Ecosystem Services and Forest Management in the Nordic Countries

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Abstract

The need to integrate a full spectrum of ecosystem services into decision-making has been long acknowledged. Despite the exponentially growing body of literature, trade-offs resulting from management activities are still poorly understood. This thesis focuses on forest ecosystems in the Nordic countries, specifically on the impacts of forest management on provision of several ecosystem services and associated trade-offs. The impacts were studied from two research domains: biophysical and socio-economic, as well as their contribution to the decision support.

Existing scientific literature on assessments of several non-market ecosystem services in relation to forest management and the extent of their integration into decision support was systematically reviewed in Paper I. The findings suggest an uneven and limited coverage of services in the reviewed literature. Existing assessments are in their majority confined to a single research domain and focus on a single non-market ecosystem service. The same trends have been revealed in studies on decision support.

In the next three papers impacts of forest management on provision of different ecosystem services were investigated. In Paper II a structured expert judgment method (the Delphi technique) was applied to preservation of biodiversity and habitat in the boreal zone. Results suggested that management intensity has a negative effect on the potential to preserve biodiversity and habitat. A wide range of estimates was provided by respondents for functional forms of relationships between preservation of biodiversity and forest characteristics, suggesting little agreement. The findings support the usefulness of the Delphi method as a complementary technique for in depth analysis of ecosystem services provision. A choice experiment approach was applied in Paper III to examine the effect of variation in two forest characteristics (tree species composition and stand height / age) on recreational value within a stand and between stands in Denmark. Results confirmed findings from previous studies – variation presents a desirable feature within a stand. The study also shows that variation between stands has a positive effect on recreational value and in some instances it may outweigh contribution of variation within a stand. Paper IV reports results of a literature synthesis on the potential to provide three ecosystem services (timber, biodiversity conservation and cultural services) for two existing forest management alternatives for oak-dominated forests in Southern Sweden (intensive oak timber production and biodiversity conservation without intervention). It also uses existing studies to draw conclusions for a third hypothetical alternative. We identified several management options which result in complimentary synergetic delivery of the three mentioned ecosystem services.

Keywords: Non-provisioning ecosystem services, biodiversity, cultural services, expert assessments, multiple-use forestry, decision support, silviculture, trade-offs, valuation

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Dedication

To my family for being the calm in every storm and ever-lasting source of inspiration

> *In nature everything is connected, and there is nothing random in it* – Mikhail Prishvin

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Filyushkina A., Strange N., Löf M., Ezebilo E.E. & Boman M. (2016) Non-market forest ecosystem services and decision support in Nordic countries. *Scandinavian Journal of Forest Research*, 31:1. 99-110. doi: 10-1080/02827581.2015.1079643.

II Filyushkina A., Strange N., Löf M., Ezebilo E.E. & Boman M. (2016) Impacts of forest management on provision of ecosystem services: An application of expert assessment on biodiversity and habitat preservation in Nordic boreal zone (Manuscript).

III Filyushkina A., Taye F., Lundhede T., Strange N. & Jacobsen, J. (2016) Effects of forest characteristics on the recreational value: the case of tree species and height variation within and between stands (Manuscript).

IV Löf M., Brunet J., Filyushkina A., Lindbladh M., Skovsgaard J.P. & Felton A (2015) Management of oak forests: Striking a balance between timber production, biodiversity and cultural services. *International Journal of Biodiversity Science, Ecosystem services & Management*. doi: 10.1080/21513732.2015.1120780.

Papers I and IV are reproduced with the permission of the publishers.

The contribution of Anna Filyushkina (AF) to the papers included in this thesis was as follows:

I AF developed the research idea and design of the systematic review together with Niels Strange and Mattias Boman. She did literature search, selection of relevant publications and most of literature synthesis. As a first author AF wrote 85 % of the manuscript and was responsible for the correspondence with the journal.

II The idea and research design were developed by AF together with co-authors. She conducted data collection and analysis. As the first author AF is responsible for writing 90 % of the manuscript.

III AF developed the idea and design for the study together with co-authors. She was in charge of coordination with the survey company and setting the experiment up online. Data analysis was done by AF (40 %) and Fitalew Taye (60 %) with support from Jette Bredahl Jacobsen, Thomas Lundhede and Niels Strange. AF (60 %) and Fitalew Taye (40 %) wrote the manuscript with input from other co-authors.

IV AF was involved in developing the idea and hypothesis together with co-authors. She contributed 15 % to collection and synthesis of literature, and 15 % to writing the manuscript.

Abbreviations

AWTT	Aggregate Willingness To Travel
CE	Choice Experiment
CICES	The Common International Classification of Ecosystem Services
DKK	Danish krona
EU	European Union
FAO	The Food and Agriculture Organization of the United Nations
IPES	The Intergovernmental Platform on Biodiversity and Ecosystem Services
MEA	Millennium Ecosystem Assessment
PES	Payments for Ecosystem Services
RPL	Random Parameter Logit
SP	Stated Preferences
TEEB	The Economics of Ecosystems and Biodiversity
WTP	Willingness To Pay
WTT	Willingness To Travel

Introduction

Humans have altered ecosystems in order to meet growing demands for natural resources, with recent decades experiencing more rapid and large scale changes than any other period in human history (Daily 1997; Vihervaara et al. 2010; MEA 2005). Management activities directed at these natural resources contributed to degradation and loss of ecosystems and biological diversity (i.e. biodiversity). At the same time people heavily rely on the functioning of ecosystems and ecosystem services (i.e. benefits people obtain from ecosystems) (Foley et al. 2005; Daily 1997; MEA 2005). The concept of 'ecosystem services' bridges social and natural sciences, arguing that most research topics extend beyond frameworks of individual disciplines (Carpenter et al. 2009; Braat & Groot 2012). Focusing on human – environment interaction the 'ecosystem services' framework has often been used as a means of demonstrating how loss of biodiversity and general degradation of ecosystems affects the capacity of an ecosystem to provide services, including those of critical importance to humans (e.g. fresh water, food, soil stabilization) (Norgaard 2010; Fisher et al. 2008). Since many ecosystem services belong to the group of the so-called non-market services (i.e. services not traded on markets), it makes these services economically invisible. This results in a lack of consideration given to them in decision-making and thus could inflict further damage to the ecosystems (Daily et al. 2009; TEEB 2011).

The need to integrate non-market ecosystem services into decision-making is widely acknowledged (Daily 1997; Daily et al. 2009; TEEB 2011; de Groot et al. 2010; MEA 2005). Examples of international policy commitments and scientific efforts include the establishment of "Ecosystem Services Partnership" (ESP 2015), "Intergovernmental Platform on Biodiversity and Ecosystem services" (IPBES 2015), the incorporation of ecosystem services in the 2020 targets set by the 10th Conference of Parties to the Convention on Biological Diversity (Larigauderie & Mooney 2010), current mapping of ecosystem services initiatives within member states of the EU (Maes et al. 2011), "The Economics of Ecosystems and Biodiversity" (TEEB 2010) as well as follow-up studies assessing ecosystem services on regional and national levels (e.g. Bateman et al. 2013; Albert et al. 2015). In the Nordic countries recent attempts to generate information to support decision-making on non-market ecosystem services include a regional TEEB study (Kettunen & Vihervaara 2013), evaluation of various approaches to assess natural capital in the Nordic context (Mazza et al. 2013), investigation of issues and options for payments for ecosystem services (Zandersen et al. 2009), report on the state of biodiversity and development of indicators (Normander et al. 2009).

However, even with an exponentially growing body of literature devoted to ecosystem services (Fisher et al. 2009; Seppelt et al. 2011), scientific understanding remains one of the limiting factors for full integration of ecosystem services into decision-making processes on the ground (Daily & Matson 2008). The following questions present some of the knowledge gaps that still need to be covered: What are the relationships between ecosystem management and provision of ecosystem services (both individually and in a mix)? How can these relationships be quantified? How can outcomes of assessments be mapped or presented otherwise for use in planning and management? (de Groot et al. 2010; ICSU et al. 2008) In addition, an uneven coverage of ecosystem services in existing literature has been reported. This pertains to the services themselves, as well as to their geographical scope and required multi-disciplinarity (Seppelt et al. 2011; Vihervaara et al. 2010; Filyushkina et al. 2016). Contribution of existing literature to the decision support has often been questioned (e.g. Fisher et al. 2009; Mazza et al. 2013; Martinez-Harms et al. 2015). In order to foster the links between science, policy and management the need for more comprehensive and integrated approaches for both assessment and incorporation of ecosystem services into decision-making that combine research efforts from various disciplines has been expressed (e.g. de Groot et al. 2010; ICSU et al. 2008; Hooper et al. 2005; Bennett et al. 2009).

Management of natural resources is often targeting provision of a single ecosystem service. This could have a detrimental effect on provision of other services, functioning of ecosystems and thus human well-being (Foley et al. 2005). Forests represent one ecosystem that has a long history of multiple use (i.e. for round timber, firewood, mushrooms and berries, recreation, cultural heritage etc) (FAO 2016; Hytönen 1995), however their management has often been focusing on delivery of provisioning services such as timber. Increasing environmental concerns and demand for other services has been reflected in a growing body of literature devoted to impacts of forest management on provision of non-market ecosystem services (e.g. Paillet et al. 2010; Gustafsson et al. 2010; Duncker et al. 2012; Frank et al. 2015; Gundersen & Frivold 2008) as well as attempts to integrate them in decision support tools (e.g. Ananda & Herath 2009; Mendoza & Martins 2006). However, a recent review concluded that the majority of existing decision support tools does not include considerations for non-market ecosystem services (Segura et al. 2014). Thus, in order to support more informed decision-making there is a need to improve the understanding of impacts of forest management on provision of non-market ecosystem services and relationships between services (Carpenter et al. 2009; Kettunen & Vihervaara 2013; Duncker et al. 2012; Kuuluvainen et al. 2012).

Objective(s)

The main objective of this thesis is to contribute to the understanding of the impacts of forest management on provision of non-market ecosystem services and identify trade-offs and synergies for forestry decision-making in the Nordic countries.

The specific objectives are:

- To provide an overview of the coverage of assessments of selected non-market ecosystem services in relation to forest management and understand the extent of their integration into decision support in existing literature in the Nordic countries (Paper I).
- To determine the effect of several forest management alternatives on preservation of biodiversity / habitat and functional forms of relationships between biodiversity and forest characteristics (Paper II).
- To evaluate the effect of variation in forest characteristics (tree species composition & height (age) structure) both within a stand and between stands on recreational value of forests in Denmark (Paper III).
- To examine the capacity of three forest management alternatives to provide societies with timber, habitat for biodiversity, and cultural services, while analyzing associated trade-offs and synergies in oak-dominated forests (Paper IV).

Background

Ecosystem services: definitions & classifications

The 'ecosystem services' concept dates back to 1970s, when Westman (1977) suggested that the social value of the benefits that are provided by ecosystems to the society ('nature's services') could be potentially enumerated so that society could make more informed policy and management decisions. In the following decades the conceptual development of ecosystem services proceeded with mainstreaming in the literature in the 1990s (e.g. Costanza et al. 1997; Daily 1997). In the early 2000's the release of Millennium Ecosystem Assessment (MEA) marked another milestone, by synthesizing knowledge on the state of ecosystems around the globe and declaring once again importance of their integration into decision-making (MEA 2003; 2005). The MEA contributed immensely to putting the ecosystem services on the political agenda and since its release the number of studies increased exponentially (Fisher et al. 2009; Vihervaara et al. 2010)(see for extensive history account Gómez-Baggethun et al. 2010).

Definitions and classifications have been extensively debated in the literature (e.g. Fisher et al. 2009). According to Daily (1997) ecosystem services are "the conditions and processes through which natural ecosystems and the species that make them up sustain and fulfil human life", whereas MEA defines them as "the benefits people obtain from ecosystems" (MEA 2003). The more recent definitions include the one from TEEB in which ecosystem services are defined as "the direct and indirect contributions of ecosystems to human wellbeing" (TEEB 2010), The Common International Classification of Ecosystem services (CICES) complimented TEEB definition with "… and arise from the interaction of biotic and abiotic processes" (Haines-Young & Potschin 2011). There is no universally accepted definition of ecosystem services, but it rather depends on the context of an individual study (e.g. whether it is performed by a natural or a social scientist). The main focus on TEEB is on economic valuation of ecosystem services, whereas CICES addresses ecosystem accounting, and MEA aims at communicating general findings. For the general scope of this thesis we adopt the MEA definition.

As with definitions a number of classifications of ecosystem services exist. According to MEA (2003) ecosystem services are divided into four categories: provisioning, regulating, cultural and supporting. *Provisioning services* refer to biotic resources that can be extracted (e.g. food, timber); *regulating services* refer to processes that affect climate, air and water quality; *cultural services* are those providing recreational, aesthetic, spiritual benefits; and *supporting services* are underpinning other services and include nutrient cycling and soil formation. This last category has often been debated and concerns for double counting in monetary environmental assessments have been raised as supporting services may be accounted for in provision of other services (for example, nutrient cycling is a supporting service, but it also helps to provide a regulating service – water flow regulation) (Fisher et al. 2009). In their classification TEEB re-introduced habitat services, which include lifecycle maintenance and gene pool protection (e.g. maintenance of genetic diversity). This classification has been employed in Paper II.

The majority of non-provisioning ecosystem services fall under the category of "non-market ecosystem services", i.e. services that are not subject to market transactions. With their implicit price of zero they are often not fully integrated into decision-making. This thesis is focusing on several non-market (non-provisioning) ecosystem services such as biodiversity preservation, recreation and aesthetics and carbon sequestration as well as a provisioning service – timber production in how their delivery is affected by forest management.

Trade-offs and synergies between ecosystem services

A choice always involves a trade-off between some factors (e.g. delivery of services, financial returns, present vs future). Land use shapes the landscape and provision of ecosystem services. Thus, choice of land use and / or management regime results in trade-offs / synergies between different ecosystem services. A trade-off between two services refers to the increase in provision of one services combined with the simultaneous decrease in provision of the other services (win – lose). Existence of a synergy implies that an increase in provision of one service has no or positive effect on provision of the other service (win – win) (Raudsepp-Hearne et al. 2010; Rodríguez et al. 2006). Both trade-offs and synergies can occur due to simultaneous response to the same factor (e.g. management activity, other disturbance) or due to interactions among services (Bennett et al. 2009). In this thesis both perspectives are considered.

Trade-offs can occur between categories of services, within services themselves (e.g. mountain biking vs bird watching, preservation of different taxa with different requirements for the habitat) as well as in time and space (Rodríguez et al. 2006). The most common trade-offs recorded in literature are between provisioning and non-provisioning (non-market) ecosystem services (e.g. Chan et al. 2006; Geijer et al. 2011; Kettunen & Vihervaara 2013; Turner et al. 2014). When management is focused primarily on delivery of provisioning services (e.g. round wood, bioenergy), generally provision of other services is being compromised. For example, more intensive forest management practices in some regions have been associated with lower ability to preserve biodiversity (Kuuluvainen et al. 2012; Duncker et al. 2012). However, there are other examples, where more intense management activities are beneficial for the provision of non-market ecosystem services. Studies suggest a possibility for synergistic relationship between timber production and recreation, i.e. in some instances people prefer managed compared to unmanaged forests (e.g. Ribe 1989; Gundersen & Frivold 2008). Existing literature suggests insignificant trade-offs and in some instances synergies between preservation of biodiversity and provision of other non-market ecosystem services (e.g. Hooper et al. 2005; Chan et al. 2006; Harrison et al. 2014). Moreover, on a landscape level greater diversity of ecosystem services is associated with provision of regulating services (Raudsepp-Hearne et al. 2010).

Improving understanding of trade-offs between ecosystem services for various land uses and their quantification is paramount for integration of ecosystem services into decision-making, especially so in the light of demand for delivery of multiple ecosystem services (Nelson et al. 2009; Foley et al. 2005; Cowling et al. 2008; Bennett et al. 2009). Without this knowledge there is a risk of unwanted declines in provision of some services and potential degradation of ecosystems. Together with goals set for the area this knowledge is guiding the choice of management alternative and specific activities within it.

Assessment of impacts of management on provision of ecosystem services

There is no disagreement among researchers on the fact that assessment of impacts of management on provision of ecosystem services and resulting trade-offs between them is paramount for their integration into decision-making (Kareiva et al. 2007; Carpenter et al. 2009). It can be performed from the perspective of different research domains (disciplines), which in the literature are sometimes also referred to as 'value domains'(e.g. Martín-López et al. 2014). De Groot et al. (2002) identify the following three domains: ecological (biophysical), socio-cultural and economic (monetary). In this thesis the two latter are combined and we focus on two research domains: biophysical and socio-economic.

Biophysical studies mainly focus on biological and ecological relationships between ecosystem services (e.g. recreation and timber production) and impacts of forest management on their provision (e.g. effect of thinning on preservation of specific taxa) (e.g. Paillet et al. 2010; Kuuluvainen et al. 2012; Framstad et al. 2013). *Socio-economic studies* address market and non-market priced ecosystem services from the human perspective in order to uncover socially desirable levels for their provision. These include revealing public preferences towards forest management practices (e.g. Lindhagen & Hörnsten 2000; Gundersen & Frivold 2008; Edwards et al. 2012a) and eliciting monetary values for non-market ecosystem service (e.g. Horne et al. 2005; Nielsen et al. 2007; Zandersen & Tol 2009). Thus, biophysical studies represent the supply side and socio-economic studies address the demand-side (Tallis & Polasky 2009; Polasky et al. 2011; Martín-López et al. 2014). Both research domains provide information on trade-offs between ecosystem services and management alternatives.

By comparing the information obtained from different research domains, Martín-López et al. (2014) show that different trade-offs are revealed depending on the research domain they are addressed by. This supports the call in other studies (e.g. Hooper et al. 2005; MEA 2005; Tallis & Polasky 2009; de Groot et al. 2010) for combining knowledge from different research domains whenever possible in order to properly inform environmental decision-making. In the thesis we adopt the framework illustrated in Figure 1 of Paper I where impacts of management on provision of ecosystem services and resulting trade-offs can be assessed from either of or two research domains (biophysical and socio-economic).

Within both research domains assessments of management impacts and trade-offs are performed either for a single non-market ecosystem service (e.g. Felton et al. 2010; Bouget et al. 2012; Edwards et al. 2012) or for a bundle (group) of such services (e.g. Nelson et al. 2009; Duncker et al. 2012; Turner et al. 2014; Biber et al. 2015). Since quantification of relationships between services is complicated by their multi-faceted and complex nature, assessments are often performed using indicators (Layke et al. 2012; Feld et al. 2009; Kettunen & Vihervaara 2013). The choice of indicators has an effect on the revealed trade-offs and synergies (Harrison et al. 2014). The number of indicators being used is growing (Layke et al. 2012; Feld et al. 2009) and there are on-going efforts in developing and structuring comprehensive indicators (e.g. Albert et al. 2015; Mononen et al. 2015). At the same time the strength of evidence for indicators for forest biodiversity has been questioned. Gao et al. (2015) conclude that most of the indicators are weakly scientifically supported.

Forest management, decision support and ecosystem services

In order to be more useful for decision-making assessments need to be conditional on decision context, i.e. performed with a specific decision (problem) in mind (Kahneman & Tversky 2000) as well as driven by demands of management (Daily et al. 2009). The contribution of existing assessments to the decision-making has often been questioned (Mazza et al. 2013). For example, economic valuation studies have been reported to often contain only general references of how they can be used without any specifics and are seldom used in decision-making (Laurans et al. 2013; Fisher et al. 2008; Pearce & Seccombe-Hett 2000).

There is a research domain that is closely linked to the assessments of ecosystem services and decision-making, often bridging the two – studies on decision support. They often involve a decision / management problem and can include a computerized quantitative systems (decision support systems) and / or conceptual models (Burstein & Holsapple 2008). Decisions in forest management are made on different levels (stand, estate, regional) and for different time frames. The most common ones include: choice of tree species and silvicultural system, thinning regime, optimal rotation age etc. These decisions are often made with considerations for timber production only, but they implicitly affect the provision of other services. An increasing complexity of issues and number of actors and processes need to be taken into account when making these decisions (e.g. climate change, environmental and social concerns etc) and thus reflected in decision support. Forest management has been evolving over time to address these concerns, introducing features desirable for non-market ecosystem services' provision (such as deadwood, retention trees) to more intensive regimes as well as more environmentally sound alternatives (such as close-to-nature forestry or continuous-cover forestry). Some of these regimes target a specific service, whereas others provide a set of features that are favorable for provision of several services.

Even-though the number of decision support systems for forest management has been growing (Reynolds et al. 2000) and historically their development has been following the trends in forest management (Vacik & Lexer 2014), the majority of them do not include non-provisional ecosystem services and focuses on market values (Segura et al. 2014). Decision support that does take into account considerations of non-market ecosystem services include but not limited to multi-objective or multi-criteria decision support systems in which non-market services are represented as objectives (e.g. Kangas 1993; Briceño-Elizondo et al. 2008) (for detailed account of such systems see Kangas & Kangas (2005); Mendoza & Martins (2006); Ananda & Herath (2009)), calculation of optimal rotation age with extension for non-market services (e.g. Hartman 1976), integer and linear programming (e.g. Næsset et al. 1997; Juutinen et al. 2004). The majority of existing decision support models is based on timber growth simulators, treatment scheduling and other components such as probability of wind-throw, nutrient balance etc. In these models non-market ecosystem services are often represented with indicators or composite indicators (i.e. combination of desirable features) such as habitat suitability models or scenic beauty indices (Borges et al. 2014).

Multi-functionality and forest management

'Ecosystem services' concept can be considered as an extension of multi-functionality / multiple use debate in forest management[1]. There is a vast body of literature devoted to multiple use forestry (e.g. Gregory 1955; Samuelson 1976; Bowes & Krutilla 1985; Hytönen 1995; Klemperer 1996; Löf et al. 2010). Similar to 'ecosystem services' framework there are also different understandings of what constitutes "multiple-use".

Klemperer (1996) provides the following examples of meanings of multiple-use: a) many outputs from each forest acre, b) "a mosaic of single uses on separate areas", c) "management for a "dominant use" and all other compatible uses", d) provision of many outputs / uses over time, e) "various forms of multiple-use, with smaller but highly intensive timber production areas". Definitions (b), (c) represent spatial specialization and definition (d) – temporal specialization and thus introduce the issue of scale and long standing debate of 'spatial specialization vs maximization of multiple use'. For each stand (unit) manager is faced with question: How many and which services

[1] In this sub-section we will use both terminologies interchangeably (ecosystem services and multiple-use / outputs).

will it provide? Is multiple-use superior to specialization on a stand level in these circumstances? Or is it better to opt for spatial specialization on a stand level and multiple-use on a forest level? A number of studies have been investigating these issues (e.g. Bowes & Krutilla 1989; Vincent & Binkley 1993; Zhang 2005; Boman et al. 2010).

The choice to follow one of outlined principles and selection of uses (services) that it involves is covered in the literature by analysis of 'production possibilities function' and 'societal benefits function'. Shape (form) of these functions reflects the trade-offs and this information is needed for decision-making. In an 'ecosystem services' framework they correspond to 'biophysical' and 'socio-economic' trade-offs, respectively. Generally concave function has been assumed for biophysical production function between timber production and non-market ecosystem services, and convex function reflecting benefits for society function (Hartman 1976; Bowes & Krutilla 1985). In addition Swallow et al. (1990) argue that the complexity of biophysical production can introduce non-convexity into the benefit function when non-market ecosystem services are considered. However, the exact shape and quantification of these production functions still remains to be determined (Bowes & Krutilla 1985; Swallow & Wear 1993; Klemperer 1996; Boman et al. 2010).

Outline of the thesis and methods

The thesis is built on four papers. They investigate impacts of forest management on non-market forest ecosystem services from perspectives of biophysical and / or socio-economic research domains, presenting a multi-methodological approach. The variety of methods employed in this thesis is demonstrated in Table 1. In this section first we outline how papers are connected to each other as well as demonstrate motivation behind each paper and the choice of the method for it. Then each of the methods used in this thesis is explained in a separate sub-section.

The basis has been laid out by a systematic review (*Paper I*) of existing research on several non-market ecosystem services, which addressed studies on biophysical and socio-economic assessments of services and decision support that integrates them. A growing body of research on non-market ecosystem services in the Nordic region (Kettunen & Vihervaara 2013) together with low reported representation of non-market ecosystem services in the forest management decision support (Segura et al. 2014) served as motivation for performing this review. Previous review efforts were often confined to a single research domain, for example concentrating solely on biophysical relationships (e.g. Gundersen & Frivold 2008; Paillet et al. 2010). Whereas in our paper we expand focus to several research domains that include biophysical relationships, socio-economic valuation and decision support. We also consider knowledge from each domain in relation to other domains.

Table 1: Overview of methods, research domains and ecosystem services used in this thesis by paper

Paper	Ecosystem service(s)	Research domain(s)	Method	Geography	Forest management / forest characteristic(s)
I	Timber production, biodiversity, carbon, recreation & aesthetics	Biophysical relationships, socio-economic valuation & decision support	Systematic literature review & synthesis	Nordic countries	Both
II	Preservation of biodiversity / habitat	Biophysical relationships	Delphi technique (structured expert elicitation method)	Nordic boreal zone	5 forest management alternatives with different intensity & list of forest characteristics
III	Recreation	Socio-economic valuation	Stated preference methods	Denmark	Variation in forest characteristics (tree species composition & height) within a stand and between stands
IV	Timber production, biodiversity & cultural services	Biophysical relationships & socio-economic valuation	Literature synthesis	Southern Sweden	3 forest management alternatives with different intensity

Biodiversity is one of the most studied forest ecosystem services, however the majority of existing studies are limited to one or two management regimes or even activities (Seppelt et al. 2011; Filyushkina et al. 2016). Tapping into the biophysical research domain in *Paper II* we first investigate the impacts of five management alternatives that form an intensity gradient on biodiversity. Since assessments of such impacts often employ indicators / proxies for ecosystem services (Layke et al. 2012; Gao et al. 2015), we also seek to determine the functional form of the relationships between different forest characteristics (such as stand density, stand age, amount of deadwood) and preservation of biodiversity. Previous studies have employed either one or a combination of the following methods of data collection: ecological modeling (e.g. Duncker et al. 2012b; Biber et al. 2015), empirical data collection (e.g. Penttilä et al. 2004; Johansson et al. 2007) or expert judgement (e.g. Kangas & Leskinen 2005; Ray et al. 2014). Since this study covers a wide range of management alternatives and forest characteristics, knowledge on which might be too descriptive and / or scattered in numerous different case studies, it was decided to use one of expert elicitation methods – Delphi technique. These methods allow to work with large degrees of uncertainty and data-poor environments (Martin et al. 2012; Morgan 2014; MacMillan & Marshall 2006; Jacobs et al. 2015; Krueger et al. 2012).

While Paper II addresses forest management impacts using a qualitative approach, Paper III is investigate another ecosystem services – recreation, using a quantitative approach. Working within socio-economic research domain the focus of *Paper III* is directed at recreation and variation in forest characteristics (tree species and height). Public preferences for various forest characteristics and their recreational values have been previously researched using two approaches: qualitative (landscape preferences) and quantitative (economic valuation). Variation in forest characteristics (such as tree height, species) has been shown to have a positive effect on recreational value of forests (Ribe 1989; Kaplan & Kaplan 1989; Ode & Miller 2011). However, most of the studies, especially those employing valuation methods, concentrate on a single stand (unit) level (e.g. Nielsen et al. 2007; Gundersen & Frivold 2008). Such approach does not fully reflect the recreational experience, during which people often visit more than one stand. We utilize the approach found in several studies from landscape preference research (e.g. Axelsson-Lindgren & Sorte 1987; Price 2007; Edwards et al. 2012) – experiencing several stands during a visit (as if you are walking through a forest) in economic valuation – stated preference methods. Thus, value for variation in forest characteristics within a stand and between stands is being assessed.

Paper II and III have been investigating individual non-market ecosystem services. However there is also a need for examination of impacts of management on bundles (groups) of ecosystem services (Filyushkina et al. 2016; Nelson et al. 2009; Raudsepp-Hearne et al. 2010) in order to determine trade-offs and synergies between services and how they change with different management. Thus, in *Paper IV* both perspectives (biophysical and socio-economic) are presented through a group of ecosystem services (biodiversity, timber production and cultural services). We investigate two management options for oak dominated forests in Southern Sweden that are currently being practiced, and evaluate a third alternative using literature synthesis.

Systematic review and literature synthesis

The traditional literature review often presents research findings on a topic and tends to summarize studies without explaining the criteria used to find and select those studies. The systematic literature review on the other hand is a scientific methodology that aims to comprehensively identify all relevant studies to answer a specific well-defined question and assess each study against inclusion criteria in explicit, rigorous and accountable manner. It involves three key activities: identifying and describing the relevant research, critically appraising it in a systematic manner and bringing together findings in coherent statement, i.e. synthesis (Petticrew & Roberts 2006; Gough et al. 2012).

In *Paper I* practice set in general literature on systematic reviews and guidelines specific for reviews in conservation were followed (e.g. Pullin & Stewart 2006). Using systematic review approach we have searched and selected relevant publications in three research domains: biophysical relationships, socio-economic valuation and decision support. Whether the publication was relevant for this study was determined by the following inclusion criteria: a) the study has to be performed in the context of forestry in one of Nordic countries and was concerned with at least one of selected non-market ecosystem services (recreation, aesthetics, biodiversity and carbon storage / sequestration); b) the study examined the impacts / consequences of a forest management decision on one or more of selected services. The final sample contained 96 publications, their findings have been synthesized.

In *Paper IV* existing scientific literature, governmental statistics and grey literature were synthesized for three ecosystem services (timber production, biodiversity and cultural services) in oak dominated forests. Three management regimes have been considered: (A) intensive oak timber production, (B) combined management for both timber production and biodiversity, (C) biodiversity conservation without management intervention. Two of them (A & C) are already typical for Southern Sweden, whereas the third (B) is hypothetical. To achieve provision of several ecosystem services in regime B the timber production aspect is confined to a sub-section of the stand, whereas the rest of the stand is left for natural development. The production-dedicated areas are essentially mini-versions of regime A, just with fewer crop trees. Since insufficient studies have been conducted to determine the precise capacity of regime B to provide ecosystem services our assessments had to rely on information derived from management regimes which closely approximated this management alternative since. Regime A serves as a reference condition for evaluating timber production potential of regimes B and C, regime C provides a reference for assessing capacity for preserving biodiversity in regimes A and B.

Delphi technique

In *Paper II* data was collected using the Delphi technique – an established research technique that seeks to provide a group opinion on a question using experts and multi-iterative structured group communication process, forging consensus whenever possible (Linstone & Turoff 2002; Landeta 2006). Originating in military forecasting the Delphi technique has been applied in natural resource management (e.g. Crance 1987; MacMillan & Marshall 2006; Orsi et al. 2011; Scolozzi et al. 2012). The main advantages of the Delphi method in comparison to other methods that use experts are two-fold: 1) reduction of negative effects related to group dynamics due to anonymity (e.g. social pressure and desirability, halo effect, domination); 2) increase of robustness of opinion gathering due to structured and repeated nature of inquiry (McBride et al. 2012; Landeta 2006; Linstone & Turoff 2002).

This study focuses on preservation of biodiversity and habitat in Boreal zone of the Nordic region, which is represented with two forest types: Norway spruce and Scots pine dominated forests. Two questions comprised the main body of the questionnaire for this Delphi study. Q1: How does the potential to preserve biodiversity and habitat change between forest management alternatives?" Experts considered five alternatives that lay on the continuum from no management to very intensive management: "no management", "close-to-nature forestry", "continuous cover forestry", "clear-cut system" and "intensive forestry". The first alterative has been divided into three age groups: 100 years old, 200-300 years old and older than 300 years old, while other four have been represented with the following three groups: establishment / young phase, middle-aged phase and adult / mature phase of stand development / age. (Q2a) "What is the relative contribution of each of the characteristics to preservation of biodiversity and habitat on a scale from 1 to 10, where 1 is the lowest?" and (Q2b) "What functional form does relationship between each of these forest characteristics and biodiversity have?" The list of forest characteristics is presented in Table 1 Paper II. Questionnaire for Round 1 and an example of a questionnaire for Round 2 are presented in Appendix A and B respectively.

Scientists whose area of expertise is aligned with the focus of this study were invited to participate. The protocol described in Novakowski & Wellar (2009) and generally applied in other Delphi studies (e.g. Edwards et al. 2012; Eycott et al. 2011) has been followed. In each round experts (i.e. researchers) were asked to fill out a questionnaire individually. After each round all responses were summarized by the moderator and together with adjusted questionnaire sent back to experts, who then had the opportunity to revise their answers based on the provided group summary. The summary shows levels of agreement and confidence levels for the group. After two rounds of deliberations stability in answers has been reached and process was completed. The final data analysis followed the same protocol as the one between rounds, however it also included additional measures such as degree of stability of estimates provided by each expert between rounds and if estimates were diverging or converging. The process was administered via e-mail. Six experts participated in both rounds, which represents a quarter of a total number of potential participants identified for this study. Examples of previous studies with similar panel size include Uhmann et al. (2001), Eycott et al. (2011).

Stated preference methods

In *Paper III* data was collected using stated preference (SP) methods, i.e. survey-based methods in which hypothetical situations are constructed and respondents are asked questions that designed to uncover their preferences or values (both in monetary and non-monetary terms). These methods are based on the premise that individual always chooses the alternative (a good or its bundles) that provides the highest welfare, and thus observing individual's choices allows inferring about individual's welfare. The hypothetical nature of these methods allows them to provide values for non-market services (Freeman 2003; Bateman et al. 2002). Two components within stated preferences methods have been applied: 1) a choice experiment, and 2) an additional exercise. Full version of the questionnaire translated into English presented in Appendix C.

Choice experiment (CE) is a method that was initially developed in marketing research (Louviere et al. 2000) and has been since numerously applied in valuation of non-market ecosystem services (e.g. Hanley et al. 1998; Scarpa et al. 2000; Carlsson et al. 2003; Horne et al. 2005; Jacobsen et al. 2012). CE is based on McFadden's Random Utility Maximization framework (McFadden 1973), which presumes that individuals are rational beings who have well-defined preferences and they maximize their utility when making a choice between alternatives, and on the Lancaster's characteristics theory of value (Lancaster 1966), which assumes that individuals derive utility from the characteristics of goods rather than directly from the goods themselves. Thus every good can be described as a bundle of characteristics and levels they take. In this study choice of forest for a recreational visit was presented as combinations of attributes (forest characteristics) that reflected both variation within a stand and between stands and were comprised of: tree species composition and stand height (age) – within a stand, diversity in tree species composition and age structures between stands and distance one needs to travel to reach the forest (for full account of attributes see Table 1 Paper III). Respondents were presented with two alternative forests and asked to select one or none of them for their next recreational visit. Each forest alternative was represented by drawings of three consecutive stands (units) horizontally aligned and distance that respondent would have to travel to reach the site (as a cost measure). Design of choice cards was intended to imitate the situation close to the actual visit to a forest, i.e. experiencing several stands (units). Data was collected using an online panel in Denmark, final sample contained 1226 respondents. Data was analyzed using Random Parameter Logit (RPL) model, which assumes stable preferences across all choice cards and accounts for preference heterogeneity (Train 2003).

In addition to the CE the questionnaire also contained another SP component, in which respondents were asked to design their ideal forest for recreation by selecting three stands from the matrix of drawings provided to them. Each drawing could have been chosen more than once. The intention for this exercise was to see whether designed forest would match individual preference estimates from the CE and thus check for consistency in findings. This data was analyzed with summary statistics, which were compared to the results of Logit model for each respondent.

Summary of papers

Paper I: Non-market forest ecosystem services and decision support in Nordic countries

Paper I reviews existing literature on selected non-market forest ecosystem services in the Nordic region in three research domains: biophysical relationships, socio-economic valuation and decision support models

The aim of this review is two-fold: (1) to provide an overview of the coverage of assessments of selected non-market ecosystem services in relation to forest management in existing literature in the Nordic countries; (2) to understand the extent of the integration of non-market forest ecosystem services into decision support in previously published papers in the Nordic countries. Our findings show that there is unevenly distributed coverage of non-market ecosystem services in the published literature of Nordic countries (both in terms of services as well as research domains). In all three research domains (biophysical relationships, socio-economic valuation and decision support) the majority of existing studies have focused on a single non-market ecosystem service. Publications on decision support contained the highest numbers of non-market ecosystem services.

The reviewed literature in biophysical and socio-economic domains in the Nordic region addressed a range of forest management regimes and activities. However, a number of knowledge gaps were observed in both domains suggesting the need on one hand for more integrated and comprehensive assessments of individual ecosystem services and on the other hand – investigation of different forest management alternatives. It has been noted that even in cases where relationships between services have been extensively documented, for example timber production and biodiversity conservation, there is still lack of approaches and data to account for temporal and spatial dimensions. This review shows that most studies assessing impacts of forest management on provision of ecosystem services including previous review efforts are still confined to a single research domain perspective. This has been mirrored in the literature on decision support – where non-market ecosystem services have been represented either with socio-economic or biophysical dimension. Even in the few studies where both perspectives are applied, they are concerned with different services.

We conclude that while existing and emerging literature on non-market forest ecosystem services in the Nordic countries offers insight into impacts of management on provision of these services, the knowledge remains patchy and confined to boundaries of separate research domains.

Paper II: Impacts of forest management on provision of ecosystem services: An application of expert assessment on biodiversity and habitat preservation in Nordic boreal zone

Paper II investigates the ability of several forest management alternatives in the boreal Nordic zone to preserve biodiversity and habitat and relationships between biodiversity and forest characteristics using a structured expert assessment process – Delphi technique

The main objective of this study is to contribute to the understanding of how forest management affects provision of ecosystem services in the boreal zone of the Nordic countries using a structured expert elicitation technique (the Delphi method). The ecosystem service at focus, preservation of biodiversity and habitat, is defined as "long-term persistence / viability of populations of species at a landscape / regional level, including also rare or red-listed species".

Our results from Q1 confirm findings of previous studies in that with increase of intensity of forest management its ability to preserve biodiversity and habitat declines, and the highest potential to preserve biodiversity is associated with "no management" (see Figure 2a&b in Paper II). This trend has been suggested by experts for both forest types as well as also observed within each forest management alternative: the older the forest, the higher biodiversity. Levels of confidence in the estimates provided by expert fell in range from 50 to 95 %. Higher levels of confidence have been associated with "clear-cut system" and "intensive forestry", for the other three they are fluctuating suggesting under representativeness of certain topics in research and / or limited knowledge for them.

As for relative importance of forest characteristics for preservation of biodiversity / habitat the characteristics ranked the highest were (in descending order): stand age, presence of broadleaved species in the stand, amount of standing / fallen deadwood, degree of temporal and spatial continuity in the landscape. However, a wide range in relative importance has been observed for many characteristics (Figure 3 Paper II). Functional forms of relationships between forest characteristics and biodiversity are presented in Figure 3 in Paper II. The majority of them are either positive or concave. For almost all characteristics experts did not agree on the same type of relationship, exception being “variation in sizes of individual pieces of deadwood” and “size of clearcut”. Medium to high levels of confidence in the answers have been reported for the estimates of relationships between the following eight characteristics and preservation of biodiversity: stand age, variation in tree size within a stand, number of canopy layers in the stand, tree species diversity in stand, presence of broadleaved trees, amount of standing / fallen deadwood, variation in sizes of individual pieces of deadwood, amount of harvesting residues and degree of spatial and temporal continuity in the landscape.

In general reluctance to provide generalized assessments has been reported by experts. In their feedback they voiced their concerns regarding complexity of questions, applicability of forest management alternatives classification in specific countries as well as their additional considerations. Moreover, some answers for Q1 and Q2 have relatively high range. One of reasons for disagreement between experts and range in estimates pointed out by experts themselves – are differences in ecological requirements of different taxa and a more general definition of biodiversity adopted in this study.

This study shows that even though ideal means of discovering impacts of land use / management on provision of ecosystem services would be including empirical observations and data representing a comprehensive range of services and management alternatives, these matters can also be informed by structured expert elicitation methods such as Delphi technique.

Paper III: Effects of forest characteristics on the recreational value: the case of tree species and height variation within and between stands

Paper III considers effect of variation in forest characteristics both on forest and stand levels on public preferences and recreational value in Denmark

In this paper we investigate the effect of variation in two forest characteristics (tree species composition and height / age structure) on recreational value of forests in Denmark both between stands as well as within a stand. Using CE methodology this study finds that variation between stands for both forest characteristics contributes positively to recreational value – public prefers to experience stands that differ in tree species composition and / or height structure in the recreational visit. We also confirm results of previous studies on a stand level – mixed tree species are preferred compared to monocultures of broadleaves and the latter are preferred over conifers. Stands consisting of trees of varying height are preferred over stands with trees of the same height and in the latter; high trees are preferred over low ones.

To put our results in perspective using estimates of WTT for individual attributes we calculate aggregate WTT (AWTT) for 364[2] different forests (which are comprised of three stands as in the CE). We find that in some instances variation between stands outweighs contribution of variation within a stand (specifically for tree species composition between broadleaved and mixed stands). In most cases presence of high trees or trees of varying height with species variation between or within stands results in the AWTT in the high end. We also calculate AWTT for all 365 possible forests for each of respondents using posterior individual coefficients from RPL model. Only for 14 % of respondent's combination with three mixed tree species of varying height resulted in the maximum AWTT. Since this forest (combination) provides little variation between stands both in terms of tree species composition and height structure, it confirms the appeal of some variation at a forest level.

Results of the exercise where respondents were asked to design their ideal forest for recreation confirm those of the CE, i.e. variation between stands matters: only 20% and 33% respectively chose the same level for tree species composition and height structure in all three stands of the forest. Moreover, for 95 % of the respondents, the AWTT of the forest they composed as their ideal for recreation lies within a 95 % confidence interval of their maximum AWTT. Thus, for management this suggests to promote both types of variation (within

[2] The combinations of attributes results in 12 possible stands, which again result in 364 possible forests comprised of three stands (where order of forest types does not matter).

and between stands) through a variety of forest characteristics and management regimes.

Paper IV: Management of oak forests: striking a balance between timber production, biodiversity and cultural services

Paper IV investigates different forest management regimes for provision of a bundle of ecosystem services (timber, biodiversity conservation & cultural services) in oak dominated forests in Southern Sweden

This study evaluates the capacity of three contrasting management regimes to provide societies with economic revenue from timber production, habitats for biodiversity and cultural services, as well as analyses associated trade-offs and synergies. Our assessments showed that regime A (intensive oak timber production) provides the highest levels of economic returns. Reduction in income from Regime B (combined management for both timber production and biodiversity) compared to Regime A is expected to be proportional to the number of crop trees plus some additional costs due to logistics during forest logging operations. For biodiversity in general, Regimes B and C (biodiversity conservation without management intervention) are more favorable than Regime A. Higher stand structural heterogeneity and tree species diversion associated with Regime B is affecting positively a number of groups, e.g. birds, Epiphytes. Higher amount of deadwood and live trees with cavities and dead branches associated with Regime C is likely to promote beetles, Saproxylic fungi as well as birds. From the perspective of cultural services management Regime A is likely to be preferred especially in the later stages of stand development, providing big trees that are well distributed, open environments and visual penetration. Regime C on the other hand may be perceived as 'messy' by the general public due to presence of high amounts of deadwood and low visual penetration. Regime B probably provides many desirable features from perspective of cultural services, e.g. high visual / structural diversity, exclusion of large disturbances such as clear-cuts, reduction of stand density. Thus it is expected to be slightly more favored by public than Regime A.

With respect to trade-offs Regime A is expected to provide the highest economic return from timber, slightly decreased cultural services and the lowest levels of biodiversity. Freely developed Regime C would result in substantially higher levels of habitat provision for a range of taxonomic groups, but at expense of wood production and cultural services. The "combined goal" management Regime B appears to provide similar potential value for biodiversity and cultural services as Regimes C and A respectively.

Thus, it may be suitable for a balanced delivery of a more comprehensive bundle of ecosystem services within a stand than the one adopted in current practice. This can provide forest owners with higher degree of flexibility in prioritization of different ecosystem services. However, since these conclusions are drawn based on information derived from studies on management regimes that are close approximations of regime B, there is a need for targeted field experiments.

Discussion

Managing forests for multiple uses or delivery of multiple ecosystem services is a necessary and complex task. Not only does it require decision makers to have access to knowledge on supply and demand for various ecosystem services for a full spectrum of management regimes, it also involves “entering” a debate of what constitutes multiple-use or provision of multiple ecosystem services and issues that arise from it. We discuss findings of four papers that constitute this thesis in relation to each other and in the light of forest management decisions.

Paper I concludes that there is a need for more comprehensive and integrated studies, which include several ecosystem services and investigate them from both research domains (biophysical and socio-economic). Moreover, it also calls for a wider coverage of non-market ecosystem services and management alternatives. While the main conclusions of Paper I are in line with general direction set for future research in ecosystem services (e.g. Hooper et al. 2005; de Groot et al. 2010; Martinez-Harms et al. 2015), more detailed assessments of individual non-market ecosystem services are still relevant and could useful for decision support. Thus Papers II and III investigate biodiversity and recreation respectively only from perspective of a single research domain. Paper IV considers possibilities for provision of three services (timber production, biodiversity and cultural services) and trade-offs between them.

Quantification of biophysical relationships represents a stepping stone in more integrated and comprehensive assessments of ecosystem services. To provide meaningful assessment biophysical trade-offs need to be assessed first, and then this change in provision of ecosystem services is subjected to socio-economic valuation. Paper I revealed trends and knowledge gaps in existing literature, showing that there are discrepancies in how much different management alternatives and forest characteristics are studied relative to each other. This has been further reflected in levels of confidence in estimates provided by experts in Paper II, i.e. less intensive alternatives such as close-to-nature forestry and continuous cover forestry were associated with fluctuating levels of confidence, whereas more intense systems received constantly higher levels of confidence. The range in estimates for different management alternatives in Paper II (Figure 2a&b) also suggests that there is a need for better understanding of impacts of forest management on provision of ecosystem services, especially so since biodiversity is one of the most studied services. Similar conclusion can be drawn from Paper IV – where we find that existing literature is mostly concentrated on two management alternatives (intense management for high quality oak timber and no management for biodiversity preservation).

Second part of Paper II is devoted to determining functional forms of the relationships between forest characteristics and preservation of biodiversity as well as relative importance of forest characteristics. Many of these characteristics are often being used in assessments and decision support as indicators for biodiversity. Development of a common set of indicators for ecosystem services that encompass both biophysical and socio-economic perspectives is one of the on-going processes nationally and regionally (e.g. Haines-Young et al. 2012; Kettunen & Vihervaara 2013). We find little agreement between experts (researchers) on both accounts, which speaks to findings of a recent review by Gao et al. (2015) that questions strength of evidence for many biodiversity indicators. Apart from being useful as indicators for ecosystem services forest characteristics can provide insight into impacts of individual activities or predict effect of a new management regime as seen in Paper IV. Findings of Paper II and III also suggest that relationships (both biophysical and socio-economic) between ecosystem services and some forest characteristics are more complicated than a linear function and need further examination.

Being able to clearly state where trade-offs and synergies exist and better yet to quantify them, be it between services or due to a management activity, is necessary in order to support decision-making. A recent review of case studies involving ecosystem services in a real world by Howe et al. (2014) concluded that, first, trade-offs are mentioned almost three times more compared to synergies, and second, that no generalizable context for win-win relationships have been identified. This suggests that even though some relationships have been characterized as trade-offs, they are not inevitable and with some adjustments they can be tilted towards synergetic relationship, as seen in Paper IV (for timber production and biodiversity conservation).

Time and space present two dimensions that are important in analysis of both trade-offs and impacts of management activities and have implications for planning and management on different levels (Rodríguez et al. 2006). Provision of some services is place specific, for example occurrence of specific taxa of threatened or red-listed species calls for their protection on that particular area, whereas carbon storage allows relative flexibility in its allocation (Chan et al. 2006; Polasky et al. 2005). Recreational areas around urban settlements often are given more attention. Paper III illustrates that a simple extrapolation of results obtained from a stand (unit) level to a forest or landscape level does not always work, i.e. even though people prefer stands of mixed tree species with trees of varying height on a unit level, they not necessarily will choose a forest entirely comprised of such units. It is also important to remember there is spatial interdependency in delivery of ecosystem services between neighboring stands (units) (Swallow & Wear 1993) as well as spatial substitution effects, i.e. value of a service at a new site depends not only on its characteristics but also on the existing alternatives (Termansen et al. 2008).

Quantification of relationships between services and impacts of management activities on their provision is only one part of the road towards integration of ecosystem services in decision-making. Operationalization of these assessments so that they are useful and applicable for decision support is an equally important issue. Even though historically development of decision support has been following the general trends in forest management (Vacik & Lexer 2014), there are two issues: first, majority of used in real life decision support does not include non-market ecosystem services (Segura et al. 2014) and secondly, adoption of scientific decision support in practice and policy remains limited (Stewart et al. 2014). Ecosystem services assessments have been criticized for not covering the core steps in decision-making or focusing more on supply of services and less on demand (Martinez-Harms et al. 2015). Generally, it is recommended for decision support to be user-inspired and user-friendly, thus encouraging stakeholder involvement in its development (Cowling et al. 2008). Moreover, analyzing the adoption of decision support systems in practice Stewart et al. (2014) argue for a shift in interaction between science, policy and practice from "bridging gaps" to "dialog between collaborating partners". At the same time compromises need be made between extent of complexity of systems (how understandable methods and information are) and comprehensiveness / completeness of analysis (Kangas & Kangas 2005). Ruckelshaus et al. (2015) argue that decision makers should be provided with relatively simple models, provided they are clearly documented, published and that validation tests reveal limitations.

With the question whether existing knowledge is sufficient for integration of non-market ecosystem services into decision-making remaining open (e.g.

Mach et al. 2015, Martinez-Harms et al. 2015), it is important to pay a closer look to the existing literature and knowledge, which has been at focus of Paper I, IV and II respectively (in the latter through the use of expert assessments). Systematic reviewing, for example, is useful in providing valuable output by concentrating on a specific, well-defined question, whereas employing expert assessment allows inclusion of some levels of uncertainty and generalization across findings of individual cases. The latter is especially important since many reviewed studies on impacts of forest management on provision of ecosystem services as well as trade-offs between services have been reported to present case-specific findings, resulting in patchy knowledge (Filyushkina et al. 2016; Kettunen & Vihervaara 2013). This could be problematic in terms of elaboration of regional and national estimates as well as their usefulness for the decision support. Thus, in this thesis we argue that these methods (systematic reviewing of literature and expert assessment techniques) are valuable in complimenting on-going empirical and modeling research and suggest that they are used more in the future research (either separately or in combination with other methods).

This thesis investigates potential of several management alternatives for provision of ecosystem services. The extent of understanding of each of the alternatives differs and there are still knowledge gaps. In order to contribute to better understanding of impacts of forest management on provision of ecosystem services, it could be useful for the future research to incorporate temporal and spatial aspects in the assessments. A more extensive and comprehensive investigation of relationships between forest characteristics (attributes) and provision of ecosystem services, especially in uncovering their functional forms, could be relevant for selection of indicators for these services as well as assessment of potential of different management alternatives to deliver services. Since often provision of more than one service is considered information on trade-offs and synergies between services is needed. Thus, more studies that identify bundles (groups) of ecosystem services and explore impacts of management on multiple services are necessary. Finally, complexity and socio-ecological nature of ecosystem services requires future research to move towards a higher proportion of inter- and trans-disciplinary investigations with joint efforts in development of indicators and approaches.

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Appendices

Appendix A: Questionnaire for Round 1 of the Delphi survey (Paper II)

FOREST ECOSYSTEM SERVICES IN NORDIC COUNTRIES

--- A Delphi survey ---

Round 1

In Nordic region, there is a growing interest in managing forests as a "win – win" land use, i.e. providing various ecosystem services such as timber, biodiversity, recreation and habitat for game to meet the demands of different stakeholders. However, there is little knowledge of how to incorporate multiple ecosystem services in forest management decisions. The main aim of this Delphi exercise is to use expert opinion to explore the influence of different forest management regimes on provision of ecosystem services and the relationship between these services in forests in the Nordic region. We are specifically interested in plantation forestry of various forest types and ecosystem services common to the region. It is hoped that this study will contribute to more knowledge regarding integrated and comprehensive assessments of ecosystem services in various forest management regimes, as well as the effects that production of one or more services have on the production of other ecosystem services.

After gathering information from the respondents in the current exercise (i.e. round 1) another exercise (round 2) will be conducted in which the respondent is provided with a summary of answers from all the respondents and will be given opportunity to revise their answers. After round 2 the survey instrument and provided answers will be revised again, necessity of a very brief round 3 will be considered.

Only the respondents' names who agree to be revealed will be included in a list that will be made available at the end of the study.

This Delphi exercise is part of a PhD project at the University of Copenhagen, Denmark in collaboration with the Swedish University of Agricultural Sciences (SLU), Sweden.

The success of this Delphi study relies heavily on as many of you participating as possible.

Thank you for agreeing to participate in this survey!

Should you find that you don't possess the expertise to answer some of the questions, we would still appreciate if you provided your opinion on the ones you can, as well as any comments / feedback you might have.

We hope that you find this exercise interesting.

Anna Filyushkina, Eugene Ezebilo, Magnus Löf, Mattias Boman & Niels Strange

Your name: ___________________________

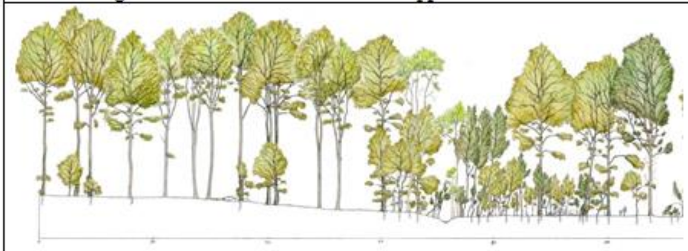
Choice of reference forest types for this study

For this Delphi survey forest types are defined by geographical location, dominant tree species and share of other tree species. Brief description of forest types is provided in Figure 1.

Figure 1. Forest types (Drawings and descriptions adopted from Larsen & Nielsen, 2007).

Norway spruce dominated forest

The forest is dominated by Norway spruce (80-95 %) with some occurrence of other species – birch, Scots pine, aspen, Sitka spruce etc (5-20 %). It belongs to poor to medium rich, well drained soils with medium to good water supply. Classic management – even-aged clear cut system with soil preparation and artificial regeneration for spruce and natural seeding for birch. Depending on degree of intensity of forest management some fertilization could be applied.



Beech dominated forest

The forest is dominated by Beech (70-95 %) with some occurrence of other species – oak, ash, maple, cherry, Scots pine, Norway spruce (5-30 %). It belongs to medium to rich, well drained soils with medium to good water supply. Classic management – shelterwood regeneration with a rapid canopy removal. Thus stands are usually even-aged.

Scots pine dominated forest

The forest is dominated by Scots pine (80-95 %) with some occurrence of other species – Norway spruce, birch, aspen etc (5-20 %). It belongs to poor and dry soils on sites with insufficient water supply. Classic management – even-aged clear cut system. Depending on degree of intensity of forest management some fertilization could be applied. Regeneration of light demanding pine occurs in larger gaps or smaller clearings.

In this study each country in the Nordic region is treated as one geographical location except Sweden that was divided into two parts, i.e. Northern (boreal) and Southern parts. Each location is represented by two forest types shown in Figure 1. We understand that there is variation in conditions and forestry within each country. However we ask you to think of typical forests and average estimates across each country and focus on relationships between ecosystem services rather than differences between different locations within the country.

Based on your scientific experience and area of expertise we would like you to select the geographical location and two corresponding forest types that you are familiar with and comfortable providing opinion related to provision of ecosystem services in the matrix below.

Location	Denmark	Southern Sweden	Northern Sweden	Norway	Finland
Forest type 1 (dominant species)	Beech	Beech	Scots pine	Scots pine	Scots pine
Forest type 2 (dominant species)	Norway spruce	Norway spruce	Norway spruce	Norway spruce	Norway spruce
Your choice					

These two forest types in a country (or part of it in case of Sweden) will serve as reference forests for your answers throughout this survey.

If none of the forest types in the matrix above reflect your research agenda / experience, you can provide a brief description of the forest type that is within your area of expertise in the space below. This will serve as reference forest for your estimates.

Comments for reference forest types:

Your experience with forest ecosystem services in the Nordic region and choice of service(s) for this study

In the table 1 you will find a list of ecosystem services that we are interested in. This classification is not by any means comprehensive: some of the listed services are overlapping, whereas others have been broken down. Each of services can be defined in a number of ways depending on the angle one is working on (socio-economic or ecological). We are interested in relationships between provision of services and forest management for timber. *Based on your experience and field of expertise we ask you to select up to two services that you are comfortable providing judgment regarding their provision in the forest type(s) you have selected.* It could be services that you have worked with in your research or simply you have been a recipient and can make a judgment based on that (for example, recreation or aesthetics). If none of the services reflect your research agenda / experience, you can add extra ones in spare rows. We also ask you to provide your definition of the service(s) you chose (in what form it / they come).

Table 1. Ecosystem service(s) of interest

Your choice of ecosystem service(s) for this survey ***(Put a "X" in the relevant row(s))***	Ecosystem services	Your definition for measurement of the service(s) you have chosen for this survey
	Timber production	
	Biomass production	
	Picking berries & mushrooms	
	Reindeer herding	
	Game / hunting	
	Water & water flow regulation	
	Carbon sequestration / storage	
	Preservation of biodiversity and / or habitat (species richness / red-listed species / other)	
	Wildlife	
	Recreation & tourism	
	Aesthetics & landscape	
	Other ______________________	
	Other______________________	

In your opinion what is the most suitable level to consider the provision of the ecosystem service chosen for your panel (Fig. 1)?

_____ stand

_____ forest / estate

_____ landscape

_____ other (please specify ____________________)

In your opinion how different are estimates for provision of the same service between boreal forests of Norway, Sweden and Finland?

_____ very different

_____rather similar

_____no difference at all

Comments for ecosystem services and their definitions:

Question 1. Potential of forest management in provision of ecosystem services on a stand level.

Brief explanation: In this question you are asked to provide estimates for the potential of forest management alternatives to provide ecosystem service(s). Brief description of management alternatives in presented in Figure 2. We assume that the surrounding stands are managed under the same regime, though could be in different stages of stand development.

We ask you to fill out Table 2[1] below using following instructions. First write down names of forest types, ecosystem services and units (b) in the respective cells. These are two forest types and ecosystem services that you chose for this survey. Please also remember to provide units / scale for your estimates. Now proceed to filling out the main body of Table 2 – your opinion on estimates for provision of these services for the five forest management alternatives. We ask you to think in a four step process:

Step 1 and 2 – think about and record lower and upper limits – an interval where in your opinion the estimate of the change in provision of the service lays. Step 3 – move to determining and recording your best guess of the change in provision of the service.

Step 4 – record your rate of confidence in your best guess estimate.

This process is repeated for each column and two forest types. *Please remember to document which forest types you are answering for in Table 2 before you start.*

If some alternatives don't make sense for the chosen forest type, please put "N/A" in the respective field. Since descriptions of forest types and management alternatives are rather brief, you also have the possibility to record any specific assumptions you have made for forest management alternatives that play an important role in determining levels of provision of services.

[1] The thesis contains only an example of Table 2 and 3 for forest type 1, respondents also receive a copy of each for forest type 2.

Table 2. Estimates of potential of forest management in provision of ecosystem services on stand level

	"No management"			"Close-to-nature forestry"			"Continuous cover forestry"			"Clear-cut system"			"Intensive forestry"		
	100 years old or less	200-300 years old	More than 300 years old	Est. & young	Middle-aged	Adult / mature	Est. & young	Middle-aged	Adult / mature	Est. & young	Middle-aged	Adult / mature	Est. & young	Middle-aged	Adult / mature
Forest type 1: ______________________________															
Lower limit, %															
Best guess, %															
Upper limit, %															
Your confidence rate, %															

Figure 2. Brief description of forest management alternatives

1. “No management” regime implies that almost no intervention is happening. The forest is left for natural processes to take over and regulate the system. Occasional cleaning of forest paths for visitors might occur. No financial goal is set for the area. Often it is forest nature reserve of some sort.

2. “Close-to-nature forestry” is an umbrella concept for which forests are managed using natural processes as guidelines. Only native and site adapted species are used. Natural regeneration is preferred. The rotation age is usually longer and harvests are done on smaller scale in order to promote development of irregular and mixed stand structure. Interventions are considered in light of enhancement of ecological functions.

3. “Continuous cover forestry” is also an umbrella concept. In Nordic countries it is represented by shelterwood forestry (group or uniform). Financial goals are becoming more important here and degree of intervention is higher than in previous alternatives. Final harvest is usually performed in two stages, which means that there is no time period with the soil being left bare. Natural regeneration is often the case.

4. “Clear-cut forestry” is very much driven by financial return from timber production but also considerations for other services are present. Generally stands are even-aged. After clear-cut stand is regenerated artificially using improved material and site preparation. Final harvest is performed by clearcutting, however residues are usually left on the site.

5. “Intensive forestry” is mainly used for biomass production and involves the shortest rotation length, whole tree harvesting and residue removal at final cutting, soil preparation and fertilization. Generally it means stands with one tree species only. Management is often performed using coppicing technique i.e. cutting trees, allowing the stumps to regenerate for some years and harvesting the stems.

In your opinion would you say that all the forest management regimes that are practiced in the Nordic region or parts of it have been covered in the Table 3?

___ Yes

___ No

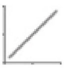
If no, please provide information about the missing ones

Comments to the question 1:

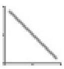
Question 2. What forest characteristics are important for provision of the service?

In this question you are asked to select all forest characteristics that are important for provision of the ecosystem service (by indicating them with “X” in columns 2&5 of Table 3 for both forest types) and make a judgment on relationship between this service and each selected stand characteristic (columns 3&6). Specifically what shape (functional form) from the list in Figure 3 you think this relationship follows. Finally we ask you to record your level of confidence in the answer on shape of relationship you provided (columns 4&7). Please remember to document which forest types you are answering for in table 2 before you start.

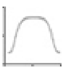
Figure 3. List of shapes of relationships to be used to fill out Table 2 in Q2



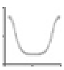
Positive (P)
Provision of service increases when the level of the characteristic increases



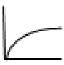
Negative (N)
Provision of service decreases when the level of the characteristic increases



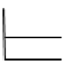
Bell-shaped (B)
Provision of service is enhanced by the characteristic, except when the level of the characteristic is very low or very high



U-shaped (U)
Provision of service is reduced by the characteristic, except when the level of the characteristic is very low or very high



Concave (C)
Provision of service is enhanced by the characteristic, except when the level of the characteristic is very low or very high



Constant (Ct)
Provision of service is not affected by the characteristic and remains on the same level

Other________

Table 3. Importance of forest characteristics for provision of the ecosystem service.

	Forest type 1:_______________		
	Important for provision of service ("X")	Function al form (shape) of relationsh ip	Your 64confid ence rate, %
Stand age - age of dominant tree species in the stand (from establishment to maturity)			
Stand density (from open (i.e. retention trees) to moderate (i.e. shelterwood / selection systems) to dense (i.e. closed canopy))			
Variation in tree size / age within the stand (from uniform to mix of different sizes / uneven-aged)			
Number of canopy layers in the stand (from one to many)			
Presence / extent of understorey (from none to moderate to dense)			
Variation in spacing between trees in the stand (from regular spaced to different sized groups of trees, patches, openings)			
Tree species diversity in the stand (from 1 to several to many tree species)			
Presence of broadleaved trees in the stand (from none to some)			
Amount of standing / fallen deadwood (volume from low to high)			
Size of individual pieces of deadwood (from small to large)			
Amount of residues left from thinning and / or final harvesting (volume from low to high)			
Size of clearcut (from small to large)			
Regeneration type (from natural to artificial)			
Occurrence and/or mimicking of natural disturbances (from none to some)			
Naturalness of forest edges – not "straight" edges (from low to high portion)			
Management of adjacent stands (from the same to different)			
Amount of similar stands in the landscape –stands with same tree sp. composition & management (from low to high)			
Other ____________________________			

Comments to the question:

Question 3. What degrees of compatibility do different combinations of forest ecosystem services have?

In this question you are asked to provide your opinion regarding compatibility of combinations of forest ecosystem services in the reference zone (region) by filling out Table 4. We are interested not only in pairs of services, but also combinations with higher number of services. Please consider all services that are relevant in the region.

Table 4. Combinations of ecosystem services according to their compatibility (on landscape level)

Degree of compatibility	Combinations of ecosystem services
"Not compatible"	
"Somewhat compatible"	
"Compatible"	
"Very compatible"	

Comments to the question:

BACKGROUND INFORMATION

Country (i.e. country where your research has mainly focused on):

____

I have been working as a researcher for …… years in the above country.

A. Your familiarity and experience with expert elicitation techniques

Have you ever used expert-based techniques in your research?

____ Yes

____ No

If yes, have you ever used the Delphi method?

____ Yes

____ No

If yes, how many times? ______

Have you participated in the expert-based techniques as an expert (respondent) before this study?

____ Yes

____ No

If yes, have you participated as a respondent in the Delphi process before this study?

____ Yes

____ No

If yes, how many times? ___

In your research have you been involved in projects related to assessment of multiple forest ecosystem services (more than 2 simultaneously)?

____ Yes

____ No

If yes, briefly outline the goal and nature of the project, as well as ecosystem services it has been exploring. In case of multiple projects, provide such information for a couple of them in the space below.

General comments:

****

Would you like to stay anonymous and not mentioned in the list of participants after the survey is completed?

_____ Yes, I would like to stay anonymous

_____ No, I don't mind being listed as a participant of this Delphi study

****

Please email your completed questionnaire, and any queries you may have to: Anna Filyushkina, Institute of Food and Resource Economics, University of Copenhagen, anfi@ifro.ku.dk.

Thank you for participating in the survey.

If you would like a copy of the final report, please type "yes" in the space: ______.

Appendix B: Questionnaire for Round 2 of the Delphi survey (Paper II)

FOREST ECOSYSTEM SERVICES IN NORDIC COUNTRIES
--- A Delphi survey ---
Round 2

Dear ______ [name of the expert],

Thank you for your patience with and dedication to this survey!

Questionnaire for Round 2 of the survey focuses on two main questions. It provides the summary of results from Round 1 for your entire panel (Preservation of biodiversity & habitat in Boreal zone). You are invited to reconsider your previous answers in the light of this information, and to revise them (or comment upon them) if you feel this is appropriate. We also included a couple of additional small questions to this round.

- **Changes to the design:** We have united 5 initial geographical zones from Round 1 (Denmark, Southern Sweden, Northern Sweden, Finland and Norway) and split them into two zones: boreal and temperate instead. Each of them is still represented by 2 typical forest types: Norway spruce and Scots pine, and beech and Norway spruce respectively. We understand that there is variation in conditions and forestry within each country and especially within each zone. However we seek to identify general trends for each zone and thus we ask you to think of typical forests and focus on overall impacts of forest management and relationships between ecosystem services rather than differences between different locations.
- Since there was a possibility of opting out of answering individual questions in R1, number of responses for each question differs.

All explanatory materials (such as descriptions of forest types, forest management alternatives etc) have been moved to appendices and are sent to you in a separate Word file.

As in previous round should you find that you don't possess the expertise to answer some of the questions, we would still appreciate if you provided your opinion on the ones you can. Comments / explanatory notes are appreciated.

The success of this Delphi study relies heavily on you responding in Round 2.

Thank you for your time!

We hope that find this exercise interesting.

Anna Filyushkina, Eugene Ezebilo, Magnus Löf, Mattias Boman & Niels Strange

QUESTION 1: Potential of forest management in provision of ecosystem service on a stand level

Brief explanation: In this question you are asked to provide estimates for the potential of forest management alternatives to provide the ecosystem service in question. We assume that the surrounding stands are managed under the same regime, though could be in different stages of stand development.

Figures 1A &B provide the summary of answers from your entire panel and Tables 1A&B – your personal answers and levels of confidence from Round 1 for two forest types in the boreal zone of Nordic countries (Norway spruce dominated and Scots pine dominated). If you would like to revise any of them, please write your new answers in the lines "Your response in R 2" in both tables. Otherwise leave the spaces blank.

Your panel details

Geography	Ecosystem service	Adopted definition of the ecosystem service	Number of experts who participate in Q1 & their country
Boreal forests of Finland, Norway & Sweden represented by two reference forest types: - Norway spruce dominated - Scots pine dominated	Preservation of biodiversity and / or habitat (species richness / red-listed species / other)	Long-term persistence / viability of populations of species at a landscape / regional level, including also rare or red-listed species	N=4 Expert #1, 2 & 3 – Northern Sweden; Expert #4 – Finland (Fig. 1)

How to read Figure 1A&B: Each line shows how potential for provision of the ecosystem service changes from one management alternative to the other (trajectories) based on answers from an expert.

How to read Table 1A&B: First two rows report your answers from Round 1 – best guess and degree of confidence in the estimate. "Best guess" – estimate of the provision of the ecosystem service as defined above (in %) under specific forest management, "Your confidence rate" – your degree of confidence in the estimate you provide.

The lower part of Table 1A&B– space for your answers in Round 2, if you decide to change some or all of them compared to those you provided in Round 1.

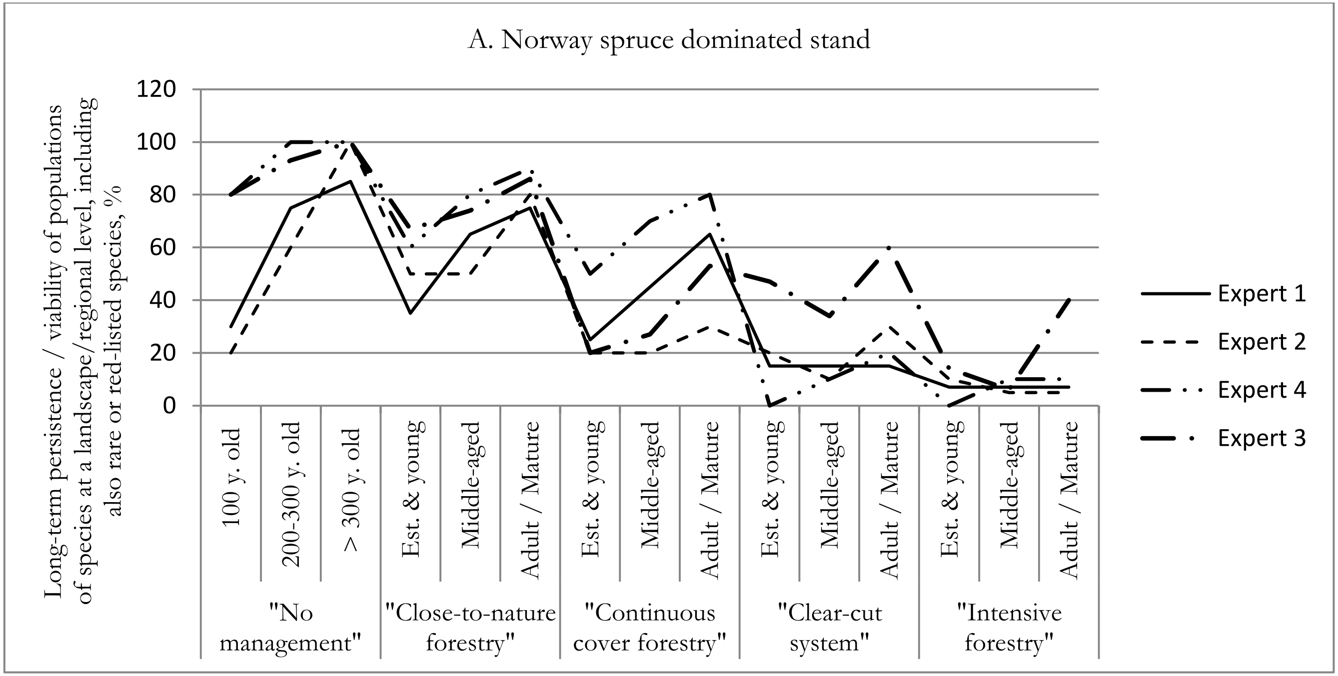


Fig 1A: Summary of answers from your panel in Round 1 for Norway spruce stand

Table 1A. Estimates of potential of forest management in provision of the ecosystem service: reprint of your answers from R1 and space for answers in R2

	"No management"			"Close-to-nature forestry"			"Continuous cover forestry"			"Clear-cut system"			"Intensive forestry"		
	100 years old or less	200-300 years old	More than 300 years old	Est. & young	Middle-aged	Adult / mature	Est. & young	Middle-aged	Adult / mature	Est. & young	Middle-aged	Adult / mature	Est. & young	Middle-aged	Adult / mature
Your response in Round 1															
Best guess	30	75	85	35	65	75	25	45	65	15	15	15	7	7	7
Your confidence rate, %	70	70	70	60	60	60	70	70	70	80	80	80	80	80	80
Your response in Round 2															
Best guess															
Your confidence rate, %															

* Respondents received also Table 1b and Figure 1b for Forest type 2 (Scots pine dominated stand)

Please write any new comments you may have on Question 1 in this textbox

QUESTION 2: Forest characteristics and provision of the ecosystem service

Brief explanation: In this question you are asked to consider forest characteristics that are important for provision of the ecosystem service in the Nordic boreal region and make a judgment on the relationship between this service and forest characteristics.

Table 2 provides the summary of answers from your entire panel and your personal answers from Round 1. If you would like to revise any of them, please write your new answers in the columns for "Your response in R 2". Otherwise leave the columns blank. There is also an additional question –on relative contribution of characteristics for provision of the service (4).

Number of expert who participate in Q2: N=5 experts, 4 of them – Northern Sweden and 1 – Finland.

Ecosystem service, its definition and geography are the same throughout the questionnaire (see Q1 for more details).

Since answers provided in R1 for this questions did not differ between 2 forest types (Norway spruce dominated and Scots pine dominated), only one table is presented in R2. Should you wish to provide separate answers for one of the forest types, please indicate below which one (by ticking it). Otherwise just leave it blank.

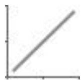
___ Norway spruce dominated
___ Scots pine dominated

How to read Table 2:

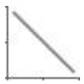
Column (1) lists all forest characteristics that have been identified by experts as important for provision of the service in Round 1.

Column (2) gives a summary of responses of your entire panel in the following format: "type of relationship (degree of confidence of expert in the answer)". Experts are separated by commas. If there are less than 5 responses, it means that some experts did not consider this characteristic to be important or didn't provide answer for the type of relationship. If no answers at all are presented for the characteristic – it was suggested by experts in Round 1.

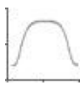
Types of relationships between forest characteristics and provision of the ecosystem service:



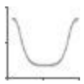
Positive (P)
Provision of service increases when the level of the characteristic increases



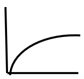
Negative (N)
Provision of service decreases when the level of the characteristic increases



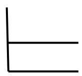
Bell-shaped (B)
Provision of service is enhanced by the characteristic, except when the level of the characteristic is very low or very high



U-shaped (U)
Provision of service is reduced by the characteristic, except when the level of the characteristic is very low or very high



Concave (C)
Provision of service is enhanced by the characteristic, except when the level of the characteristic is very low or very high



Constant (Ct)
Provision of service is not affected by the characteristic and remains on the same level

Column (3) reports your personal answer regarding the type of relationship between characteristic and ecosystem service in Round 1 and provides space for the answer in Round 2.

Column (4) is an added in Round 2 question on the relative contribution of each of forest characteristics to the provision of the service. It is done using weights from 1 to 10 where 1=the lowest and 10=the highest. The same weight can be assigned to more than one characteristic.

Column (5) reports your personal answer regarding the degree of confidence in your estimates (in %) from Round 1 and provides space for the answer in Round 2, where we ask you to rate it using the following scale: "low", "medium" or "high".

Table 2*. Forest characteristics & provision of the ecosystem service: summary from R1 and your answers in R2

#	(1) Forest characteristics important for provision of the service in the Nordic boreal zone	(2) Type of relationship between characteristic & service (degree of confidence in answer): *summary of responses from R1* (the most common answer(s) in bold)	(3) Relationship between characteristic & service		(4) Relative contribution of this characteristic to provision of the service (from 1=the lowest to 10=the highest)	(5) Degree of your confidence in provided estimates	
			Your response in R1	Your response in R2		Your reponse in R1, %	Your response in R2 (select from "low", "medium" or "high")
1	*Stand age* - age of dominant tree species in the stand (from establishment to maturity)	**P** (80), P (100), P (-), C (80), C (99)	Concave			80	
2	*Stand density* (from open (i.e. retention trees) to moderate (i.e. shelterwood / selection systems) to dense (i.e. closed canopy))	**B** (80), B (99), **N** (60), N (65)	Bell-shaped			80	
3	*Variation in tree size / age within the stand* (from uniform to mix of different sizes / uneven-aged)	**P** (80), P (75), P (-), C (99)	Positive			80	

* The thesis contains only fraction of the table, respondents were presented with a full version (containing all forest characteristics)

Please write any new comments you may have on Question 2 in this textbox

QUESTIONS REGARDING THE DELHI SURVEY EXPERIENCE

Have you revised / changed any of your answers from Round 1?

____Yes (all of them)

___ Yes (some of them)

___ No (no changes were done)

If yes, to what extent did each of matters below was responsible for the change in the estimates you provided?

___ summary of answers from other respondents

___ change from country level to the region level (e.g. from considering Northern Sweden to boreal zone in Fennoscandia in general)

___ other

Other comments:

****

Please email your completed questionnaire, and any queries you may have to: Anna Filyushkina, Institute of Food and Resource Economics, University of Copenhagen, anfi@ifro.ku.dk.

Thank you again for participating in the survey.

****

Appendix C: Questionnaire for the Choice experiment (Paper III)

Welcome to the survey!
How would you prefer the forest you visit to look like?

We would like to investigate Danish population's preferences on how forests for recreation should look like. This knowledge potentially can then be used for management of forests that would better meet demands of Danish population for outdoor recreation.

The survey is carried out by University of Copenhagen. It is an independent research, not requested by any organization or authorities. We are interested in your opinion and we kindly ask you to answer honestly. Answers will be treated anonymously.

It will take approximately 20 minutes to fill out the questionnaire.

Thank you for your cooperation!

****

Your birth year:

19___

Your gender:

__ Female
__ Male

In which region do you live:

__ Copenhagen Area
__ Zealand
__ Southern Denmark
__ Central Jutland
__ Northern Jutland
__ Abroad
__ Don't know

What is annual income of your household before the tax?

__ Under 100,000 kr.
__ 100,000 – 149,999 kr.
__ 150,000 – 199,999 kr.
__ 200,000 – 249,999 kr.

__ 250,000 – 299,999 kr.
__ 300,000 – 349,999 kr.
__ 350,000 – 399,999 kr.
__ 400,000 – 449,999 kr.
__ 450,000 – 499,999 kr.
__ 500,000 – 549,999 kr.
__ 550,000 – 599,999 kr.
__ 600,000 kr. or more

Part I. General information about your visits to forests for recreation
We would like to ask you about your visits to forests for recreation. By visit to a forest we mean visit to forests that are outside of cities (not parks).

How far away do you live from the nearest forest?

_____ Km
If it is less than 1 Km, ___________ Meter

How often have you visited **any forest** for recreation in the last 12 months?
__ Once
__ 2-5 times
__ 6-10 times
__ More than 10 times
__ I have not visited forest for recreation in the last 12 months

On the next three pages we will ask you to indicate which forests you have visited during last three visits. For each visit we will also ask you to mark on the map, where was your point of departure (for example home, summerhouse etc).

You can zoom in on the map and mark forests by clicking the mouse.

If you visited the same forest more times in the last three visits, we are asking you to mark it on each map.

If you can't remember your last visit to the forest, it is not necessary to indicate where it was.

Please mark the forest of **your most recent visit** for recreation and from where you departed.

[Interactive google map]

- First click to indicate the area you visited
- Then click to indicate where you travelled from

Please mark the forest of your **<u>second most recent visit</u>** for recreation and from where you departed.
[Interactive google map as shown in the question above]

- First click to indicate the area you visited
- Then click to indicate where you travelled from

Please mark the forest of your **<u>third most recent visit</u>** for recreation and from where you departed.
[Interactive google map as shown in the question above]

- First click to indicate the area you visited
- Then click to indicate where you travelled from

Now consider the last visit to forest for recreation, the <u>most recent</u> of the three visits you mapped

How long time ago was your last visit to a forest?

__ A day
__ 1 to 6 days
__ 1 to 2 weeks ago
__ 2 to 4 weeks ago
__ 1 to 2 months ago
__ 3 to 4 months ago
__ 5 to 6 months ago
__ 7 to 8 months ago
__ 9 to 10 months ago
__ 11 to 12 months ago
__ Over a year ago
__ Don't remember

Which mode of transport did you use to reach the forest for this visit?
Pick one of the alternatives. Should you have used more than one, please indicate the one with the longest duration.

__ By foot
__ Bicycle
__ Motorbike / scooter
__ Personal car
__ Bus / rutebil
__ Train / S-tog
__ Other (please specify _____________)

How long did you stay in the forest during your last recreational visit?

__ Less than 5 min
__ 5-30 min
__ 31-60 min
__ 1-2 hours

__ 3-4 hours
__ 5-8 hours
__ More than 8 hours
__ Don't remember

Which of the following recreational activities did you undertake during this visit to the forest? (Tick all relevant)

__ walking with a dog
__ walking (without a dog)
__ experiencing nature / place
__ studying nature / place
__ wildlife / bird watching
__ fishing
__ running
__ orienteering
__ horseback riding
__ cycling (not mountain biking)
__ mountain biking
__ gathering wild mushrooms, berries, plants etc
__ hunting
__ camping
__ playing with children
__ appreciating scenery from your car
__ other (please specify) ____________________________

What were two most important motivations for you for this visit to the forest?
(Tick all relevant)

__ to experience nature
__ to meet other people
__ to exercise your dog
__ for health or exercise
__ to entertain children
__ to enjoy scenery
__ to enjoy / observe wildlife
__ for fresh air
__ to relax and enjoy peace and quiet
__ to spend time with friends
__ other (please specify) _______________________________

Who did you go with to the forest during this last visit?

__ Alone
__ With my family or friends
__ Trips organized by associations or local entities
__ Other (please specify __________________________________)

Part II. Danish forests
[Split with a quiz, half of respondents in all three blocks, random allocation]

Forests in Denmark consist of different tree species. Not all species are equally easy to recognize, and some are rarer than others. Therefore, in the next questions we will ask you answer "Do not know" if you do not know them.

Leaf of which tree species is shown on this picture?

__ oak
__ beech
__ Scots Pine
__ Norway Spruce
__ I don't know

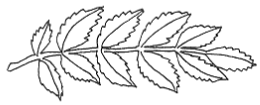
Leaf of which tree species is shown on this picture?

__ Scots pine
__ Norway spruce
__ birch
__ Hazell
__ I don't know

Leaf of which tree species is shown on this picture?

__ birch
__ beech
__ maple
__ lime
__ I don't know

Leaf of which tree species is shown on this picture?



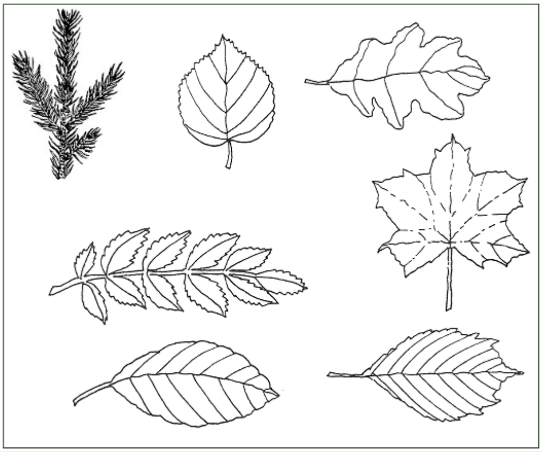
__ rowan
__ maple
__ beech
__ ash
__ I don't know

Not all trees that grow in Danish forests are native to Denmark, some of them are introduced by people.
Did you know that?
__ Yes
__ No

[If yes]:
Which of these tree species do you think are native to Denmark?
(Tree species is native, if it has naturally migrated to Denmark, and not native if it has been brought by people)

	Native	Not native	Don't know
Beech			
Norway spruce			
Oak			
Birch			
Tilia			
Acer			
Scots pine			
Elm			

[Split without a quiz, other half of respondents]
Forests in Denmark consist of different tree species, for example beech, oak, elm, Norway spruce. Some of them are native to Denmark, while others have been introduced by people. Below you can see drawings of leaves of some of these trees.



When you are in the forest, do you notice that forests consist of different tree species?
__ Yes
__ No

Part III: Preferences for forests

In the following questions we ask you to think about forests for recreation, and how you would like forests to look like when you visit them.

We will ask you eight questions, in which you can choose between different options for your next visit to forest for recreation. If you don't want to visit neither of the two forests, you can choose the third option "I would rather not visit either of these forests".

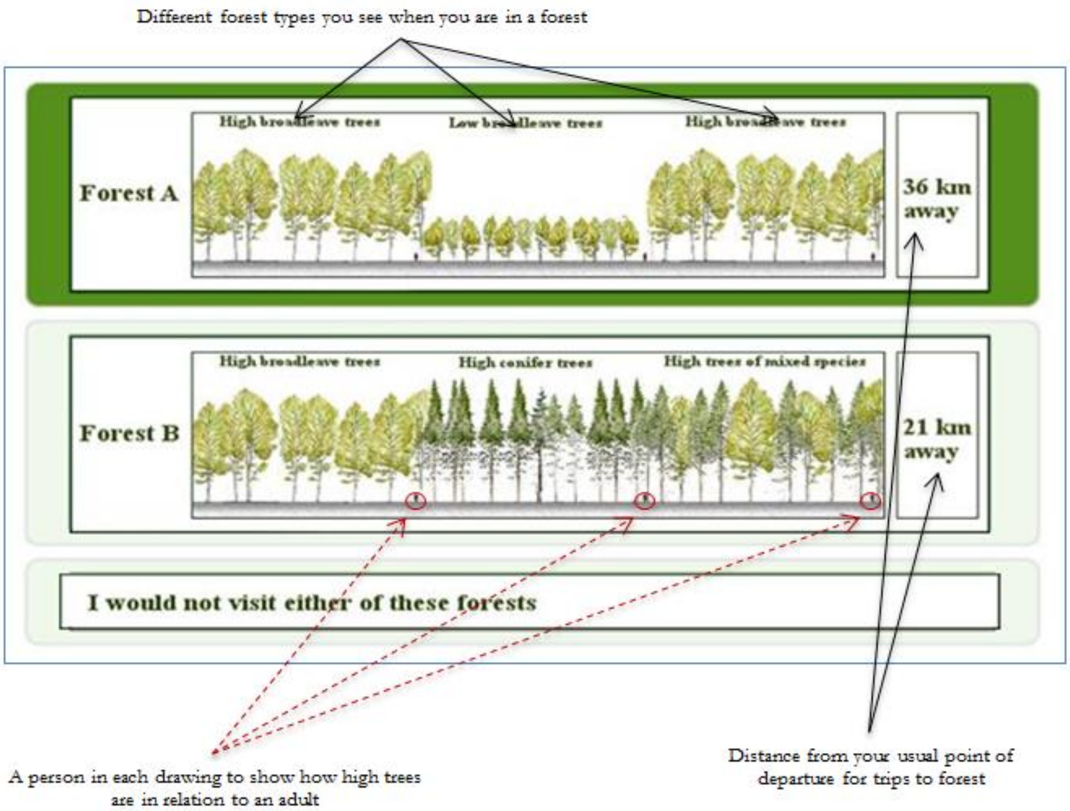
When you visit the forest, its appearance might change as you go through it. On the next page we will show you, how forest with different forest types can look. When you answer the questions you should imagine that you are seeing all three forest types on your visit to the forest. Imagine that the forest consists of shown forest types, but not necessarily in the same order.

For each forest you can visit, there is a distance that you would have to travel to reach it (from the departure point you would normally use, f.eks. your home, summer house etc).

We ask you to imagine that two shown alternatives are your options for the next visit to forest for recreation, regardless which alternatives you have in reality.

Please also take into consideration that normally you can use your time for something else than visiting a forest, for example it could be that none of the forests meet your requirements or both of them are too far away.

Here you see an example of how the questions we'll be asking looks like:



[8 choice questions as presented in Figure 1 Paper III]

[Follow-up if respondent in each choice set chose the 3rd option "I would NOT go to any of these the forests"]

You chose "I would not visit any of these forests" in all the above choices. What were the reasons for selecting this option?

__ I don't like to recreate in the forest
__ The provided alternatives are too far away
__ I could not imagine, how shown forests would look in reality
__ Forests that are shown don't exist where I live
__ I live in the city and going to the forest is not an option for me
__ I don't think people should interfere in how forests look
__ Other (please specify)________________________________

[OR: If they choose at least one of the alternatives A and B in one out of eight questions]

When making choices in previous 8 questions what was the main recreational activity you had in mind?

__ walking with a dog
__ walking (without a dog)
__ experiencing nature / place
__ studying nature / place
__ wildlife / bird watching
__ fishing
__ running
__ orienteering
__ horseback riding
__ cycling (not mountain biking)
__ mountain biking
__ gathering wild mushrooms, berries, plants etc
__ hunting
__ camping
__ playing with children
__ appreciating scenery from your car
__ other (please specify) ___________________________
__ I did not think about any specific activity

When making choices in the previous questions what was the main mode of transportation you had in mind?

__ By foot
__ Bicycle
__ Motorbike / scooter
__ Personal car

__ Bus / rutebil
__ Train / S-tog
__ Other (please specify ___________)

The choices were shown with forest pictures in summer. Forests look different in winter, f.eks. broadleaved trees do not have leaves. Would your choices have been different if it was a winter trip?
__ Yes
__ No
__ Don't know

[If yes, pop-up with]:
Please describe what would you have paid more attention to if you were in forest in winter.
____
____

When you were deciding in 8 choice questions, did you take into account the forest that you have visited last?
__ Yes
__ No

[If yes, pop-up with]:
How did you take into account your last visit to the forest?
__ I chose the forest, that reminded me most the forest I visited last
__ I chose the forest that is different from my last forest visit
__ Other (please specify___________________)

What was the most important for you when you made your decision in 8 choice questions?
__ How shown forests look – no matter how far away they are
__ How shown forests look and how far away they are
__ I always chose the closest forest
__ I imagined how the forest I most often visit look and chose the one that reminded me of it
__ I put emphasis on other things (please specify ______________________)

Do you think, that it is difficult to choose between different forest types?
__ Yes, very
__ Yes, some
__ Yes, a little
__ No

[If yes, pop-up with]:
What was most difficult for you in choosing between forest types?

__ Many consecutive choice sets
__ Difficult to relate to many different forest types
__ Alternatives were not realistic
__ Difficult to relate to how far the forests are
__ Difficult to see differences on drawings
__ Difficult to imagine how forests look in reality
__ Difficult to relate to tree's height
__ Difficult to relate to tree species
__ Other (please specify)______________________________

Part IV. Designing your ideal forest for recreation

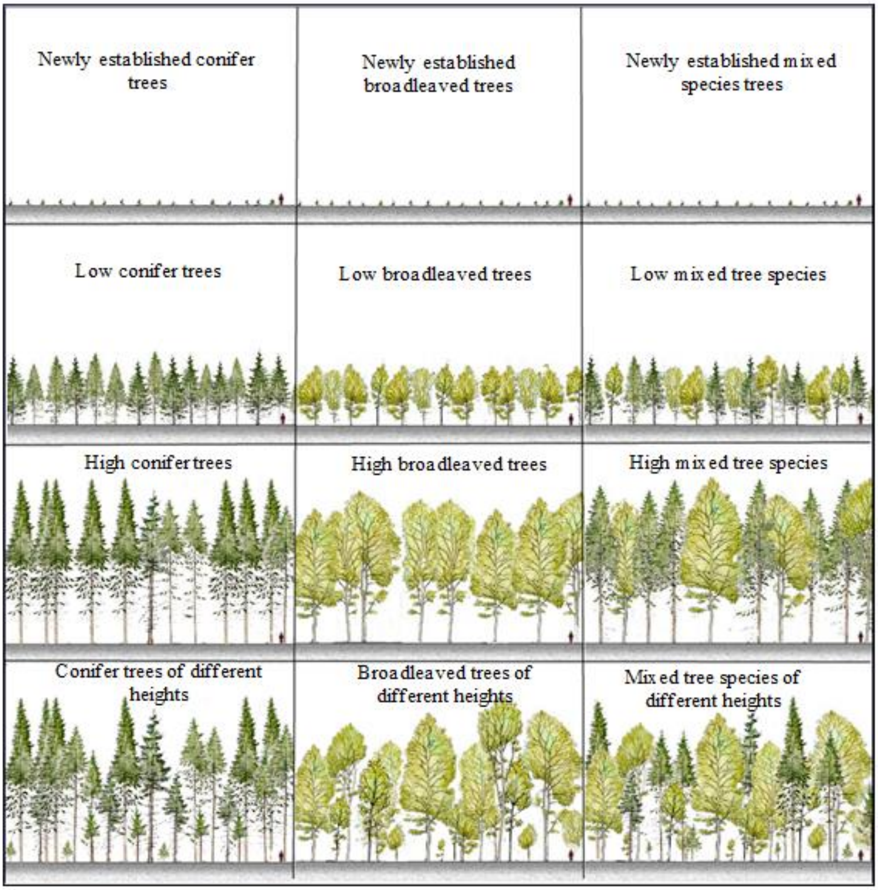
Imagine how forest should look like for you to have the best recreational experience.

Below you see 12 drawings of different forest types. You have already seen most or all of them in the previous questions.

On next pages we will ask you to choose three drawings that show the ideal forest composition. As above, we ask you therefore imagine that the forest may consist of different forest types. You can choose whether to have 3 same forest types or whether they should be different.

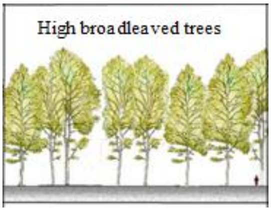
Please pick the first forest type in composition of ideal forest for recreation for you.

Your ideal forest for recreation:



Now you can see the first forest type you chose.
Please choose the second forest type. It is up to you if it is the same forest type as the first one or a different one.

Your ideal forest for recreation:

[Matrix of drawings of 12 forest types as presented in previous page]

Now you can see the first and second forest types you chose.
Please choose the third forest type. It is up to you if it is the same forest type or a different one.

[Table "Your ideal forest for recreation" with two cells filled.
Matrix of drawings of 12 forest types as presented in previous page]

Now you can see your preferred forest. Does it look the way you wanted?
If you would like to make changes, you can click on "Back" and make adjustments

[Table "Your ideal forest for recreation" – all three cells filled]

When you made your choices above, did you only consider recreational aspects, or did you also take into account other functions of forests?
__ I only took into consideration recreational aspects
__ I also considered forests as habitat for animals and plants
__ I also considered timber production
__ I took into consideration other things (please specify ___________________)

Part V. About yourself
Last we will ask a few questions about you. Remember that all answers will be treated confidentially.

In which post code do you live?

____

What is your highest level of education?

__ Primary school

__ High school

__ Vocational education

__ Short, higher education

__ University degree, B.sc

__ University degree, M.Sc

__ Other

Do you have any education related to forestry or environment?
__ Yes
__ No

[If yes, pop-up with]:
What kind of education related to forestry and environment do you have?______________________________________

What is your present occupation?
__ Self-employed
__ House person
__ Employed full time (at least 32 hours per week)
__ Employed part-time (hourly)
__ Unemployed
__ On leave
__ Undergoing education
__ Førtidspentionist
__ Efterlønsmodtager
__ Folkepentionist
__ Other

How many people is your household comprised of?
(Household consists of people who live in the same address and who are dependent on the same income, typically a family).
Number of adults: _____
Number of children (under 18 years old): ____
Number of adults contributing to the household income:_____

Which of the following best describes the area you live in now and the area you lived in during your childhood (from 0 to 14 years old)?

	Now	Childhood
I live / lived in Greater Copenhagen		
I live / lived in a big city (more than 100.000 inhabitants)		
I live / lived in a city (between 20.000 and		

100.000 inhabitants)		
I live / lived in a town (between 500 and 20.000 inhabitants)		
I live / lived in the countryside / not a city		
I don't know		

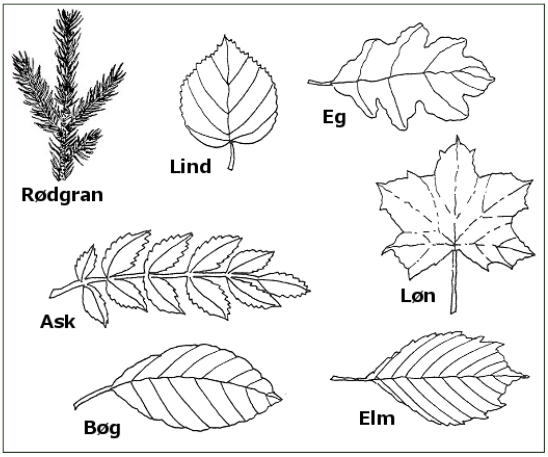
Are you a member of any of the following outdoor or environment associations?

__ Danish Nature Conservation
__ WWF
__ Birdlife Denmark
__ Hunter's association
__ Angler's association
__ Mountain bikers association
__ Association for the protection of animals
__ Other organization / association connected to nature or environment (please write the name)____________________
__ I am not a member of any organization / association connected to nature or environment

Thank you for your answers.
If you have comments / questions to this survey, please write them in the space below.

____

Thank you for your time!
Click "Next" to finish the survey



Drawings of tree leaves are from Eva Wulf (www.skoven-i-skolen.dk).
Drawings of forest types were made by Anders Busse Nielsen.