and forestry to changes in climate, while still managing to provide sustainable levels of different ecosystem services. Another two articles (15%) identify multifunctional management practices as the main directive of climate change adaptation strategies for forests (Angelstam et al., 2022; Friedrich et al., 2021), while one (8%) draws no direct link between adaptation and multifunctionality of forest ecosystems (Moen & Keskitalo, 2010). In direct contrast, one article (8%) characterises them as interrelated and describes multifunctional forest management as a climate change adaptation strategy and vice versa (Benz et al., 2020).

Staying with the previous defined subsample of 13 articles, which took a closer look at multifunctional forest management in the context of climate change, it becomes clear that multifunctionality as an adaptive measure is currently not playing a major role in the literature.

Again, the reviewed literature was distinguished into different categories. The first category contained articles that focused on climate change adaptation measures for forests that have been already implemented. The second category included articles that examine potential management plans for adaptation or give clear recommendations on how those plans could be shaped. This division shows a great discrepancy between both categories. Just two articles (15%) deal with adaptation practices that are currently employed in practice (Benz et al., 2020; Yousefpour et al., 2009), with only one of those giving examples as to how current forest management includes adaptation to climate change. The only practiced adaptation measure within contemporary forest management as presented by the reviewed literature is the conversion of monocultural stands into mixed species forests, which happens especially in Germany with the conversion of pure coniferous stands (Yousefpour et al., 2009).

All other remaining articles, as well as the two just mentioned above, study potential management practices or come up with clear recommendations for a multifunctional forest management themselves. The most common recommendation to increase adaptation to climate change and minimise losses in ecosystem service provisioning is a general diversification of forest structures and forest management practices (nine times) (e.g., Díaz-Yáñez et al., 2019; Friedrich et al., 2021). As mixed forests seem to outperform monocultural stands regarding resilience and resistance against extreme weather and disasters, proposed diversification measures include an increased mixture of tree species (e.g., increasing the share of deciduous trees in forests dominated by coniferous trees), increasing un-even aged forest stands and flexible management strategies. But it is further emphasised that to achieve effective improvements in resilience, not only ecological but social resilience too, fundamental changes in the traditional forestry sector are required (Angelstam et al., 2022). Besides that, the adoption of continuous cover forestry practices is recommended (three times) (e.g., Lagergren & Jönsson, 2017; Peura et al., 2018). This is not only to support biodiversity but to decrease clear-cut areas and therefore strengthen the forests' ability to withstand wind and storm damage, as forest edges of new clearfellings are especially prone. Alternatively, Norway spruce forests, which are especially prone to wind damage, could profit from shorter rotation periods (two times) (e.g., Lagergren & Jönsson, 2017; Triviño et al., 2017), as it decreases the time where the tree would be at risk of wind. Nevertheless, this would require an increased area of unmanaged forest or continuous cover forestry to stay in line with biodiversity goals.

Further recommendations emphasised the need of long-term planning to anticipate future conditions and demands and promote forest characteristics accordingly (three times) (e.g., Benz et al., 2020). Moreover, the requirement of other 'currencies' to estimate the values of ecosystem services, as not all can be measured with monetary values (e.g., regulating services that moderate and mitigate local temperatures) (one time) (Angelstam et al., 2022) is mentioned. Finally, the importance of high standard forest education to generate well-educated forest scientists and forest practitioners (one time) is recommended (Benz et al., 2020).

It can be concluded that climate change adaptation is not a main concern for multifunctional management within the reviewed literature. However, multifunctional forest management practices are certainly use- and impactful strategies to achieve climate change adaptation within forest ecosystems. Therefore, building up multifunctional forest properties can be characterised as an impactful climate change adaptation measure, also further strengthening the case for adopting ecosystem service multifunctionality as a main management directive.

5.4 Multifunctionality in policy documents

The concept of multifunctionality is widely recognized within policy documents of German federal states. Nevertheless, its closer understanding can vary between different states with most of them using the concept to still put greater emphasis on economic management objectives.

All 11 reviewed documents of 7 German federal states that were accounted for in the case study generally acknowledge the importance of the concept of multifunctionality. However, only approximately half of the reviewed documents mention multifunctionality explicitly (see appendix table A2, document IDs BW1; HE1; LS1; SA1; RP1; BA2). The other documents refer to multifunctionality implicitly or describe the concept in a more indirect way (see appendix table A2, document IDs BA1; BW2; HE2; HE3; BB1).

Most reviewed publications refer to multifunctionality as an objective or ambition that is to be achieved (e.g., IDs BB1; RP1). In doing so, most documents underline the wide range of forest functions and formulate as a goal that this diversity is to be preserved (e.g., IDs HE2; HE3). Additionally, the various requirements and societal interests in forests are to be considered and balanced (e.g., IDs BB1; SA1).

To describe the dimensions of multifunctionality, most policy documents divide the concept into different categories. The two most used categorizations divide multifunctionality into economic, ecological, and social functions on the one hand (e.g., IDs RP1; SA1; BW1; LS1; HE1; BB1) and use, protection, and recreation functions on the other (e.g., IDs HE3; SA1).

In most reviewed policy documents, multifunctionality is regarded as an overarching concept, mission statement, or best practice model and not as concrete instructions for action or specific management options (e.g., IDs LS1; RP1). Thus, multifunctionality of forests is mentioned and classified as a desirable state, but concrete steps towards such a state are often missing (e.g., IDs SA1; BB1). An exception is the Bavarian State Institute of Forestry, as it very specifically advises tree species mixing to foster the multifunctionality of forests (ID BA2). Another example is the Hessian Ministry for the Environment, Energy, Agriculture and Consumer Protection, which prioritizes the different dimensions of multifunctionality in case of conflicting objectives. Additionally, a holistic management approach is recommended to facilitate multifunctionality, however, more concrete information on what that entails is not given (ID HE1).

The federal states accounted for in this case study classify multifunctionality differently in the discourse. In some policy documents, the continuity of a multifunctionality-focused management approach is underlined (e.g., ID LS1). Other publications indicate that a focus on multifunctionality rather represents a paradigm shift in forest management, compared to previous approaches that spatially segregated different management objectives (e.g., ID SA1).

By following the principle of multifunctional forest management, the federal states aim to balance different ecosystem services and societal interests. Although a range of services provided by forests are mentioned, the analyzed policy documents tend to have a stronger focus on the economic dimension of multifunctionality, compared to ecological and social aspects. The "forest vision 2030" published by the Ministry for Infrastructure and Agriculture of Brandenburg, for example, emphasizes the consideration of protection and recreation functions of forests to exploit their full economic potential (e.g., ID BB1). In addition, some documents indicate that the shift towards a multifunctionality-focused forest management can be explained by reduced economic viability and increased vulnerability of spruce monocultures (e.g., ID BA2; BB1; LS1). Thus, it can be concluded that in practice, a shift towards multifunctional forest management is often determined by economic drivers and continuously guided by the economic principle.

6 Discussion

In this thesis I systematically analysed peer-reviewed literature studying multifunctional forestry and forest management. First, I aimed to answer the following research question: *How does the current forest management in Germany, Sweden, and Finland address multifunctionality in forest ecosystems?* Secondly, I explored *what role does multifunctionality play for climate change adaptation in current forest management?* Subsequently, to shed light on the more practical side of multifunctional forest management, I formulated the third sub-question, which reads as follows: *How do forest management guidelines of German Federal States address the concept of multifunctionality?* This discussion splits in three main parts to discuss each main finding. First, I will discuss the reviewed literature and how it characterized the state of current multifunctional forest management. Second, I will discuss the concept of multifunctionality and its current strengths and weaknesses. The third part deals with the role of climate change within the reviewed forest management literature. And lastly, I will reflect on potential limitations of my work process and give an outlook of possible implications for the field of sustainable science.

The evaluation of the reviewed literature shows a discrepancy between the theoretical concept of multifunctionality and its practical implementation, identifying the minor role the concept currently plays within forest management. Nevertheless, the literature presents a wide array of recommendations for solutions and management opportunities to increase multifunctional properties of forest ecosystems. Further, the analysis demonstrates that climate change adaptation is not a main concern for multifunctional management as of now. However, multifunctional management practices show great potential to increase forest ecosystems' resilience and resistance to exacerbating climate and weather events. Generally multifunctional forest management is seen as an impactful mechanism to enhance climate adaptation of forests.

To answer the third sub-question, I reviewed policy documents published by different responsible federal ministries. The analysis shows that in most policy documents, multifunctionality is rather characterised as an overarching concept than as concrete management instructions. Therefore, interpretations of the concept and emphasis on certain multifunctional properties vary between different federal states. Nevertheless, there is a tendency that in all examined federal states economic dimensions are put at the centre of multifunctional management objectives, and therefore conflicting with the inherent idea of multifunctionality to balance different management objectives.

6.1 Discussing Forest management recommendations

Comparing the current state of forest management as presented within the reviewed literature and the intended management state that is necessary to support multifunctional ecosystems shows a great gap between presented recommendations and their implementation. Closing this gap to achieve multifunctional forest ecosystems is not only becoming increasingly urgent considering the anticipated consequences of climate change but also, for example, in Sweden, more and more a demand that is voiced by the public (Hertog et al., 2022).

The main recommendations coming from the reviewed literature focus on promoting a change in the dominant management systems either towards a single new management approach, or a mix of different approaches (e.g., Angelstam et al., 2022; Eyvindson et al., 2021; Parkatti & Tahvonen, 2021). In both cases special emphasis is put on continuous cover forestry and its contributions to multifunctional management. Another common recommendation includes a management approach towards a heterogenic forest structure instead of even-aged monocultures that are currently predominant (e.g., Messier et al., 2021; Parkatti & Tahvonen, 2021; Simons et al., 2021).

Continuous cover forestry is a popular recommendation as it is suggested to have greater potential to maintain multifunctional forests than, for example, rotation forest management (Peura et al., 2018). Other studies also conclude that continuous cover forestry delivers more species habitats, increases carbon sequestration potentials, and yields of non-timber products as wild berries and mushrooms (Calladine et al., 2015; Peura et al., 2018; Pukkala, 2016). Additionally, studies suggest that the economic profitability of continuous cover forestry compared to rotation forestry is surprisingly high (Parkatti & Tahvonen, 2021), or, depending on the context, even found to be better (Peura et al., 2018; Pukkala, 2016; Tahvonen et al., 2010; Tahvonen & Rämö, 2016). Furthermore, an increasing heterogenic forest structure and landscape with a more diverse set of tree species improves biodiversity and delivers higher levels of multiple ecosystem services (Gamfeldt et al., 2013; Thomsen et al., 2022). To strengthen this effect, it is suggested to mix tree species that support complementary subsets of ecosystem services (Messier et al., 2021; Simons et al., 2021). Further studies support this by concluding that trait diversity is of greater importance for multifunctionality than just species richness, as the level of ecosystem services that gets provided depends on specific mixtures of tree species (Jonsson et al., 2019; Mensah et al., 2020).

Still, there are significant obstacles in implementing such management objectives. Hertog et al. (2022) reveal that, for example, in Sweden some forest practitioners tend to see forests solely as timber plantations. This way, clear-cut forestry is the quickest and easiest management option, which also constitutes the most predictable way to achieve economic gains. Furthermore, conservatism makes the culture more resistant to change (Hertog et al., 2022). Mason et al. (2021) support this finding and conclude that culture and forestry traditions not only hinder adaptation of silvicultural approaches in Sweden, but in several countries throughout Europe. This resonates within the reviewed literature when intensive management practices, such as clear-cut forestry are framed as traditional practices

(Gustafsson et al., 2012; Mattila et al., 2015). Additionally, forest companies and owner associations exert great influence through timber merchants and contractors on the management of private forests (Hertog et al., 2022). While it is easy to generate acceptance within the industrial forestry sector for changes and modifications of even-aged management, it becomes increasingly difficult to add another forest management system, such as continuous cover forestry (Angelstam et al., 2022).

Where cultural, silvicultural, or other obstacles hinder forest owners from implementing mixed stands and multifunctional management approaches, it is argued that a combination of monocultural stands can deliver the same set of ecosystem services (Friedrich et al., 2021; Simons et al., 2021). However, multifunctionality is rarely considered on the landscape level (Manning et al., 2018). It is suggested that ecosystem service relationships might not translate to different scales, meaning simple extrapolations could potentially cause misinformed actions with undesirable outcomes (Qiu et al., 2018). So, at least the repeated recommendation of a zoning approach needs to be further investigated before its general consideration.

Therefore, as the example of continuous cover forestry illustrates, the gap between recommendations and practical implementation does not only include a gap in numbers, with recommendations outnumbering actual implemented alternative practices. But also, a gap between what is suggested to be necessary (e.g., changes in management practices on a large scale, or even a management regime shift), and what currently seems to be possible to be achieved in the short run.

6.2 Discussing the definition of the concept of multifunctionality

Existing endeavours to create a standard and uniformly applied framework of multifunctionality as well as earlier studies examining multifunctionality in ecosystems emphasize the necessity of using a general definition. This should be done to decrease confusion around the concept and make findings more comparable. Nevertheless, the systematic review shows that in current research a stringent application of the concept is still missing. In the reviewed sample of articles, multifunctionality is defined broadly according to four different categories of definitions: the simultaneous provision of multiple ecosystem services (e.g., Messier et al., 2021; Tebenkova et al., 2020; van der Plas et al., 2018), the provision of additional ecosystem services besides timber production (Ekström et al., 2021; Simons et al., 2021) the state in which all ecosystem services are as close to their potential maximum as possible (Pohjanmies et al., 2021), and the ability of an ecosystem to maintain high levels of multiple ecosystem functions (Van der Plas et al., 2016).

Although the great majority of publications applies the concept in line with land management research, only a small series of articles defines multifunctionality as the simultaneous supply of ecosystem services relative to their human demand. Meaning, only a small subsample explicitly defines multifunctionality as being relative to the beholder, too (Benz et al., 2020; Tebenkova et al., 2020). Additionally, some of the reviewed articles do not differentiate between ecosystem services and ecosystem functions (Sarvasova et al., 2014). Instead, articles use the terms almost interchangeably. The concept of ecosystem services and their differentiation to ecosystem functions however represents a crucial pillar in the framework of ecosystem multifunctionality (Manning et al., 2018).

Thus, the concept of multifunctionality is still missing a clear definition which is stringently used throughout the literature. Additionally, it is characterised as a more overarching concept that is rather a permanent process than a reachable distinct final stage (Benz et al., 2020). The interplay of these factors combined with the gap in how to practically apply the concept contributes to it being a simple yet still nebulous concept (Manning et al., 2018). Clearing up the uncertainties around the concept could not only benefit future research in the fields of biodiversity–ecosystem functioning research and land management research, but also improve its usage in policy. Instead of its vague and mostly economically driven application in policy documents, it could become an impactful tool to also lead a transition in policy guidelines.

Nevertheless, as multifunctional forest management tries to balance properties of economic growth, environmental care, and social wellbeing, it combines and accounts for all three pillars of sustainable development and can be therefore characterised as such. Or as Benz et al. put it, "sustainability and multifunctionality are two sides of one single coin" (2020, p. 18). Theoretically the concept of multifunctionality is a powerful tool to strengthen a sustainable usage of multifunctional forest ecosystems. But its practical implementation so far often showed an unequal development of the three pillars, with environmental care and social well-being often getting the short end of the stick.

6.3 Discussing the role of climate change within forest management literature

Climate change is posing a great risk to forests, not only in the studied countries of Germany, Sweden, and Finland (Krikken et al., 2021; Popkin, 2021; Venäläinen et al., 2020), but globally (Begemann et al., 2021). Moreover, current research suggests that even a modest change in temperature can have severe impacts in boreal forests. That could, for example, cause regeneration failure which in the end could lead to the loss of ecosystem services (Reich et al., 2022). Already in 2003, almost two decades ago, it was argued that climate change and sustainable development should be tackled with an integrative approach comprising both concepts (Swart et al., 2003). Therefore, it is as much surprising as it is discouraging that almost a third of the reviewed articles (N = 9) do not at all mention climate change within their research (e.g., Ekström et al., 2021; Gren & Amuakwa-Mensah, 2019; Jönsson & Snäll, 2020). And further, nine out of 22 articles mentioning climate change do so just three times or less (e.g., Parkatti & Tahvonen, 2021; Simons et al., 2021; Tebenkova et al., 2020). In another study that is discussing climate change, forests are attributed a critical role in, for example, global climate regulation and the mitigation of climate change. Nevertheless, the article concludes that their resulting projections and findings are not able to account for impacts of climate change (Pohjanmies et al., 2021). Altogether, only 13 articles out of the total number of reviewed articles (*N* = 31) put a greater thematic emphasis on climate change adaptation (e.g., Angelstam et al., 2022; Friedrich et al., 2021; Messier et al., 2021).

These results raise the question, if this lack of thematic focus on climate change is merely a characteristic of the specific set of reviewed articles, or if it is a general tendency that can be found in wider literature on forest management. To find out whether this tendency is merely the result of a rather small sample size of reviewed articles, or a more general trend, further research projects should address this exact question. This is of particular importance for forest ecosystem management, where decisions made today have long lasting impacts, which are likely to be amplified under changing climate conditions. Hence, research on forest ecosystem management cannot ignore these changing conditions in their analyses. Therefore, sustainability science, especially with a focus on ecosystems and landscape management, would greatly benefit from adopting a 'climate change lens' to their research. Ideally, further research is entirely conducted through such a lens, but as a minimum, all findings should be discussed within such a context in a coherent way. This is necessary to ensure that research findings remain valid regarding changing climate conditions.

6.4 Limitations

This study is primarily limited in its rather small sample size of reviewed articles, mainly due to the performance of the systematic review through a single reviewer. Therefore, one should be careful to make general statements about the literature on forest management based on this research. Nevertheless, the study can identify certain trends within the literature that could be easily taken up by further research. Additionally, besides just peer-reviewed academic literature I also reviewed a set of policy documents. Making a diverse set of views on the topic a qualitative strength of this thesis. Nevertheless, in comparison to larger systematic reviews done by a team of researchers I could not carry out a test run to compare results. Instead, in- and exclusion criteria for the literature review, as well as in- and exclusion decisions were made by a single reviewer. Meaning, in- and exclusion decisions could therefore potentially include biases.

6.5 Discussing contributions to Sustainability Science

Reviewing forest management through the lens of ecosystem service multifunctionality and characterising multifunctional forest management as a sustainable development strategy clearly situates this thesis within the realm of sustainability science. Thus, this study identifies significant sustainability challenges that remain to be solved.

First, the gap between recommended solutions for multifunctional management options and their practical implementation needs to be bridged, or at least reduced. As the reviewed literature clearly states as to what is necessary to be done, it is now important to analyse how these changes can be implemented effectively. This sheds light to the social and economic aspects of the problem, and the divergence between science and policy, researchers, and practitioners. To reduce the gap between scientific recommendations and practical implementation, it is required to strengthen the science-policy interface and focus on how collaboration can be further facilitated. This aims at enhancing practical usability of research and fostering evidence-based decision-making concerning forest ecosystem management.

Second, the concept of multifunctionality, gaining more importance and becoming a common objective for forest ecosystem management, needs to be applied according to a general definition with clearly defined metrics. If that is the case, the concept of multifunctionality has the potential to provide important understanding for ecosystem science and provide support in landscape-decision making (Manning et al., 2018).

Third, ecosystem management and land management research could greatly benefit from applying a general 'climate change lens'. Especially research on forest management, where today's decisions have long lasting impacts on forest ecosystems' structure, health and adaptation ability that will reveal themselves in the upcoming decades. I argue that research on forest ecosystem management cannot be done without the consideration of climate change and its effects on ecosystems.

7 Conclusion

The aim of my study was to assess how the current forest management in Germany, Sweden, and Finland addresses multifunctionality in its forest ecosystem management practices. Further, I set out to examine the role that multifunctionality plays for climate change adaptation in current forest management as well as its framing in policy documents. By carrying out a systematic review of peer-reviewed academic literature I was able to draw conclusions about the current implementation of multifunctional forest management practices within forestry and further, about the general application of the concept of multifunctionality in forest management research. My research shows that although the necessity to adapt forest management practices to future demands and circumstances is widely recognized and acknowledged, an overall trend towards a widespread adoption of multifunctional practices is still missing. Instead, there exists a discrepancy between the theoretical concept and its practical implementation. Additionally, the literature displays a gap between recommended solutions and their practical realization. This gap can be partly explained by cultural, traditional, and economical obstacles. Furthermore, the validity of the concept of multifunctionality on a larger scale is still up for certain debates. Moreover, my research showed that climate change adaptation is just a minor concern of current management objectives, therefore, multifunctionality is also of slight concern for adaptation strategies. Nevertheless, multifunctionality was identified as a promising concept to increase adaptation and resilience of forest ecosystems to future climate conditions. The review of policy documents showed a similar pattern as the review of the academic literature regarding the framing of multifunctionality. In both cases the concept was not defined and applied according to a clear and stringent definition but varied between different instances.

My research identifies several opportunities for future research. First, trends that have been identified in this study should be checked within a larger body of academic literature to strengthen the reliability of the results of this study and contextualize them on a larger scale. Second, the current literature offers a great array of recommendations and solutions to improve and adapt management practices to changing demands and conditions, but little as to how these recommendations can or should be implemented. Therefore, further research should concentrate less one the 'what' and instead more on the 'how' and produce practical knowledge to bridge the current still existing gap between these two. Third, the concept of multifunctionality needs to be applied according to a clear definition, then it has the potential to facilitate important understanding for ecosystem science and offer valuable support in landscape-decision making. The worked-out framework by Manning et al. offers here a great opportunity. And lastly, ecosystem management and land management research need to adapt a 'climate change lens' to ensure the validity of its findings in the context of climate change and strengthen the reliability of its knowledge production. This is a crucial point that is currently still missing in extensive parts of the reviewed literature.

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Appendix

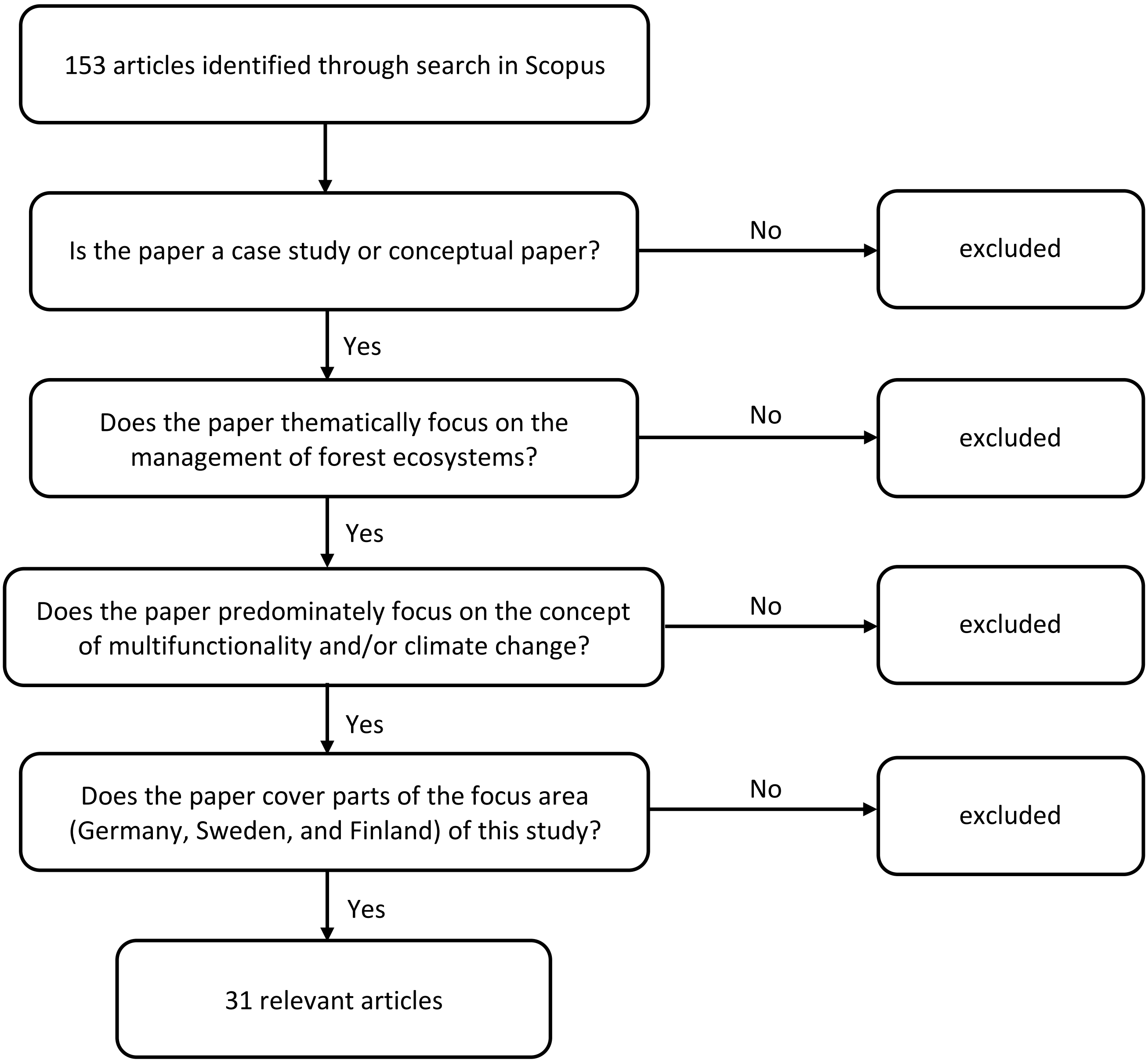

Figure A1. Decision tree describing the systematic review process

Table A1. Literature that was reviewed for the systematic literature review

Authors	Title	Year
Angelstam P., Asplund B., Bastian O., Engelmark O., Fedoriak M., Grunewald K., Ibisch P.L., Lindvall P., Manton M., Nilsson M., Nilsson S.B., Roberntz P., Shkaruba A., Skoog P., Soloviy I., Svoboda M., Teplyakov V., Tivell A., Westholm E., Zhuk A., Öster L.	Tradition as asset or burden for transitions from forests as cropping systems to multifunctional forest landscapes: Sweden as a case study	2022
Simons N.K., Felipe-Lucia M.R., Schall P., Ammer C., Bauhus J., Blüthgen N., Boch S., Buscot F., Fischer M., Goldmann K., Gossner M.M., Hänsel F., Jung K., Manning P., Nauss T., Oelmann Y., Pena R., Polle A., Renner S.C., Schloter M., Schöning I., Schulze E.-D., Solly E.F., Sorkau E., Stempfhuber B., Wubet T., Müller J., Seibold S., Weisser W.W.	National Forest Inventories capture the multifunctionality of managed forests in Germany	2021
Parkatti V.-P., Tahvonen O.	Economics of multifunctional forestry in the Sámi people homeland region	2021
Friedrich S., Hilmers T., Chreptun C., Gosling E., Jarisch I., Pretzsch H., Knoke T.	The cost of risk management and multifunctionality in forestry: a simulation approach for a case study area in Southeast Germany	2021
Larsson Ekström A., Bergmark P., Hekkala A.-M.	Can multifunctional forest landscapes sustain a high diversity of saproxylic beetles?	2021
Pohjanmies T., Eyvindson K., Triviño M., Bengtsson J., Mönkkönen M.	Forest multifunctionality is not resilient to intensive forestry	2021
Messier C., Bauhus J., Sousa-Silva R., Auge H., Baeten L., Barsoum N., Bruelheide H., Caldwell B., Cavender-Bares J., Dhiedt E., Eisenhauer N., Ganade G., Gravel D., Guillemot J., Hall J.S., Hector A., Hérault B., Jactel H., Koricheva J., Kreft H., Mereu S., Muys B., Nock C.A., Paquette A., Parker J.D., Perring M.P., Ponette Q., Potvin C., Reich P.B., Scherer-Lorenzen M., Schnabel F., Verheyen K., Weih M., Wollni M., Zemp D.C.	For the sake of resilience and multifunctionality, let's diversify planted forests!	2021
Eyvindson K., Duflot R., Triviño M., Blattert C., Potterf M., Mönkkönen M.	High boreal forest multifunctionality requires continuous cover forestry as a dominant management	2021
Teben'kova D.N., Lukina N.V., Chumachenko S.I., Danilova M.A., Kuznetsova A.I., Gornov A.V., Shevchenko N.E., Kataev A.D., Gagarin Y.N.	Multifunctionality and Biodiversity of Forest Ecosystems	2020

Jonsson M., Bengtsson J., Moen J., Gamfeldt L., Snäll T.	Stand age and climate influence forest ecosystem service delivery and multifunctionality	2020
Jönsson M., Snäll T.	Ecosystem service multifunctionality of low-productivity forests and implications for conservation and management	2020
Benz J.P., Chen S., Dang S., Dieter M., Labelle E.R., Liu G., Hou L., Mosandl R.M., Pretzsch H., Pukall K., Richter K., Ridder R., Sun S., Song X., Wang Y., Xian H., Yan L., Yuan J., Zhang S., Fischer A.	Multifunctionality of forests: A white paper on challenges and opportunities in China and Germany	2020
Díaz-Yáñez O., Pukkala T., Packalen P., Peltola H.	Multifunctional comparison of different management strategies in boreal forests	2020
Gren I.-M., Amuakwa-Mensah F.	Multifunctional forestry and interaction with site quality	2020
Strengbom J., Axelsson E.P., Lundmark T., Nordin A.	Trade-offs in the multi-use potential of managed boreal forests	2018
van der Plas F., Ratcliffe S., Ruiz-Benito P., Scherer-Lorenzen M., Verheyen K., Wirth C., Zavala M.A., Ampoorter E., Baeten L., Barbaro L., Bastias C.C., Bauhus J., Benavides R., Benneter A., Bonal D., Bouriaud O., Bruelheide H., Bussotti F., Carnol M., Castagneyrol B., Charbonnier Y., Cornelissen J.H.C., Dahlgren J., Checko E., Coppi A., Dawud S.M., Deconchat M., De Smedt P., De Wandeler H., Domisch T., Finér L., Fotelli M., Gessler A., Granier A., Grossiord C., Guyot V., Haase J., Hättenschwiler S., Jactel H., Jaroszewicz B., Joly F.-X., Jucker T., Kambach S., Kaendler G., Kattge J., Koricheva J., Kunstler G., Lehtonen A., Liebergesell M., Manning P., Milligan H., Müller S., Muys B., Nguyen D., Nock C., Ohse B., Paquette A., Peñuelas J., Pollastrini M., Radoglou K., Raulund-Rasmussen K., Roger F., Seidl R., Selvi F., Stenlid J., Valladares F., van Keer J., Vesterdal L., Fischer M., Gamfeldt L., Allan E.	Continental mapping of forest ecosystem functions reveals a high but unrealised potential for forest multifunctionality	2018
Peura M., Burgas D., Eyvindson K., Repo A., Mönkkönen M.	Continuous cover forestry is a cost-efficient tool to increase multifunctionality of boreal production forests in Fennoscandia	2018
Sutherland L.-A., Huttunen S.	Linking practices of multifunctional forestry to policy objectives: Case studies in Finland and the UK	2018
Lagergren F., Jönsson A.M.	Ecosystem model analysis of multi-use forestry in a changing climate	2017

Borrass L., Kleinschmit D., Winkel G.	The "German model" of integrative multifunctional forest management—Analysing the emergence and political evolution of a forest management concept	2017
Triviño M., Pohjanmies T., Mazziotta A., Juutinen A., Podkopaev D., Le Tortorec E., Mönkkönen M.	Optimizing management to enhance multifunctionality in a boreal forest landscape	2017
Van Der Plas F., Manning P., Soliveres S., Allan E., Scherer-Lorenzen M., Verheyen K., Wirth C., Zavala M.A., Ampoorter E., Baeten L., Barbaro L., Bauhus J., Benavides R., Benneter A., Bonal D., Bouriaud O., Bruelheide H., Bussotti F., Carnol M., Castagneyrol B., Charbonnier Y., Coomes D.A., Coppi A., Bestias C.C., Dawud S.M., De Wandeler H., Domisch T., Finér L., Gessler A., Granier A., Grossiord C., Guyot V., Hättenschwiler S., Jactel H., Jaroszewicz B., Joly F.-X., Jucker T., Koricheva J., Milligan H., Mueller S., Muys B., Nguyen D., Pollastrini M., Ratcliffe S., Raulund-Rasmussen K., Selvi F., Stenlid J., Valladares F., Vesterdal L., Zielínski D., Fischer M., Schlesinger W.H.	Biotic homogenization can decrease landscape-scale forest multifunctionality	2016
Van Der Plas F., Manning P., Allan E., Scherer-Lorenzen M., Verheyen K., Wirth C., Zavala M.A., Hector A., Ampoorter E., Baeten L., Barbaro L., Bauhus J., Benavides R., Benneter A., Berthold F., Bonal D., Bouriaud O., Bruelheide H., Bussotti F., Carnol M., Castagneyrol B., Charbonnier Y., Coomes D., Coppi A., Bastias C.C., Muhie Dawud S., De Wandeler H., Domisch T., Finér L., Gessler A., Granier A., Grossiord C., Guyot V., Hättenschwiler S., Jactel H., Jaroszewicz B., Joly F.-X., Jucker T., Koricheva J., Milligan H., Müller S., Muys B., Nguyen D., Pollastrini M., Raulund-Rasmussen K., Selvi F., Stenlid J., Valladares F., Vesterdal L., Zielínski D., Fischer M.	Jack-of-all-trades effects drive biodiversity-ecosystem multifunctionality relationships in European forests	2016
Mattila O., Häyrinen L., Tervo M., Toppinen A., Berghäll S.	Challenges of municipal greening and multifunctional forest management: The case of Finland	2015
Suda M., Pukall K.	Multifunctional forestry between inclusion and extinction (essay) [Multifunktionale Forstwirtschaft zwischen Inklusion und Extinktion (Essay)]	2014

Sarvašová Z., Cienciala E., Beranová J., Vančo M., Ficko A., Pardos M.	Analysis of governance systems applied in multifunctional forest management in selected European mountain regions	2014
Gustafsson L., Baker S.C., Bauhus J., Beese W.J., Brodie A., Kouki J., Lindenmayer D.B., Lhmus A., Pastur G.M., Messier C., Neyland M., Palik B., Sverdrup-Thygeson A., Volney W.J.A., Wayne A., Franklin J.F.	Retention forestry to maintain multifunctional forests: A world perspective	2012
Pukkala T., Lähde E., Laiho O., Salo K., Hotanen J.-P.	A multifunctional comparison of even-aged and uneven-aged forest management in a boreal region	2011
Keskitalo E.C.H.	Climate change, vulnerability and adaptive capacity in a multi-use forest municipality in northern Sweden	2010
Yousefpour R., Hanewinkel M., Le M.G.	Evaluation of biodiversity for multi-purpose forest management using a non-linear optimization approach	2010
Moen J., Keskitalo E.C.H.	Interlocking panarchies in multi-use boreal forests in Sweden	2010

Table A2. Sighted policy documents of German federal states on multifunctionality in forest management.

Publisher	Title	Year	Type of document	Document-ID
Baden-Württemberg State Ministry for Rural Areas, Nutrition and Consumer Protection	Eckpunkte der Waldstrategie Baden-Württemberg [Cornerstones of the forest strategy Baden-Württemberg]	n.d.	Forest strategy	BW1
Bavarian State Ministry for Food, Agriculture and Forestry	Der Wald im Klimawandel: Acht-Punkte-Programm für zukunftsfähige Wälder in Bayern [The forest in a changing climate: Eight-step-program for sustainable forests in Bavaria]	2019	Action plan	BA1
Federal Forest Service of Baden-Wurttemberg	Waldstrategie Baden-Württemberg 2050: Auf dem Weg zur Waldstrategie – Bericht zum Waldstrategie-Prozess [Forest strategy Baden-Württemberg 2050: Towards a forest strategy – Reporting on the forest strategy process]	2021	Forest strategy	BW2
Hessian Ministry for the Environment, Energy, Agriculture and Consumer Protection	Richtlinie für die Bewirtschaftung des Staatswaldes [Directive for forest cultivation]	2018	Forest management guideline	HE1
Hessian Ministry for the Environment, Energy, Agriculture and Consumer Protection	Wichtiger Lebensraum. Wir machen den Wald klimastabil. [Important Habitat. We make the forest resilient for climate change]	n.d.	Status report	HE2
Hessian Ministry for the Environment, Energy, Agriculture and Consumer Protection	Wald von morgen [Forest of tomorrow]	n.d.	Forest Vision	HE3
Lower Saxony Ministry of Food, Agriculture and Consumer Protection	Wälder für Niedersachsen: Wald, Forst- und Holzwirtschaft im Wandel [Forests for Lower Saxony: Changes in forest and forestry]	2017	Position paper	LS1
Ministry for Infrastructure and	Waldvision 2030: Eine neue Sicht für den Wald der Bürgerinnen und Bürger	2011	Forest Vision	BB1

Agriculture of Brandenburg	[Forest vision 2030: A new view on society's forest]			
Saxon State Ministry of the Environment and Agriculture	Waldstrategie 2050 für den Freistaat Sachsen [Forest strategy 2050 for the Free State of Saxony]	2013	Forest strategy	SA1
State Ministry of Environment and Energy, Food and Forestry Rhineland Palatinate	Unser Wald ist Klimaschutz: Beitrag des Waldes und der Forst- und Holzwirtschaft von Rheinland-Pfalz zum Klimaschutz [Our forest is climate protection: Contribution of forests and forestry in Rhineland-Palatinate for climate protection]	2019	Status report	RP1
The Bavarian State Institute of Forestry	Vielseitige Wälder für mehr Artenvielfalt [Versatile forests for more biodiversity]	2022	Position paper	BA2