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Forest ecosystem services in Norway: Trends, condition, and drivers of change (1950–2020)

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ABSTRACT

Some regions like Europe have experienced a net gain in forest areas over the last decades, but intact areas of natural forests are declining worldwide, accompanied by changes in forest ecosystem functions and benefits to humans. We conduct a biophysical assessment of trends, condition, and drivers of change of forest ecosystem services in Norway from 1950 to 2020. Four main results are highlighted. First, industrial forestry, large scale measures of re- and afforestation, and infrastructure development (e.g., roads and recreational homes) have been the main direct drivers of forest transformation. Second, deep transformations in the Norwegian economy shaped trends of forest ecosystem services over the study period. Third, with the shifts towards the tertiary (service) sector and the mechanization of forestry, the economic and material relations between forests and local communities are waning. Overall, people's primary relationships to forests have shifted from livelihood to recreation. Fourth, forest management in Norway has largely favored provisioning services at the expense of supporting services and some cultural and regulating services. Consequently, while Norwegian forests retain strong capacity to deliver provisioning services, the overall ecological condition is relatively poor. Our assessment provides an approach to identify and explain trends of ecosystem services at a national scale, over a long period of time. We argue that growth in forest area and biomass are insufficient indicators for sustainable forest management, and that future forest polices would benefit from improved knowledge on forests ecological condition, resilience against climate change, and socio-cultural contributions to human well-being.

1. Introduction

The Millennium Ecosystem Assessment (2005) found that two thirds of the world's ecosystem services were declining, and the recent global assessment report from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services documents an acceleration of global drivers of ecosystem degradation (IPBES, 2019).

Forests cover nearly-one third (30 %) of the global land area (World Bank, 2020). A majority of terrestrial species of animals and plants reside in forests (FAO, 2020) and this biodiversity sustains critically important ecosystem services, including raw materials, food production, outdoor recreation, sense of place, and carbon sequestration (Brockerhoff et al., 2017; Gauthier et al., 2015; Jenkins and Schaap, 2018; Shvidenko and Gonzalez, 2005). Deforestation and forest degradation constitute severe threats to forest ecosystems (FAO, 2020), and global forest areas have been reduced by more than two thirds (68 %) from pre-industrial levels (IPBES, 2019). The rate of global forest loss has declined since the 1980s, but forests are still rapidly disappearing in many tropical regions (Díaz et al., 2019). The area of "intact" forests is declining in both developed and developing countries (IPBES, 2019), resulting in losses of biodiversity and environmental values (Watson et al., 2018).

Some regions like Europe have experienced a net gain in forest areas over the last decades, although at a lower rate in 2010–2020 compared to 2000–2010 (FAO, 2020; Keenan et al., 2015). The drivers leading to increases in some temperate and boreal forests are diverse, and include restoration of natural forest, planting of monocultures with fast growing tree species (IPBES 2019), and abandoning of agricultural land (Navarro and Pereira, 2012). However, increases in forest biomass and extent are often accompanied by fragmentation and changes of forest functions

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(Díaz et al., 2019), e.g. with decline in habitats for species. Such forest changes entail social, environmental and economic costs that often remain unrecognized or undervalued in forest management (TEEB, 2010).

Forests have been part of the main global ecosystem service assessments (MEA, 2005; IPBES, 2019), regional assessments such as the Mapping and Assessment of Ecosystems and their Services (MAES) in Europe (e.g., Maes et al., 2020), and some national ecosystem assessments [NEA] (e.g., the Spanish NEA, 2013; and the UK NEA, 2011). The European MAES provides important advancements within ecosystem service framework and methodologies, as well as key policy insights for the EU Forest Strategy 2030 (European Comission, 2021).

To date, however, most assessments of forest ecosystem services are local case studies (e.g., García-Nieto et al., 2013; Joshi and Joshi, 2019), often focused on specific services (Mengist and Soromessa, 2019). Although many countries face policy dilemmas associated with sustainable forest management (Lindahl et al., 2017; Edwards et al., 2022; Pohjanmies et al., 2017), we find few broad assessment of forest ecosystem services at national scales. Further, national forest policies may be informed by knowledge on how relevant drivers of change affect trends in ecosystem service over time (see e.g., Berglihn and Gómez-Baggethun, 2021).

Here, we conduct a biophysical assessment of forest ecosystem services in Norway for the period 1950–2020. Although extensive research has been conducted on aspects such as total biomass, carbon sequestration, and the ecological condition of Norwegian forests, major knowledge gaps remain, including overall trends in forest ecosystem services (Lindhjem and Magnussen, 2012) and a comprehensive overview of associated drivers of change (NOU, 2013). With the aim of covering these knowledge gaps, the specific objectives of this paper are: i) to identify the most important ecosystem services provided by forests in Norway, ii) to assess the trends and condition of forest ecosystem services, and iii) to identify the most important direct and indirect drivers of change affecting forest ecosystem services.

2. Study area

Norway has a mainland area of 323 808 km^2. With 5.3 million inhabitants and an average of 16 persons per km^2, Norway is one of the most sparsely populated countries in Europe (SSB, 2019). Forests cover more than one third (37.4 %) of the country (SSB, 2019), amounting to 2.28 ha of forest per person. The Norwegian forest area is dominated by a mix of Norway spruce (27.3 %), Scots pine (29.6 %), birches and other boreal deciduous trees (40 %) (NIBIO, 2020b).[1] Most of the forest biomass is concentrated in the south-eastern part of the country (Fig. 1).

Just above 70 % (87 000 km^2) of the forest area is defined as productive,[2] while the remaining 30 % is not deemed economically viable (NIBIO, 2020b; SSB, 2020c). About ¾ (77 %) of the productive forest land is privately owned (Statskog, 2015). Most rights for extracting raw materials (e.g. logging, hunting, and fishing) belong to the landowner, while permission for picking wild berries, mushrooms, and plants in forests is granted through the principle of common access rights to all uncultivated land known as the "the right to roam" (Outdoor Recreation Act, 1957, section 2) (Reusch, 2021).

Norwegians have historically altered their forests to sustain livelihoods and rural settlements, e.g. through the provision of food, firewood, and timber (Hoen et al., 2019). Over the last 5000 years, most coastal areas with deciduous woodland in Western Norway were gradually deforested to cultivate land and provide winter pastures for livestock (Hjelle et al., 2018). Human pressure on Norwegian forests increased during the Middle Ages, partly due to growing coal pit burning for iron production. Mining, glass production, and harvesting of timber (particularly oak) for boatbuilding and exports further increased pressures on forests during the 16th and 17th centuries (Müller, 2018; Storaunet and Framstad, 2020). Amount and quality of accessible timber declined gradually, but by the end of the 19th century new wood processing industries could make use of smaller sizes and lower quality of timber (Storaunet and Framstad, 2020).

By 1916, scientists warned that the timber resources in Norwegian forests had been strongly reduced and degraded (NIBIO, 2019; SSB, 2015), spurring the Norwegian Government to develop national plans for large scale reforestation and afforestation processes.[3] From around 1950, the dominant forest management model in Norway shifted from dimensional logging and intensive selective cutting towards so-called even-aged forestry, where a whole forest stand is cut and re-planted as a unit. Following these policy shifts, the total forest biomass has tripled over the past century, while the forest area has increased by around 10 % (NIBIO, 2019; SSB, 1927; Storaunet and Framstad, 2020).

Forests are an important renewable resource contributing to value creation locally, regionally, and nationally in Norway (MAF, 2016, 2019), but the relative economic importance of forestry has declined over recent decades. Forestry employment dropped from around 28 500 in 1950 to 6 600 in 2018 (Tomter and Dalen, 2018), and forestry's contribution to Norwegian GDP has gone down from 2.5 % in 1950, to 0.2 % by 2020 (SSB, 2019). Over the last decade, however, a rise in timber prices has been accompanied by increased timber harvest. In 2021, the timber harvest peaked at 11.5 million m^3 timber sold for industrial purposes, with a total timber value of about 5.4 billion NOK (around 540 million EUR) (NAA, 2021a). Forests are also increasingly promoted as important renewable resources contributing to the "green shift" and towards a future *bioeconomy* (MAF, 2016, 2019).

Besides economic contributions measurable in money, Norwegian forests also provide a wide range of cultural, regulating, and supporting ecosystem services. Forests off-set close to half the Norwegian carbon emissions (NEA et al., 2017), and are home to about half of the endangered species in Norway (Artsdatabanken, 2021). Forest areas are also widely used for outdoor recreation (NEA, 2020a). Multiple functions of forests gained prominence on the national policy agenda from around 1980–90, e.g. with the emergence of the concept of "multiple use forestry" (Halberg, 1999).

3. Methods

Our assessment was developed in four main steps: i) classification and categorization of ecosystem services, ii) development of assessment indicators, iii) definition of indicators for drivers of change, and iv) validation of results.

3.1. Classification and categorization of ecosystem services

Important ecosystem services from Norwegian forests were identified from a comprehensive literature review. Data sources included scientific papers and reports, policy documents, books, and data from official national statistics. Starting from a broad, historical review of forests and forest governance in Norway, we drew on relevant classifications and criteria (see below) to identify the most important services for our study period. As the term ecosystem services is of relatively recent use in Norwegian policy and scholarship, it was rarely mentioned explicitly in the relevant literature, so descriptions of nature's benefits under different rubrics (e.g., natural resources, cultural values,

[1] The remaining forest area consists of temperate deciduous trees and forest area temporarily without tree cover.

[2] Forest with a production of at least 1 m^3 timber per hectare per year (SSB, 2020c).

[3] In Norway, the term afforestation («skogreising») is used about measures of planting species of trees that can give higher production than native species (mainly in coastal areas), or planting of forest in areas with no previous forest cover (Tomter and Dalen, 2018).

Fig. 1. Map of Norway showing areas of forest and water, 2020 (Geonorge, 2020).

ecosystem functions) were translated and coded into the language and framework of ecosystem services.

Following established international classifications from the Millennium Ecosystem Assessment (MEA, 2005) and The Economics of Ecosystems and Biodiversity (TEEB, 2010), we classified ecosystem services into the four *main categories* of provisioning, cultural, regulating and supporting services. In lines with the UK NEA, cultural ecosystem services are defined here as "ecosystems' contributions to the non-material benefits (e.g., capabilities and experiences) that arise from human–ecosystem relationships" (Chan et al., 2011:206). Under each main category we identified the most important *types* of ecosystems services, adapting categories from international classifications to the Norwegian context (we e.g., identified *raw materials* and *food production* as the most relevant types of provisioning services).

Criteria for choices of most important services were i) relevance for people and communities, ii) importance to the national economy and/or policy, and iii) whether the contribution of forest ecosystems in providing the service could be clearly identified and described. Further, we attempted to avoid services with too much overlap. To prioritize the most important services, we drew on recent assessment of Norwegian forest ecosystem services (Lindhjem and Magnussen, 2012; NOU, 2013:10, 2013), and on discussions in an interdisciplinary expert workshop (see 3.4. for details). Some ecosystem services that were considered in the initial mapping, were not included in the final assessment based on the above criteria and inputs from the expert workshop.

When appropriate, we broke down ecosystem service types (e.g., raw materials) into *subtypes* (e.g., timber and bioenergy). Some activities, like hunting and harvesting of wild foods, have a hybrid character between provisioning and cultural services. In such cases we defined indicators that best reflected the relevant purpose of the activity related to the service (cf. Gómez-Baggethun et al., 2019). For example, to assess *food production*, we used number of animals felled as a proxy indicator, while to assess *outdoor recreation*, we used the number of active hunters that have paid the hunting license fee, as well as number of people registered in the national "Register of Hunters".

3.2. Definition of ecosystem service indicators

We assessed trends and condition for each ecosystem service. In line with recent developments in the ecosystem services literature, our definition of trends distinguished ecosystem service *capacity*, *flow* and *demand* (Baró et al., 2016). Capacity is defined here as "an ecosystem's potential to deliver services based on biophysical properties, social conditions, and ecological functions" (Villamagna et al., 2013:116) whereas flow is defined as "the service actually received by people" (Villamagna et al., 2013:118). As an example, standing timber biomass is an indicator of capacity whereas volume of harvested timber is an indicator of flow (Burkhard et al., 2014). Demand is defined here as "the amount of a service required or desired by society" (Villamagna et al., 2013:116). Since many ecosystem services are public goods and operate outside markets, trends in societal demand were assessed with reference to national policy targets (Baró et al., 2016).[4]

Table A.1. in the supplementary material (Appendix 1) provides an overview of the indicators chosen for our assessment. Capacity for *provisioning services* was measured directly through biophysical properties (e.g. forest area or tree biomass), while capacity for *cultural services* was proxied by combining biophysical properties and anthropogenic conditions (e.g., quality and accessibility) (Villamagna et al., 2013). We measured capacity for *regulating services* through aggregated data on biophysical properties defining regulating functions of forests that provide benefits to people and communities. In cases where quantitative data was not available, we relied on qualitative descriptions of changes in relevant biophysical properties and ecological functions over the study period. For measuring capacity of habitat provision (*supporting services)*, we e.g., used data from the Nature Index of Norway and assessments of the ecological condition of forest ecosystems in Norway (Aslaksen et al., 2015; Certain et al., 2011; Framstad et al., 2022; Storaunet and Framstad, 2020).

Flow was measured either directly through indicators assessing the amount of a service delivered, or by proxy indicators, e.g. number or share of beneficiaries (Villamagna et al., 2013). For ecosystem services that are difficult to quantify (e.g. sense of place), data from qualitative descriptions was used as a supplement to numerical data (Chan et al., 2012a).

The UK NEA (2014) bring attention to some particular challenges of measuring cultural service (see also Chan et al., 2012b; Plieninger et al., 2013), and emphasize that cultural services arise from human-nature relationships (Church et al., 2014). Our distinction between trends in *capacity* and *flow* allows for addressing different aspect of each service, and thus broadening this relational understanding. For example, for outdoor recreation and tourism, indicators of flow give information about how much people use forest for recreation, while indicators of capacity give a broader picture of forests ability to provide the service (e.g., *accessibility*). However, the ways in which forests contribute to people's recreational experiences – and to people's *sense of place* – will vary across cultures and individuals. Accurate measurements and descriptions of cultural ecosystem services thus depend on local studies with in-depth knowledge of the relationships between communities and ecosystems (see e.g., Kaltenborn et al., 2020).

[4] National policy targets can also be important drivers of change. In our assessment, we distinguish between *trends in demand* (measured by policy targets), and indirect drivers of change (assessed and described in section 4.2.1.), although these are closely connected.

Trends in ecosystem service *capacity* and *flow* over the study period were classified as increasing, stable, or declining. The time-period 1950–2020 was chosen because i) it is broadly consistent with the time frames of the MEA (2005) and IPBES (2019) which allows for comparison with global ecosystem assessments, ii) it covers the period of the so-called *great acceleration* (Steffen et al., 2015), which also involved fast transformations in Norwegian forests, and iii) it provides a relevant time frame to inform policy and planning. When data for the 1950–2020 period was not found, available data closest to this period was used and specified. Uncertainty in data sources was acknowledged and labelled as i) low, ii) medium, or iii) high depending on data quality and level of consistency across consulted sources (see also Gómez-Baggethun et al., 2019).

Data from the Norwegian Forest Inventory (NFI) (SSB, 2022b) and the Nature Index of Norway (Certain et al., 2011; Storaunet and Framstad, 2020) were used to collect information on the overall status of Norwegian forest ecosystems. Building on these data, we classified the *condition* of forests to deliver each type of ecosystem service as i) good, ii) acceptable, or iii) poor. Condition was classified as good when forests have good ecological status and/or high capacity to supply the relevant service, relative to the current levels of use (flow) and demand for the service.

3.3. Characterization of drivers of change

We adapted the classification of drivers of change from the MEA (2005) framework. This framework differentiates direct and indirect drivers of ecosystem change, defined as "natural or human-induced factors that directly or indirectly cause a change in an ecosystem" (2005:64). Direct drivers are driving forces that "unequivocally influences ecosystem processes", while indirect drivers operate more diffusely "by altering one or more direct drivers" (2005:64).

In addition to data from previous global and sub-global assessments (IPBES, 2019; MEA, 2005), we used knowledge about drivers of change from earlier studies of forest ecosystems in Norway (Framstad et al., 2022; Lindhjem and Magnussen, 2012; NOU 2013:10, 2013). Table A.2. in the supplementary material shows the selected indicators for assessing direct and indirect drivers of change.

3.4. Expert workshop

In order to validate/revise our results, a workshop with 19 forest experts from different institutions and disciplinary backgrounds was convened on 27th of May 2021. Participants included ecologists, economists, and social scientists. The workshop consisted of three main parts. First, details on methodology, selected indicators, and preliminary results were presented to the experts. Next, experts worked in groups providing feedback on trends of capacity and flow for specific ecosystem service categories. Finally, the experts conducted qualitative assessments of the impact of specific drivers of change on different categories of forest ecosystem services. Inputs from the workshop were used to verify or adjust preliminary results on trends, condition, and drivers of change.

4. Results

4.1. Ecosystem service trends and condition

We identified eight types of ecosystem services, including two provisioning services, two cultural services, three regulating services and one supporting service. Some services were classified in several subtypes, which trends in capacity and flow were also assessed. Table 1 provides an overview of trends in ecosystem service capacity, flow, and demand from 1950 to 2020 for all identified ecosystem service types and subtypes (based on indicators identified in Table A.1. in Appendix 1). Table 1 also shows the condition of each ecosystem service type.

Table 1
Classification of forest ecosystem services in Norway, 1950–2020: trends of capacity, flow, and demand, and the condition of forests to supply the relevant service. (See below-mentioned references for further information.)

Ecosystem service type	Ecosystem service subtype	Capa-city	Flow	Demand	Condi-tion	Overall trend	Main sources,see also Table A.3
Provisioning services – Physical goods obtained from forest							
Raw materials		↑	↑	↑	(green)	Capacity for extracting energy and materials from forest for direct use or processing has increased considerably with growth in timber biomass, while flow has had a small increase.	(Lindhjem & Magnussen, 2012; MAF, 2016; SSB, 1954; SSB, 2020e; SSB, 2020f; Tomter & Dalen, 2018)
	Timber	↑	↑				
	Bioenergy	↑	↑				
Food production		↑	↔	↔	(green)	Capacity for game meat has increased with growing numbers of wild ungulates, while capacity for livestock grazing and wild foods has remained relatively stable. Increase in use (flow) of game meat, while decline in livestock grazing and harvesting of wild foods.	(Asheim & Hegrenes, 2006; Austrheim et al., 2008; Harstad, 2018; Harstad, 2021; SSB, 2019; Strand et al., 2021),
	Livestock grazing	↔	↓				
	Game meat	↑	↑				
	Wild foods	↔	↓				
Cultural services - Ecosystems' contributions to the non-material benefits that arise from human–ecosystem relationships							
Outdoor recreation and tourism		↔	↑	↑	(green)	Increases in capacity with growth in enabling infrastructure, although infrastructure developments and industrial forestry has also caused decline in some attractive qualities for recreation. Increases in use (flow) for hiking, hunting and tourism, while there has been decline in skiing and harvesting of wild foods.	(Andersen & Dervo, 2019; Breidenbach et al., 2017; Lindhjem & Magnussen, 2012; NEA, 2014; NEA, 2020a; SSB, 2017; Tomter & Dalen, 2018)
	Hiking	↔	↑				
	Skiing	↔	↓				
	Hunting	↑	↑				
	Wild foods	↔	↓				
	Tourism	↔	↑				
Sense of place		↔	↔	↔	(yellow)	Qualitative transformations, with no clear upward or downward trend, as the primary relation to forests has shifted from livelihood to recreation	(Lindhjem & Magnussen, 2012; SSB, 2015; Tomter & Dalen, 2018)
Regulating services - Benefits humans derive from ecological regulation processes							
Carbon sequestra-tion and storage		↑	↑	↑	(green)	Carbon sequestration has increased, due to growing biomass. However, there are uncertainties regarding sequestration and storage in old-growth forests, and in forest soils.	(Bartlett et al., 2020; NEA, 2020b; Stokland, 2021; Søgaard et al., 2019; Tomter & Dalen, 2018)
Nutrient cycling		?	↓	↑	(yellow)	Industrial forestry and increased sulfur and nitrogen deposition through long-range air pollution has negatively affected capacity - although the extent of a declining trend is uncertain.	(Austnes et al., 2018; Bernes, 1993; Helmisaari et al., 2011; Lindahl & Clemmensen, 2016; Sterkenburg et al., 2019; Tomao et al., 2020)
Moderation of extreme events		↓	↓	↑	(yellow)	Capacity declined in some areas, mainly due industrial forestry, with increased reliance on management of monocultures of even-aged forests and harvesting through clear-felling.	(Hofstad, 2020; Nordrum et al., 2020; Norsk Klimaservicesenter, 2017; VKM, 2021; NOU 2013:10; NGI, 2013)
Supporting services - Services necessary for the production of all other ecosystem services							
Habitat provision		↓	↓	↑	(red)	Decline in capacity and flow due to declines in wilderness-like areas and in share of not previously clear-felled forests. Norway also has little old-growth forests, and the ecological condition of forest is relatively poor.	(Artsdatabanken, 2021; Certain et al., 2011; Framstad et al., 2022; NEA, 2018; Storaunet & Framstad, 2020; Storaunet & Rolstad, 2020)

Source: Own elaboration with icons by Jan Sasse for TEEB (except for icons 'outdoor recreation' and 'sense of place'). ↑=increased; ↔=remained stable; ↓=decreased and? =Not assessed due to lack of data and/or large level of uncertainty. Condition of main type of ecosystem service is indicated by colors; green (good), yellow (acceptable), red (poor). See detailed data, descriptions, and sources in Table A.3 in the supplementary material.

Detailed data and descriptions of trends within capacity and flow of each ecosystem service (type and subtypes), can be found in Table A.3 in the supplementary material.

4.1.1. *Provisioning services*

Forests' *capacity* for providing *raw materials* has increased notably, as standing timber biomass has grown from 322.3 million m^3 in 1933 (SSB, 1954) to 974 mill. m^3 in 2018 (SSB, 2020c). Over the same time period, the productive forest area has increased by around 10 % (Storaunet and Framstad, 2020). The amount of timber harvested (flow) for sale to industrial purposes grew from 7 123 000 m^3/year in 1950 (SSB, 1950) to 10 242 000 m^3/year in 2020 (SSB, 2021b). Furthermore, national statistics report an increase in production of bioenergy[5] over the years of the study period for which data were available, e.g. from 9.9 TWh of bioenergy produced overall in Norway in 1990 to 13 TWh in 2020 (SSB, 2021a).

Capacity to supply food through game meat increased along with a growth in populations of wild ungulates in the forests (Austrheim et al., 2008; Larsson and Sandved, 2018). The capacity to sustain livestock,

[5] Bioenergy ("biobrensler") is also produced from other inputs than forest biomass, but national energy statistics do not distinguish between bioenergy from forest biomass and other types of biomasses.

measured by “fodder units”[6] in outfield pastures and the ecological condition of grazing forest, has remained relatively stable (Framstad and Bendiksen, 2018; Strand et al., 2021). When it comes to flow, the use of outfield pastures for *food production* has more than halved since 1950, but there has been a strong growth in game-meat from forests, e.g., from 660 red deer felled in 1950 to 46 356 in 2020 (Asheim and Hegrenes, 2006; Austrheim et al., 2008; SSB, 2020b). Hence, the overall use (flow) of food production has remained relatively stable.

A growing human population, higher consumption per capita, and recent policy developments to promote a bioeconomy through increased use of forest resources (MAF, 2019, 2016; SSB, 2019), signals a growing societal demand for raw materials and food production. Overall, the condition of these services is classified as good, as forests maintain high capacity to supply them (e.g., Strand et al., 2021; Tomter and Dalen, 2018).

4.1.2. Cultural services

Some of forest’s *capacity* to contribute to *outdoor recreation and tourism* has increased through improved accessibility, facilitated by e.g., increased public transport and enabling infrastructure. However, capacity has also been negatively affected by deforestation close to settlements and negative effects of climate change on activities such as skiing (Breidenbach et al., 2017; Lindhjem and Magnussen, 2012; Norwegian Climate Foundation, 2016). Further, as industrial forestry has changed the structure of wide areas of the forest landscape to younger and more homogeneous forests (Kuuluvainen, 2009), the experiential values of the forests may be substantially reduced for some people (Gundersen and Frivold, 2008). The overall use of forests for recreation (flow) has increased in both absolute and relative (per capita) terms (Kirkemo et al., 2020; SSB, 2017), while the number of recreational homes and revenues from forest-based tourism has also increased (e.g. Andersen and Dervo, 2019; Norges Skogeierforbund, 2012; SSB, 2007b, SSB, 2020d). Trends within flow of subtypes vary, and detailed descriptions of these trends can be found in Table A.3. in the supplementary material.

Sense of place has experienced qualitative transformations, with no clear upward or downward trend, as the primary relation to forests has shifted from livelihood to recreation (SSB, 2015, SSB, 2017, SSB, 2020d). In the mid-20th Century, forest management still relied largely on human labor and most farmers managed their own forests, acquiring local ecological knowledge and experienced-based skills that were intertwined with local values and norms. By contrast, most forest management today is outsourced to specialized firms (SSB, 2015), and the majority of forestry work is mechanized (SSB, 2007b). On the other hand, the growing use of forests for outdoor recreation (MCE, 2018; NEA, 2014; SSB, 2017) testify to how recreational aspects of forests increasingly contributes to many Norwegians’ *sense of place*.

Demand for outdoor recreation and tourism is high and growing, and the condition is classified as good. Although trends have worked in opposite directions, forests overall capacity to supply recreation is high, due to large extent of forested areas, recreational infrastructure (e.g., lodges and a wide network of marked paths), and accessibility (e.g., through public transport). Sense of place is classified as acceptable, and there are uncertainties regarding how qualitative shifts in human-forest relationships affects capacity for this service.

4.1.3. Regulating services

Capacity of forests to *sequester and store carbon* has increased over the study period along with the above reported increases in biomass. Although increases in timber harvest have detracted capacity for carbon sequestration, timber biomass has grown at a faster rate than the timber harvest, resulting in an overall increase of carbon sequestration capacity. The carbon stocks in living biomass of forest trees were 345 million tons in 1990, and 470 million tons in 2015 (Tomter and Dalen, 2018). By 2018, the net-uptake of CO_2-equivalents in Norwegian forest were 28 million tons, with forest biomass offsetting approximately 54 % of domestic carbon emissions (NEA et al., 2017; Tomter and Dalen, 2018). However, there are also significant uncertainties regarding sequestration and storage in old-growth forests, and in forest soils (Bartlett et al., 2020; Stokland, 2021).

Although clear-felling has increased dramatically since 1950, leaving the branches of trees in the forest after harvesting has remained a common practice, thereby securing that significant amounts of nutrients remain in the forests (expert workshop, 2021). However, clear-felling can interrupt the local functioning of mycorrhizal fungi in *nutrient cycling* for up to several decades (Lindahl and Clemmensen, 2016; Sterkenburg et al., 2019; Tomao et al., 2020). Increased nitrogen fertilization (NIBIO, 2020a) and draining of wet forests since the 1950s (Bernes, 1993) are also likely to have changed nutrient cycles, while long-range air pollution (e.g. from industry in the UK) has increased sulphur and nitrogen deposition in forests, resulting in leaching of nutrients from forest soils in southern parts of Norway over several decades (Austnes et al., 2018; Falkengren-Grerup et al., 1987; Steinnes et al., 1993). Combined, these factors have negatively affected nutrient cycling in forests, although the extent of a declining trend is uncertain.

Lack of aggregated data at national level (Lindhjem and Magnussen, 2012; Nordrum et al., 2020) and drivers acting in opposite directions make it hard to determine overall trends in forests’ capacity for *moderation of extreme events*. On the one hand, increases in forest area may suggest a positive trend. On the other hand, the increased share of even-aged forest monocultures and harvesting through clear-felling, have likely reduce resilience against storms, landslides, and floods in the affected areas (Nordrum et al., 2020; VKM, 2021; NGI, 2013). Hence, industrial forestry practices combined with deforestation close to settlements, indicate that the capacity to prevent flooding and landslides has declined in areas located close to infrastructure (where this service is needed). Further, the Norwegian Scientific Committee for Food and Environment (VKM) find that diversification of Norwegian forests would improve resilience towards future climate change (2021).

Increased prominence of climate mitigation policies has driven a strong growth in demand for *carbon sequestration and storage* (NEA, 2020b), and due to high and growing capacity, the condition of this service is classified as good. The condition of nutrient cycling is classified as acceptable, e.g., due to uncertainty of the extent of the declining trend in capacity. An increase in the frequency of extreme weather events (Norsk Klimaservicesenter, 2017) has contributed to growing societal demand for *moderation of extreme events,* while the condition is classified as acceptable.

4.1.4. Supporting services

The Norwegian Nature Index (Certain et al., 2011; Storaunet and Framstad, 2020) measures biodiversity status, thereby offering a good proxy to assess changes in the *capacity* for habitat provisioning. The index classified the biodiversity status of Norwegian forests as relatively poor by 2020, with a value of 0.41 against a reference value of 1.[7] The index suggests a relatively stable trend over the 30 years assessed (1990–2020) but increases in infrastructure and industrial forestry (with clear-felling) negatively affected habitat provision since 1950. As an illustration, around 1940, one third of Norwegian land area was

[6] One fodder unit is defined as 6900 kJ net energy (kJ NE), equivalent to the value of 1 kg standard barley for milk production (Harstad, 2018).

[7] The reference value is based on natural forest with a small degree of human interventions, in which natural disturbance processes with subsequent succession stages are present on all forest area (Storaunet and Framstad, 2020).

classified as wilderness-like,[8] whereas by 2018 this share had declined to 11.5 % (NEA, 2018). Further, although Norway had only marginal areas of old-growth forest left by 1950 (due to intensive forestry, especially since the mid-1800s), few forest areas were at the time affected by clear-felling. Despite the increases in total forest area over the study period, only a very small share of the productive forest area is today older than 160 years (2.5 % in 2016) (Tomter and Dalen, 2018), while the share of not previously clear-felled forest has dropped to around 30 % of the productive forest area (Storaunet and Rolstad, 2020). This increase in the prominence of semi-natural forests and forest plantations at the expense of remaining old, not previously clear-felled forests poses significant challenges to the 84 % of threatened forest species which depend on old forests (Artsdatabanken, 2021; Framstad et al., 2022).

There is growing demand for habitat provision resulting from changes in social values and the endorsement of international biodiversity treaties and forest protection policies. Lack of historical data for most species makes it hard to indicate the extent of a declining trend in habitat provision, but the current ecological condition is classified as poor (Framstad et al., 2022).

4.2. Drivers of change

Changes in Norwegian forests and forest ecosystems services over the study period are caused by a range of indirect and direct drivers specified below.

4.2.1. Indirect drivers

We identified a complex mix of economic and sociopolitical factors as the most important indirect drivers affecting forest ecosystem services. Major indirect drivers of change such as population and economic growth, urbanization, and consumption are shown in Fig. 2, together with indication of variations in their scale over the study period.

First, forest ecosystem services have been largely shaped by deep transformations in the Norwegian *economy* connected with economic growth, trade liberalization, outsourcing of industry, and the emergence of the oil and gas sector. Norway's GDP increased from approximately 259 billion NOK in 1950, to 2059 billion NOK in 2011 (in 2005-prices), during which the economy shifted its primary reliance from agriculture and industry towards the tertiary (service) sector (SSB, 2019, SSB, 2020a). Sustained economic growth was an important driver of infrastructure developments in forest and mountainous areas, such as roads and recreational homes (Kjensli, 2018), while the shift towards the tertiary sector caused abandonment of marginal agriculture, leading to forest expansion in many coastal and mountain areas (Bryn et al., 2013). Technological development, relative decline in timber prices (Tomter and Dalen, 2018), and increased wages, were all important drivers for the mechanization of forestry (Halberg 1999). Further, the paper and pulp industry developed in the 1950s and 1960s has declined strongly over the last decades (SSB, 2015, Tomter and Dalen 2018).

Second, forest ecosystem services have been strongly affected by *sociopolitical* drivers. Leading up to 1950, forest researchers debated if the best option for future Norwegian forestry would be selective felling of uneven-aged forests or clear-felling of even-aged, monoculture forests (Nygaard and Øyen, 2020). The latter option was strongly inspired by scientific forestry and ideas of modernity.[9] In 1938, the Norwegian government adopted a forestry plan that included the reforestation of 1500 km^2 of sparse coniferous forest with "deficient rejuvenation", with the aim of securing future access to raw materials (Bækkelund, 2020). The plan was designed around even-aged forestry, which resulted in the adoption of this practice as the official forestry model, and marked a start of modern, industrial forestry in Norway. From around 1980, forest management has been increasingly influenced by international climate and biodiversity treaties, while changes in legislation have promoted "multiple use forestry" (Halberg, 1999; Hoen et al., 2019). This is also reflected in increased protection of forest areas (NEA, 2019), as well as in the growing recognition of outdoor recreation as an important forest function (MCE, 2018; NEA, 2014). At present, approximately 5.2 % of the total forest area, and 3.9 % of productive forest area, is protected, while the national goal is to protect 10 % of all forest area (MCE, 2013; NEA, 2019; NEA, 2022).

Third, forest dynamics have been affected by population growth and by urbanization. Norway's population grew from 3.2 to 5.2 million during 1950–2020 (SSB, 2019), and the share of population living in densely populated areas increased from 52 % in 1950, to 80 % in 2020 (MLGM, 2018). Consequently, pressure on some peri-urban and urban forest ecosystem have increased.

Finally, cultural drivers are also relevant, particularly in combination with economic drivers. As average working time declined by one third since 1946 (SSB, 2007a), and household consumption more than tripled from 1958 to 2019 (measured in fixed prices) (SSB, 2019), more time and money have been used for travelling, outdoor recreation, and e.g., recreational homes in forest areas.

4.2.2. Direct drivers

We identified changes in forest management, infrastructure development and climate change, as the most important direct drivers of change. Major direct drivers of change are shown in Fig. 3.

First, forests and their services have been deeply transformed by changes in forest management, primarily by the introduction of industrial forestry practices like mechanized even-aged forestry and clear-felling, and by measures of re- and afforestation. Rarely practiced before 1950, clear-felling affects today between 60 and 70 % of the productive forest areas in Norway (Storaunet and Rolstad, 2020). After 1950, large scale afforestation projects were carried out in Western and Northern Norway. Around 4,5% (3900 km^2) of today's productive forests have been afforested over the last 70 years (Tomter and Dalen, 2018). Non-native tree species have been planted on approximately 800 km^2 since 1950 (Tomter and Dalen, 2018). Forest management has become increasingly mechanized, and the share of the timber harvested with machines increased from 4 % in 1978 to 91 % by 2007 (SSB, 2007b).

Second, forests have been transformed through the development of infrastructure like recreational homes, roads, and power lines, which together have led to fragmentation of forest areas and to a significant decline in the share of wilderness-like areas (NEA, 2018). As an example, the average size of recreational homes increased from 62.2 m^2 to 96.2 m^2 between 1983 and 2020, and the demand for infrastructure such as roads, electricity, sewage in relation to recreational homes has also increased (SSB, 2020d). Further, some forest areas such as peri-urban forests, have been deforested as a result of expansion of urban settlements (Breidenbach et al., 2017).

Finally, increases in annual average temperature (approximately 1 °C up from 1900 until 2014) and in annual precipitation (approximately 18 % up from 1900 to 2014) (Norsk Klimaservicesenter, 2017) have contributed to increased forest growth. Further, an increased frequency of extreme weather events such as heavy rainfall, periods of drought, and storms, puts pressure on forest resilience against events of windthrows, forest fires, and landslides (VKM, 2021).

4.2.3. Relationships between drivers of change and ecosystem service trends

Fig. 4 provides a framework (adapted from MEA, 2005) to illustrate the relationship between the drivers of change and ecosystem services

[8] "Wilderness like" nature areas are defined as areas with more than 5 km distance to significant technical interventions. Examples of such technical installations are all types of roads, railways, water reservoirs, power lines and other energy facilities. These areas represent habitat with limited human impact and are thus a relevant indicator for habitat provision.

[9] Scott (1999) argue that scientific forestry/even-aged forestry builds on a "high-modernist" ideology with strong belief in progress of science and technology.

Fig. 2. Major indirect drivers of change affecting forest ecosystem services in Norway, 1950–2020 Sources: (MLGM, 2018; NEA, 2019; SSB, 2019; SSB, 2020a; Tomter and Dalen, 2018).

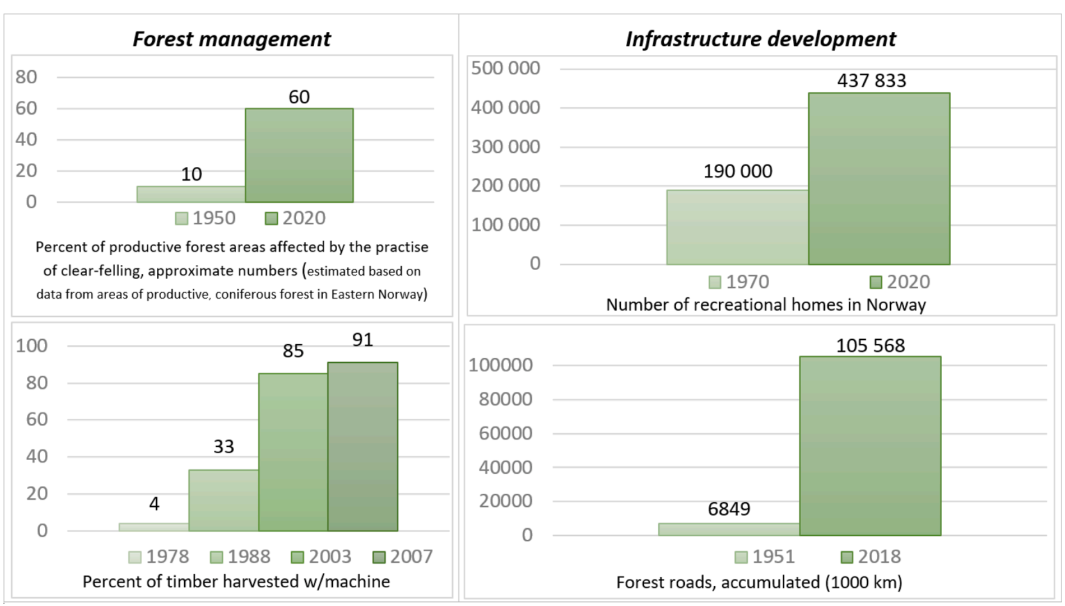

Fig. 3. Major direct drivers of change affecting forest ecosystem services in Norway, 1950–2020 Sources: (NAA, 2021; SSB, 2007b; SSB, 2019; SSB, 2020d; Storaunet and Rolstad, 2020).

trends over the studied period. Overall, we found that economic and sociopolitical factors have been particularly prominent in shaping direct drivers of change, while forest management, infrastructure development, and climate change have been the most important direct drivers. The strength of the direct drivers was established from assessments across indicators, and from discussions in the expert workshop.

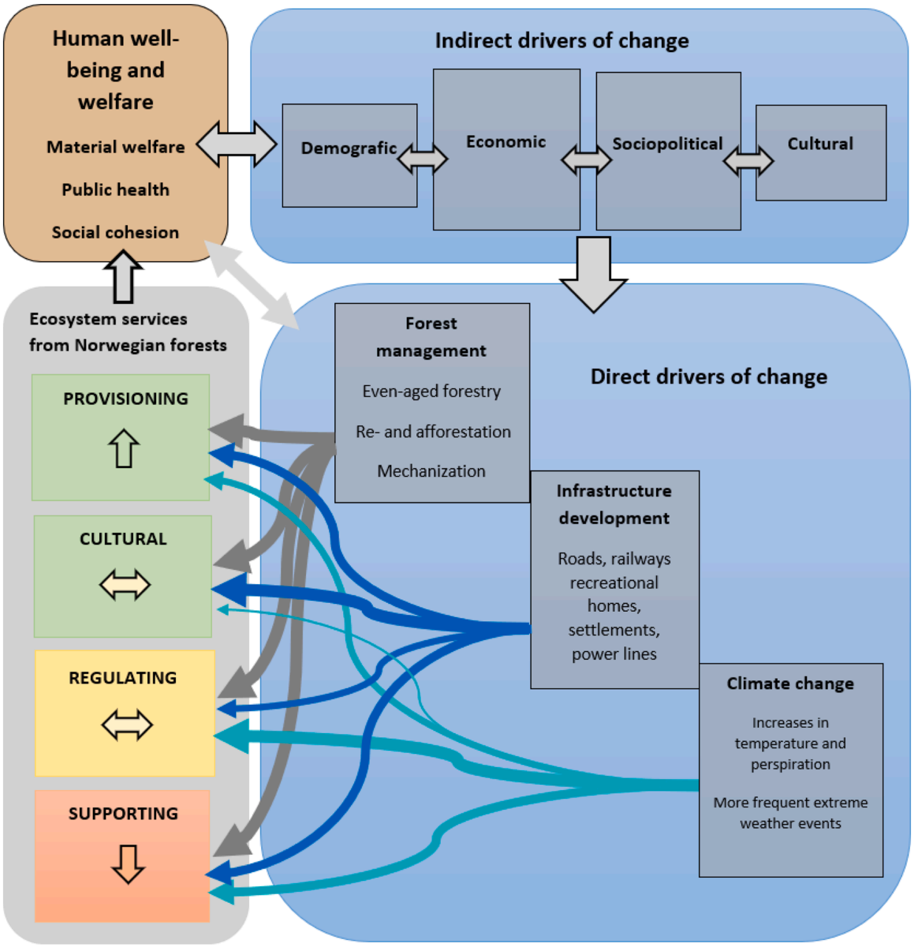

Fig. 4. Conceptual framework illustrating the impact of different drivers of change.
The framework (adapted from MEA (2005)) illustrates how indirect and direct drivers of change have affected trends and condition of ecosystems services from Norwegian forests, 1950–2020. The relative importance of indirect drivers is indicated by different size of the boxes. The arrows going from indirect drivers to the different ecosystem service categories have different color to distinguish them. Different thickness of the arrows going from the direct drivers indicates the degree to which they have affected trends and condition of different categories of forests ecosystem services. In each of the ecosystem service main categories, trends across *capacity* and *flow* are indicated with ↑=increased; ↔=remained stable; ↓=decreased, while forests condition to provide the services is indicated by colors; green (good), yellow (acceptable), red (poor) (see more detailed descriptions in chapter 4.1., in Table 2, and in Appendix 2). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Forest management has had strong effects on trends within all main categories of ecosystem services. Infrastructure developments have particularly affected provisioning, cultural, and supporting services, while climate change has had strongest effects on regulating, supporting, and provisioning services.

5. Discussion

Over the study period (1950–2020), forests in Norway have been directly shaped by policies aimed at increasing the supply of provisioning services, mainly through reforestation, afforestation, and intensification of forest management (Tomter and Dalen, 2018). Despite growing attention to biodiversity in recent decades, Norwegian forest management has overall favored provisioning services at the expense of supporting services, and some regulating and cultural services (Lindhjem and Magnussen, 2012). Overall, trade-offs have gone in favor of *efficiency* in the provisioning of timber, at the expense of the *ecological condition* and *resilience* of forest ecosystems.

If growing calls for a stronger role of forests in the bioeconomy come into being (The Norwegian Government, 2016), forests are arguably set to recover, at least partially, its historically important role in the Norwegian economy. The so-called "green shift" towards renewable energy and materials (see e.g. MAF, 2019) is likely to increase the demand for provisioning services from forests, which in turn might increase the pressure on other ecosystem services. A key insight from the ecosystem service framework is that tradeoffs in benefit supply is unavoidable (Turkelboom et al., 2018). Likewise, recent studies show that all desired aims for forest management cannot be achieved simultaneously, illustrating the need to deal with trade-offs associated with different forest functions and services (Krøgli et al., 2020; Lindahl et al., 2017; Triviño et al., 2017).

As an example, forest *resilience* to climate change may be improved by diversifying forests with mixed species of un-even aged trees (VKM, 2021). Further, recent research brings attention to how alternative forest practices, such as continuous-cover forestry (Peura et al., 2018), increased rotation times within forestry (Nordén et al., 2018), and close-to-nature silviculture (Báliková and Šálka, 2022) may enhance a broader array of forest ecosystem services (Pohjanmies et al., 2017). However, such shifts in forest management practices are also likely to reduce *efficiency* related to timber harvest and would depend on deliberate forest policy aimed at the enhancement of regulating and supporting services.

Trends in ecosystem services from Norwegian forests from 1950 to 2020, serve to illustrate that policy measures to increase growth in biomass are not sufficient to safeguard multiple functions and services from forest ecosystem. Comprehensive, biophysical assessments of trends and drivers of change can contribute to identify and explain ecosystem service changes at a national scale, over long periods of time. This can provide an important knowledge basis for policy choices. However, the lack of detail and accuracy of indicators at a national scale, makes this approach less suited as policy tool for prioritizing between specific services at local and regional scale.

Overall, a broader set of indicators are needed to capture and describe changes in forest ecosystem functions and their benefits to humans (Brockerhoff et al., 2017; Pohjanmies et al., 2017). While comprehensive monitoring systems have been put in place to provide relevant data for timber production, it is difficult to find accurate data for regulating and cultural services, at a national scale. Thus, there is a need for improved knowledge and systematic monitoring of indicators covering regulating and supporting services. Further, the qualitative shift in forest contribution to *sense of place* (from livelihood to recreation), calls for improved understanding of how human-nature relationships may contribute to well-being, and to satisfying human needs (Kaltenborn et al., 2020).

6. Conclusion

Through our assessment of the most important ecosystem services from Norwegian forests, we identified eight main types and ten related subtypes, including two provisioning services, two cultural services, three regulating services and one supporting service.

Over the last 70 years, Norwegian forests have been growing in biomass and extent, but this has occurred in parallel with loss of wilderness-like areas, deforestation of forest areas close to settlements, and an increasing share of clear-felled forests. These trends are consistent with international reports signaling fragmentation and changes in functions in boreal and temperate forests (Díaz et al., 2019; Gauthier et al., 2015).

Further, and in line with results from IPBES's global ecosystem assessment (IPBES, 2019), our results indicate that pressure from economic, sociopolitical, demographic and cultural drivers have accelerated over the past 50 years. Economic and sociopolitical drivers have been particularly prominent at shaping forests and forest ecosystem services, both in establishing even-aged forestry as a dominant management practice, and by facilitating infrastructure development in forest areas (e.g., roads and recreational homes).

These changes entail both increases and declines in different forest ecosystem services, and there are uneven trends across ecosystem service categories. Infrastructure expansions have increased pressure on forests, while also enhanced opportunities for outdoor recreation through increased access and enabling infrastructure. However, in line with the MEA (2005), we find that forests' capacity to provide some important *regulating* and *supporting* services are in decline.

We argue that broad and interdisciplinary assessments of trends in forest ecosystem services at a national scale that integrate ecological, economic, and social information can provide valuable insights for governments to inform their forest policies, e.g., by helping policy makers to identify priority areas. Our assessment provides one such approach to identify and explain trends of ecosystem services, over a long period of time. Our results suggest the need to develop a broader set of indicators to guide national forest policy in Norway and beyond. However, forest policies are not made in isolation from other drivers in society. The strong influence of economic and sociopolitical drivers in shaping trends of forest ecosystem services indicates support for the call for *transformative societal changes* to protect and sustainably use nature (IPBES, 2019).

Declaration of Competing Interest

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

Data availability

Data sources included scientific papers and reports, policy documents, books, and data from official national statistics. All data sources are listed as references in the article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2022.101491.

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