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Mapping and assessment of Ecosystem Services in Norway

Examples as support for implementation of ecosystem accounting

Erik Stange
Graciela M. Rusch

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Abstract

Stange, E. and Rusch, G.M. 2021. Mapping and Assessment of Ecosystem Services in Norway: Examples as support for implementation of ecosystem accounting. NINA Report 2012. Norwegian Institute for Nature Research.

This report presents examples of the ecosystem services (ES) work that NINA has either lead or contributed to since the publication of the Millennium Ecosystem Assessment (MEA 2005), involving several different aspects of both ES mapping and assessment. The examples presented illustrate conceptual and methodological advances made since the MEA was published. They also identify important knowledge gaps and challenges associated with using the ES framework as a means to mainstream biodiversity and nature values in a broad set of decision-making situations concerning how nature is used, enjoyed and/or impacted by human action.

We present examples of ES assessments and/or mapping in six major ecosystems in Norway: wetlands and waterways; forests; urban and peri-urban areas; mountains; cropland; and coastal/marine. A key message drawn from the experience built in Norwegian research environments, which we try to capture with the examples in this report, is that there is a large range of possible approaches to conduct ecosystem services assessments and mapping. Deciding which approach to use will depend on the data available, and the capacity and expertise of those involved in the assessment. Given that the ES framework is both multi- and cross-disciplinary, good communication and harmonization of concepts and products are necessary for the assessment to achieve reliability and legitimacy among the decision-making processes that the assessment aims to inform. The capacity of nature to generate ES varies spatially. In many instances, ES cannot be adequately assessed without a geographical reference. Examples from the urban and peri-urban ES, for example, demonstrate how natural areas' proximity to populated areas largely determines residents' opportunities for participating in nature-based recreation. Models of pollination services in cropland must similarly account for locations of crops and pollinator habitat, as well as pollinator flight distances, to assess the level of pollination service in crops.

The level of spatial resolution, size of the geographic extent, and the accuracy and reliability and accuracy of ES data used will combined determine the situation ES assessment and mapping can inform and how it can be applied. Similarly, the purpose of ES assessment must be in line with the of data, methods and capacities available. The degree of specificity and data accuracy/reliability requirements for ES applications can range from comparatively simple and illustrative awareness raising about the value of nature to monetary valuation of ES as an incentive for farmers to adopt practices that provide specific ES. The examples we present attempt to capture this range of assessments and mapping purposes and approaches. For example, a review of carbon stocks of Norwegian ecosystems serves the purpose of raising awareness of climate change mitigation generated by ecosystems. Quantitative cost-benefit and trade-off analysis among forest ecosystem services and biodiversity provides an example of ES assessment with higher spatial resolution and data accuracy.

We conclude the report with some considerations about the role of ES science and practice within the newly-adopted framework for ecosystem accounts. The United Nations System for Economic Environmental Accounts – Ecosystem Accounts (SEEA-EA), adopted by the UN Statistics Commission in March 2021, is based on the ES framework using spatial explicit modelling approaches. The European Commission has heavily supported this work, starting with the integration of the Mapping and Assessment of Ecosystem Services (MAES) initiative as one of the pillars of the EU Biodiversity Strategy for 2011-2020. ES science will need to support this process by bridging methodological gaps and helping remove barriers to the implementation of the SEEA-EA framework.

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Sammendrag

E. Stange og G. M. Rusch. Mapping and Assessment of Ecosystem Services in Norway: Examples as support for implementation of ecosystem accounting. 2021. NINA Rapport 2012. Norsk institutt for naturforskning.

Denne rapporten presenterer en gjennomgang av studier fra økosystemtjenesteforskning, utredninger og kartlegging som har blitt utført i Norge siden «*Millennium Assessment*» rapporten ble publisert i 2005. Vi bruker disse eksempler for å illustrere konseptuelle og metodologiske forutsetninger, kunnskapshull og utfordringer i økosystemtjenester rammeverket for å integrere biologisk mangfold og naturverdier i et bredt sett med beslutningssituasjoner der naturen brukes, nytes og / eller påvirkes på forskjellige måter av menneskelig handling.

Vi presenterer eksempler fra økosystemtjenestevurderinger og/eller kartlegging i seks hoved økosystemer i Norge, dvs. våtmark og vannveier, skog, urbane og nærbyområder, fjell, dyrket mark, og hav og kyst. Et viktig budskap hentet fra erfaringen fra norske forskningsmiljøer og eksemplene er at det er et stort utvalg av tilnærminger som lemper seg for å gjennomføre økosystemtjenestevurderinger og kartlegging, avhengig av tilgjengelige data, og kapasiteten og kompetansen til de involverte i evaluering. Gitt at rammene for økosystemtjenester er fler- og tverrfaglig, er god kommunikasjon og harmonisering av konsepter og produkter nødvendig for at vurderingen skal kunne bidra på en pålitelig og legitim måte i de beslutningsprosesser som utredningen er tenkt for. Et annet hensyn er at naturens kapasitet til å frembringe økosystemtjenester varierer i rom, slik at økosystemtjenester i mange tilfeller ikke kan defineres eller vurderes uten geografisk representasjon. Eksemplene av økosystemtjenester i urbane og nærbyområde viser at omfanget av bruk av naturbaserte rekreasjonsmuligheter bestemmes i stor grad av tilgjengelighet og nærhet til tettbefolket områder. På samme måte tar pollineringstjenester modellene hensikt til plassering av habitat for boplasser og pollinatorenes flyveavstand for å vurdere nivået på pollineringstjenesten i avlinger.

Nivået på romlig oppløsning, geografisk utstrekning og mengden empiriske data som brukes, bestemmer også hva slags situasjoner økosystemtjenester utredninger kan informere. Formålet med økosystemtjenester-utredningen må på en lignende måte være i tråd med den typen data, metoder og kapasiteter som er tilgjengelige. Forskjellige formål for bruk av økosystemtjenester utredninger kan for eksempel variere fra en generell bevisstgjøring om naturens verdi til monetærverdsetting av økosystemtjenester, noe som kan fungere som et insentiv for bønder til å ta i bruk og forvalte økosystemtjenester i sin produksjon. Eksemplene i denne rapporten viser en rekke vurderinger og kartleggingsformål og tilnærminger. En sammenstilling av karbonlagring i norske økosystemer, hadde målsetning om å øke bevisstheten om deres betydning for klima avbøtende tiltak, og en kvantitativ kostnadsnytte- og avveiningsanalyse mellom økosystemtjenester og biologisk mangfold i skog.

Vi avslutter rapporten med noen betraktninger om rollen som økosystemtjenester vitenskap og praksis har i det nylig adopterte rammeverket for naturregnskap. FNs system for økonomisk miljøregnskap - økosystemregnskap (SEEA EA), vedtatt av FNs Statistiske kommisjonen i mars 2021, er basert på rammeverket for økosystemtjenester ved bruk av romlig eksplisitte modelleringsmetoder. EU-kommisjonen har støttet dette arbeidet sterkt, og startet med integreringen av kartleggingen og verdsetting av økosystemtjenester (MAES) -initiativet som har vært en av søylene i EUs Strategi for biologisk mangfold 2011-2020. Dermed, vil noe områder innen økosystemtjeneste forskning trenge støtte for denne prosessen gjennom å dekke kunnskapsmangel over metoder for utredninger og kartlegging, og for å bidra med kunnskap for å fjerne barrierer for implementering av SEEA – EA rammeverk.

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Contents

Foreword

This report is a contribution to the project 'Services provided by main types of ecosystems in Poland - an applied approach'. Funding for the project comes from Liechtenstein and Norway within the EEA Financial Mechanism 2014-2021, in addition to cofounding from Poland.

The project aims to share European scientific knowledge about ecosystem services, and thereby assist with the process of mapping and assessment of ecosystem services in Poland. The project also seeks to increase the scientific potential and the ability of administration and other interested societal groups for implementing an ecosystem accounting-based approach to land use planning and other aspects of environmental management.

This report represents an effort to share insights gained through the work NINA has done in the years since the publication of the Millennium Ecosystem Assessment with our colleagues in Poland and elsewhere.

June 10, 2021
Erik Stange

1 Introduction

The publication of the Millennium Ecosystem Assessment (MEA 2005) inspired tremendous growth in the mapping and assessment of ecosystem services (ES) across the globe. This work in Norway has its roots in the Millennium Assessment itself, which included a Norwegian pilot case for freshwater systems (Nybø & Sandlund 2005). Since then, a series of projects and national initiatives have contributed to capacity building and products to assist advancement in operationalizing the ES framework, with the aim to better integrate biodiversity considerations into economic and political decision making.

In October 2011, the Norwegian government appointed an expert commission to assess and study the value of ES, chaired by Stein Lier Hansen. The commission was asked—among other things—to describe the societal consequences of degradation of ES, to identify how relevant knowledge can best be communicated to decision-makers, and to make recommendations about how greater consideration can be given to ES in private and public decision-making. On August 29, 2013, the Commission submitted its recommendations to the Minister of the Environment in the form of a Norwegian Official Report: "NOU 2013: 10 Natural benefits – on the values of ecosystem services" *("Naturens goder – om verdier av økosystemtjenester"*; Lier-Hansen et al. 2013). In September 2013, the report was distributed for a broad public consultation among affected stakeholders—including the public authorities, business and industry, academic communities and NGOs.

The NOU report (Lier-Hansen et al. 2013) articulates how ecosystems provide the basis for the production of food, medicines and many materials; that ecosystems contribute with critical functions including cleaning the air and water, storing carbon, protecting against floods, landslides, storms and erosion; and that ecosystems provide society with opportunities for both spiritual and physical experiences. The NOU further stressed that the rapid growth in the world's population and the technologies that have been developed enable society to exploit and impact ecosystems in a way not previously possible, and that the current level of exploitation of nature is unsustainable. It stresses that ecosystems can only continue to deliver these vital services for the foreseeable future if ecosystems are utilized and managed in a sustainable manner. Lier-Hansen et al. (2013) refer to a main finding of the MEA (2005): i.e., that 15 of 24 important ES categories were in decline. The recent IPBES Global Assessment report (2019a), reaffirms this unfortunate trend. Of the 18 ES included in the IPBES assessment (referred to by the IPBES as "nature's contributions to people"), only provisioning ES have increased in the past 50 years. The majority of regulating and non-material contributions (or cultural ES) have declined. The NOU report concludes that national accounts and other overriding reporting systems must be developed to demonstrate ES values.

As a follow up of the NOU report, Statistics Norway (SSB) and several other Norwegian research entities have been involved over the past decade in the development of the United Nations' System of Environmental Economic Accounts and Ecosystem Accounts (SEEA-EA). The SEEA-EA methodological framework was recently adopted as the international standard for reporting on and monitoring the state of ecosystems and their economic contributions to society (UN 2021). Ecosystem Accounts (EA) methodology is grounded in the concepts and methods developed within ES science. Norwegian researchers have actively participated in the SEEA - EA process by both contributing to the development of the framework, methodologies and indicators, as well as by piloting its operationalization—primarily in urban systems. Norwegian partners have also worked on developing indicators of components of the accounts, particularly those related with ecosystem condition (Aslaksen et al. 2015, Jakobsson & Pedersen 2020, Töpper & Jakobsson 2021).

Norwegian research organizations have participated in a series of projects—with international (i.e., EU) and national funding—that have addressed conceptual, methodological and operationalization questions of the ES framework. Examples of this work include POLICYMIX, OpenNESS, and ESMERALDA (all EU 7FP), SIS-Urban and SIS-Pollination (Research Council of

Norway – NINA strategic funding); ENABLE and IMAGINE (BiodivERsA); KIP, INCA and MAIA (all EU H2020), as well as several more included in this report's reference list. These projects have enabled the development of ES science in Norway including conceptualization (e.g., Barton et al. 2018, Jacobs et al. 2018, Jax et al. 2018, Potschin-Young et al. 2017); mapping methods (e.g., Soy Massoni et al. 2018, Stange et al. 2017) and valuation methods (e.g., Barton et al. 2018, Barton & Lindhjem 2013, Cimburova & Barton 2021, Harrison et al. 2018, Magnussen et al. 2018). Norway-based scientists also contribute actively to the IPBES process, such as the European and Central Asia regional reports (IPBES 2018), the Global Assessment Report (IPBES 2019a), and the report of the values and valuation of nature (ongoing).

The governance and/or decision-making context, and the purpose of the ES assessment, determines both the scale and resolution of the analysis and amount and level of detail of the data on which the analysis builds (**Figure 1**, Barton et al. 2018). Although **Figure 1** refers specifically to economic valuation of ES in a urban spatial context, the framework it depicts is applicable for all the aspects of mapping and assessment of ES—including non-economic valuation. **Figure 1** depicts the range of decision contexts (or governance purposes) of ES valuation along the horizontal axis running from left to right, but the conceptual model **Figure 1** illustrates is applicable also more generally to any ES mapping efforts. These decision contexts include (i) awareness-raising, (ii) natural accounting, (iii) priority-setting (e.g., of conservation measures), (iv) policy instrument design, and (v) litigation situations. Schröter et al. (2014b) proposed a similar ordering of study purposes in the context of ecosystem accounting at regional and national scales.

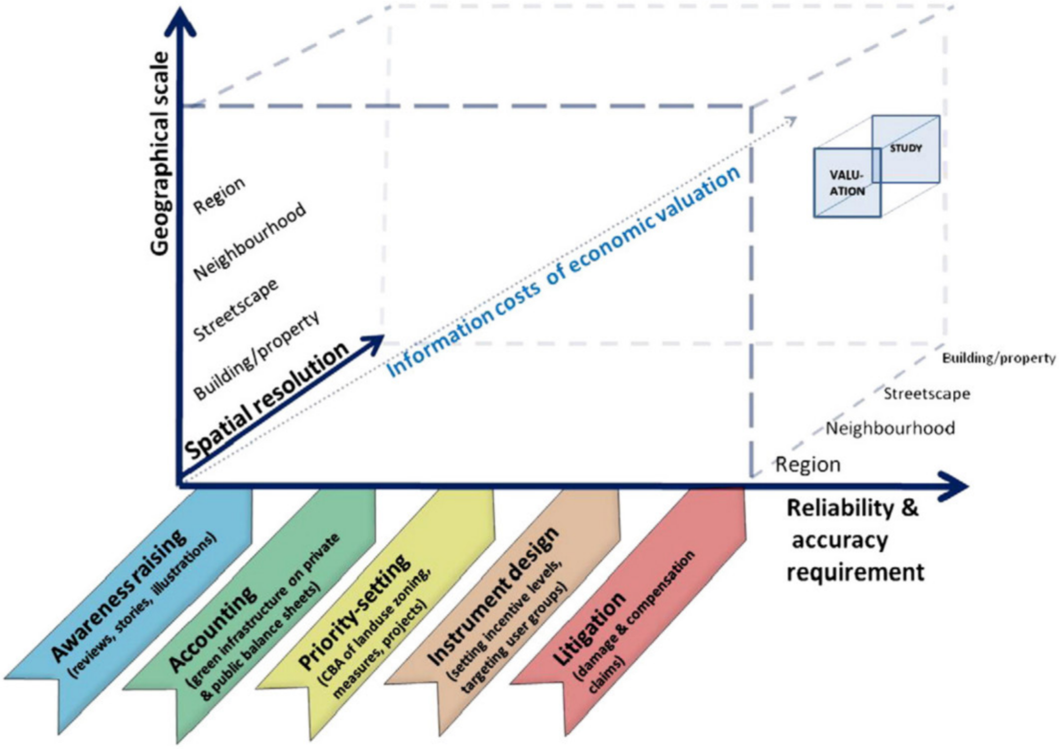

Figure 1*: A framework for decision contexts for economic valuation of ecosystem services. Source: Barton et al. (2018).*

The axis along which the decision context of ES assessments and mapping can be organized represents a gradient of increasing decision-maker expectations for accuracy and reliability (Barton et al. 2018, Schröter et al. 2014b). Accuracy and reliability of different ES appraisal methods are key concerns for practitioners (Dick et al. 2018, Dunford et al. 2018, Harrison et al. 2018), and a major challenge with ES mapping and analysis is the time and resources needed to obtain and analyze data, and to communicate results—also referred to as the *information costs*. Both decision-makers and ES appraisers need to have a common terminology for ES appraisal uncertainty and decision-purposes to avoid experiencing a gap in expectations (Barton et al. 2018). A thorough overview of the data used in the ES assessment will also help identify the decision context that a proposed ES assessment might meaningfully inform.

In this report, we present several examples of work involving ES mapping and assessment, conducted in Norway for key ecosystems. We use these examples to illustrate the context in which the ES framework has been used. In the descriptions of these examples, we include the purpose and/or the decision-making context, the methodological approaches, the geographic scale and resolution of ES mapping, and the methodology used. We highlight primary findings, and briefly identify challenges the work encountered and issues concerning uncertainty of either mapping or valuation.

We have elected to organize the examples by ecosystem type. We have also attempted to include a representative selection of work with respect to the ES category they address (provisioning, regulating or cultural), the spatial scale and level of resolution of analysis, the types of data involved, and the methodologies used for both data collection and analyses for mapping and/or assessment of one or more components from the ES framework. These ES framework components include ecosystems' biophysical elements and their characteristic structures and functions (Nature), the ES that these elements generate (i.e., the characteristics that are important to people), the benefits the ES provide humans, and the level of importance attributed to these benefits (i.e., the monetary and non-monetary values attached to these services).

The volume of work that NINA and other Norwegian research organizations have done on topics either directly or indirectly related to ES (before and after publication of the MEA) is considerable. This work also represents sizable diversity in both the systems studied and the methodology used. We endeavored to select examples that can represent this diversity in our report, based on the criteria specified above. Nonetheless, there are many examples of relevant work that we were simply unable to include in this report. In some cases, this was because the ties connecting the work to the ES framework were largely implicit (i.e., the investigators did not use standard ES terminology or address more than a single component in the ES framework). This made the relevance of such work to ecosystem accounting less obvious. We also made the choice to include some examples where the same ES was studied in two different ecosystem types (e.g., carbon storage in both forests and mountains, and pollination in both croplands and urban ecosystems). We did this to illustrate how a similar approach can be used in different ecosystem contexts.

2 Wetlands and waterways

2.1 SusWater Project

Primary purpose of work: Sustainable governance of river basins with Hydropower production (SusWater) is a research project that focuses on water management in regulated rivers. Its work involves exploring various avenues towards a more unified water management that is accepted both locally and nationally, while still meeting international obligations.

Involved parties: SusWater was led by SINTEF, an independent multi-disciplinary research institute. Work package leaders included researchers from NINA, the Norwegian University of Science and Technology (NTNU), and the Norwegian Institute of Water Research (NIVA). The project is a part of the Centre for Environmental Design and Renewable Energy (CEDREN), a joint operation funded by The Research Council of Norway, the private energy industry, and the aforementioned research institutes and universities.

SusWater funding came from the Norwegian Research Council's EnergiX program, in addition to Sira-Kvina power company, entities from the public and private energy industry (Statkraft, Hydro, Agder Energi, Lyse, BKK, TrønderEnergi, Energi Norge, Sogn og Fjordane Energi), Energy Norway (a non-profit industry organization representing about 300 companies involved in the production, distribution and trading of electricity in Norway) and the Norwegian Environmental Agency.

Methodology: The most relevant work from this project comes from Work Package 3 (WP3): "Socio-economic indicators for sustainable river basin management." This WP explores qualitative, quantitative and economic techniques to assess benefits on local, regional and national scale. Case study areas included Eksingedals and Teigdals watershed areas in Hordaland county of western Norway, and the SiraKvina watershed areas in Vest Agder county in southwestern norway, where BKK and Sira-Kvina KS respectively are hydropower producers.

Nesheim and Barkved (2019) present results from a study exploring how an ES framework can guide the assessment of benefits provided by human-modified landscapes (e.g., where hydropower production modifies watersheds). The paper presents beneficiaries' perspectives on the benefits provided by modified watersheds and perspectives on how those benefits are assessed (i.e., economic, quantitative or qualitative methods). The watersheds were selected for fieldwork as these are regulated for hydropower production, and since both are subject for coming revision of their license conditions. Data collection in the study included face-to-face interviews, a phone-based survey, focus group discussions, workshops, and two internet based surveys.

The investigators distinguished between ES provided from the broader watershed[1] and those received from regulating the watercourse[2] (i.e., a water use function).

Spatial and temporal scale and extent: Primary data were collected through one-on-one, semi-structured interviews, in workshops, and as part of focus group discussions. Additionally, the study used sources from a wider spatial range, i.e., beyond the case areas, referring to desktop data from different EIAs and existing benefit assessments of freshwater and other natural environments. The article does not specify the exact extent, but it is presumed to be at the regional (sub-national) scale. An online survey among key groups of actors was undertaken to obtain data on the important characteristics of the indicators and methods relevant for assessing benefits in regulated watercourses.

[1] Watershed is defined as the terrestrial surface area where precipitation or runoff drains into a watercourse.
[2] Watercourse is defined as the bed along which water flows (e.g., a brook, stream or river); can also be called a waterway.

The study started in 2015 with data collection continuing through 2018.

Key findings: Study participants identified four broad categories of beneficiaries with value perspectives of the benefits provided by waterways in human-modified landscapes: (i) economic beneficiaries from river regulation (water use function, not ES); (ii) economic beneficiaries from ES; (iii) socio-cultural beneficiaries from ES; (iv) the intrinsic value of nature, irrespective of human presence. Several activities, such as fishing and kayaking, generated benefits to both economic and socio-cultural beneficiaries. Participants identified the geographic relevance of the main benefits derived from waterways in modified landscapes. Only a small subset of these benefits (power supply security and flexible regulation, climate change regulation and compliance with binding international environmental regulations) were deemed not relevant at a local level. Main benefits for economic beneficiaries and socio-cultural beneficiaries of ES were viewed as predominantly relevant at a local level, with some having regional and national level relevance as well.

The groups of beneficiaries appreciated different types of assessment methods, although all agreed that methods need to be chosen based on the situation of the watershed and that no single approach is equally relevant and appropriate in all situations. Participants reported that assessments had a tendency to address biophysical situations, with little to no reference made to the beneficiaries and how they might perceive benefits. Nesheim and Barkved (2019) contend that the ES framework, as it is often applied at a regional or continental perspective, does not provide adequate support for decision makers.

Challenges and uncertainty: Nesheim and Barkved (2019) collected information on the perspectives of stakeholders. Uncertainty is therefore associated with the degree to which the participants in the study were representative of the broader population of individuals whose lives (economic and social/ cultural wellbeing) are affected by management decisions.

2.2 VALUESHED Report

Primary purpose of work: The VALUESHED report (Barton et al. 2012) is a synthesis report on economic valuation of ES from watersheds in the Nordic countries, as a complement to references compiled by the Millennium Ecosystem Assessment (MEA 2005) and “The Economics of Ecosystems and Biodiversity” (TEEB; Kumar 2010). The report provides estimates of ES economic values in selected watersheds in at least two Nordic countries as decision-support for specific policy scenarios and for general demonstration of the importance of such services.

Involved parties: The Nordic Council of Ministers commissioned the Norwegian Institute for Nature Research (NINA), the Norwegian Institute of Water Research (NIVA) and Sweco Norge (a private consulting firm) to prepare the report. Participants in the Nordic valuation experts’ workshop (21 September, 2011) in Oslo contributed to the report’s discussion section and provided case study examples featured in the text.

Methodology: The report starts with a review of valuation studies in the Nordic countries. This consists of both a presentation of some of the key international valuation studies and an overview of the watershed valuation literature in the Nordic countries. The latter is intended “*to give a sense of what types of services have been valued, which methods have been used and where the main gaps and challenges are*.” (p. 33) It is not a systematic review, but rather a “quick review” of studies valuing ES of wetlands and water quality-related benefits from the five Nordic countries (Norway, Sweden, Denmark, Finland and Iceland).

Barton et al. (2012) provide detailed examples of valuation studies from two Nordic watersheds: the Glomma-Lågen watershed in central and eastern Norway and the Odense river basin in central Denmark. The Glomma-Lågen example addresses valuation of reduction of flood peaks and the Odense example addresses valuation of improved water quality. Both examples are also reviews of previously published work that addresses either the biophysical conditions, indicators of the potential supply and demand for the an ES, the benefits that ES provides and attempts to capture the benefits in economic valuation.

Spatial and temporal scale and extent: The Glomma-Lågen river basin is the largest in Norway, with a surface area of 41 541 km^2. The baseline for this example is set by available data, which extend back to the year 1900. Spatial resolution (addressed in terms of flooding effects that result from changes in land cover) extends to sub-catchments as small as 3-7 km^2. Valuation estimates for flood prevention measures are expressed per hectare for comparison across systems. However, this does not necessarily mean that the measurements of waterway biophysical attributes or value were made at this resolution. Flood risk was assessed in terms of the frequency of flooding of a given severity might occur (up to once every 500 years).

The Odense river's catchment area is 1046 km^2. Estimates of value were expressed as willingness to pay (WTP) per household per year. Valuation was assessed at different spatial scales reflecting improvements in water quality for sections of the Odense river (15 km) and the whole Odense river length (60 km).

Key findings: Barton et al. (2012) conclude from their literature review that the watershed ES valued are quite similarly across the Nordic countries. The services addressed are mainly provisioning services such as food and fresh water supply, as well as cultural services such as aesthetic value and opportunities for recreation and tourism. Valuation studies of regulating ES were underrepresented in the literature.

Studies from the Glomma-Lågen river basin demonstrate that establishing the link between flood risk and the condition of ecosystems in the watershed is a complex biophysical modelling task. Difficulty in valuation of flood reduction services provided by upstream ecosystems increases with increasing watershed size, storm event size, and the watershed's extent of regulation by man-made infrastructure (reservoirs, transfers, channeling). The value of flood damage reduction depends on a combination of preventive, avoidance and mitigation actions throughout the catchment, and in particular in the downstream areas at risk of flooding.

Barton et al. (2012) found a fairly large number of survey-based stated preference studies of water quality, in particular related to eutrophication, from the Nordic countries. These contingent valuation and choice experiment studies focused either on improving bundles of goods and services through hypothetical management measures of "whole watersheds", or focused on valuing incremental changes in suitability for specific water uses, using different variations of a water quality ladder. Barton et al. (2012) determined that valuation studies looking at definitions of "good ecological status," as defined under the EU Water Framework Directive, are not necessarily useful for either finding per hectare values for ecosystems or attempting benefit transfers to other watersheds where such studies have not been conducted. They further conclude that more run-off and pollution modelling is required to assign water quality service values to land uses. Aggregation of values of water quality improvements and defining "the extent of a market" is possible with valuation studies that evaluate "distance decay" of willingness to pay depending on how far respondents live from water bodies. Research findings are mixed on the strength of "distance decay" for use values of water bodies. Non-use or existence values related to improvements in watershed services, which may also be substantial, will likely be more stable across spatial scales.

The report presents several recommendations for research on watershed ES and their economic valuation. The following have the greatest relevance for non-Nordic nations:

- Conduct primary valuation studies that are representative at a national and county/regional level for other cultural ES to help inform policy alternatives

- Demonstrate possibilities and limitations in scaling available water body and watershed specific valuation studies for purposes of ecosystem capital accounting
- Initiate valuation studies that evaluate the spatial patterns of ES values and their dependence on distance, direction, scale and resolution, and implications for improvements in national accounting, priority-setting and instrument design
- Support the development of visualizations and illustrations of ES and in countries' national languages to help promote public awareness, as an alternative to economic valuation
- Promote similar reviews to VALUESHED of specific other ecosystems (e.g. forests, coastal wetlands and open sea ecosystems), addressing interdependencies of valuation estimates between ecosystems (e.g. off-site ES of forests)

Challenges and uncertainty: The VALUESHED report identifies and discusses the many methodological challenges associated with economic valuation of watershed ES. It is beyond the scope of our report to address in detail or even summarize all of them here. However, we present several examples to provide an indication of the scope of the topic in the VALUESHED report. To begin with, the authors stress the importance of using accurate and precise descriptions of the ES being valued. Not doing so can lead to "*very lengthy discussions between economists and natural scientists about the policy relevance and boundaries of a valuation study"* (p. 22).

Challenges associated with valuation within the context of flood prevention include: (i) identifying the chain of watershed service providers and beneficiaries the length of the watershed, (ii) predicting effects of upstream measures on downstream water levels (ecosystem function), (iii) determining both ES/benefits and disservices/costs of upstream land-uses. In the context of water quality improvement of the Odense river, Barton et al. (2012) identified how variation in local ecosystem use can be a challenge for estimating average WTP along larger sections or the whole of a river's total length.

The literature review revealed that many of the published valuation studies done at the time of the report were concentrated on identifying and demonstrating ES values, and the authors found little evidence that the valuation had affected policy. This may be due to the challenges of obtaining the level of information that is necessary to be applied to policy design and implementation. Barton et al. (2012) discuss the trade-off that occurs between spatial extent and resolution in both ecosystem function and economic valuation. To value differences in flood risk of different types of land and infrastructure, we need spatial information at the municipal or lower resolution. However, the scale at which regulating ecosystem functions are provided is at the larger watershed scale. The information costs of valuation increase with increasing scale, resolution and accuracy required for policy application (Fig. 1). Valuation of ES for awareness raising demands little accuracy compared with using ES valuation for either accounting (i.e., assessing whether ES provision is increasing or decreasing), priority setting, or policy instrument design.

2.3 Valuation of wetland ES

Primary purpose of work: "*Verdien av økosystemtjenester i våtmark*" (The value of ecosystem services in wetlands; Magnussen et al. 2018) is a literature survey of the most important ES provided by Norwegian wetlands, gauging their current and possible future value to society.

Involved parties: The Norwegian Environment Agency commissioned a report to assess all ES generated by wetlands with respect to IPBES framework. The expert group that conducted the work was headed by Kristin Magnussen (leader of the Menon Center for Environmental and Resource Economics). The group also consisted of two NINA researchers and two researchers from Norwegian universities.

Methodology: Magnussen et al. (2018) is not a systematic review, and the report does not provide insight into the methodology used to gather the references it used. The mandate for the project produced a list of topics to be included in the report (220 pages, including appendixes). These topics included:

i. Discussion of the assignment and selected approach
ii. Status and trends of Norwegian wetlands
iii. Value estimates of ES provided by wetlands
iv. Future provision of ES from wetlands
v. Possible measures for improved management and conservation of wetlands
vi. Lessons learned, and applicability to other ecosystem types

Magnussen et al. (2018) present information on the status and trends of Norwegian wetlands that the authors gathered from the scientific literature. In chapter 3, the report presents "an extensive overview of the many ways society makes use of wetlands." This includes a review of the various approaches to visualization, assessment and valuation (both monetary and non-monetary) for different categories of ES. They provide an aggregate overview of the most important ES provided by wetlands, which provides numerical and—in some cases—monetary estimates of ES values.

Chapter 3.3 presents an overview of the range of methods used for ES valuation, as an introduction to the methods used in the cited references. This text presents some theory behind, awareness raising, evaluation and valuation, the rationale behind both qualitative and quantitative valuations, with brief discussion of when it is appropriate to use the different approaches. The authors stress that total social value for ES consists of both use (direct, indirect and option) and non-use (existence, conservation and bequest) values. The methodology for monetary valuation presented in the report includes revealed preferences (travel cost method, hedonic pricing, avoidance costs, replacement costs) and state preferences (choice experiments and contingent valuation).

The report also includes a description of how traditional ecological knowledge (TEK) provided by the Sami communities in Finnmark county can be used to map ES connected to wetlands in wilderness areas (Chapter 3.4).

Spatial and temporal scale and extent: The literature survey was intended to include the entire country, and all categories of wetlands. Magnussen et al. (2018) used a typology for Norwegian wetlands that includes the following categories:

i. Mires (i.e., fens and bogs)
ii. Springs
iii. Wet meadows
iv. Carr (waterlogged woodland terrain) and floodplain forests, typically dominated by *Salix* and *Alnus* spp.
v. Reed marshlands
vi. Shallow submerged water plant beds
vii. Persistent snow beds
viii. Wet heath
ix. Active deltas.

Data describing status and trends includes a historical perspective that extended back to the end of the most recent ice age (ca. 10 000 years before present era). More detailed descriptions of estimated changes in the extent and type of wetlands are reported for the period between 200 years ago to the present. The report presents data on changes in ecosystem condition for wetlands from 1990 to 2017, which are principally provided by the Norwegian Nature Index (www.naturindeks.no), with references to other published reports.

Projections for ES delivery from wetlands in the future (Chapter 4) used two contrastingly extreme scenarios of societal change (IPCC's A2 and B1) at two time horizons (2030 and 2050). The A2 scenario involves little geopolitical co-operation in addressing climate change and little to no political emphasis on sustainability and the environment. The B1 scenario involves greater international cooperation and greater emphasis on sustainability and environmental protection.

Key findings: The report identifies the most important ES for wetlands in Table S1 (page 72), together with descriptions and estimates of the value they generate on a per annum basis. These ES include:

Provisioning services: Berries and mushrooms (estimated value between 10-50 million NOK); Reindeer grazing (15 million NOK); timber (200 NOK per decare[3] per year); peat harvest (170 million NOK per year)

Regulating services: Flood reduction (no monetary value provided); carbon storage (2 000 billion NOK); water purification (up to 4000 NOK per decare per year);

Cultural services: recreational opportunities, aesthetics, mental and physical health (20-40 million recreation days per year, with a corresponding monetary value between 1.5 to 3 billion NOK); non-utility values tied to conservation of biological diversity and place identity (4-25 billion NOK).

Chapter 3 also identifies which categories of wetlands contribute most to which ES, rating each category to ES link with a Likert-type scale ranging from 0 to 2. Examples of the wetland types that are important for specific ES include mires and floodplain forests (provision of freshwater and bioenergy); mires and wet meadows (berries and grazing for reindeer); floodplain forests (water flow regulation); reed marshlands, floodplain forests and shallow submerged plant beds and active river deltas (water filtration); mires and active deltas (climate regulation); active delta and floodplain forests (recreation) and mires, wet meadows, floodplain forests and active deltas (biological conservation).

Projections for future development, status and trends of wetland ES based on the A2 and B1 scenarios suggested that some types of wetland will decline (persistent snow fields, wet heath), whereas others will show a net stability in size and abundance (bogs and mires), and again other may even increase (floodplains). Despite considerable uncertainty associated with the scenarios used as the basis for projections, the authors contend that some conclusions were more certain:

1. Some types of wetlands will likely decrease in area, regardless of the climate and social scenario. Biological diversity tied to these types will be under greater pressure with consequences for cultural ES in particular.
2. Most wetland ES will be reduced under the A2 scenario, with the exception of peat harvest and timber extraction. Increased delivery of these two ES will have a negative effect on wetland capacity to capture and store carbon.
3. The potential for conservation and sustainable use of Norwegian wetlands will be considerably better under the B1 scenario, but this scenario entails radical (transformative) changes in society's resource use and behavior, and institutional changes.
4. The authors consider a business as usual scenario to be more like the A2 scenario than the B1 scenario. Unless new measures are implemented, the future will bring reduced delivery of ES from Norwegian wetlands.

Challenges and uncertainty: Magnussen et al. (2018) found a distinct shortage of empirical valuation studies from Norwegian wetlands in the primary scientific literature. They also found that

[3] 1 decare = 1000 m^2 = 0.1 hectare

available data and knowledge on Norwegian wetlands and their ES is highly limited. Georeferenced local data in particular are critical when non-commodified benefits and non-use values are to be included properly in regional planning and local project implementation decisions. Furthermore, wetlands occur in a larger landscape setting where water from the surrounding catchment collects locally to form one of many different typical Norwegian wetland types. Often, an ES is not tied either to a single wetland or even a collection of wetland features. Instead, the ES occurs and must be assessed within the context of the wetlands' larger surroundings.

The authors highlighted the considerable uncertainty connected to scenarios for projected climate and geopolitical/social change that made projecting changes in both the future extent of wetlands and delivery of ES from them difficult. They considered uncertainty connected to societal developments—resulting in changes in land use and land cover—to be greater than that of climate change.

<u>Connections to other work:</u> In their report, Magnussen et al. (2018) relate their synthesis of Norwegian wetland ES valuation estimates to international studies (Chapter 3.9.5). Here they primarily use the meta-analysis from *The Economics of Ecosystems and Biodiversity for Waters and Wetlands* (Russi et al. 2013). Rusch (2012) presents a review of the role of wetlands and other ecosystems in Norway for climate mitigation and adaptation.

2.4 Other related work in wetland and aquatic ecosystems

Peatlands are a broad type of wetlands that includes several of the categories identified by Magnussen et al. (2018): mires, wet meadows, carrs, and wet heath. The year-round waterlogged conditions in peatlands slow the process of plant decomposition to such an extent that dead plants accumulate to form peat. Over millennia this material builds up and becomes several meters thick and storing substantial amounts of carbon. Because damaged peatlands can quickly become a carbon source, peatland conservation and restoration is an important potential component in Norway's strategies for climate change mitigation. About 80 peatland sites have been restored in the past five years across Norway, primarily within protected areas. The Norwegian Environmental Agency (NEA) and its field supervision department (SNO) have been responsible for the implementation of peatland restoration actions. In 2016, NEA and the Norwegian Agricultural Agency developed a five-year national action plan for the restoration of wetlands, with a focus on peatlands. The action plan was updated in December 2020 and extended for another five years, until 2025. The plan considers three goals: (1) reduce GHG emissions, (2) mitigate the impacts of climate change, and (3) improve the ecological condition of mires at the national level. Most of the peatland restoration activities have been conducted in raised bogs, a habitat type that is red-listed in Norway (Norwegian Red list of habitats 2018).

2.5 Relevant issues for mapping and assessment of wetland ES

Wetlands cover roughly 10 % of Norway's total land area. However, wetland ecosystems have been poorly mapped—primarily because most land cover maps have been developed to serve forestry and agriculture purposes, which also match the LULUC reporting units under the United Nations Framework Convention on Climate Change (UN 1998). Newer, alternative mapping approaches have identified considerable divergence in the estimated area of peatland (Bartlett et al. 2020, Bryn et al. 2018).

ES related to carbon stocks (ecosystem condition), and carbon fluxes (emissions and removals) are the key ES elements in Norwegian peatland. These are, in turn, related to the level of drainage and/or modification of the hydrological dynamics through infrastructure construction (including wind parks for renewable energy), and peat extraction. Currently, there are no maps representing different conditions of peatland and other wetland types. Remote sensing indicators can be used to detect the level of drainage, but it can be difficult to detect cases of forested or agricultural land on former peatland areas.

We presently have limited data on ES flows, and there are few quantitative assessments of wetland carbon fluxes. Many of the extant data is based on measurements taken three decades ago in temperate systems: e.g., drained peatland estimates from Armentano and Menges (1986), as reported in de Wit et al. (2015). Yet data availability is growing rapidly with the establishment of eddy covariance towers and local flux measurements. Such data are necessary for assessing ES and generating ecosystem accounts. For example, they are being used in cost benefit analyses of renewable energy projects: assessing whether savings in carbon emissions from wind parks are enough to compensate for the carbon released from peatland that is disturbed during wind park construction (Bartlett et al. 2020). More accurate mapping of the spatial variation in wetland carbon fluxes is also needed to identify areas that will provide the greatest gains if protected or restored (Brown 2020).

Quantitative data on wetland water flow regulation and water cleaning functions in Norway is presently lacking. This limits the range of environmental policy processes wetland ES can inform (see **Figure 1**). Similarly, there is inadequate knowledge about the how these functions and benefits vary in space, which is critical to target ES-informed decisions and actions.

3 Forests

3.1 Carbon storage

Bartlett et al. (2020) estimated the carbon budgets for five key Norwegian mainland ecosystem groups (forest, alpine and cryosphere, agriculture/ grassland, wetland, and freshwater/coastal), specifically focusing on the potential for carbon storage and sequestration. The purpose of the work was to emphasize the vital ecosystem service that Norwegian landscapes and ecosystems provide in sequestering carbon, and to explore how climate change and management practices may aggravate or mitigate this function. The published report gives a summarized overview of the potential of carbon storage within key Norwegian ecosystems, with suggestions for measures that can preserve or encourage the sequestration and storage within them.

Involved parties: Bartlett et al. (2020) is a NINA report, commissioned by the World Wildlife Foundation (WWF) of Norway. WWF helped determine the topics the report should address, but the contents and the orientation of the work was determined by the NINA researchers credited with authorship of the report.

Methodology: The report combines statistics on land use and land cover (LULC) covering the entire land area of mainland Norway (excluding the territory of Svalbard). The authors collected estimates for the carbon budgets using data from studies published in the scientific literature. Parameters used to calculate on carbon stocks and flows (primary production, respiration, and storage) are from recent studies conducted either in Norway or other countries whose forests are ecologically similar.

The report also addressed benefits with regards to the contributions carbon uptake and storage make to global carbon cycles and global climate mitigation.

Spatial and temporal scale and extent: The analyses detailed in the report are conducted at a national scale for a single point in time. LULC data from both aforementioned sources is available as polygons, and reported to the nearest km^2. The report discusses the proposed changes to carbon stocks and flows as consequences of changing climate, LULC, and forestry management practices.

Key findings: Forests cover 121 000 km^2, or 37 % of Norway's total mainland area. This makes them the country's largest ecosystem type. Forests contain the largest stores of carbon in Norway, with estimates of total storage ranging between 1.6 and 2.8 million Gg[4] C, or an estimated 32 % of total stored carbon. Furthermore, the authors estimated that Norway's ecosystems contain 0.18 % of the world's total stored carbon, despite having only 0.07 % of the world's land mass.

Challenges and sources of uncertainty: Bartlett et al. (2020) identify several methodological challenges and sources of uncertainty in their calculations. These include knowledge gaps arising from:

- A lack of accurate maps detailing ecosystem types and capable of describing the variation in vegetation and species composition that occurs within the broad categories of ecosystems.
- Parameters for above- and below-ground carbon stocks are from studies that were conducted in other countries, and may not be fully representative of Norwegian ecosystems.
- Carbon flux and storage can either be highly variable or inadequately studied for different ecosystems types. For example, there are no studies capable of providing reliable

[4] Gg = 1 000 ton = 1 000 000 kg

estimates for either forest respiration or the export of either live or dead forest biomass. This substantially limits the authors' ability to calculate forests' net carbon uptake.
- There are major gaps in our understanding of the role that biodiversity might have in determining carbon flows (i.e., carbon uptake) and storage. Land cover in the available data is treated as "forest," without accounting for variation in the composition of either the canopy tree species or forest understory vegetation.

Connections to other work:
Boreal forest soils store an estimated 80% of the forest carbon. In emissions accounts and reporting to the UNFCCC (UN 1998), however, forest soil carbon content is associated with high uncertainty that is not related to variation induced by different forestry practices and management. There are ongoing projects and planned research activities in Norway addressing questions of forest soil carbon stocks and fluxes under different management systems, and their linkages with soil biodiversity.

3.2 Accounting for capacity and flow of ES

Primary purpose of work: Schröter et al. (2014a) sought to understand how the flow (i.e., the actual use) of ES relates to the capacity of ecosystems to generate the ES, as a means to assess the sustainability of ecosystem use. The focus of the study was to spatially quantify a suite of nine ES during one year, making use of both ecosystem (biophysical) and socio-economic data.

Involved parties: The paper's lead author was affiliated with NINA as a PhD candidate at Wageningen University in the Netherlands, collaborating with another NINA researcher and two researchers from the Environmental Systems Analysis Group at Wageningen University.

Methodology: The study focused on the forested lands in the former Telemark county (Telemark was merged into a larger administrative unit in 2020), located in southern Norway. The land area (15 300 km^2) was divided into land cover/ ecosystem functional units comprising 25 vegetation types. The study generated separate spatial models for both capacity and flow for the following ES: (i) moose hunting, (ii) sheep grazing, (iii) timber harvest, (iv) forest carbon sequestration, (v) carbon storage, (vi) avalanche (snow slide) prevention, (vii) recreational residential amenity (viii) recreational hiking, and (ix) pristine natural areas without infrastructure. The models used ecosystem and socio-economic data from several different sources. We summarize some additional details on the structure and rationale for each model:

Moose hunting capacity was expressed as individuals per, with km^2 that could be found on specific land cover types (wood and mires) as identified with a national land resource dataset (AR50, vector format with resolutions that range from 1:20 000 to 1:100 000). Moose population numbers for each municipality derived from a model published in Austrheim et al. (2011), using abundance data from a national registry. The flow model is based on registered number of harvested moose per km^2 for the same area.

Sheep grazing capacity was expressed as number of sheep per km^2 and modelled using vegetation maps based on satellite imagery, combined with corresponding assessments of grazing values for specific vegetation types. Flow was modelled as the total number of lambs and sheep released, minus the number of lost animals per km^2.

Timber harvest capacity was expressed as $m^3\ ha^{-1}\ yr^{-1}$ and modelled using a national land resource dataset (AR5, vector format at 1:5 000 resolution), which covered all of Telemark county below treeline. The dataset included site quality classes for forested lands ("*bonite*t"). This information was combined with statistics on annual biomass regrowth from the most recent national forest inventory (2005-2009). Flow (harvested timber in $m^3\ ha^{-1}\ yr^{-1}$) was modelled using national harvest statistics, where the lowest available resolution was the municipality level. Flow estimates also included wood harvested for firewood, using data from 2005 (the most recent data available). Flow was delineated with the help of a harvest cost model that accounted for the accessibility-related terrain-specific costs. This delineation effectively reduced the area of productive forests from the capacity model, eliminating areas where production did not exceed the rate that was necessary to meet extraction costs.

Forest carbon sequestration capacity was expressed as kg C m^{-2} yr^{-1} and modelled as net ecosystem production (NPP). NPP calculated as the difference between net primary productivity (derived from MODIS satellite imagery) and soil respiration (modelled with temperature and monthly precipitation). Soil respiration was included only when it was not higher than NPP (e.g., areas with bare rock). Carbon removed through harvest was deducted as the average value per municipality (kg C ha^{-1}).

Forest carbon storage capacity was expressed as kg C ha^{-1}, and modelled with a look up table (LUT) that combined the values for carbon stored for tree variety classes (i.e., broadleaf, conifer or mixed) and site quality classes. Flow was not considered because the benefits of carbon sequestration occur at a global scale.

Avalanche prevention capacity was based on forest cover and terrain model of avalanche susceptibility model developed by (Derron & Sletten 2016)[5] to cover all of Norway. Capacity was modelled as the areas covered by forest (using AR5 land cover dataset) and areas where slope of terrain was between 30° and 55°. Flow was modelled to include the areas where slopes continue into avalanche propagation areas from the susceptibility model that also contain at least one building (input gathered from the Norwegian registry of buildings).

Recreational residential amenity capacity was expressed as the suitability for land to provide a location for second homes (cabins). The authors' approach used MAXENT software and involved three models for coastal cabins, non-coastal cabins in the proximity of alpine resorts and non-coastal cabins not in the proximity of alpine resorts. See Schröter et al. (2014a) for the complete list of environmental data inputs for these three models.

Recreational hiking capacity was expressed as the density of hiking trails (km km^{-2}) within a search radius of 1 km for the whole county, and modelled with information from the most recent national road and trail dataset from the Norwegian Mapping Authority (2010). Flow was estimated using data on municipal population size and tourist overnight stays in camp sites, cabins, guesthouses and hotels. Models of flow were validated with visitor count data from guest book entries from 19 mountain tops in six municipalities in Telemark county.

The existence of areas without technical infrastructure capacity and flow models were identical and generated through identifying natural areas where the linear distance from existing heavy technical infrastructure is > 1 km. Heavy technical infrastructure is defined as roads and fortified routes with a length of at least 50 m, railways, powerlines and regulated water bodies.

To explore variation of ES capacity and flow values with respect to different land cover units, ES capacity and flow maps were overlaid with maps of vegetation type. Flow was subtracted from capacity for two exemplary ES (moose hunting and sheep grazing), and the feasibility of similar analyses for the remaining ES. The authors report balances of absolute ES quantities for timber harvest, moose hunting, sheep grazing and avalanche prevention.

Spatial and temporal scale and extent: Spatial units used for analyses in this study were 100 x 100 meter rasters, which the authors chose to reflect the appropriate level of spatial variability while still "being able to handle big data volumes." The temporal scale of the study was one year (2010). It did not consider variations of ES capacity or flow within a year or across years.

[5] Reference refers to a newer technical report describing the methodology

Key findings: The authors present their models for capacity and flow of the nine ES. The resolution of the different services differed depending on methods and spatial data sets used. Three groups of ES models could be distinguished. First, models primarily based on LC and satellite-derived spatial information (timber harvest capacity, carbon sequestration and storage, avalanche prevention, recreational residential amenity capacity) allow for relatively high spatial variability. Second, where such high-resolution data is missing, administrative boundaries determine the variation in ES values using a look up table approach (moose hunting, sheep grazing, timber harvest flow). Third, a group of models is primarily spatially determined by human infrastructure (pristine natural areas without infrastructure, recreational hiking, recreational residential amenity flow).

The two examples of ES capacity-flow balance are illustrated in **Figure 2**. Estimates of moose harvest rates are slightly above recruitment rates throughout the county, with the exception of one municipality. The same can be said for sheep grazing, suggesting that vegetation was sufficient for the number of sheep grazing in the year of the study and should even be able to provide enough fodder for additional sheep.

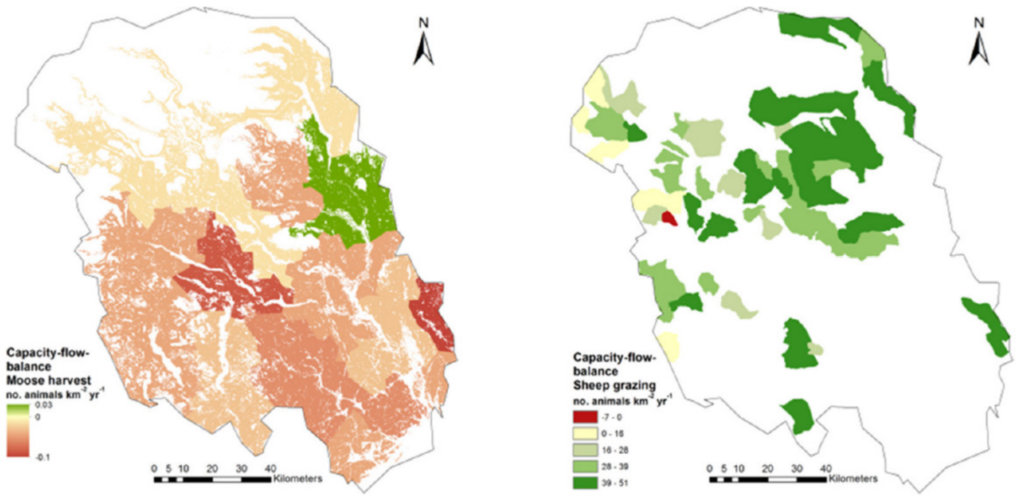

***Figure 2** Capacity-flow-balance for two examples of ES, moose hunting and sheep grazing.*
***From**: Schröter et al. (2014a)*

Challenges and uncertainty: Schröter et al. (2014a) devote considerable attention in their discussion to describing the challenges involved in modelling ES capacity and flow in Telemark. These challenges generally relate to the biological realism of the models they used (i.e., level of abstraction), the limits of the data available for model inputs, and the assumptions that underly model design. Examples of models' shortcomings include:

- In the model for moose hunting capacity, the authors acknowledge that their approach, unlike similar models of moose habitats at smaller spatial scales and using radio-telemetry tracking data, did not account for movement corridors (habitat connectivity), local hotspots or avoided habitats. An additional weakness in the model may arise from not accounting for animals' seasonal migration.
- Sheep grazing model does not account for other factors that affect sheep abundance in mountain areas, just as increased mortality from wild predators (e.g., lynx, wolverine).
- Carbon sequestration and storage models also represent an acknowledged simplification, as they do not consider variation in carbon flows within single classes of land cover types.

- Avalanche prevention model is a binary model (existence vs. absence) of this ES, and does not account for different qualities of forests in preventing slide severity.
- The recreational hiking model assumes that hiking takes place on trails, and not in the open terrain, and does not account for variation in landscape preferences that might make hiking in certain areas more attractive, independent of trail density.

Connections to other work: Models in this paper were used in analyses of trade-offs between conservation priorities and timber production for the Telemark county forest areas. (**Chapter 3.3**).

3.3 Using ES to evaluate priorities for conserving forest biodiversity

Primary purpose of work: Schröter et al. (2014b) present work from a study that analyses how incorporating ES as conservation features can affect conservation of forest biodiversity and how different opportunity cost constraints can change spatial priorities for conservation.

Involved parties: The study's lead author was a PhD candidate working on ES which partly consisted of a Norwegian case, based at Wageningen University, and collaborated with NINA researchers on the work.

Methodology: Schröter et al. (2014b) created spatially explicit cost-effective conservation scenarios for 59 forest biodiversity features and five ES in Telemark county with the help of *Marxan with Zones: a* heuristic optimization tool for systematic conservation planning, that compares 'benefits' (desirable conservation features) with 'costs', to select areas that together optimize benefits compared to costs. The benefits were modelled as 59 biodiversity features, and five important regulating and non-material ES delivered by forest areas, for which spatial models had already been developed (see **Chapter 3.2**): (i) wilderness-like areas, (ii) recreational hiking areas, (iii) carbon storage, (iv) carbon sequestration, and (v) avalanche protection. The monetary value of timber production—the key provisioning service in Norwegian forests—was used to calculate the opportunity cost of biodiversity conservation under two conservation instruments, where forestry is either completely (non-use zone) or partially restricted (partial-use zone). Biodiversity features are essentially weighed in *Marxan with Zones* models by setting conservation targets that reflect the proportion of the feature to be protected.

The study addressed three questions. First, how conservation outcomes in terms of the amount of biodiversity features potentially protected differ between two scenarios that either (1) took only biodiversity into account, or (2) incorporated the set of regulating ES as well as biodiversity. Second, the study assessed the trade-off between biodiversity/ regulating ES conservation goals on one side, and timber production on the other, at different levels of timber exploitation. Timber production was regarded as a private good, and the regulating ES was regarded as public goods. Third, they explored the differences in conservation burden between the municipalities within Telemark county.

Spatial and temporal scale and extent: This study also used Telemark county. The forest area was divided into 43 513 grid units measuring 500 x 500 m (25 ha). The study did not explore changes over time.

Key findings: The study is suitable for highlighting the economic consequences of including regulating services (in addition to biodiversity) as criteria to target conservation efforts. In addition, it illustrates the potential for improving the effectiveness of conservation actions through targeting areas with high biodiversity and regulating services—while maintaining similar levels of costs—using systematic, spatially-explicit conservation planning. By including regulating ES provision into optimized land planning, the sum of the areas where forestry was partially restricted increased by 36.2 % when compared to the scenario where only biodiversity was considered. This means that the protection of both biodiversity and regulating ES would require more land than if only biodiversity criteria were used to select areas for conservation. The analysis also shows that there is not full spatial overlap between sites with high biodiversity conservation value and the areas providing regulating ES.

The authors also described the trade-off created when forestry is restricted in order to achieve conservation targets. **Figure 3** shows the production possibility frontier (PPF), that indicates the optimal amount of benefits obtained at each level of opportunity costs (avoided timber extraction). The analyses show, first, that the level of biodiversity covered in current protected areas (under both partial and full protection) is comparatively low, given the opportunity costs of these areas. An optimal solution would have covered more protected biodiversity for each Norwegian crown (*krone*) invested in setting aside forest land. Secondly, the results show that at high levels of opportunity costs, there is a potential for significantly increasing the level of biodiversity conservation with comparatively lower increases in opportunity costs.

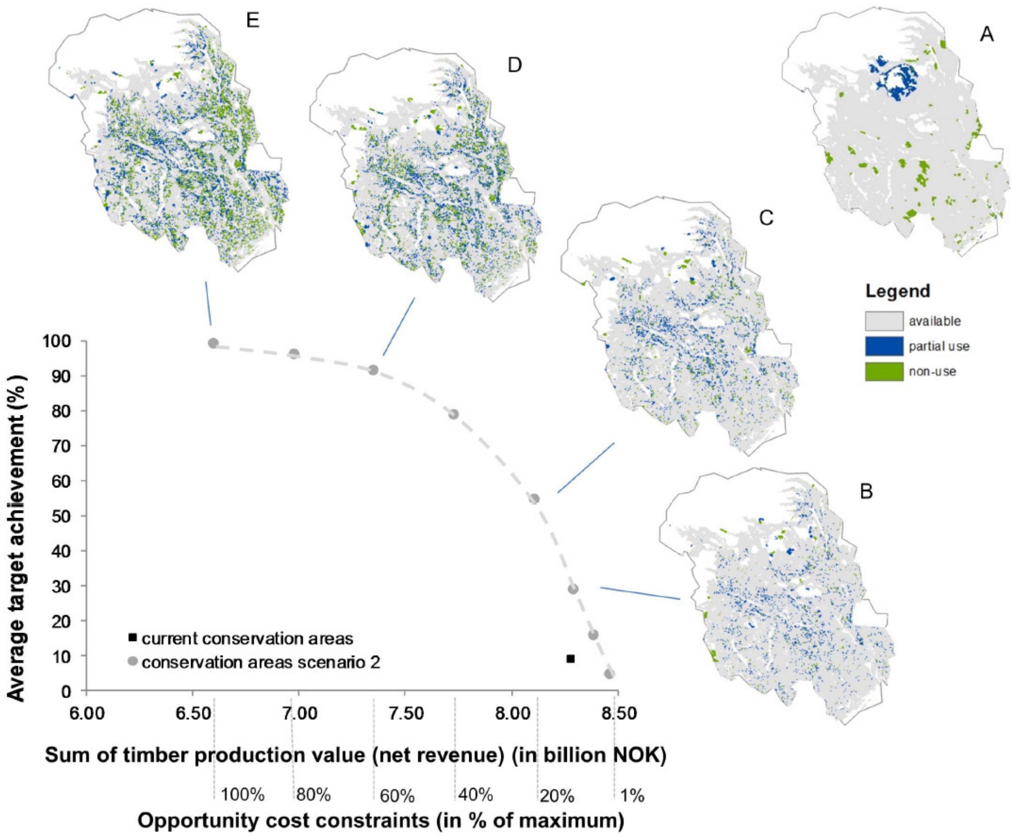

Figure 3** Forest conservation- timber production possibility frontier (PPF). The maps indicate current reserve network (A) and selected available, partial and non-use areas when current reserves are not locked-in, showing the trade-offs between net revenues from timber production and average conservations target achievement, along a range of opportunity costs constraints.* ***From *Schröter et al. (2014b).*

<u>Challenges and uncertainty</u>: The lack of area coverage of biodiversity and other features (i.e., that all spatial units in the analysis have a known or estimated value for all features included in the analysis) is a considerable limitation to systematic conservation planning because spatial units with unknown values are treated as though they lack these features. Hence, the sites with known biodiversity occurrences will be prioritized over units where values are missing. In their

analysis, Schröter et al. (2014b) only had observations of some biodiversity features for a few spatial planning units. In contrast, many of the ES and other biodiversity features such as old-growth forest, had more complete coverage (more of the possible planning units) from values based on modelling. Furthermore, the models do not account for how forestry activities might impact beyond presumed incompatibility of logging and biodiversity conservation within a single parcel. The spatial context (e.g., possible effects of logging of parcels adjacent to protected parcels) is not considered.

The carbon accounts (net atmospheric carbon removals) are based on Norway's reports to the Kyoto Protocol (UN 1998). Despite the apparent simplicity of applying CO_2e (carbon dioxide equivalent) as a universal metric or atmospheric Green House Gases (GHG) emissions and removal, an accurate assessment of these values is difficult. Current GHG emission and removal accounts in forests are based on data from the National Forest Inventory (NFI) program, which are skewed in terms of which elements of the terrestrial carbon budget are considered and how they are estimated. The NFI provides systematic accounts of the standing stocks of living trees (Breidenbach et al. 2020). The NFI uses the Yasso07 (Liski et al. 2005) to estimate soil and deadwood carbon, parameterized primarily with Norwegian data from 1988–92 (de Wit & Kvindesland 1999, Grønlund et al. 2010), and partly with data from elsewhere (Dalsgaard et al. 2016, De Wit et al. 2006). The NFI does not include either trees with dbh < 5 cm, or most understory vegetation (*Vaccinium myrtilus*, or bilberry, is the one exception). The NFI also does not adequately account for variation in soil biomass (Rusch et al. under review), which is problematic because there is 3–4 times more carbon in Norwegian forest soils than in the forest trees' biomass (Søgaard et al. 2019). While dead wood is carbon-dense organic matter, areas with high dead wood volume are currently located in the forest reserves which cover only 5% of Norway's forested area (Norwegian Environment Agency et al. 2019). Despite the forestry practices' considerable impact on the forest carbon budget, their impacts on emissions are not properly accounted for because all the relevant carbon stocks and processes that affect them are not incorporated in the accounting.

The approximation of forest carbon used by (Schröter et al. 2014b) is sufficient for awareness raising and rudimentary accounting (**Figure 1**, Chapter 1). However, its shortcomings present limitations for governance processes with higher accuracy and reliable requirements, such as determining specific climate mitigation actions, including priority setting of areas to target carbon off-setting schemes or establishing concrete climate mitigation actions such as afforestation (Bartlett et al. 2020).

Connections to other work:
- Evaluation of the Norwegian climate mitigation implementation plan, the Climate Cure (Bartlett et al. 2020).
- Ecosystem accounting (SEEA-EA; UN 2021). See Chapter 8 for more detail.
- Review of ecosystem functions related to climate change adaptation (Aarrestad et al. 2015).
- Review of ecosystem functions related to climate change mitigation and adaptation (Rusch 2012).

3.4 Public perceptions related to management of forest wildlife

Primary purpose of work: Bredin et al. (2015) investigated the perceived and actual trade-offs related to Norwegian wildlife management, which is a prominent and perpetual source of conflict in Norway. These deep-rooted conflicts pertain to rights and resources, and are not easily or effectively addressed by monetary valuation. The authors sought a better understanding of stakeholder positions, the values that underpin them, and how they relate to the ES framework.

Norwegian forests are home to several large ungulate game species (moose – *Alces alces*, red deer – *Cervus elaphus*, and roe deer – *Cervus capreolus*) and free-grazing domestic sheep. The gradual recovery in the populations of large carnivore populations (wolf – *Canis lupus*, Eurasian lynx – *Lynx lynx*, brown bear – *Ursus arctos*, and wolverine – *Gulo gulo*) within these multi-use forest ecosystems over the past 30-35 years has sparked a wide range of conflicts. The different species groups (sheep, wild ungulates, large carnivores) are important components of a wide range of diverse ES that are valued and experienced in very different ways by stakeholders at different scales.

Involved parties: This study was part of the BESAFE project "Biodiversity and ecosystem services: Arguments for our future environment", supported by the European Commission under the 7th Framework Program for Research and Technological Development. The work was conducted by a team of NINA researchers, with participation from stakeholders from key that represented the interests of farmers, hunters, forest owners, nature and carnivore management, animal welfare and nature conservation, tourism, and sheep farming.

Methodology: Bredin et al. (2015) used *Q methodology*: a form of discourse analysis originally from psychology that has since been applied to a range of fields (Addams & Proops 2000). Q methodology combines both quantitative and qualitative data to explore different opinions about a topic, and gives insight into how opinions on a topic might differ or converge. The authors generated 40 statements pertaining to management of sheep, wild ungulates and large carnivores in South-eastern Norwegian forest ecosystems, and identified how these statements aligned with the main ES categories as defined by the Common International Classification of Ecosystem Services (CICES).[6] The statements in the Q-methodology battery represented a range of positive and negative opinions, facts and assumptions about wildlife management, retrieved from scientific and popular publications, blogs, information websites and newspapers.

The authors interviewed 26 informants from the eight key stakeholder groups identified above, with 2-4 informants from each group. The informants were asked to rate their level of agreement with each statement on a scale ranging from disagree most (-5) to agree most (+5). Data from the interviews were analyzed either through a primary components analysis (PCA) or a centroid factor analysis (CENT). The work did not involve any geospatial or temporal components.

Key findings: Three narratives emerged from the 40 Q statements, which the authors labeled as "Intrinsic" (ecocentric values), "Cultural" (focused on cultural heritage values), and "Utilitarian" (extractive use of natural resources). While the cultural and utilitarian narratives were reasonably well correlated (0.6295), the intrinsic narrative had low correlations with the other two narratives. The intrinsic narrative values favored carnivore conservation, focused on intrinsic or existence values, and comprised the opinions of nine people coming from organizations that worked with animal welfare and nature conservation, tourism, or nature and carnivore management. The cultural narrative focused on cultural landscape values and food security, i.e. the cultural and provisioning aspects of traditional farming are closely related within this group. The seven stakeholders that fell within this narrative came from organizations that worked with farmers, tourism, and nature and carnivore management. Stakeholders that fell within this narrative viewed sheep as a natural element in Norwegian wildlands and something that provided important cultural ES. The utilitarian narrative focused on the extractive uses of the Norwegian wildlands, and was comprised of stakeholders that worked within organizations for hunters, lobbyists for carnivore management reform, and forest owners. This group viewed hunting as an important cultural ES and a provisioning ES.

Across the three narratives, the stakeholders disagreed on 16 of the 25 statements that were deemed relatively more important (as reflected in the strength of disagreement/agreement). However, the three stakeholder groups agreed on 15 of the 40 statements—with varying degrees of consensus as determined by statistical analyses of the difference in statement scores. These areas of agreement provide a basis for conflict resolution with regard to incompatible perspectives across stakeholder groups. For example there was evidence that moose and roe deer

[6] http://cices.eu/

management are areas where ES trade-offs cause little critical discord among stakeholders. Areas of agreement between the diverse stakeholders provide possibilities for shared engagement as a precursor to moving onto more complex and divisive issues. Areas of common ground are also The statements with the greatest consensus were the following:

- “It is a joy to know that there is lynx in Norwegian forests”
- “The chance of being attacked by a bear, when one is out in the forest, is so low that it can be ignored”
- “Large roe deer populations increase the risks of contracting tick-borne diseases”
- “Conflicting political guidance creates unnecessary tensions between sheep farming and carnivore management”

The results illustrate how many interpretations of ES have strong cultural heritage component—even for ES that are primarily either provisioning or regulating. This complicates delineation of ES into categories and how monetary and non-monetary valuation might be applied. The results also illustrated how specific ES can be viewed as positive by some and as negative (an ecosystem *disservice*) by others. Areas were ES and their valuation (i.e., their perceived benefit) are in strong conflict, and where trade-offs are unavoidable, present considerable challenges when designing policies. The standard economic policies that rely on compensation or incentives may not work because they cannot address the underlying, deep-rooted value conflicts and equity issues.

<u>Challenges and uncertainty</u>: The authors acknowledge that Q methodology does not allow for generalizations about the attitudes of larger populations. They contend that they were likely able to capture the breadth of opinions in both the Q statement battery and the stakeholders they involved, but they have no basis to evaluate how these opinions translate to the public.

3.5 TRANSFOREST

<u>Primary purpose of work</u>: The TRANSFOREST project focuses on the hardwood (i.e., broadleaf or deciduous) forests, which contain high species richness and many rare and threatened species from a broad range of forest-dwelling taxa. Hardwood forest extent is substantially reduced in Norway due to logging practices that favor conifer monocultures, and there is a considerable need to restore this forest type. The TRANSFOREST project seeks to test different alternatives for hardwood forest restoration that can both provide timber and other important services—such as pollination, carbon uptake/storage and recreational opportunities—in addition to preserving forest biodiversity.

<u>Involved parties</u>: The project is led by NINA researchers, with participation from the Norwegian University of Life Sciences (NMBU), the Institute for Rural and Regional Research (Ruralis) the Norwegian Institute for Bioeconomy Research (NIBIO) the Swedish University of Agricultural Sciences (SLU) and the University of Gothenburg. The project was financed through a grant from the Norwegian Research Council.

<u>Methodology</u>: The project studied possible restoration sites at 26 locations with relatively young mixed species stands: 13 in Norway and 13 in Sweden (**Figure 4**). Mixed species stands refer to forest areas containing both hardwood tree species and softwood (conifer) tree species, where conifers could be removed to promote hardwood tree growth. Effects of restoration methods were assessed by dividing each location into one manipulated and one control plot, with each measuring approximately 1 ha. Manipulated plots had standing tree volume thinned by approximately 25 %, removing spruce, birch and understory bushes. Researchers used a stand simulator (analytical model) to investigate how hardwood forests contribute to forest carbon sequestration. Models described what effects restoration the restoration measures might have on carbon stores over a 100-year timeframe.

The study also includes a spatial planning analysis of biodiversity and cultural ES (i.e., nature-based recreation) provided by hardwood forests, using a series of indicators for biodiversity and outdoor recreation, as well as their associated costs. This work uses Marxan with Zones, the same methodology as Schröter et al. (2014b), and is ongoing.

Spatial and temporal scale and extent:

The sites were located around Oslo Fjord in Norway (10 000 km^2 total extent) and over a 90 000 km^2 region in southern Sweden. Researchers thinned experimental stands in 2016, and measured the effects in 2019.

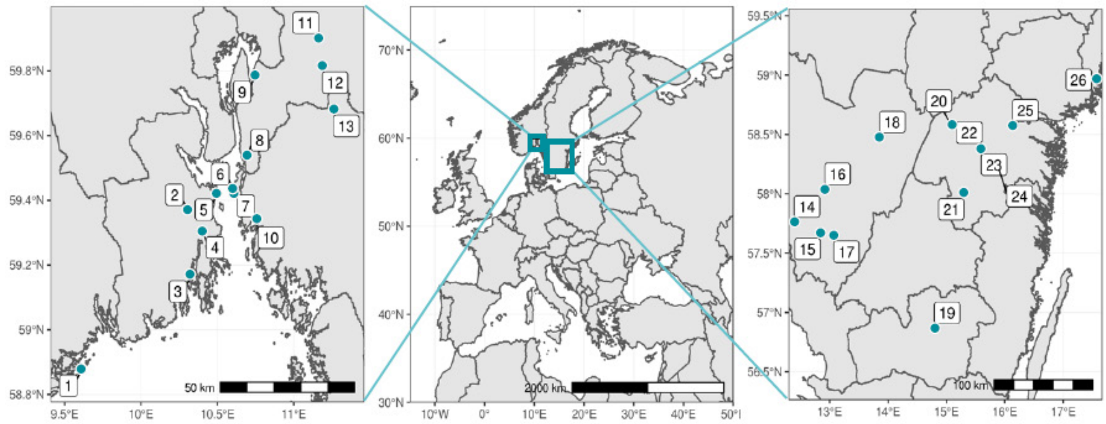

Figure 4. *The locations used in TRANSFOREST field surveys of possible hardwood forest restorations sites.*

Key findings: The thinning treatments had demonstrably positive effects on biodiversity. The thinning provided positive effects on the number of plant species and their flowering. Insects (beetles, butterflies and hoverflies) were also more abundant and had higher species richness in thinned stands.

Removal of biomass through selective cutting of softwood trees had generally positive effects on carbon uptake. According to a model for carbon dynamics, restored stands (where conifers were removed from mixed species stands) had more carbon stored in standing biomass than unthinned stands. Model results suggested that the potential for carbon storage in restored hardwood stands is potentially lower than it would be in pure spruce stands with maximum stem density and forest management optimized for carbon uptake and storage. However, carbon uptake and storage in the restored stands (i.e., those that increased the proportion of hardwood stems) continued to increase over a 100-year period. Therefore, the total carbon uptake of these restored hardwood forests may not be appreciatively less than for pure spruce stands over longer time periods.

Challenges and uncertainty:
This study has provided empirical quantitative evidence of the effects of restoration practices on biodiversity and three key ES generated by these systems: timber/biofuel production, carbon uptake and sequestrations and recreation.

One obstacle to using the ES framework to target restoration actions is a need for more accurate and empirical (not simulated) data of carbon emissions and removals, as well as data on soil carbon stocks in the different forest conditions (before and after restoration).

Connections to other work:

The work of TRANSFOREST is related to ecological restoration research and practice. ES assessments can inform decisions on ecosystems' type and location for prioritizing restoration actions.

Forests receive more attention in discussions of Norway's possible climate mitigation actions than any other ecosystem type. Many of the proposed measures, such as planting trees in open habitats and fertilizing forests with nitrogen to accelerate tree growth, entail forest management strategies that have negative effects on biodiversity protection and other ES that forests provide (Bartlett et al. 2020). Unfortunately, forest *restoration* (i.e., promoting a transition to old growth forests without logging) has not been regarded by most policy makers as an option for investments that might increase carbon uptake and sequestration. Forest restoration has the potential to help achieve both climate and biodiversity conservation objectives, but promoting forest restoration requires awareness about the conservation and climate mitigation (and adaptation) potential of forest restoration—as well as designing new economic and policy mechanisms to promote investment in these actions. Currently, incentives for climate mitigation actions in the land use, land-use change and forestry (LULUCF) sector are directed exclusively at forestry. There is a need for packages or policy mixes that target synergistic projects that enhance and protect carbon stocks and other co-benefits—including the protection of biodiversity and other regulating services and non-material ES.

3.6 Relevant issues for mapping and assessing forest ES

New research is presently investigating forest soil biodiversity and the processes underlying soil carbon dynamics. The aim of this work is to obtain more robust evidence about how forest soil biodiversity is affected by forest management practices—and the possible consequences for forest carbon dynamics—to provide more accurate carbon emissions reporting and better informed climate mitigation actions. Research into the carbon flux and storage of Norwegian ecosystems is in its early stages. NINA's ForBioFunCtioN project is one example of such work that seeks to gather essential information on forests and this important ES.

Norway's maps of forest types and forest conditions have insufficient resolution and detail, but there are ongoing efforts to improve GIS databases. To effectively monitor changes in forest condition, its biodiversity, and the ES forests generate, we need accurate representations of forest types and their condition that are capable of capturing effects generated by changes in land use and management practices. We also need to improve our understanding of the relationships between the structures that can be captured through mapping (e.g., indicators) and their contributions to either ES or biodiversity. The robustness of the information in these maps will determine their applicability for regional and local land planning, which is a key instrument to improve the protection of biodiversity and ES (Bartlett et al. 2020). ES assessments are sensitive to the geographic context. To serve specific intended land planning purposes, they need to have the appropriate spatial representation (Burkhard et al. 2012).

The Norwegian Nature Index[7] (NI; Nybø et al. 2010) is the most comprehensive summary of data on biodiversity in Norway, and a non-spatially explicit metric for assessing the ecological condition of Norwegian forests (and other ecosystem types) at the national and regional level (see Chapter 8.2.1 for more detail). It is designed to show trends in major ecosystems, based on a large number of indicators (260 in total for all ecosystem types) representing different aspects of biodiversity. Indicators for the NI include species from the main taxonomic groups (algae, lichens, fungi, plants, invertebrates, fish, amphibians, birds and mammals) as appropriate for each of the major ecosystems. Indirect indicators give additional information on the biodiversity potential of an area (e.g., presence of dead wood in forests). The NI's main methodological framework was developed prior to the first release in 2010. Since then, major improvements in

[7] results in English are available at www.naturindeks.no

indicator use and data analyses have been developed (Jakobsson & Pedersen 2020, Töpper & Jakobsson 2021). These improvements have been tested first within forests (Framstad et al. 2021).

4 Urban and peri-urban areas

4.1 Nature-based urban recreation

Primary purpose of work: Four studies provide examples of work that modelled the ES of outdoor, nature-based recreation in urban settings. Venter et al. (2020a) mapped recreational services and analysed changes in recreational activity during the COVID outbreak in Oslo, as a measure of importance of urban green infrastructure in time of crisis. Soy Massoni et al. (2018) mapped and assessed nature-based outdoor recreation opportunities in Oslo with a focus on a typology of urban green spaces and the activities and preferences associated with them. Suárez et al. (2020) investigated the accessibility of green spaces and discussed the results in the context of environmental justice, combining statistical analysis with spatial modelling to assess recreation preferences and distribution of nature-based recreation opportunities. Finally, Cimburova and Barton (2021) tested the Norwegian guidance on mapping and valuation of recreation areas (M98-citeria; Miljødirektoratet 2014).

Involved parties: The work presented in Soy Massoni et al. (2018) and Suárez et al. (2020) was a collaboration between scholars from Spain and NINA researchers. It was supported by the Urban-SIS project, a NINA strategic project on Cultural Ecosystem Services, and the ENABLE project, with funding from the 2015-2106 BiodivERsA COFUND call for research proposals. The work presented in (Venter et al. 2020a) was supported by funding from URBAN EEA project—Experimental Ecosystem Accounting for Greater Oslo and URBAN-SIS.

Methodology: Venter et al. (2020a) developed a methodology for accounting of recreational services by using mobile tracking data that enables the analysis of high resolution spatio-temporal changes in recreational activity.

Soy Massoni et al. (2018) used a non-monetary approach to valuation of urban parks by combining a multidimensional biophysical mapping of the areas' structural diversity index (SDI) with users' importance scores. The study systematized the information about the biophysical elements of urban green space following the approach by Voigt et al. (2014) and classified green spaces according to three dimensions: natural elements, abiotic site conditions, and recreational infrastructure. The study extended Voigt et al. (2014)'s approach by estimating a 'relative importance score' that combines the biophysical qualities and their functional importance for recreation as perceived by green space users. The mapping exercise recorded the presence of 30 structural elements occurring in green spaces. Structural element selection was based on spatial data availability, and the recreational value was assessed with a literature review. The study evaluated 547 green space polygons, mapped by Oslo Municipality.

Suárez et al. (2020) used a locally adapted version of ESTIMAP (Ecosystem Services Mapping Tool) recreation module to map the potential supply of nature-based recreational activities, based on ecosystems' biophysical characteristics. ESTIMAP is a collection of spatially-explicit models to support the mapping and modelling of ES at a European (continental) scale (Zulian et al. 2013). Suárez et al. (2020) used ESTIMAP to map potential supply, capacity and demand for recreational opportunities provided by green spaces. They estimated potential supply based on four attributes: degree of naturalness, tree density, proximity to lakes and the fjord, and size of continuous forests. They defined capacity as areas with high recreation potential, cross-tabulated with distance from residential areas with respect to estimated walking time. They estimated potential demand based on the share of population living within two distance buffers from those areas: 10 and 30 minutes walking distance.

Suárez et al. (2020) used a web-based survey of 1157 Oslo residents to gather information on recreation preferences, as well as background demographic (socio-economic) characteristics of the participants—including age, gender, district, type of housing, country of birth, education level, household size, number of children under 18, number of years living in Oslo, occupation, and personal income. The authors used ordination methods (principal component analysis (PCA) and redundancy analysis (RDA) to identify patterns in preferences. First, they applied a PCA to identify correspondence between recreational facilities and the biophysical characteristics of green spaces. They then used several RDA to analyze (i) correspondence between respondents' socio-demographic characteristics and preferences for green space characteristics, (ii) whether stated preferences depend on their place of residence, and (iii) whether the distance from respondents' residences to green spaces has an influence on respondents' preferences.

Cimburova and Barton (2020) tested the applicability of GIS methods and datasets to map and value recreation services generated by green infrastructure in Oslo. They observed that available GIS data for recreation area qualities have only been used to a limited extent in municipal assessments on the recreational value of these areas. Their work tested how far the available GIS and mobility data can be used to implement the M98 national guidelines' multiple criteria for map and value recreation opportunities (Miljødirektoratet 2014). M98 main criteria include area attributes such as user frequency, whether areas attract regional and national users (as contrasted with local residents), experience quality, symbolic value, area function, area suitability, and on-site facilitation. M98 supporting criteria include attributes such as noise, presence of infrastructure, area extent, accessibility, and potential use. Cimburova and Barton (2020) sought to demonstrate which criteria have a high correlation between "big data," (i.e., algorithm-based scoring of area attributes) and the scores assessed by local groups.

The methodologies from all four studies can be applicable in other cities and metropolitan areas to map green spaces, and assess their importance for generating recreation opportunities, and differences in accessibility to outdoor recreation opportunities.

<u>Spatial and temporal scale and extent:</u> Soy Massoni et al. (2018) addressed the City of Oslo's built area (15 270 ha). Urban green space covers a considerable amount of Oslo's built area (19%), and is comprised of public open spaces (14%), parks (3%) and cemeteries (1%). Parks are defined as the managed green spaces within the built zone, and public open spaces are largely unmanaged green spaces open to the public. Six percent of Oslo Municipality is fresh water, with ten main streams running through the urban area. Oslo is situated at the end of Oslo Fjord. The built area is bordered by seawater and islands to the south, and boreal forests to the North and East. Suárez et al. (2020) included the greater Oslo Metropolitan area beyond the built area (5732 km^2). Municipal maps are in vector form (polygons) at 1:5 000. Cimburova and Barton (2020) use the area of the municipality of Oslo for their analysis.

Venter et al. 2020 is based on an analysis of temporal variation, exploring variation across years at the resolution of both days and diurnal (within day) temporal scales. There was no temporal dimension in the other studies.

<u>Key findings:</u> Venter et al. (2020a) found that outdoor recreational activity increased by nearly 300% compared to a 3-year average, and equated to 86 000 extra activities per day over the entire municipality. The magnitude of the increase increased with the remoteness of trails and paths used for walking, running and biking. Pedestrian activity increased in parks, peri-urban forests and protected areas, which documents the importance of access to green open spaces that are interwoven into the urban landscape and provide "resilience infrastructure" in a time of crisis.

Soy Massoni et al. (2018) found that parcel size is a weak and non-linear determinant of structural diversity of green spaces in Oslo, and that stated preferences are correlated with structural elements. Urban green space classification could be improved by combining structural diversity indicators with structural preference studies, but the study did not cover the full range of recreational ES across the spectrum of urban green spaces. The authors proposed potential extensions of the structural diversity index for urban green space that would be capable of covering a wider range of green spaces—from cemeteries to peri-urban forest—and the recreational opportunities provided by them.

Suárez et al. (2020) found that most survey respondents prefer large wooded green areas, a high density of trees, and the presence of water—although preferences differ depending on age and place of residence. The study addressed environmental justice (pertaining to the UN's Sustainable Development Goal 10: "Reduce inequality") by evaluating the extent to which access to urban green space is a suitable indicator of social equity. While areas for daily recreation in Oslo are accessible to the whole population in the study area, they are unequally distributed. Immigrants and low-income households generally had lower access to these areas.

Cimburova and Barton (2020) found that GIS-based methods are highly suitable for modelling user frequency, suitability, experience quality, and on-site facilitation and could possibly replace subjective-based scoring. GIS-based methods were also highly suitable for modelling supporting criteria such as noise, area extent and accessibility. The authors concluded that GIS-based methodology could in many cases supplement, and in some cases replace, the valuation performed by local groups—providing more complete data with lower information costs.

<u>Challenges and uncertainty:</u> Soy Massoni et al. (2018) illustrate the challenge of linking green infrastructure qualities with the value of recreational services provided by urban green infrastructure. For instance, a higher diversity of structural elements does not necessarily offer more opportunities for people with diverse recreational interests. Preferences are highly heterogeneous and low structural diversity of green infrastructure with certain elements was highly valued by a large number of respondents. Also, people enjoy the same structural elements
for a number of different activities. Current typologies of urban parks, including the SDI, fail to adequately describe the richness of elements in all green spaces with a more natural character. These include larger areas used for recreation in urban fringes, forest and semi-natural habitat remnants within the build-up zone, as well as cemeteries. These areas are important and complementary in terms of the recreational services they provide.

Suárez et al. (2020) built their preference-analyses on a structured questionnaire, using random samples stratified to be representative of city districts' populations. The results indicate two possible situations: (i) people's preferences adapt to the neighborhoods they live in (habituation), or (ii) people self-select their residence's location based on their pre-existing preferences. The study acknowledges that the relationship between access to green space and environmental justice can be complex, and that injustice may not automatically result from uneven access. In-depth, interview-based methods are required to further understand local preferences and make statements about issues of environmental justice.

Suárez et al. (2020) used an ESTIMAP model that was adapted for the Oslo metropolitan area with higher resolution data (10 m) than a European case study (Vallecillo et al. 2018). This provides more precise results that are useful for urban and peri-urban planning, but it does limit comparison with other cities that do not have access to such high resolution spatial data.

Degree of naturalness and presence of water are two characteristics usually included in ESTIMAP model to map recreation potential supply. However, there are other preferred characteristics—such as tree density and size of continuous forest—which are not usually included in ESTIMAP models. Mapping them may be a difficult task at national or continental scales, but can be more easily done at urban and metropolitan scale. Moreover, the studies could distinguish the two preference groups identified in Oslo (i.e., people who prefer more 'natural' recreation areas and people who prefer more 'urban' areas), so it is not possible to simplify this multi-criteria evaluation methodology of recreation potential to a few proxy variables. Preferences may differ by location, thus a previous assessment to select potential supply components would be recommended for each local case study. Suárez et al. (2020) also discuss the question of which elements should be included to define green infrastructure and biophysical structures (both with or without man-made structures), and how the choice of green space elements affects the accounting green infrastructure's capacity to generate recreation services.

4.2 Pollination

Primary purpose of work: Pollinating insects serve several roles in urban ecosystems. Pollinators provide many benefits for human wellbeing that extend beyond pollinators' contributions to agriculture and food production (IPBES 2016). Because an estimated 250,000 species of flowering plants depend on biological pollinators (Abrol 2012), pollinators are integral in the life cycles of the many wild plant species that generate ES involved in regulating and maintaining desired ecosystem attributes. Furthermore, the flowers that plants produce for attracting insect pollinators have broad aesthetic appeal, and flowering plants' presence helps define many of the attributes that contribute to the values we assign to virtually all of the cultural ES (Stange et al. 2018).

Pollination is crucial for cultivating fruits and vegetables that many urban residents grow in back yards or allotment gardens. Fruit and vegetable gardening in urban environments is, of course, a means of producing food. However, the volume of food produced in urban areas is low compared to agricultural landscapes. Urban gardening should therefore be viewed as more of a recreational pursuit that provides an opportunity to learn about natural processes and transfer this knowledge across generations and social groups (Barthel et al. 2010). The gardens, orchards and other urban green spaces where pollinators forage and facilitate plant reproduction are often landscape features that help define many urban residents' sense of place and their cultural heritage. The increased contact that residents have with green spaces through gardening in urban environments has many health benefits as well, including positive psychological effects (Tzoulas et al. 2007) and decreasing the prevalence of allergies and chronic inflammatory diseases (e.g., Hanski et al. 2012).

Stange et al. (2017) describes one of the many studies currently exploring pollination services in urban and peri-urban areas of south-eastern Norway. Their study developed a model for describing how habitat quality for pollinators varies within the municipality and depicting the distribution of an important aspect of Oslo's overall biodiversity with contributions to several (primarily cultural ES). Combining pollinator habitat hotspot mapping with locations of both threatened wild bee species and domestic honeybee hives could also provide greater accuracy for identifying areas where domestic honeybee foraging might exert stress on wild bee species through competition for flower resources, and can help evaluate criteria for Oslo municipality's policy for limiting beekeeping activity in these areas.

Involved parties: NINA researchers led the work, supported by funding from the OpenNESS research project (EU FP7 funding). Collaborators included researchers from the European Commission's Joint Research Center, representatives from Oslo Municipality's Urban Environmental Agency (Bymlijøetaten), a local beekeeping group (ByBi), and experts on pollinating insect ecology from the Norwegian University of Life Sciences.

Methodology: ESTIMAP is a collection of spatially explicit models developed to support the mapping of ES at a national and continental scale to provide the informational support necessary for drafting and enforcing EU environmental policy (Zulian et al. 2013). ESTIMAP's pollination model was developed based on the InVEST model (Lonsdorf et al. 2009), and uses land cover category data to estimate the capacity of different landscapes for providing pollinating insects with food and shelter. Experts on pollinator biology provide value weights for land cover categories that reflect the floral resource and nesting site availability. The model also incorporates the foraging distances for a given group of pollinator bee species, combined with an activity index based on local climatic conditions (temperature and solar irradiance), to derive an index of relative pollinator abundance for each cell of a land cover map. At the European continental scale, the model uses CORINE Land Cover data, which produces an output map with a 100 x 100 M (1 ha) resolution that is particularly useful for illustrating where agriculture might experience pollinator deficits at a regional scale.

Stange et al. (2017) modified the ESTIMAP continental model by using spatial data provided by Oslo and conferred with experts familiar with local pollinating insect taxa and used an iterative process to arrive at consensus values that express land cover categories' relative habitat suitability for pollinating bee community in Oslo. Land cover was expressed as a combination of both municipal and national data sources (polygons), and satellite imagery (Sentinel 2). Land cover categories that are incapable of providing either floral resources or nesting sites (e.g., water surfaces or densely built areas) were valued at or near zero. Land cover categories that represent the best possible habitat within the study area were valued at 1. Based on the experts' contention that nesting site availability was far less likely to limit populations of pollinating insects in Oslo than floral availability, Stange et al. (2017) chose to simplify the ESTIMAP model for Oslo Municipality by using a combined habitat suitability score with greater emphasis on floral resource availability. They validated their model with samples of the pollinating insect community using pan traps (Westphal et al. 2008) over three time periods at 74 locations distributed throughout the study area.

Stange et al. (2017) modelled the distribution of domestic honeybees foraging Oslo, with data from the ByBi beekeepers' organization for permanent beehives' locations and the number of hives per location. They used a simple diffusion model from these locations, using parameters from Couvillon et al. (2014) and Garbuzov et al. (2015) on honeybee foraging distances in Brighton, UK: an urban landscape with a population density similar to that of Oslo (3 445 ind/ km^2).

<u>Spatial and temporal scale and extent</u>: The study focused primarily on pollinator habitat suitability within Oslo's built zone (147 km^2), where virtually all of Oslo's residents live. However the model also covered the undeveloped peri-urban forests (*marka*) to the north and east of the built zone. Municipal and national data on land cover were provided by vector layers, and the Sentinel 2 satellite data used to capture the heterogeneity within polygons of a single land cover categories was available at a 10 m resolution. Field sampling of pollinating insects for model validation occurred over a single season.

<u>Key findings</u>: The map of pollinator habitat suitability illustrates a considerable spatial heterogeneity within Oslo municipality (**Figure 5**). The heavily developed city center presumably provides relatively few floral resources for insect pollinators. However, the model does indicate higher habitat suitability provided by the park-like gardens surrounding the Royal Palace as well as a number of smaller parks within a 1.5 km radius of the city's center. The map also illustrates a swath of low habitat suitability values extending from the city center to the northeast, corresponding with areas of dense commercial and industrial infrastructure and high levels of automobile traffic. Because the model includes satellite-derived high-resolution spatial data, its map illustrates numerous collections of pixels with high habitat suitability scores along this corridor (**Figure 5**, inset).

Because of bees' integral role in the reproduction of flowering plants, bees can function as indicator species for the status of the flowering plant community (Couvillon & Ratnieks 2015, Kevan 1999). The distribution of habitat suitability scores can serve as a useful presentation of the spatial variation in Oslo's broader urban biodiversity. Urban planners may use maps of pollinator abundances to identify greenspace areas with particularly high biodiversity values that are worthy of protection from future development, as well as areas where biodiversity values may be lacking and would benefit from restorative measures.

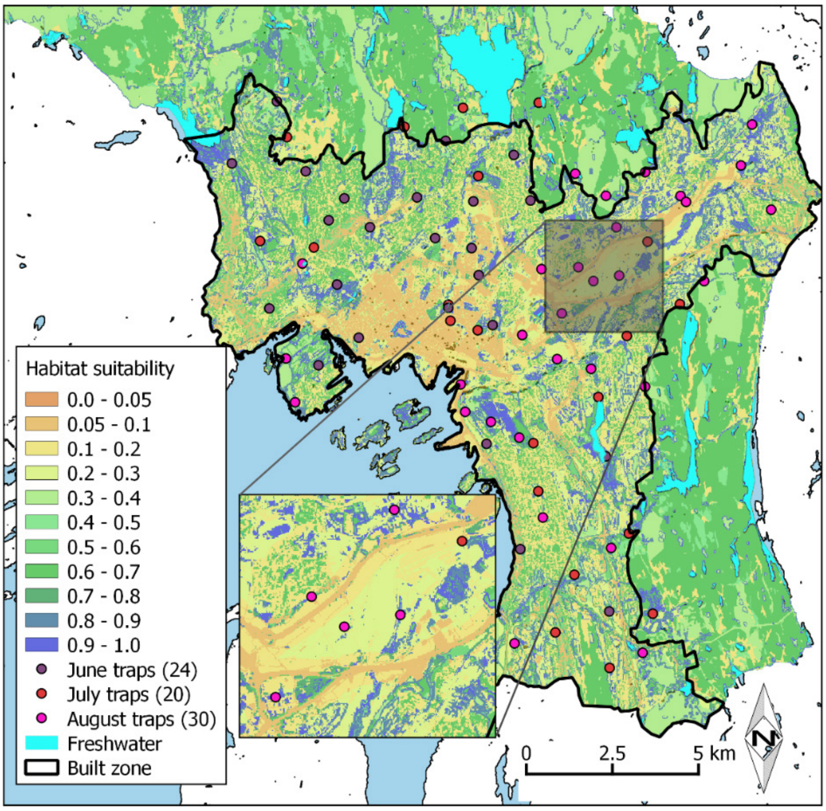

Figure 5*. Map of pollinator habitat quality scores and locations of pant traps used for model validation.* ***From*** *Stange et al. (2017)*

The overlay of honeybee density on habitat suitability illustrates areas within the study area where abundance of foraging honeybees may have a greater potential to exceed local floral availability. Foraging honeybee activity is greatest in the city center, where both habitat suitability scores tend to be lower and beehive density is highest (**Figure 6**). The model indicates relatively low expected pressure from foraging honeybees in three of the six “precautionary areas” that the Oslo Urban Environmental Agency proposed establishing to limit beekeeping activity where honeybees might pose a threat to wild bee species that live within the municipality’s built zone. The model also predicts relatively low honeybee foraging pressure in the lower half of the largest sensitive area that extends along the eastern shoreline of Oslo Fjord.

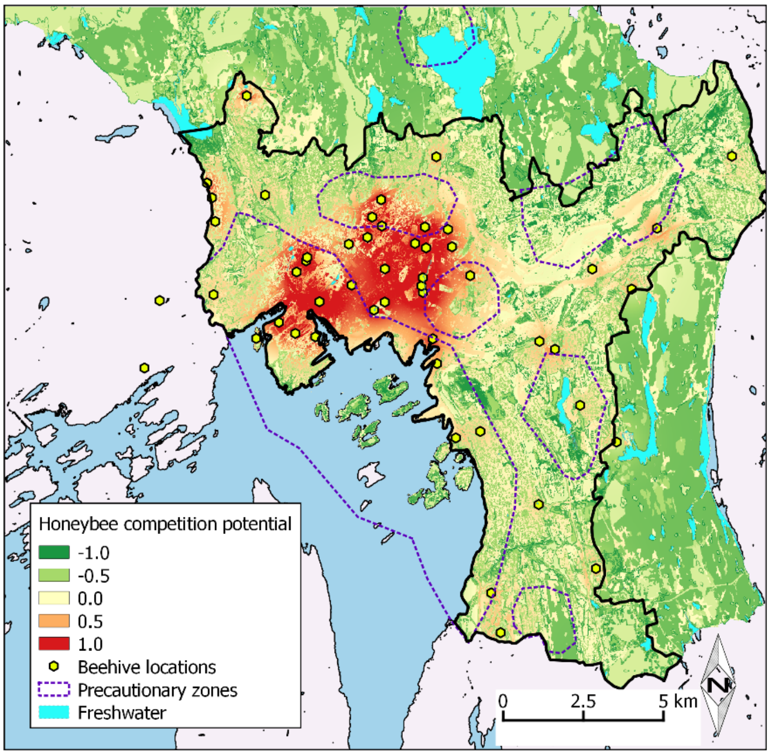

***Figure 6**. Map of the relative resource demand of foraging honeybees, accounting for the floral resource availability of the Oslo municipality landscape. Precautionary zones represent areas proposed by Oslo Urban Environmental Agency to protect potentially sensitive populations of red-listed wild bee species from competition with domestic honeybees. **From** Stange et al. (2017)*

Challenges and uncertainty: A major modification that Stange et al. (2017) made to the InVEST pollination model was to eliminate the flight distance component. They found that at high spatial resolutions, flight distances had a smoothing effect on pixels' habitat quality values. This can be particularly unfortunate in complex landscapes like Oslo and other urban settings, because the smoothing masks much of the land cover's spatial heterogeneity and thereby hides the presence of small patches with high habitat suitability.

The assessment Stange et al. (2017) present is not sufficient for determining the actual threat domestic urban honeybees pose for the conservation of certain wild bee populations. Both honeybees' and wild bees' foraging is highly heterogenous—spatially and temporally—and requires extensive sampling that was beyond the scope of their study. More focused insect trapping within the areas where likelihood of competition is greater (**Figure 6**) could reveal whether areas with higher potential for honeybee competition actually produce negative correlations between honeybee density and wild bee abundance and/or richness. Visual observations, either timed or along transects, would also be able to assess whether recourse overlap might be greater in these areas.

Connections to other work: The ESTIMAP pollinator model for Oslo has been the basis for several reports used to model green infrastructure in urban areas, including Stavanger (southwestern Norway; Stange et al. 2019b) and Ski (southeastern Norway; Stange et al. 2019a). It has also been used as part of the economic valuation of pollinator contributions to agricultural production in Ås municipality (Chapter 6.2).

4.3 Economic valuation of urban ES

Primary purpose of work: describe a study of benefit transfers and value transfers for selected urban ES in Oslo, as a part of the OpenNESS project "Operationalizing natural capital and ES", financed by the EU Commission's FP7 program (2014-2017). The Oslo case was one of several urban case studies in OpenNESS, where values of ES were assessed with monetary and non-monetary valuation methods.

The value transfer methods demonstrated in Barton et al. (2015a) are necessary for ES valuation when investigators do not have either time or financial resources to collect new data. The goal of the report was to demonstrate, through the use of relatively simple methods using existing data sources (i.e., publicly available reports and GIS data), that valuation could be accomplished through simple approaches and provide valuable information regarding urban planning and development. The four examples described in Barton et al. (2015a) include (i) assessing replacement value of urban trees, (ii) the recreational value of urban parks and green spaces, (iii) the capital value of blue-green areas on residential property values, and (iv) the value of recreational opportunities in the peri-urban forested area located along the northern boundary of Oslo's built zone (*Oslomarka*). The examples included in these valuation examples were selected to focus the discussion on the value of ES tied to recreation and mental and physical health.

Involved parties: NINA researchers lead the work, in cooperation with VISTA Analyse (a consulting company). Participants included visiting researchers/ graduate students from the University of Girona (Spain) and the University of Copenhagen. Representatives from Oslo's municipal authorities included the Urban Environmental Agency (*Bymiljøetaten*), the Water and Sewage Agency (*Vann- og Avløpsetaten*) and the Agency of Planning and Building (*Plan- og Byggningsetaten*)

Methodology: Barton et al. (2015a) use four monetary value transfer methods from environmental economics:

1. **Hedonic pricing**, looking at the connections between accessibility/proximity to green infrastructure and the corresponding prices in Oslo apartments. Based on findings from a sample of 9000 apartments sold in Oslo between 2004 – 2013, the values were then transferred to all Oslo apartments.
2. **Meta-analysis of willingness to pay** involved transferring a weighted average of willingness to pay for recreation in urban green areas from a sample of foreign university students studying in Oslo.
3. **Value of leisure time use** involved transferring various values for leisure time, exercise and leisure visits derived from a small sample of Oslomarka visitors to the entire population of Oslo to estimate the total value of recreation in Oslomarka.
4. **Economic replacement value** involved using the replacement value for destruction of public trees and transferring these values to all tress on private and public property within Oslo's built environment (the urban area), to estimate the total value of all trees in Oslo.

The report also explores the potential policy relevance for two non-monetary valuation examples:

5. **Blue-green factor (BGF) scoring** of property in the built zone of Oslo scores blue and green structures[8] according to their ability to deliver ES.
6. **Health impacts of green infrastructure** in Oslo on both physical and mental health.

Further details on the materials and methods used in these valuation approaches are provided in "Materials and methods appendix for valuation of ES of green infrastructure in Oslo" (Barton et al. 2015b).

[8] *Green structures* refer to individual elements of parcel-scale components of *green infrastructure*. Green infrastructure is the network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ES.

Spatial and temporal scale and extent: The valuation examples represent a single time step, although many of the data used were collected over a period that spanned up to a decade.

Key findings: To calculate the value of green infrastructure reflected in real estate pricing, the authors mapped the distance to green areas for each apartment in Oslo and multiplying this figure by the *value per meter proximity to green infrastructure* for an average apartment sold in the period 2004-2013 (a parameter generated from the analyses of 9000 apartments sold, as reported in Vågnes Traaholt 2014), Barton et al. (2015a) estimate that green infrastructure has the following effects on property prices:

- For every meter an apartment is closer to a city park, the expected value of the apartment increases by between NOK 162 – 368.
- There are 160,722 apartments within 500 meters of public parks in Oslo. Overall, the added value for proximity to a park for all these apartments is between NOK 8.3 - 18.9 billion, compared with average apartments without such proximity. This is a capital value, i.e., not value per year.
- If a park has one water element nearby, it is even more valuable. The total expected added value for apartments near parks with water elements is between 2.8 - 6.6 billion (53,083 apartments).
- Large parks have an additional value of between NOK 0.3-2.3 billion (31,147 apartments).
- Apartments less than 500m from cemeteries have an added value of NOK 2.1-5 billion (45,356 apartments).
- Apartments located less than 1,000 m from the fjord have an added value of NOK 4.7-7 billion (34,965 apartments).
- Apartments located within 500m from edge of the Oslomarka have an added value of 0.8-4.1 billion (36,310 apartments).

Green areas in Oslo's built zone total approximately 28 km^2 and are distributed in more than 500 different places in the city. If willingness to pay for the protection of similar green space among urban populations in other countries is representative for Oslo, a conservative estimate of the value of Oslo's total green area in the built zone is about NOK 1 billion $year^{-1}$. This corresponds to an average of NOK 1,985 $year^{-1}$ for every Oslo citizen over the age of 15.

Willingness to pay (WTP) methods also provide numerous complementary perspectives of Oslomarka's perceived value as a venue for outdoor recreation. Oslo residents make an estimated 23.4 million visits to Oslomarka each year, which corresponds to 73 million hours spent in the area for all Oslo residents over the age of 15. If visitors chose to visit Oslomarka instead of a training center downtown, this time equates to at WTP of NOK 2.7 billion $year^{-1}$. If visitors opted to visit Oslomarka instead of pursuing paid work, this time equates to a WTP of NOK 13.3 billion $year^{-1}$ after taxes in foregone personal earnings. Using data from a meta-analysis of travel expenses from other countries, the effort made by Oslo residents to get to Oslomarka for recreational activities results in a WTP of NOK 3.4 billion $year^{-1}$.

Oslo's Urban Environmental Agency conservatively estimates that the city has between 0.7 and 1.2 million trees with a crown height > 5 m. Oslo municipality requires that anyone responsible for destruction of a city tree, either willfully or by accident, must pay for the cost of its replacement. The size of the fee is based on a formula that accounts for the tree's condition and qualities, including several attributes connected to the ES the tree provides (ecological suitability aesthetics, architectural value, and other environmental values, see Chapter 4.4). Using the median qualities of Oslo's urban trees, the replacement value for a typical individual tree is approximately NOK 40 000. By transferring this figure to Oslo's entire tree inventory, Barton et al. (2015a) arrive at NOK 28 – 42 billion as the total replacement value for all of Oslo's trees.

The Blue-Green Factor (BGF) values only a subset of the ES provided by blue-green structures at the property level. BGF gives high priority to water and drainage surfaces regulating run-off, as well as trees. Structures providing biodiversity habitat, aesthetics and recreation are seen as 'additional' ES. The BGF focus on simplicity means that each structure is scored the same no matter where the assessment takes place. The assumption is that the marginal value of each structure in terms of surface area or number of individual trees is the same whether upstream or downstream in an urban catchment.

Barton et al. (2015a) did not find any examples in the literature of the health effects associated with the ecosystem functions of vegetation and water. They hypothesize that the 'missing link' between economic valuation of health benefits and use of green infrastructure is the epidemiological study of physical and psychological health impacts, and they provide examples from the literature of studies that have attempted to address this knowledge gap.

Challenges and uncertainty: Barton et al. (2015a) recognize that the estimations generated through value transfer methodology carry a large degree of uncertainty. In the example for tree valuation they describe their approach as a "thought experiment." Nonetheless, the authors contend that even these simplistic valuation approaches that document socio-economic values of green infrastructure can strengthen municipal arguments about increased funding for protection, investment and maintenance in green infrastructure. They assert that value transfer is a cost-effective method that can be used to highlight values of green infrastructure that may be taken for granted and used for public information (awareness raising) purposes and to assess whether further investigations are necessary to increase the resolution of valuation studies to a point where they could be relevant in decision support.

Connections to other work: A study exploring potential models for hedonic pricing valuation for blue and green infrastructure for based on their proximity to Oslo apartments is described in Vågnes Traaholt (2014).

4.4 Valuation of urban trees: i-Tree software

Primary purpose of work: The i-Tree Eco software application (i-Tree n.d.) provides estimates of regulating ES generated by urban forests. However, existing municipal tree inventories may not contain data necessary for running i-Tree Eco, and field surveys generally used to collect this information are costly and time consuming. Cimburova and Barton (2020) demonstrate the potential of geospatial and machine learning methods to supplement missing and incomplete i-Tree Eco attributes in Oslo's existing municipal tree inventories. Results from their approach can provide rapid, low-cost urban ecosystem accounting.

Involved parties: This work was conducted exclusively by NINA researchers, as a part of Zofie Cimburova's PhD thesis at the Norwegian University of Science and Technology (NTNU).

Methodology: i-Tree Eco model was developed by the United States Department of Agriculture Forest Service for the valuation of urban trees and forests, and is capable of providing a municipality with both (i) site-specific service quantification and benefit valuation and (ii) ecosystem accounting of city-wide tree populations that are currently only partially inventoried. The main input to i-Tree Eco analysis is a database of individual trees and their attributes comprising tree species, dimensions, condition or spatial context measures—information that is generally obtained through time consuming field survey work.

Cimburova and Barton (2020) used both Oslo's existing tree inventory and auxiliary spatial datasets for land use, buildings, and laser scanned tree crown geometries) to derive a final tree dataset suitable as input for the i-Tree software. This dataset included information on tree crown diameter, total tree height and height to live top, height to crown base, crown light exposure, distance and direction to building, land use, and percent crown missing. Obtaining information on tree species was not possible for this study, although the authors mentioned the potential for doing species classification through airborne optical imagery and airborne laser scanning, as described in Wang et al. (2019).

The dataset was then used a i-Tree model to generate estimates of annual ecosystem service indicators (air pollution removal, avoided runoff carbon sequestration, and building energy savings) and the associated monetary values. These outputs were then linked back to individual trees in the final tree dataset. The authors used a Bayesian Network (BN) analysis to emulate ES indicators and asset values and generate probability distributions for the variables with missing values: trees' diameter at breast height (dbh) and species.

<u>Spatial and temporal scale and extent</u>: The study area is the city of Oslo built zone regulated for urban development, where the analyzed tree inventory is located. The Oslo built zone covers 147 km^2, of which 47 % was covered by vegetation in 2017. Vector maps of land use and land cover in the built zone had a reference scale of 1:5 000. The raster layers for digital surface and digital terrain models had a 1-meter resolution.

<u>Key findings</u>: The average value of air pollution removal, according to the i-Tree outputs constitutes the largest proportion (93.5 %) of the annual monetary value of an average tree. The proportions of values associated with other ES indicators are considerably smaller. Avoided runoff = 4.3 %, carbon sequestration = 1.4 % and building energy savings = 0.8 %. Much of the variation in ES supply can be explained by tree size.

The estimated mean asset value, based on the BN emulation and the municipal tree dataset was 1443 USD $tree^{-1}$. Oslo has many small trees and comparatively fewer tall large-canopy trees with exceptional asset value (> 10 000 USD $tree^{-1}$), which make scaling up to the aggregated value of all of Oslo's trees sensitive to the presumed distribution of tree size classes. The expected total asset value based on different assumptions regarding tree size distribution can range between 33.1 – 43.8 million USD.

<u>Challenges and uncertainty</u>: The present inability of remote sensing methods to detect trees' dbh and species mean that the inputs required by the i-Tree model must be inferred from other data. Bayesian Networks are well suited to consider data and model uncertainty, and provide quantifications of the uncertainty associated with specific parameters and model outputs.

The dominant monetary value of air pollution removal, relative to the other ES, highlights the importance of correct estimation of air pollution at tree location

<u>Connections to other work:</u> NINA has a growing body of work addressing mapping and assessment of urban trees and the ES they provide. We provide details of three of the most recent examples.

Norwegian tree assessors typically use the Danish *Verdsetting af Træer* (VAT03) method, which accounts for several aspects of amenities and recreational ES trees provide. The VAT method was updated in 2019, and the new VAT19 methods now also include valuation of regulating ES through expert assessment. Nollet et al. (2021) describes the development, testing and documenting of a protocol for linking the VAT19 field methods with the i-Tree Eco model described above. Unlike the original VAT19, this new protocol (called the "VAT19-i-Tree field protocol") can utilize spatial data to model tree variables (e.g., tree crown dimensions).

Hanssen et al. (2019) describe a method for mapping urban tree cover using airborne laser scanning (ALS). The authors combined ALS and orthophoto (arial photography) imagery of Oslo's built area to identify individual tree crowns. They used their method to evaluate trends in tree canopy characteristics in the suburban "small house areas" that are currently experiencing rapid increases in building density. They found that the number of trees > 10 m tall decreased in the “small house” areas of Oslo, leading to a potential decline in the generation of regulating ES that large trees provide.

Venter et al. (2020b) investigated the role that urban trees have in reducing the severity of summer extreme temperatures, and the benefits of this cooling effect on reducing risk of human heat exposure. Recorded surface temperatures in Oslo were negatively correlated with tree cover and land cover NDVI (a measure of greenness from vegetation). By combining modelling results with census data, the authors estimated that each tree in Oslo currently mitigates additional heat exposure of one heat sensitive person by one day—indicating that maintaining and restoring tree cover provides the regulating ES of heat reduction.

4.5 Other related work in urban ecosystems

The IMAGINE project (Integrative Management of Green Infrastructures Multifunctionality, Ecosystem integrity and Ecosystem Services: From assessment to regulation in socioecological systems)[9] is a BiodivERsA funded project completed in 2021. IMAGINE used a multidisciplinary approach across six case study territories spanning a European north-south gradient from the boreal zone to the Mediterranean, the IMAGINE project sought to quantifying the multiple functions, ecosystem services and benefits provided by Green Infrastructures (GI) in different contexts from rural to urban. Researchers at the Norwegian Institute for Nature Research led the work package addressing Adaptive Landscape Planning for the Allocation of Green Infrastructure, and the city of Trondheim was one of the six case studies.

4.6 Relevant issues for mapping and assessing urban and peri-urban ES

Many of the ecosystems that provide important provisioning and regulating services are located far outside cities, rendering these ecosystems services virtually invisible to city inhabitants. However, city residents are able to directly perceive and experience many *cultural* ES more locally. Cultural ES therefore provide clearer and more intuitive examples of environment-to-benefit linkages than many material ES and can be a useful tool for both managing urban green spaces and promoting urban sustainability (Andersson et al. 2015).

Urban settings also tend to represent a higher degree of spatial heterogeneity in land cover than other ecosystems. The vector-format spatial data available from municipalities with high spatial precision (1:5 000) was incapable of capturing much of the variation in biophysical structure that is important for generation of ES. Satellite imagery (such as that available from Sentinel 2) and airborne laser scanning are two examples of methods that can provide this level of detail.

[9] BiodivERsA: IMAGINE

5 Mountains

5.1 Livestock grazing

Alpine areas occupy ca 32% of the Norwegian land area, generating important ES, where grazing by domestic and semi-domestic livestock is a key activity. Livestock grazing importantly shapes the Norwegian alpine ecosystems, especially by affecting the upper elevation of the tree-line, which in turn affects climate change related processes, including carbon sequestration, emissions and albedo reflection. Further, since the agricultural area in Norway is very limited (ca 3% of cropland), alpine ecosystems are important for food production.

Here we summarize a study on the effect of grazing on the condition of grazed alpine systems, especially related to the impacts on the tree-line, but other recent studies address different aspects of the value of high altitude systems including those of pastures (i.e., Steinshamn et al. 2018) and those about the costs related to conflicts with biodiversity conservation (i.e., Hansen et al. 2019).

Primary purpose of work: The ManEco project (MANaging ECOsystem services in low alpine cultural landscapes through livestock grazing) sought to investigate the effects that grazing in alpine areas had on both important ecosystem processes and cultural ES provided by these areas. The upper elevation of tree growth (tree-line) in Norway has been kept artificially low by land uses associated with traditional (agri-) cultural practices. However, reduced grazing intensity and a warmer climate can interact to cause an elevational advance of the tree-line.

Sheep are by far the most important large herbivore in alpine and subalpine areas in southern Norway, acting as a driver of multiple ES including provisioning services (meat, trees), regulating services (tree-line encroachment, carbon) cultural services (e.g. landscapes important to traditions, outdoor life), supporting services (clean water, soil productivity) as well as biodiversity.

Involved parties: Gunnar Austrheim (Norwegian University of Science and Technology, NTNU) was project leader for ManEco. Other Norwegian participants included researchers from NTNU, the University of Oslo (UiO), and the Norwegian University for Life Sciences (NMBU), the Norwegian Environment Agency and a consultant with expertise in scenario analysis and strategic planning. International partners included researchers from the James Hutton Institute (UK), the Centre for Ecology and Hydrology (UK), and the Swiss Centre for agricultural research Argoscope (Switzerland). The project received funding from the Norwegian Research Council.

Methodology: The ManEco project built on a 10-year experimental case study at a landscape scale to assess the effects of alternative sheep densities on ES in alpine cultural landscapes, and identify stakeholder ES preferences. Two of the project's work packages investigated effects of grazing and climate change on key ecosystem properties that are essential for the services provided: nutrient dynamics and birch encroachment. A third work package addressed the relationships between multiple ES within the context a case study in the Hol and Setesdal municipalities. Two other work packages addressed cultural ES and stakeholder preferences in alpine landscapes.

This project was multifaceted and used several different methodological approaches. Several of the work packages generated published scientific articles and reports that provide information that is related to evaluation of ES, but that largely address topics with less relevant to the focus of this report. It is beyond the scope of this report to catalog all methods for this project. We have chosen to present a brief description of the work performed by a focus group, and their recommendations for new management practices related to sheep grazing (Fagerheim et al. 2014). The objective for the focus group was to evaluate that level of grazing pressure was most desirable, and which management practices could secure conservation of ES and biodiversity in alpine areas, with particular emphasis on cultural ES.

The focus group consisted of representatives from resource management (agriculture, environment, and cultural), as well as special interest groups associated with conservation, vacation dwellings, outdoor recreation, and property owners. The focus group met three times for workshops between 2012-2014, where results from the previous workshop were used to structure the discussions in the subsequent workshop.

Key findings: The focus group recommended a moderate to high grazing pressure in the mountains, with partial or complete restrictions on grazing in selected areas. The goal of increased sheep grazing in alpine ecosystems is to increase food production in mountain areas, with consideration given for variation in site specific environmental conditions. Some of the recommendations for prevailing management principles are:

1. Grazing must be assessed in the context of biodiversity. It must contribute to promoting biodiversity rather than generating a negative impact.
2. Alpine management must generate landscape heterogeneity, which is necessary for maintenance of biodiversity in these ecosystems.
3. Predator removal to protect grazing sheep is not sustainable.
4. Grazing represents both cultural and aesthetic values that are important for peoples' identity.

Based on these principles, the group recommended that management be based upon five main themes:

1. Ensure sustainable economics for sheep farmers
2. Develop better structure for organized grazing to ensure appropriate grazing pressure
3. Contribute to innovation in sheep farming
4. Strengthen the social acceptance for sheep grazing
5. Strengthen the administrative and legal tools for managing alpine grazing

5.2 ES generated by wild reindeer

Purpose of work: Kaltenborn et al. (2017b) provide an example of the work NINA has contributed to exploring issues related to the ES provided by wild reindeer living in the Norwegian mountains.

Involved parties: Kaltenborn et al. (2017b) describe an opinion survey of residents from two regions with extensive reindeer habitat in southern Norway. The work was a collaboration between NINA researchers and a member of the Norwegian University of Science and Technology (NTNU) faculty. The work was funded through a grant from the Norwegian Research Council.

Methodology: The authors used a data collection agency to administer a structured questionnaire to 1000 participants. The researchers identified a sample population of residents of Rondane and Setesdal region such that survey participants were represented the demographics for the 10 municipalities in these two regions. The surveys used three batteries of statements (39 statements total) that dealt with (1) potential management objectives for wild reindeer in a larger land use planning context, (2) the role of reindeer in mountain communities, and (3) wildlife value orientations. Statements about reindeer covered consumptive and non-consumptive uses of reindeer, and addressed the possible benefits to both individuals and communities. The authors used Partial Least Squares path modeling to explore possible relationships between wildlife values, attitudes towards management and the perceived importance of reindeer for mountain communities.

Spatial and temporal scale and extent: Rondane and Setesdal regions each cover a contiguous area bounded by a 100 x 100 km extent. Respondents' addresses were not specified nor georeferenced beyond the region in which they live. There was no temporal component to the work.

Key findings: More than half of the respondents expressed either great or very great interest in the issue of wild reindeer management, and only 12% expressed no interest in the topic. The benefits of wild reindeer include both the consumptive (provisioning ES) and non-consumptive (cultural ES) objectives. A majority of those who expressed interest in reindeer management generally had little or no interaction with them: attesting to the importance of cultural ES that reindeer generate. The authors generated an *ecocentric to anthropocentric* axis of environmental orientation from the survey responses, using the New Environmental Paradigm scale (Dunlap 2008, Dunlap et al. 2000). The ecocentric value orientation was more related to the non-consumptive management objectives, rooted in concerns about local development and the educational potential of wildlife in maintaining culture and harvesting traditions. However, Kaltenborn et al. (2017b) found that the NEP axis did not explain residents' attraction to reindeer. Instead, interest in reindeer was influenced by sustainability concerns (i.e., relative importance of ecological dynamics versus human benefits) and to what extent reindeer interests should be given priority over other land uses.

Challenges and uncertainty: This this assessment of ES associated with wild reindeer did not involve georeferencing. Uncertainty is largely limited to the representativeness of the respondents with respect to the regions' residents, and how we might draw inference with relevance to management from their answers.

Connections to other work: It is important to note that the authors never mention ES explicitly in their paper. Instead, they use other terminology (e.g., benefits and values) that identify the work's links to an ES framework and the ES cascade conceptual model. NINA has a long tradition of research addressing both the ecological and social aspects of managing wild reindeer populations in mountain ecosystems. Explicit reference to ES and use of an ES framework is absent in much of it. This generally means that relevance to ES mapping/assessment—as well as ecosystem accounting—may not be immediately apparent.

NINA has also worked with several projects that involve integrating emerging concepts regarding cultural ES with pre-existing concepts from the social sciences like *well-being* and *sense of place.* We provide another example in Chapter 7.3 (from the Lofoten archipelago).

5.3 Carbon storage

Purpose of work: Bartlett et al. (2020), which we present in Chapter 3.1, also included estimates of the carbon budget (i.e., potential of carbon storage and sequestration) in alpine and cryospheric (frozen) ecosystems. Again, the purpose of the work was to emphasize the vital ES that Norwegian landscapes and ecosystems provide in sequestering carbon, and explore how climate change and management practices may aggravate or mitigate this function. The published report provides a an overview of the potential of carbon storage within key Norwegian ecosystems, with suggestions for management strategies to preserve or encourage the sequestration and storage within them.

Involved parties: Bartlett et al. (2020) is a NINA report, commissioned by the World Wildlife Foundation (WWF) of Norway. WWF helped determine the topics the report should address, but the contents and the orientation of the work was determined by the NINA researchers credited with authorship of the report.

Methodology: The report combines statistics on land use and land cover (LULC), covering the entire land area of mainland Norway (excluding the territory of Svalbard). The authors collected estimates for the carbon budgets using data from studies published in the scientific literature. Parameters used to calculate on carbon stocks and flows (primary production, respiration, and storage) are from recent studies conducted either in Norway or other countries whose mountain areas are ecologically similar. Bartlett et al. (2020) calculated the land area made up of alpine zones from land cover estimates provided by area frame surveys conducted through the 'Norwegian land cover and land resource survey of the outfields' (abbreviated as AR18x18), as described by Bryn et al. (2018). An area frame survey provides land cover information based on representative and unbiased sample of wall-to-wall mapped plots, and was completed after 10 years of field work. Data on the area covered by glaciers was taken from the online database, provided by Norwegian Water Resources and Energy Directorate (Norges Vassdrags- og Energidirektorat NVE) (2019). Data on the extent of permafrost was taken from a model-derived map of permafrost for Norway, Sweden and Finland (Gisnås et al. 2017).

Bartlett et al. (2020) generated values for primary production, respiration, and net carbon flow (all measured in Gg C yr^{-1} for the entire country), as well as total storage (Gg C for all of Norway) for alpine areas using estimates from the literature, differentiating between zones based on categories of vegetation types. Values for glacial carbon content were similarly drawn from the literature. Estimating the role of permafrost in the global carbon budget is an active area of study, and Bartlett et al. (2020) present their evaluations of how recently published work can be extrapolated to Norwegian land cover, but advise caution in interpreting estimates due to a high degree of uncertainty concerning permafrost depth and rate of warming.

This work primarily addressed the ecosystem process and function. The report also addressed benefits with regards to the contributions carbon uptake and storage make to global carbon cycles and global climate mitigation.

<u>Spatial and temporal scale and extent:</u> The analyses detailed in the report are conducted at a national scale for a single point in time. LULC data from both aforementioned sources is available as polygons, and reported to the nearest km^2. The report discusses the proposed changes to carbon stocks and flows as consequences of changing climate, LULC, and forestry management practices.

<u>Key findings</u>: Alpine and cryospheric ecosystems in Norway are the nation's second largest stock of stored carbon, behind forests. Estimates vary from 708 000 to 2 420 000 Gg C, with most storage occurring in the alpine heath and shrub vegetated areas. Both of these areas are approximately equally large, with each covering nearly 40 000 km^2.

<u>Challenges and uncertainty</u>: Sources for information about alpine and cryospheric land cover extent are both current, easily accessible and have low uncertainty. Assessment of carbon stores is less certain. Bartlett et al. (2020) generated estimates using data from the published literature, which either described work conducted in Norway or in neighboring countries with comparable conditions. Validating estimates was beyond the scope of their work.

6 Cropland

6.1 SIS-Pollination

Primary purpose of work: NINA has worked on several projects provide examples of mapping and assessment of pollination in agricultural, or cropland, ecosystems. One example, called SIS-Pollination, assessed how wild pollinators (bumblebees and solitary bees) respond to variation in landscape features in the agricultural landscapes in South-East Norway with production of apples and red-clover seed. Kallioniemi et al. (2017) describes work from this project that investigated how the local resource quality and landscape composition influence pollinators, and if and how the effects vary in space and time.

Involved parties: The project was led by the Norwegian Institute for Nature Research (NINA) in cooperation with the Norwegian Institute of Bioeconomy Research (NIBIO) in the red-clover part of the project. It was also linked to a Norwegian initiative to support the global process under the IPBES assessment of states and trends of pollinators, supported by the Norwegian Environment Agency.

Methodology: Kallioniemi et al. (2017) investigated how variation in resources availability at both the landscape (2 km radius) and local (50 m transects) scale influenced bumblebee species richness and abundance. They collected data over two years in south-eastern Norway, where agriculture is highly modernized but landscapes still show limited spatial homogenization. The study involved 26 landscape areas clustered in two regions (**Figure 7**), with apple and red clover fields located in the center of each landscape area. Investigators recorded bumblebee occurrences by netting as they walked along transects, and recorded flower resources (species and abundance).

Spatial and temporal scale and extent: The 26 landscapes were clustered in two areas in south-eastern Norway, covering a representative area of the apple and red-clover seed production in the region.

Key findings: Bumblebee density and species richness was strongly and positively correlated with local (transect-scale) flower density and species richness. However, local bumblebee abundance was actually lower in landscapes with higher landscape-level flower species richness. Early and late mass flowering crops had clear, but contrasting, effects. The total area of early-flowering crops had a consistent negative impact on bumblebee density and species richness throughout the season, while late flowering crops had a positive impact in the beginning of the season before their bloom—suggesting a carry-over effect from previous years. The authors proposed that the negative effects of early flowering crops could result from competition between bumblebees and the domestic honeybees that are widely used in these crops.

Bumblebee density and species richness were clearly negatively correlated with the total area of forest and flower-poor land use areas, including grass fields and cereals. In contrast, bumblebees abundance was positively associated with most linear elements in the landscape (especially pasture and cropland verges). Roads were an exception, and decreased bumblebee densities, possibly due to increased mortality. The results show that the quality and the spatial and temporal distribution of flower resources within the landscape are important drivers for bumblebees, but can create counterintuitive distribution patterns depending on the temporal and spatial resolution of the survey. Increasing flower resources in linear elements and the amount of late mass-flowering crops may be viable management measures to improve conditions for bumblebees in moderately intensified landscapes.

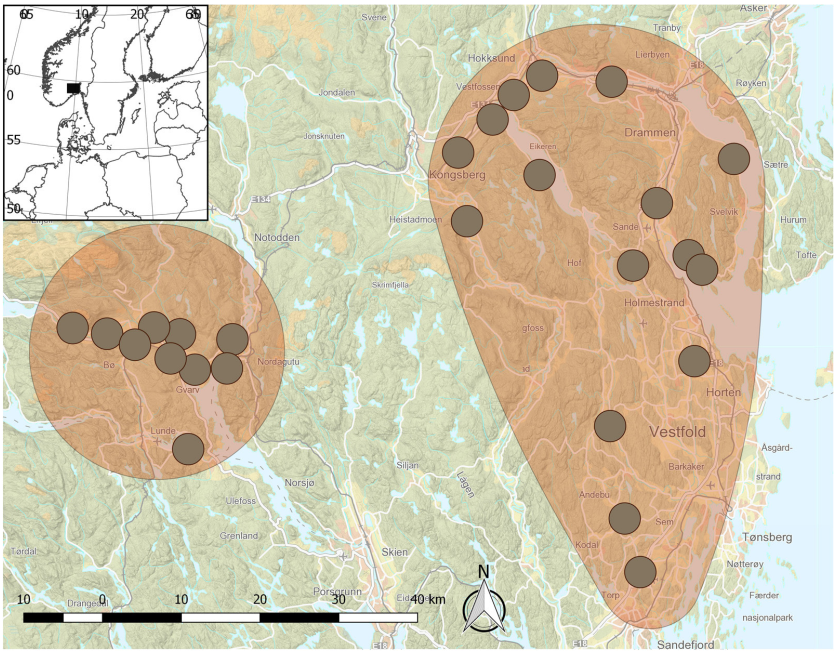

Figure 7: *Map with locations of the 26 study landscapes of 2 km radius (plotted to scale) in southern Norway covering in total 327 km². The study locations were divided into east and west clusters for the analysis as shown.* ***Source****: Kallioniemi et al. (2017)*

Challenges and uncertainty: This study provides empirical quantitative data on bumblebee occurrences, the quality of the landscape and of the floral resources. The conclusion that management practices of the crop (such as the use of honey bees as pollinators) affect the abundance of wild pollinator populations indicates that these factors need to be considered when assessing the contribution of biodiversity in agriculture. Likewise, crop management practices need to be incorporated into models describing the ecological condition of agricultural ecosystems and pollinator ES supply.

More accurate quantitative estimates of habitat quality and pollination effectiveness need to be collected to help shape and target policy instruments, such as direct payments to farmers to enhance wild-pollinator habitats (agri-environmental schemes) or financial penalties for use of practices that harm pollinators (e.g., pesticide use). Three ongoing projects on wild bees and other pollinators aim at improving the evidence in these areas.

Connections to other work: NINA researchers contributed to a test of the United Nations Food and Agriculture Organization (FAO)'s protocol for assessing pollination deficits (Vaissière et al. 2011), which was part of a global initiative aimed to support the assessment on pollinators and pollination services under the IPBES (Potts et al. 2016). The results of this assessment have been reported by Garibaldi et al. (2016). This FAO pilot used a coordinated protocol across regions and crops to quantify to what degree enhancing pollinator density and richness can improve yields. Data were collected from 344 fields in Africa, Asia, and Latin America—including a Norwegian case from apple orchard landscapes—with 33 pollinator-dependent crop systems in small and large farms. The investigators measured flower-visitor species richness, and concluded that it would be possible to increase crop yield, particularly in smaller parcel sizes, with greater abundances and diversity of pollinators.

6.2 Economic valuation of pollinator contributions in Ås municipality

Primary purpose of work: Researchers from NINA and Statistics Norway (SSB) demonstrated how existing data could be used in economic valuation of pollination services provided by wild bee species. The work was part of the development of methodology for ecosystem accounts (see Chapter 8).

Involved parties: Statistics Norway (SSB) and NINA contributed to the report, which was part of a Eurostat project lead by SSB.

Methodology: SSB and NINA collaborated to use satellite imagery, together with national land resource maps for Ås municipality, to create detailed maps of agricultural production in the municipality. This map identified all crop types, including those that were dependent upon pollination for optimal growth. The authors used the ESTIMAP pollination module developed for Oslo (described in Chapter 4.2) to generate a map of habitat suitability for wild pollinators (bumblebees and other wild bee species) in Ås and the neighboring municipalities. They then assessed the availability of wild pollinators for pollination of crops grown in Ås municipality through a simple proximity (spatial overlap) analyses, using the criteria described by Klein et al. (2007) to identify which crops have production that is demonstrably sensitive to receiving cross pollination from insects. For the Ås municipality study site, these crops included strawberries, cabbage, potatoes, onions/leeks, rapeseed/canola, fruits/berries, vegetables and carrots. However, because carrot seeds, starter cabbage plants and potato tubers are produced elsewhere, estimates of pollinator contributions to production in Ås do not include consideration of these crops.

The authors then used the same approach as Remme et al. (2018) to estimate pollinator visitation, and pollination effect for each crop type. They then assign a % yield loss expected in the absence of pollinators, based on pollination dependence as described in Klein et al. (2007). They calculated the potential yield losses in the absence of pollinators, based on the area of each crop and crop production per unit area. Estimates for avoided yield loss are then converted to estimates of economic value using relative production volumes and market prices for the various crop types, which represents an estimate for the value of the pollination ES.

Spatial and temporal scale and extent: Ås municipality covers 103 km^2. Land resource maps were available in vector form (1:5 000), and Sentinel 2 satellite imagery provided information on vegetation at 10 m rasters. Data for agricultural production was available for a single growing season.

Key findings: Pollinator dependent crops grown in Ås municipality are capable of being accessed by the wild bee pollinators that presumably live in suitable natural habitat. All parcels of all pollinator-dependent crop types were within 500 meters of areas described by ESTIMAP as containing optimal or near optimal (> 0.8) habitat (Figure 8)[10]. Moreover, the area within a 500m radius of the parcels containing crops consistently had mean ESTIMAP habitat suitability scores close to 0.5. Together, these results indicate that the landscape surrounding crops is likely capable of supporting populations of wild bee species outside of the period of time when crop plants are flowering. Pollinator contributions to crop production may be greatest when crop parcels are surrounded by areas with moderate pollinator habitat suitability. Moderately lower abundance of natural floral resources can give foraging bees a greater incentive to seek crop plants' flowers for pollen and nectar resources during periods when crop flowering is at its peak.

[10] ESTIMAP pollinator model describes pollinator habitat suitability with values between 0 and 1, where 1 represents optimal habitat with abundance flowering resources and 0 represents area with no flowers or potential nesting sites. See Chapter 4.2 for additional detail on the ESTIMAP-pollination model.

Crops in Ås municipality that are either moderately or greatly dependent upon animal pollinators cover 1305 decares, or 4.5 % of the municipality's total area used for agricultural production. Most of the crops grown in this area are grains and cereals, which are wind pollinated. Pollinator contributions to crop yield will naturally be greater in regions that focus more on pollinator dependent crops. For the crops grown in Ås that are highly pollinator dependent (e.g., rapeseed, strawberries and fruits and vegetables), close to two-thirds of their production could be lost without contributions from wild pollinators.

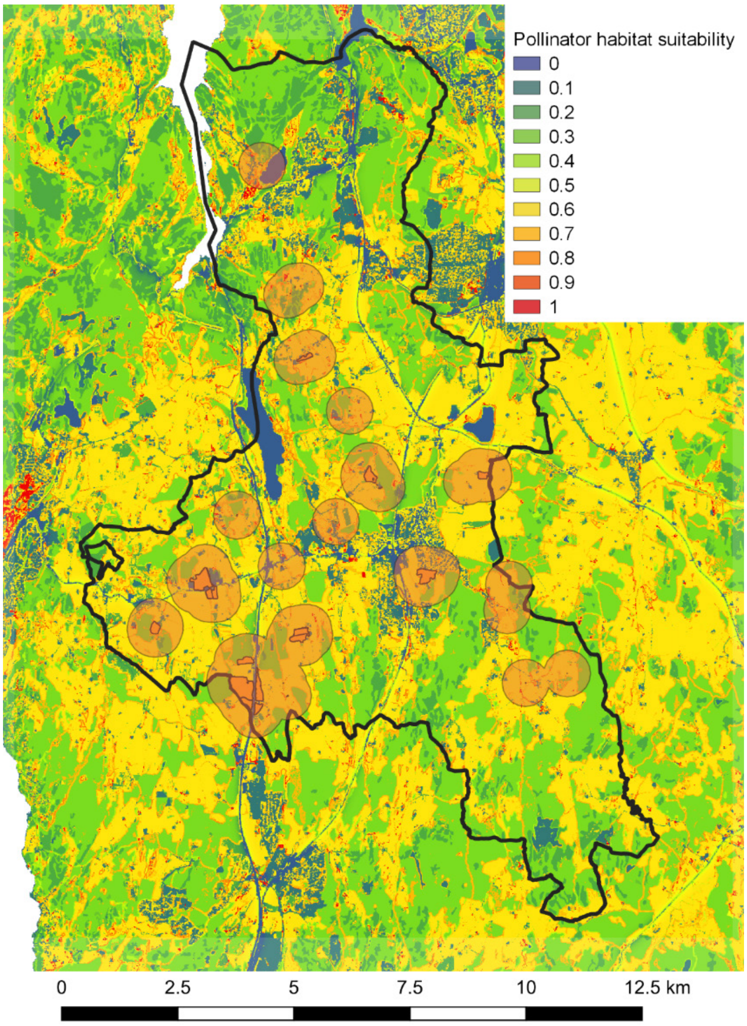

Figure 7. An example of a spatial overlap analyses to assess proximity of optimal wild bee pollinator habitat to crop locations. Orange polygons indicate areas used for cultivating rapeseed/ canola, with 500 m buffers surrounding these areas.

<u>Challenges and uncertainty:</u> The estimated economic value pollinating insects make to crop production is subject to several assumptions. Firstly, this approach assumes that our model of pollinator habitat quality reflects actual pollinator abundances for this area, and that the pollinators will contribute to crop pollination when the areas used for cultivating crops are within foraging distances of insects' nest sites. While the ESITMAP model was been verified with field sampling of pollinator insects (Stange et al. 2017), pollinating insect visits in the agricultural areas have not been evaluated. While the parameter for flight distance used in the analyses comes from the Netherlands, it is consistent with reported flight distances in Norway. The ESTIMAP model also does not include any consideration of climate effects that can affect pollinator activity. Unusually cool (< 15°C), wet and windy weather decreases insect flight activity and foraging ranges.

However, the proximity of high quality habitat to pollination dependent crops in Ås municipality was such that that pollinator visitation rates are unlikely to decrease even with substantially shorter flight distances in years with cooler summer temperatures.

6.3 Other related work in cropland ecosystems

The Norwegian government launched a strategy to protect wild pollinators in 2018 (Norwegian Ministries 2018), and an implementation plan is currently being defined. The strategy has stimulated applied research on pollinators, including the following ongoing projects:

- POLLILAND, which aims at producing prediction models of wild bee habitat suitability based on GIS layers of climate and soil conditions and flower resources in hay meadows and other open habitats in the agricultural landscape (Sydenham et al. under review). POLLILAND covers practically the entire area of South-eastern Norway, which is an important agricultural area and a bee diversity hotspot in the country. POLLILAND is funded by the Norwegian food and agriculture agency.

- MetaComNet, which addresses the two main questions: (i) how are plant-pollinator interaction frequencies affected by assembly processes acting at regional, landscape, and community spatial scales?, and (ii) can we use this information to predict the structure of interaction networks and the resulting pollination function? MetaComNet will estimate the relative influence of the scale-dependent species assembly processes through a series of predictions, each linked to a specific spatial scale and thereby with direct or indirect influences on pollination function on crops and wild plants. Similarly to POLLILAND, MetaComNet also covers the South-eastern region in Norway.

- APPLECORe and POLYGON are two associated projects that aim to assess pollination effectiveness of fruit crops and the correspondence between wild pollinators diversity and landscape composition. The projects both use advanced molecular techniques, and address four central research themes. The first research theme outlines a series of experiments with the goal of ascertaining the relative pollination capabilities for wild and managed pollinator species for pome fruit production. The second theme presents the application of a novel method to analyze population genetics data to infer pollen-mediated gene flow in the landscape, its role in improving fruit yield and quality, and identify landscape features and management practices that can facilitate or hinder geneflow. The third theme integrates data collected in the project with existing data in biodiversity databases to investigate the role of climate in regulating pollinator assemblages and make predictions for how changes in these pollinator assemblages resulting from climate change will effect pollination provisioning and fruit yields. In the fourth theme, APPLECORe will test the introduction of a wild mason bee species in apple orchards and assess the effect of this introduction on pollination effectiveness. APPLECORe works in the two main fruit production areas, i.e. south-eastern and western Norway, respectively. APPLECORe is funded by the Ministry of Agriculture and Food through the Research Council of Norway, and the Grofondet (a research fund established by the fruit production and retail industry). POLYGON is a strategic institute program at the NINA.

6.4 Relevant issues for mapping and assessing cropland ES

Designing instruments for spatial planning and incentives for farmers (e.g., European Commission 2020b, a) will require maps with higher resolution and greater accuracy that can capture important attributes related to pollination services and other cropland ES (e.g., pest control by natural enemies). These attributes include small patches with resources for pollinators such as crop field verges, flower strips, and smaller areas of semi-natural grassland and other early succession vegetation (Sydenham et al. 2020), as well as maps of suitable nesting sites and other environmental conditions (Sydenham et al. in review).

There are also important knowledge gaps about how the quality of these habitats might influence both pollinator diversity and other agricultural biodiversity. We have limited understanding of how the spatial variation in agricultural biodiversity corresponds with pollination effectiveness in crops, and subsequently to crop yields. Other aspects of cropland management—including the use of agricultural chemicals (herbicides and pesticides), the timing of mowing (affecting flower and habitat availability), and the use of managed bees—are also critical factors affecting the condition of cropland ecosystems that are presently not well represented in a spatially explicit way.

Whereas ES assessments generally seek to communicate with stakeholders in the environment sector, the system of ecosystem accounts seeks to facilitate communication with representatives from the corporate sector. Yet there is still considerable uncertainty related to the economic value of pollination services. For instance, we have only a very general understanding of wild pollinators' effectiveness at crop pollination (a central topic addressed in the APPLECORe project) or how we might assign a monetary value to this service. The approach used by Remme et al. (2018) described above (Chapter 6.2) provides a framework for including the value in crops, but this approach remains unvalidated. Other models have been developed and tested to value pollination using a welfare-based valuation approach, where consumer and producer surpluses are considered (e.g., Hanley et al. 2015). However, there are presently no proper valuation studies of pollination in an accounting context that use a valuation approach in which consumer surplus is not considered.

7 Marine and coastal

7.1 Values in Oslo Fjord

Primary purpose of work: Chen et al. (2019) provide the state of the knowledge on the economic values of Oslo Fjord, using ES as a methodological framework for their report. They used existing data to estimate the value of cultural ES (in particular the outdoor recreational use and tourism), regulating ES (carbon storage and sequestration) and provisioning ES (commercial fishing). The work also calculated estimates for the values of wastewater treatment, sediment remediation and oil spill protection that improve environmental quality and support various uses of the fjord.

Involved parties: The project was led by the Norwegian Institute for Water Research (NIVA), with contributions from NINA, Menon Economics consulting, and Statistics Norway (SSB). The work was financed principally through a contract from the Norwegian Environmental Agency.

Methodology: Chen et al. (2019) use several different approaches to economic valuation of ES:

1. Market prices, which are the direct utility values of provisional ES (tourism, commercial fishing and lobster harvest) and expenses associated with environmental quality improvement (water treatment and cleansing polluted sediments)
2. Capital costs, which are the direct utility values of property connected to cultural ES (motorized leisure boats and real estate near Oslo Fjord)
3. Time valuation, which are the direct utility values of cultural ES (walking and recreational boating)
4. Simulated prices and transaction values, the direct utility values of (water quality connected to outdoor recreation activity)
5. Hedonic property (real estate) pricing the direct utility values for cultural ES (aesthetics, as pertaining to prices of residential real estate near Oslo Fjord)
6. Willingness to pay, which are the direct, indirect and non-utility values in measures for environmental quality improvement (water quality, preventing oil spills and cleaning of polluted sediments).

The report also mentions travel costs (the direct utility values for cultural ES), although the authors conclude that there are no relevant examples from either Norway or other Nordic countries that support use of this method for Oslo Fjord. Finally, the authors stress that the results from these methods are not necessarily comparable or commensurable. Different methods have different purposes (awareness raising, accounting, prioritization and evaluation of measures, policy development, and legal replacement).

Spatial and temporal scale and extent: The study investigated valuation for two regions that contain and surround the Oslo Fjord. The Inner Oslo Fjord, which includes the 7 municipalities at the northernmost portion of the fjord, falls within an extent covering roughly 1500 km^2. The outer Oslo Fjord, which includes the 20+ municipalities along the southernmost portion of the fjord, lies within an extent covering roughly 10 000 km^2. Information on residents' use of the fjord for general outdoor recreation was available for three years: 2010, 2013, and 2016. Other metrics, such as the number of bathers in the fjord, were available for all years between 2010 – 2016. Many of the variables (e.g., km of shoreline walking paths, and number of households that own boats) are expressed at a municipality scale. These metrics were then aggregated into either the Inner or Outer Oslo Fjord region. Other variables, such as distance of a residence from the fjord's waterline, were available as continuous variables ranging from 50 m up to 600 m (beyond which the effect of distance was approximately equal).

Key findings Outdoor recreation activities represent the most valuable ecosystem service among the services that Chen et al. (2019) managed to quantify. The annual recreational value to the population living in municipalities along Oslo Fjord for walking on the beach or along the coast, boating and swimming in the sea is estimated at 25.7 billion NOK $year^{-1}$.

Actual annual cost of about 2.7 billion NOK year^{-1} are spent on municipal treatment of wastewater to comply with health regulation and the requirements of good ecological status. Based on results transferred from freshwater environments, the annual willingness to pay of the population along Oslo Fjord for wastewater treatment that ensures the quality of outdoor recreational activities is estimated at 4.3 billion NOK year^{-1}. Operational and capital costs for recreational boating amount to 2.6 billion NOK year^{-1}, confirming the large willingness to pay for the access to leisure activities in the fjord. Investments in housing near the coastline also indicates the large willingness to pay for access to the fjord. Proximity to the fjord is valued at 63.5 billion NOK in the markets for individual houses and apartments around the Inner Oslo Fjord. This is equivalent to 1.5 billion NOK year^{-1} with a 0.9% discount rate over 50 years. The authors did not estimate the fjord's contribution to the housing market in Outer Oslo Fjord area due to lack of available studies. The monetary values of commercial fishery and tourism are relatively low compared to other ES. Willingness to pay for current recreational fishing is also relatively low comparing to values of other recreational uses. Actual costs for sediment remediation amounts to several hundred million NOK for harbors located in both the Inner and Outer Oslo Fjord areas.

Challenges and uncertainty: Beyond the uncertainty associated with methodological challenges and data availability, Chen et al. (2019) stress that user conflicts also create uncertainty about the projection of value estimates into the future. The authors summarize media analysis together with expert knowledge in a user conflict matrix, identifying how reduced access to the beach zones, invasive species such as the pacific oysters, marine litter, risks of oil spills, risks of boat accidents and noise from boat traffic may threaten the values of outdoor recreational activities for other users in Oslo Fjord.

The report concludes that information on ecosystem extent, environmental quality and user data for both the water's edge and the fjord will improve the valuation knowledge basis. Such data, the authors contend, could be acquired through integrating maps and data registered with environmental authorities, municipalities and NGOs in a georeferenced database. Additional investment in spatial user data from satellite imagery, mobile phone apps and mobile networks could provide information on waterfront and fjord use that can assist with analyzing policy measures.

7.2 Developing a Coastal Barometer for Northern-Norway

Primary purpose of work: The goal of the Ocean Health under Blue Transformations (BlueTrans) research project is to create a Coastal Barometer where the local population, interest groups and decision makers can get information on the social, environmental and economic state of coastal communities in Northern Norway tied to marine ecosystems, and whether conditions are sustainable. This entails developing indicators that reflect the status of locally relevant sustainability goals.

Involved parties: NINA researchers lead the work. Other participants include researchers from the University in Tromsø (UiT), The Norwegian Institute of Food, Fisheries and Aquaculture Research (Nofima), The Norwegian Institute for Water Research (NIVA), and Norwegian Institute of Marine Research (Havforskningsinstituttet); as well as two consulting firms. The project recruited 54 stakeholders from six municipalities along the North-Norwegian coast. These individuals represented a wide range of sectors, including tourism, fish farming, environmental protection and outdoor recreation, hunters and fishermen, seafood industry, developers, architects, students, and more. The project received funding from the Norwegian Research Council.

Methodology: Engen et al. (2020) summarizes input collected from stakeholders using questionnaires, interviews and focus groups from the six aforementioned coastal communities in

Northern-Norway. Data collection involved use of the “Nominal Group Technique,” which is a qualitative method for eliciting judgement from stakeholders (Hugé & Mukherjee 2018). This began by soliciting individuals’ responses to questionnaires and continued with brain storming and group discussions during focus group meetings.

Based on the stakeholders’ input, the research team identified local sustainability principles and criteria that reflect whether current development trajectories comply with these principles. The report also includes assessments of whether data are available for measuring these criteria, identifies areas of data deficiency, and looked at the opportunity to acquire lacking information using surveys during the project period.

The Coastal Barometer (CB) has its origin in the “Ocean Health Index,” (OHI)). The OHI gives municipalities, regions, or countries a value of 0-100 based on how sustainable the state and trend is for several provisional, regulating and cultural ES combined (Halpern et al. 2012). These ES are:

1. Food provision: production (i.e., aquaculture) and harvest of seafood
2. Artisanal (i.e., traditional) fishing opportunities
3. Harvest of non-food natural ocean products
4. Carbon storage
5. Protection coastal of habitats that safeguard shores against erosion and flooding
6. Livelihoods and economies
7. Tourism and recreation
8. Sense of place: protecting iconic species and special places
9. Clean waters
10. Protecting biodiversity

The goal of the CB is to develop indicators for the ES that are relevant for local decision makers and populations in Northern Norway with respect to spatial scale and local drivers.

Spatial and temporal scale: The project area for the Coastal Barometer includes all 81 coastal municipalities in Northern-Norway, spanning a stretch of the Norwegian coast that is roughly 1000 km long (**Figure 8**). The six municipalities are Vega, Vågan, Tromsø, Skjervøy, Hammerfest and Vardø.

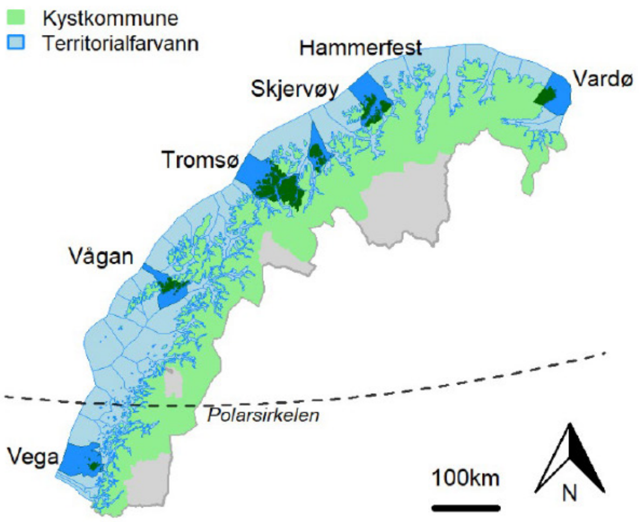

***Figure 8**. The project area for the Coastal barometer include all coastal municipalities in Northern-Norway, including both the green land areas and the light blue ocean areas. Municipalities where local stakeholders participated in indicator development are highlighted. From Engen et al. (2020).*

Key findings: The work with developing sustainability indicators was ongoing at the time that this report was being prepared, and the list of indicators to be used for each attribute of coastal sustainability was still being evaluated for feasibility and appropriateness. Engen et al. (2020) provide several potential indicators, including both the locally- relevant sustainability principles and the criteria necessary to evaluate whether the principles are met. While we do not attempt to provide a complete list of all candidate indicators, we do provide some examples:

1. **Food provisioning** was divided into two subcategories: aquaculture and fisheries. Principles for sustainability included good regulation and management, no pollution, biodiversity maintenance, effective use of resources, local and small-scale production, utilization of a broad range marine species, among others. Potential indicators included
    a. Aquaculture: production of Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta trutta*), and rainbow trout (*Oncorhynchus mykiss)*, in tons ocean area^{-1}; parasitic salmon fluke abundance and distribution; consumption of fish feed (data supplied the Norwegian Directorate of Fisheries, or NDF); and the level of local pollution.
    b. Fisheries: Fish harvests will be assessed according to recommendations based on maximum sustainable yield (MSY; Halpern et al. 2012); the NDF fisheries tables can provide information about effects of the different fisheries on the ocean floor (i.e., the benthic flora and fauna), bycatch, and loss of equipment that can lead to ghost fishing.
2. **Local fishing opportunities**. Principles for sustainability include recruitment of fishers, access to resources, opportunities for sale and export of catches, and harvesting a broad range of marine species. Indicators included metrics for catch in relation to MSY of harvested species, and other indicators identified under fisheries above.
3. **Harvest of non-food natural ocean products** is an attribute of the OHI that is not included in the Norwegian CB.
4. **Carbon storage**. The principle for sustainability is simply to utilize the possibility for carbon storage in marine plants. Indicators include data from models of large brown algae (*Laminaria hyperborea*) and sugar kelp (*Saccharina latissimi*), and potentially data on kelp harvesting along the coast of Northern Norway.

5. **Protection of coastal habitats that safeguard shores against erosion and flooding** is an attribute of the OHI that is not included in the Norwegian CB.
6. **Livelihoods and economies**. Aside from the principles for sustainability addressed in the context of fishing and tourism, both the principles and criteria for this attribute have limited relevance to ES.
7. **Tourism**. Principles for sustainability include care and maintenance of quality experiences for visiting tourists and little to no negative environmental impact—plus others with less relevance to ES. Indicators included use of data from social media and visitor surveys to collect new data on visitor attitudes; and new local resident surveys to collect new data on the environmental impacts of tourism.
8. **Recreation and sense of place** are combined in the CB for Northern Norway. The nine principles for sustainability included safeguarding locally important places, the environment, and local traditions—plus several others with less relevance to ES. Here Engen et al. (2020) propose that a representative segment of the local population participate in a mapping exercise to identify locally important areas. Data on undisturbed natural areas can also be utilized.
9. **Clean waters**. The sustainability principle is simply the need to remove existing pollution and prevent further pollution of coastal waters, to make them free of pathogenic (disease-causing) organisms, waste and pollution. The CB will use a water quality classification to measure the degree of eutrophication, environmental pollution, and condition of biological factors such as benthic fauna and common eel grass (*Zostera marina*). Monitoring of plastic waste in marine environments can be measured with using two beaches that are participating in a monitoring program, but there is uncertainty regarding the beaches' representativeness. Lack of data presents problems with measuring other aspects of pollution (e.g., pathogenic organisms).
10. **Protecting biodiversity**. The sustainability principle is simply to prevent and halt the loss of biodiversity. Possible indicators include observing the diversity of fish species along the coast using data collected by the Norwegian Institute for Ocean Research (*Havforskningsinstituttet*), as well as looking for changes in the abundance and distribution of seabirds from a national program for monitoring seabird populations in Norway (SEAPOP). Other indicators include data on the condition and extent of kelp forests and coral reefs, which are available through the MAREANO research project.

Challenges and uncertainty: Long-term funding for annually updating and revising sustainability indicators based on new data and increased knowledge is needed.

Connections to other work: The Coastal Barometer draws on the framework of the Ocean Health Index and is as such connected to other local, national or regional efforts to measure Ocean Health worldwide. The CB is also connected to other Fram Centre funded projects such as ArcticStakes[11] and InclusiveCoasts[12] and the Norwegian Research Council project OPTIMAKELP[13]. Future projects will also be based on the CB. It provides a synthesis of large amounts of social, ecological and economic data which can be used to assess a range of research questions. The CB also serves as a multi-stakeholder platform for ongoing dialogue about coastal sustainability.

7.3 ES in the Lofoten archipelago

Primary purpose of work: NINA researchers have published a series of papers exploring the socio-cultural context of the ES generated by the coastal ecosystems of the Lofoten archipelago.

[11] https://arcticsustainability.com/2020/06/15/arcticstake/
[12] https://arcticsustainability.com/2020/06/15/inclusivecoasts/
[13] https://www.optimakelp.net/

The Lofoten archipelago in Northern Norway is a an example of a resource-rich rural region facing difficult choices about the best strategies to adopt when moving towards a sustainable future. The ongoing political debate concerns whether the region should be open for off-shore oil- and gas development, or reserving the waters and islands for traditional fisheries and world class nature-based tourism (Høgi, 2010; Misund & Olsen, 2013). Furthermore, the region is struggling to manage the massive tourism pressure that results from growing global recognition as an attractive travel destination. While the archipelago is a coastal environment, the dominant landscape features are the mountain peaks that rise from the shoreline to 1000 m above sea level, and it is these mountains which provide much of the aesthetic-cultural ES for this area.

Several papers from the same project present interesting insights into how coastal communities balance competing interests and trade-offs between different ES. Kaltenborn et al. (2017a) described how the benefits derived from ES are fundamental building blocks in the local vision of quality of life for the residents of the islands of Røst municipality at the southern end of the archipelago. Kaltenborn et al. (2019) used in-depth interviews of tourists (domestic and international visitors) to ascertain the core elements of the tourism experience for those visiting Lofoten. Finally, Kaltenborn et al. (2020) surveyed a representative sample of the population in the archipelago to examine how public interest in management issues and attachment to place influence the appreciation of cultural ES benefits.

<u>Involved parties</u>: The studies were funded by the Norwegian Research Council. NINA researchers used a polling agency to conduct telephone interviews.

<u>Methodology</u>: Kaltenborn et al. (2017a) collected data from the Røst municipality in three stages: (1) five semi-structured interviews with key informants to collect preliminary information; (2) observations of practice and informal encounters with 30 people; and (3) participatory scenario process with twelve Røst residents representing political, educational and commercial sectors. Kaltenborn et al. (2019) used a qualitative study approach and convenience sample to gather data on tourists in Lofoten, with interviews conducted during two periods in the summer at six locations that are popular tourist attractions (i.e., focal points for recreational opportunities).

Kaltenborn et al. (2020) collected data through telephone interviews from 403 persons in five of the six municipalities in the Lofoten archipelago's area. Each interview lasted approximately 20 minutes. The survey contained four sets of questions, a) place attachment to the Lofoten islands, b) interest in management issues, c) the role of ES benefits as a source of good experiences. Place attachment included four dimensions relating to the natural aspects of the physical surroundings: sea, recreational opportunities, the mountains, and wind/weather. This and other dimensions were derived from statements describing links between ES "good experiences and basic human needs and effects of levels of place attachment."

<u>Spatial and temporal scale and extent</u>: The Lofoten archipelago lies between 67 - 68° N, including seven major islands and a large number of smaller ones. The group of islands has a land area of 1 300 km^2, spread across six municipalities, with a total population of approximately 25 000 residents—as well as a large number of seasonal workers in the tourism and fish processing industries. The landscape is characterized by rugged mountains (rising to 1000 masl), fjords and inlets, small and medium sized towns, and smaller areas suitable for agriculture and livestock.

<u>Key findings</u>: Røst municipality's residents viewed their natural environment and its abundant fish stocks as an integral part of their cultural heritage, resulting in cultural ES that are closely intertwined with provisional ES. Residents' sense of wellbeing was closely tied to maintaining cultural identity through traditional natural resource harvesting practices (i.e., fishing), nurturing skills, and acting meaningfully in one's local environment (Kaltenborn et al. 2017a). The interactions with nature are what provided meaning to the cultural ES, and it was difficult to separate the contributions from natural and social capital to the locals' sense of a good life.

The main message that emerged from the interviews with Lofoten visitors was that the nature, landscape and recreational potential is what draws tourists to the archipelago (Kaltenborn et al. 2019). Compared with other categories of cultural ES, the spectacular scenery and recreational opportunities seemed to be more important than other attributes or services linked to the environment. The attractiveness of the landscapes also generated potential for social relations: the area was viewed as a “favorable arena” for meeting friends and family for social gatherings, as well as making new friends.

The traditional hallmarks of the Lofoten islands—the mountains and the seascape, as well as weather and light conditions—were deemed quite significant for the local sense of place (Kaltenborn et al. 2020). Survey participants indicated that the mountains were a key dimension of their place attachment: mean score = 4.34 on a 5-point scale, where 4 = fairly large importance and 5 = very large importance. For example, the statement, “The Lofoten environment gives me many beautiful experiences of nature” had a mean score = 4.87 on the same 5-point scale.

These findings suggest that cultural ES provide an important contribution to quality of life in this region, and help satisfy numerous needs: understanding, creation, identity, freedom, participation, protection and leisure. Cultural ES also constitute prominent environmental attributes which contribute to the basic needs of being, having, doing and interacting. Kaltenborn et al. (2020) found that the importance of ES benefits for well-being increases with increasing attachment to the Lofoten environment.

Challenges and uncertainty: The authors state that “Improved concepts and methods for identifying how the environment contributes to quality of life emerges as a paramount challenge cross-culturally,” and present their study as a small step in the direction of that goal by showing that both cultural and provisioning ES can act as satisfiers of human needs (Kaltenborn et al. 2020). The challenges associated with all three studies have less to do with data collection or uncertainty of the results, and more to do with how to apply these insights to a management or policy context. More specifically, how can articulation of cultural ES importance be combined and compared with other sources of information related to instrumental values, so that different types of values can be assessed and ranked. (Kaltenborn et al. 2017a) managed to link emerging ecosystem cultural service concepts with pre-existing “good life” concepts from the social sciences which can link new frameworks with tried and tested concepts.

8 Ecosystem accounts

The System of Environmental Economic Accounting - Ecosystem Accounting is the integrated statistical framework for ecosystem accounting (UN 2021). The SEEA-EA comprises a consistent system of accounts, developed over the last 10 years, that organizes information on ecosystems and the benefits that they provide to society—building largely on the conceptualization of ecosystem services (Haines-Young & Potschin 2018, van Dijk et al. 2018) and the methodological approaches that support their assessment (Dunford et al. 2018, Geneletti et al. 2020, Harrison et al. 2018). Ecosystem accounting aspires to provide ecosystem valuation as integrated geospatial information, in which multiple layers of information (geographical, environmental, ecological, and economic) are brought together and summarized in accounts (UN 2021).

The United Nations Statistical Commission endorsed the SEEA-EA framework as a new field of national accounting in March, 2021. The framework has been under development and testing in Norway and several other countries—including those participating the EU-funded project MAIA[14] (Mapping and Assessment for Integrated ecosystem Accounting), which aims to use the SEEA-EA as a methodological basis to promote mainstreaming of natural capital accounting in EU Member States and Norway. The MAIA project is being implemented in 11 countries, with 20 partners.

The SEEA-EA is the first example of ecosystem accounting that uses a spatially explicit approach. It is built on five core accounts, following the "cascade" conceptualization of ES (sensu Haines-Young & Potschin-Young 2018, Haines-Young & Potschin 2010). The ES delivery process is deconstructed into a linked set of five key components that span both the supply and demand aspect of the ES (**Figure 9**). The core accounts are compiled using spatial data and information about the functions of ecosystem and the ES they produce. The SEEA-EA's spatially explicit approach differs from the SEEA Central Framework (UN 2014), which uses a spatially implicit approach to look at individual environmental assets—such as water or energy resources.

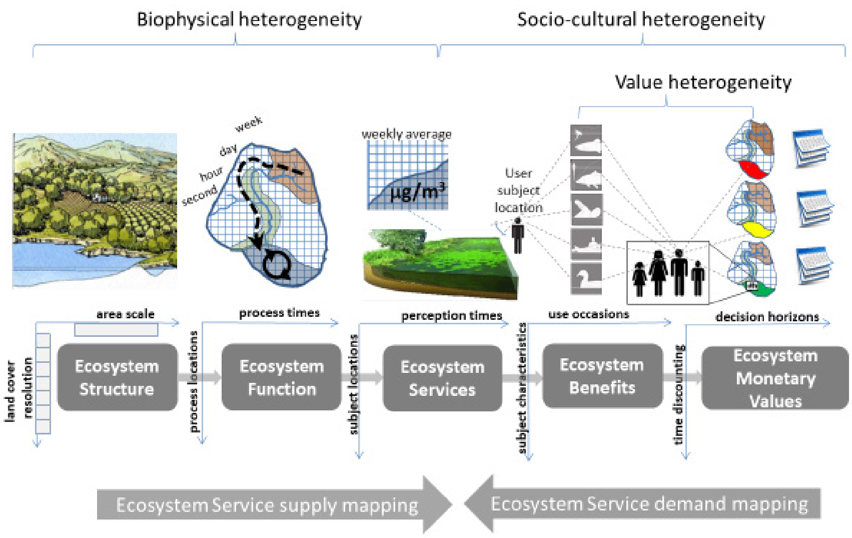

Figure 9. *The ecosystem services cascade conceptualization provides the structure for SEEA-EA. Representation of the components of the cascade (ecosystem structure, function, services, benefits and values) are all context dependent, and can vary according to variables represented by the axes that surround each component, creating both biophysical and socio-cultural heterogeneity.* ***Source:*** *adapted from Barton et al. (2018), Barton et al. (2015a)*

[14] https://maiaportal.eu/

The five ecosystem accounts are:

1. Ecosystem extent accounts record the *total area* of each ecosystem, classified by type, within a specified geographical context (the "ecosystem accounting area"). Ecosystem extent accounts are measured over time in ecosystem accounting areas (e.g., nation, province, river basin, protected area, etc.). They can illustrate the changes, or transitions, in the extent of area from one ecosystem type to another over the accounting period. A prerequisite for ecosystem accounts is a operational typology of ecosystems and their geographical representation. (We provide details of the work that contributes to further development of ecosystem extent accounts in Chapter 8.1)

2. Ecosystem condition accounts record and represent the features of ecosystems' assets in terms of selected characteristics at specific points in time. Repeated measures at regular intervals record potential changes to the features over time, thus describing trends in the features' status. Continued development of the SEEA-EA framework will require identifying appropriate spatially-explicit indicators of ecosystem condition. (We provide details of the work that contributes to further development of ecosystem condition accounts in Chapter 8.2)

3. & 4. Ecosystem service flow accounts (physical and monetary) record the supply of ES by ecosystem assets (3) and the actual use of those services (4). Different models represent ES flows, including InVEST (Natural Capital Project[15]), ESTIMAP (a European adaptation of InVEST models developed by the Joint Research Centre) and ARIES[16].

5. Monetary ecosystem asset accounts record information on stocks and changes in stocks (both additions and reductions) of ecosystem assets. This includes accounting for the changes in ecosystem condition (both degradation and enhancement). The development of the methodologies for these accounts are still under development.

While the ES cascade conceptual model provides the general structure for the SEEA-EA, the ES cascade and the SEEA-EA differ slightly in how they address and partition the biophysical attributes of ecosystems that provide for basis for ES generation. The ES cascade model depicted in **Figure 9** (Haines-Young & Potschin-Young 2018) describes ecosystems in terms of *ecosystem structure* and *ecosystem functions*. Ecosystem *structures* refer to the biological and physical elements within an ecosystem (e.g., its vegetation, fungi, and animal life—as well as how these elements are distributed in 3D space). Ecosystem functions refer to the ecological processes: the biological, chemical and physical interactions among ecosystem components (e.g., primary productivity, evapotranspiration, reproduction, vegetative growth, predation, etc.). The SEEA-EA ecosystem extent accounts capture one aspect of ecosystem structure as conceptualized in the cascade model (i.e., the area of an ecosystem) and the ecosystem condition accounts encompass both the structure and function components in the of the ecosystem. The characteristics and processes described through ecosystem structure and function are observable and measurable, but are not themselves flows of ES as defined in ecosystem accounting (UN 2021). The connection to users and the context of this connection are what defines an ES and the importance users attach to these ecosystem structures and functions. For instance, the process of primary productivity can be translated into the amount of carbon sequestered by the ecosystem, a desirable ES that generates benefits related to climate mitigation actions. Both the cascade and the SEEA-EA are alike in terms of how they conceptualize the links between ES and the benefits they provide and value can be assigned to those benefits.

We use pollination of agricultural products (Chapter 6.2) to illustrate how the SEEA-EA can be applied to a specific ES:

[15] https://naturalcapitalproject.stanford.edu/software/invest
[16] https://aries.integratedmodelling.org/

1. The model starts by identifying an ecosystem asset. In this case it is the extent of areas with natural vegetation and soil or deadwood substrates that provide foraging resources and nesting habitat for wild pollinators. Ecosystem assets are measured in area units (e.g., Sydenham et al. in review)
2. The asset can be further described in terms of its condition, through indicators that reflect it overall quality. Ecosystem condition can be evaluated based on per cent cover with flowering plants, amount of nesting substrate, wild bee species' relative abundance, number of species, or species compositional diversity (e.g., Kallioniemi et al. 2017, Sydenham et al. in review).
3. The insects living in these ecosystems generate an ES by pollinating the pollinator-dependent crops. ES can be expressed based on pollination visitation rates to crops in growing in fields within flying distance of wild pollinator habitat (e.g. POLYGON and APPLECORe projects in described in Chapter 6.3).
4. The benefits generated by pollinating insects are the increase in crop production, or avoided loss that would have occurred if pollinators hadn't contributed. (measured both with mass per area unit (e.g., kg/ha) and monetary valuation (e.g., Chapter 6.2).
5. The beneficiaries are both the agricultural producers (farmers) who achieve better yield from their efforts and the consumers (households) who avoid paying higher prices for food (measured in local or international currency).

Work conducted within the Urban-EEA project[17] has sought to facilitate the implementation of ecosystem accounts in Norway through pilot studies based on urban green infrastructure and the ES it generates. Urban-EEA has mapped and assessed ES in the Oslo Region, and explored methods for ecosystem accounting at the municipal level. It has developed new spatially explicit indicators for the various accounting components and integrated these indicators with those generated in earlier projects that also addressed green infrastructure ES. The GIS data generated through Urban-EEA have been compiled in an open access GIS resource platform: the Oslo's Urban Nature Atlas[18] (Kruse et al. In press).

8.1 Ecosystem extent

Reliable information of land cover provides the basis for ecosystem accounts. Statistics derived from land cover data also permit monitoring of how climate and land-use changes impact ecosystems. However, much of the existing land cover information available at the national and regional scale in Norway uses insufficient resolution and lacks important detail regarding variation in land cover classes (ecosystem types). Data from field surveys can provide a greater level of detail, but only smaller areas have presently been mapped using this approach (Bryn et al. 2018).

Data for country-level land cover mapping have also been limited, with an overrepresentation of intensively managed land, especially agricultural land. Forest types have also been coarsely mapped, despite forest covering almost 40% of Norway's land area (Bartlett et al. 2020). Forest maps from Norway's national forest inventory (Breidenbach et al. 2020) include data and forest classification criteria that are meaningful for forestry, but are less useful for assessing forest condition with respect to its capacity to generate other ES.

Norway's most recent land cover map is based on a standard vegetation type mapping system (VK25) where vegetation types represent more or less stable entities of plant communities characterized by physiognomy (the overall structure or physical appearance of a plant community), plant species composition, indicator species, or a combination of all three (Bryn et al.

[17] https://www.nina.no/english/Fields-of-research/Projects/Urban-EEA
[18] http://urban.nina.no/maps/?limit=100&offset=0

2018). The VK25 mapping system is adapted to an intermediate scale (between 1:20 000 and 1:50 000) with a minimum polygon size of 0.5 ha (Bryn et al. 2018). It describes vegetative cover at two hierarchical levels: groups (12) and types (54). The area frame survey methodology used in the VK25 has revealed considerable underestimation in previous estimates of some ecosystems' extents. For example, VK25 increases percentage wetlands cover from 5.8 to nearly 9 % of the total land area (Bryn et al. 2018).

The coarse spatial and thematic resolution of these maps can present limitations for national scale mapping of small-parcel habitat types, such as the areas that provide flower resources and nesting sites for pollinating insects. For this reason, there are ongoing efforts underway to produce maps with higher resolution that can accurately represent important habitats with small area (e.g., Venter et al. 2019). including urban green infrastructure (Cimburova & Barton 2020, Cimburova & Barton 2021, Soy Massoni et al. 2018, Stange et al. 2017). The pilot project on green infrastructure accounting in Oslo, the Urban – EEA project, has produced fine scale maps of multiple urban green spaces and structures, including nature-based solutions as green roofs (Venter et al. In press).

A major initiative is underway to address shortcomings in both spatial and thematic resolution at a national scale. Norway's newest system for classification of natural land cover is *Natur i Norge*[19] (Nature in Norway, or NiN). NiN describes three hierarchical levels of diversity (i) landscape type, (ii) ecosystem and (iii) living conditions at the organismal scale. These levels are defined such that they capture all levels of biodiversity. NiN has a separate section for habitat mapping, which is still under testing and further development. NiN mapping uses five different spatial resolutions: 1:500, 1:2500, 1:5000, 1:10 000 and 1:20 000. To date, mapping has been conducted primarily in protected areas and in ecological research projects and directed mainly at threatened/red-list habitats.

8.2 Ecosystem condition

8.2.1 The Norwegian Nature Index (*Naturindeksen*)

Norway developed the Nature Index (NI) as a metric to express the condition of biological diversity of ecosystems and selected species groups. It is designed to show trends in major ecosystems, based on a large number of indicators that represent different aspects of biodiversity. Indicators for the NI include species from the main taxonomic groups (algae, lichens, fungi, plants, invertebrates, fish, amphibians, birds and mammals) with data from monitoring programs and other sources in seven main ecosystems in Norway: the ocean, coast, freshwater, wetland, forest, mountain and open lowland ecosystems. Indirect indicators give additional information on the biodiversity potential of an area (e.g., presence of dead wood in forests). The latest assessment (Jakobsson & Pedersen 2020) uses a total of 260 indicators to summarize the state of biodiversity in Norway for the years 1990, 2000, 2010, 2014 and 2019 (**Figure 10**).

[19] Natur i Norge (artsdatabanken.no)

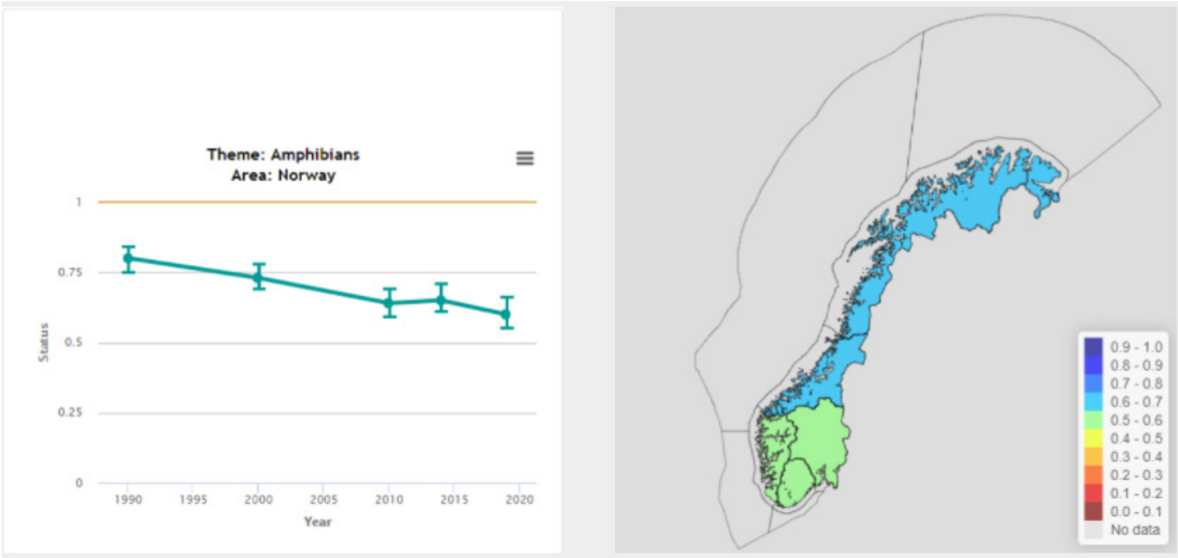

Figure 10 *Status of amphibians in Norway from 1990 - 2019. Source: The Nature Index for Norway https://www.naturindeks.no/*

The main methodological framework for NI was developed prior to the first release in 2010 (Certain et al. 2011, Nybø et al. 2010, Skarpaas et al. 2012). The NI framework builds on the concept of a reference condition, which is defined for each ecosystem as a "state with negligible human impact, with given climatic conditions and species distributions in the climate normal period (1961–1990)" (Jakobsson & Pedersen 2020). For semi-natural systems, the reference state is represented by a condition that has been shaped by historic, low intensity management practices but without other substantial human impact.

The NI provides a national- and regional-level metric of the state of biodiversity to report in the national statistics. In this sense, it has an awareness raising function (**Figure 1**). Through the use of expert assessments, NI values can be linked to the direct drivers responsible for deviations from the reference condition. In the 2020 assessment, for instance, the NI values of terrestrial and freshwater ecosystems are mainly driven by impacts due to land use change and infrastructure development. In contrast, climate change and the direct exploitation of marine species seem to be the main pressures on the NI for marine ecosystems (Jakobsson & Pedersen 2020). These NI assessments mirror the approach used by the IPBES in its global assessment of the drivers responsible for change in terrestrial, aquatic and marine ecosystems (IPBES 2019a).

At present, however, the NI does not provide information necessary for formulation and/or implementation of instruments supporting local decisions (i.e., provide spatially explicit data on ecosystem condition at the county, municipality or parcel level). Moreover, the indicators used in NI are also poorly suited to provide insights into the ecological condition of ecosystems, and specifically the functions that underpin ecosystems' capacity to generate ES.

8.2.2 Technical system to assess ecological condition of ecosystems

Building on similar principles regarding reference state and sets of indicators in the NI and the NiN classification, Norway has developed a technical system for assess the ecological condition of ecosystems (Nybø & Evju 2017). The Ministry for Climate and Environment commissioned the development of a comprehensive technical system that would rely on *"scientific indicators" and "existing and accessible scientific knowledge on the condition and development of Norwegian ecosystems, and build on and supplement existing relevant classification systems".* The system covers all terrestrial ecosystems and marine systems not covered within the standards developed under the EU's Water Framework Directive (WFD). This includes forest, alpine, arctic tundra, wetlands, semi-natural systems, natural open ecosystems below the tree line and marine ecosystems.

The technical system describes ecosystems by seven properties that reflect ecosystem structure and function, while considering ecosystems' natural dynamics, to a large extent in agreement of those proposed in the UN Statistics Commission guidelines (2021). These include primary production, distribution of biomass between trophic levels, diversity of functional groups, important species and biophysical structures, area estimates in relation to species survival (landscape ecological patterns), the change in species composition, and abiotic factors. The report recommends a set of 336 separate indicators for these properties. Data currently exists for 213 of these indicators, but new monitoring will need to be developed and implemented for 123 of them.

Like the WFD, the EU Marine Strategy Framework Directive (MSFD), and Norway's NI, the recommended technical system described in Nybø and Evju (2017) also proposes assessing ecological condition with reference to a designated reference condition that generally represents intact nature. An ecosystem with "good ecological condition" is defined as one with small deviations from its reference state, or not significantly affected by modern industry and systemic human impacts. As with the NI, the technical system uses what they deem the Normal Period 1960−1990 as a reference for climate, and accounts for management practices that shape semi-natural ecosystems (grazing, haymaking, fire, hunting). The technical system describes the assumptions behind setting reference states, including those underpinned by ecological theory, the challenges of defining a reference state in the Anthropocene, and the normative content of establishing the desirable condition of ecosystems given societal needs and the trade-offs that arise among multiple nature management goals.

The report (Nybø and Evju 2017) sets the Norwegian technical system in the context of EU and international criteria for the assessment of good ecological condition and associated indicators. These include the MSFD[20], Natura 2000[21], restoration objectives, the Living Planet Index[22], the GLOBIO model[23] and the Natural Capital Index[24].

The system is currently being tested on various ecosystems (e.g., forests; Framstad et al. 2021), and with regards to the recent adoption of the SEEA-EA framework (UN 2021). Statistics Norway (SSB) and the research organizations behind the development of both NI and the technical system for the assessment of ecological condition have actively participated in the SEEA – EA process (Aslaksen et al. 2015, Framstad et al. 2021, Jakobsson & Pedersen 2020, Töpper & Jakobsson 2021).

8.3 NINA's contributions to the development of the SEEA-EA framework

Several projects have made considerable conceptual and methodological advances to the SEEA-EA framework. NINA has had important roles in many of them, building on both early and ongoing projects that include: (1) The OpenNESS http://www.openness-project.eu/ project which aimed at operationalizing the concept of ES, where NINA lead the work package on ES valuation methods. (2) The ESMERALDA http://www.esmeralda-project.eu/ project provided methodological support to the Mapping and Assessment of Ecosystem Services process under Target 5 of EU's Biodiversity Strategy 2011-2020. (3) Statistics Norway and NINA are partners

[20] EU Marine Strategy Framework Directive | European Commission (europa.eu)
[21] Natura 2000 - Environment - European Commission (europa.eu)
[22] Living Planet Index | WWF (panda.org)
[23] GLOBIO - Global biodiversity model for policy support - homepage | Global biodiversity model for policy support
[24] World Natural Capital Index (solability.com)

in the MAIA project https://maiaportal.eu/ whose specific aim is the mapping and assessment for integrated ecosystem accounting. (4) Norwegian researchers from NINA are coordinating lead authors of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) report on Values and Valuation of Biodiversity (forthcoming).

In both OpenNESS and MAIA, NINA has piloted accounting of urban green infrastructure in Norwegian cities (e.g., Kruse et al. In press) with several examples of economic monetary and non-monetary valuation of ES (e.g. Venter et al. forthcoming). We provide other examples of economic valuation of urban ES under Chapter 4, and an economic valuation of pollinator contributions to crop production in Chapter 6.2.

8.4 Decision contexts and the ES framework components addressed by examples in this report

We have plotted the examples we presented in this report (**Figure 11**) in the same three-dimensional space as **Figure 1**. Most of the ES mapping and assessment efforts attempted to date have been limited to either awareness raising or accounting (where reliability and accuracy requirements of ES-related data are lower). Only very few have been intended for use for either priority setting, instrument design, or litigation (values 3-5 on the reliability and accuracy axis). Acquiring detailed information for ES assessment at large scales with high spatial detail is costly, and few examples have attempted to do both.

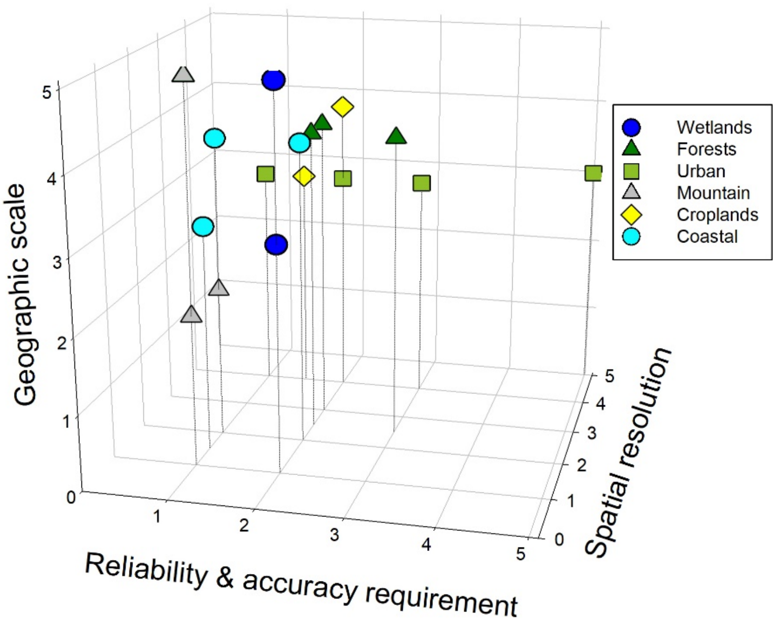

Figure 11. *Examples of ES mapping and assessment (**Chapters 2-7**), distributed in a 3-dimensional space (reflecting the scale, resolution and the accuracy requirements for potential governance purpose) similar to that depicted in **Figure 1**.*

The examples we present in this report are, with few exceptions, not examples of ecosystem accounting. Accordingly, only very few of the example address all of the components of the ES cascade that correspond with the various SEEA-EA accounts (**Table 1**). Nonetheless, the examples provide insight into conceptual approaches and methodology that can be useful in ecosystem accounting contexts. Because the majority of these examples come from projects that preceded the development of the SEEA-EA framework and are independent of an accounting context, we present **Table 1** in relation to the components of the ES cascade (Haines-Young & Potschin 2010) and not the SEEA-EA framework.

Table 1. *Examples of ES mapping and assessment projects presented in this report, together with the components of the ES cascade that the projects address. Filled table cells represent cascade components address explicitly (either quantitatively or qualitatively). Cells with (x) represent cascade components addressed either implicitly or indirectly.*

Example	Name	Ecosystem structure	Ecosystem function	Ecosystem service	Ecosystem benefits	Benefit value
2.1	SusWater			X	X	X
2.2	VALUESHED		(x)	X	X	X
2.3	Valuation of Wetland ES	X	X	X	X	X
3.1	Carbon storage in Forests	X	X	X	(x)	
3.2	Capacity and flow of ES	X	X	X	X	X
3.3	Using ES to evaluate priorities	X	X	X	X	X
3.4	Wildlife management	(x)	(x)	X	X	X
3.5	TRANSFOREST	X	X	X	(x)	(x)
4.1	Urban nature-based recreation	X		X	X	X
4.2	Economic value of urban ES	X		X	(x)	X
4.3	ESTIMAP urban pollination	X	(x)	(x)	(x)	
4.4	Valuation of urban trees	X	(x)	X	X	X
5.1	Livestock grazing in mountains	X	X	X	X	
5.2	ES generated by wild reindeer			(x)	X	
5.3	Carbon storage in mountains	X	X	X	(x)	
6.1	SIS-pollination in croplands	X	X	X	X	X
6.2	Economic valuation of pollinator contributions in Ås municipality	X	X	X	X	X
7.1	Values in the Oslo fjord			X	X	X
7.2	Coastal sustainability barometer	X	X	X	X	X
7.3	ES in Lofoten archipelago	(x)		X	X	(x)

8.5 Prospects for future work

Development of a system of economic ecosystem accounts (SEEA) has been underway for about a decade, building upon advances in ES science that include the Economics of Ecosystems and Biodiversity report (TEEB 2010). The goal of this work has been to identify tools and mechanisms that can make the value of biodiversity (i.e., its *importance*) visible and capable of informing economic decision-making by showing the interdependence of human well-being with biodiversity and the condition of ecosystems. The IPBES Global Assessment expressed the importance of using an ES perspective to enact the “transformative changes” (IPBES 2019b) that will be necessary if the global community is to achieve the UN’s 17 goals for sustainable development[25]. Tools like the SEEA-EA methodology can help achieve a transition towards sustainability (McElwee et al. 2020, Turnhout et al. 2021). As a spatially explicit framework representing ecosystems and ecosystem services, SEEA-EA is suited to inform decisions related to land

[25] THE 17 GOALS | Sustainable Development (un.org)

planning. Ecosystem Accounting can help design and implement actions to address habitat destruction that occurs through land use intensification and homogenization, which is the major direct driver of biodiversity loss and degradation of terrestrial ecosystems (IPBES 2019).

In Norway, ecosystem accounting can inform processes and decisions that have an impact on land-use and land-use change. This will include informing the implementation of the Plan and Building Act that regulates infrastructure development and urbanization (Plan og bygningsloven; KMD 2008) and the Energy Act that regulates development of renewable energy infrastructure (Energiloven; OED 1990). Ecosystem accounting can also contribute to the implementation of the Biodiversity Act that regulates the management and protection of threatened species and habitats (Naturmangfoldloven; KLD 2009), which provides the basis both for national strategies for protecting species and species groups (e.g., the national strategy for protection of wild pollinators; De norske departmenta 2018) and for guidelines for environmental impact assessments.

Future work can bridge information gaps by improving maps of ecosystems at the scale, resolution, and accuracy necessary to inform the desired level of decision-making (Figure 1; Barton et al. 2018). When reviewing the case studies we describe in this report, we have identified several critical gaps that must be bridged so that we may implement a system of biophysical ecosystem accounts in Norway. These include:

1. Establishing a coherent institutional platform, cross-disciplinary and cross-sectoral, with clear mandates and roles, to enable development of the needed capacities and coordinate the work.
2. Establishing the infrastructure for data sharing that enables interoperability of data sources and open access, following the FAIR principles of environmental data sharing. Existing sources for relevant data are presently highly fragmented.
3. Improving the geographic representation of ecosystems at appropriate scale for a designated accounting context. The current characterization and monitoring of land use and land-use changes are based on old methods that are not suitable for ecosystem accounting purposes (i.e., they are a skewed representation of ecosystems towards agriculture and forestry, covering only ca. 40% of Norway's land area). The current methods do not allow annual monitoring of changes. Bridging this gap will require a new approach to ecosystem mapping, using technology that couples remote sensing and ground data.
4. Developing reliable, spatially-explicit indicators of ecosystem condition that can represent ecosystems' different states and thereby have relevance for reporting and monitoring changes. Remote sensing techniques, validated by robust ground data, provide a promising opportunities for the biophysical mapping of ecosystem condition (Kissling et al. 2018, Venter et al. 2021) and ES (Venter et al. 2020b).
5. Selecting and parametrizing models that describe ES capacity (i.e., the amount or level of an ES that can be generated) as a function of ecosystem condition.
6. Continuing work that establishes methodologies for economic valuation, and
7. Refining methods to recognize cultural ES and their implicit non-monetary values, and incorporating these values in analytical approaches together with economic valuation.

The ecosystem accounting conceptual approach provides exciting opportunities for a broader set of applications within the sphere of decision-making support. Examples include informing performance-based direct payments to farmers through the implementation of the new common agricultural policy (CAP; European Commission 2020a) and reporting of corporate social and environmental responsibility standards (European Commission 2020b). However, the information costs for designing economic policy instruments, like direct payments, are considerably higher than the costs of acquiring the information needed for awareness raising or for generating public or private accounts (Barton et al. 2018). Policy instrument design requires greater data reliability and accuracy, at larger geographic scales and with higher resolution than what is currently available. Realizing SEEA-EA's potential will involve innovations in generating the necessary data for ecosystems' extent, condition and the ES these ecosystems generate.

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