



Applying the Delphi method to assess impacts of forest management on biodiversity and habitat preservation



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ABSTRACT

This study applied a structured expert elicitation technique, the Delphi method, to identify the impacts of five forest management alternatives and several forest characteristics on the preservation of biodiversity and habitats in the boreal zone of the Nordic countries. The panel of experts consisted of a number of scientists in the field. The data was collected using a semi-structured questionnaire distributed via e-mail in two rounds. Our findings demonstrated that an increase in management intensity for timber production is likely to have a negative effect on the biodiversity and habitats with intense management alternatives such as a “clear-cutting system” resulting in the strongest adverse impact. The presence of deadwood, mixture of trees of different sizes and increase in stand age were expected to promote preservation of biodiversity and habitats. However, there was little agreement between experts regarding the functional form that relationships between preservation of biodiversity and forest characteristics take. The Delphi method was found useful in investigating the existing knowledge base and capable of contributing to a more comprehensive assessment for decision support as a valuable addition to on-going empirical and modeling efforts. The findings could assist forest managers in developing forest management strategies that generate benefits from timber production while taking into account the trade-offs with biodiversity goals.

1. Introduction

Despite a growing body of literature addressing impacts of different land uses on the provision of ecosystem services (e.g. Foley et al. 2005; Nelson et al. 2009; Burkhard et al. 2010; Raudsepp-Hearne et al. 2010; Scolozzi et al. 2012), analysis of ecosystem services to support land use decisions still faces challenges related to a limited understanding of their flows and how they are affected by management (Carpenter et al., 2009; de Groot et al., 2010; Filyushkina et al., 2016; Kettunen and Vihervaara, 2013). These difficulties in assessment and quantification of ecosystem services arise from challenges in linking ecological processes with services, dealing with the complex dynamics of the re-

lationships between management and provision of ecosystem services, and accounting for multiple spatial and temporal scales. Moreover, since many ecosystem services are challenging to monitor, researchers often have to rely on a variety of indicators (indirect and composite) (Egoh et al., 2012; Layke et al., 2012), for most of which the strength of evidence for the relationship has not been determined (Gao et al., 2015). The choice of indicator(s) for ecosystem services affects revealed trade-offs and impacts (Harrison et al., 2014) and thus it is important to determine a comprehensive and robust set of indicators to inform decision-making (Filyushkina et al., 2016; van Oudenhoven et al., 2012).

Forests and forest management is an example of land use, where multi-functionality and service provision is an inherent feature (FAO,

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2016; Hytönen, 1995). However, provisioning services such as timber production have been dominating in the past while in recent decades the demand for other (non-provisioning) services (e.g. recreation, carbon sequestration, biodiversity, and soil and water protection) has been increasing (Berg et al., 2007; Kriström & Boman, 2001; Norman et al., 2010). In the Nordic countries, there is a growing interest in managing forests as a so-called multi-functional land use, e.g. to simultaneously provide high-value timber, biodiversity, opportunities for recreation and game habitat from forests to meet societal preferences and demands (Boman et al., 2010; Ezebilo et al., 2015, 2012; Löf et al., 2016). Elsewhere, this is also reflected in the vast number of studies devoted to decision support tools that integrate non-provisioning services (e.g. Mendoza & Martins 2006; Diaz-Balteiro & Romero 2008) and revealing impacts of forest management on them (e.g. Spiecker 2003; Torras & Saura 2008; Paillet et al. 2010; Gustafsson et al. 2010). However, the majority of existing studies included only one or two management alternatives or forest characteristics, and applied growth simulations and ecological modeling to assess impacts on the provision of ecosystem services (e.g. Duncker et al., 2012b; Biber et al. 2015; Frank et al. 2015). At the same time, a review of existing decision support tools concluded that the majority of these tools do not include non-provisioning ecosystem services (Segura et al., 2014). Thus, there is a need for better understanding of impacts from various forest management regimes on delivery of non-provisioning ecosystem services in order to make more informed decisions (Duncker et al., 2012b; Filyushkina et al., 2016; Kuuluvainen et al., 2012; Trivino et al., 2016).

In this study we used the Delphi technique – a structured expert assessment method, to deal with a large degree of uncertainty and complexity (MacMillan and Marshall, 2006; Martin et al., 2012). Previously, the Delphi technique has been extensively applied in healthcare, technological and environmental forecasting and other fields since its development in the 1950s. Applications of the Delphi in natural resource management include studies such as deriving habitat suitability models (e.g. Crance 1987; Uhmman et al. 2001; MacMillan & Marshall 2006), estimating potential of different land uses in provision of ecosystem services (e.g. Geneletti 2007; Scolozzi et al. 2012), selecting focal species in open space wildlife planning (e.g. Gobbi et al., 2012; Rubino and Hess, 2003), and valuation of global ecosystem services (e.g. Strand et al., 2017). Others include development of indicators for identification of forest restoration projects (e.g. Orsi et al. 2011) and biodiversity conservation (e.g. Oliver 2002; McBride et al. 2012). However, few such studies have focused on forest ecosystems in the Nordic boreal zone (e.g. Kangas and Alho, 1998; Edwards et al., 2012).

The objective of this study was to determine the effects of five forest management regimes on preservation of biodiversity and habitats in the Boreal zone of the Nordic countries using expert assessment technique. The study involved experts assessing the potential of five forest management alternatives along a continuum of management intensity levels. The relative importance of forest characteristics for preservation of biodiversity and habitat as well as functional forms of their relationship

were explored. Findings from this study could complement on-going empirical and modeling efforts in quantifying the effect of forest management on provision of ecosystem services and provide further insights for decision support.

2. Methods and materials

2.1. Delphi methodology

Expert elicitation techniques are associated with a range of advantages such as ability to work with a large degree of uncertainty and data-poor environments (Martin et al., 2012). They are often relevant in cases when there is a need for generalization while still being able to capture the complexity of the system. However expert judgments have been criticized for being subjected to cognitive, motivational, subjective and other biases (e.g. framing, overconfidence, anchoring, halo effects, dominance), poor calibration and self-serving (Hasson and Keeney, 2011; Kynn, 2008; Tversky and Kahneman, 1974). Structured elicitation processes are meant to minimize these biases (McBride et al., 2012; Waldron et al., 2016). The Delphi technique is a multi-interaction structured group communication process that seeks to provide a group expert opinion on the defined question(s), forging a consensus through anonymous deliberations whenever possible. In each round experts (participants) are asked to fill out questionnaires individually and anonymously. After each round all responses within a panel are summarized by the moderator and reported back to the panelists, who then have an opportunity to revise their answers in the light of others in the group. The process continues until a set level of stability in answers is reached (Linstone and Turoff, 2002; Novakowski and Wellar, 2008).

Apart from advantages common to all expert elicitation techniques the Delphi method is associated with reduction of negative issues related to group dynamics due to anonymity of participants (e.g. social pressure and desirability, domination, halo effect), increase of robustness of opinion gathering due to structured and repeated nature of inquiry, possibility of engaging geographically dispersed experts and lower costs (Jolson and Rossow, 1971; Landeta, 2006; Linstone and Turoff, 2002; McBride et al., 2012; Novakowski and Wellar, 2008; Waldron et al., 2016). These characteristics, as well as previous applications in complex and multi-faceted issues with a high degree of uncertainty and poor data environment, make the Delphi method suitable for addressing questions related to impacts of land use on the provision of ecosystem services.

2.2. Data collection procedure

The data for this study were collected using a Delphi survey following the protocol described in Novakowski & Wellar (2008) and used in Eycott et al. (2011) and Edwards et al. (2012). The process comprised six steps as illustrated in Fig. 1.

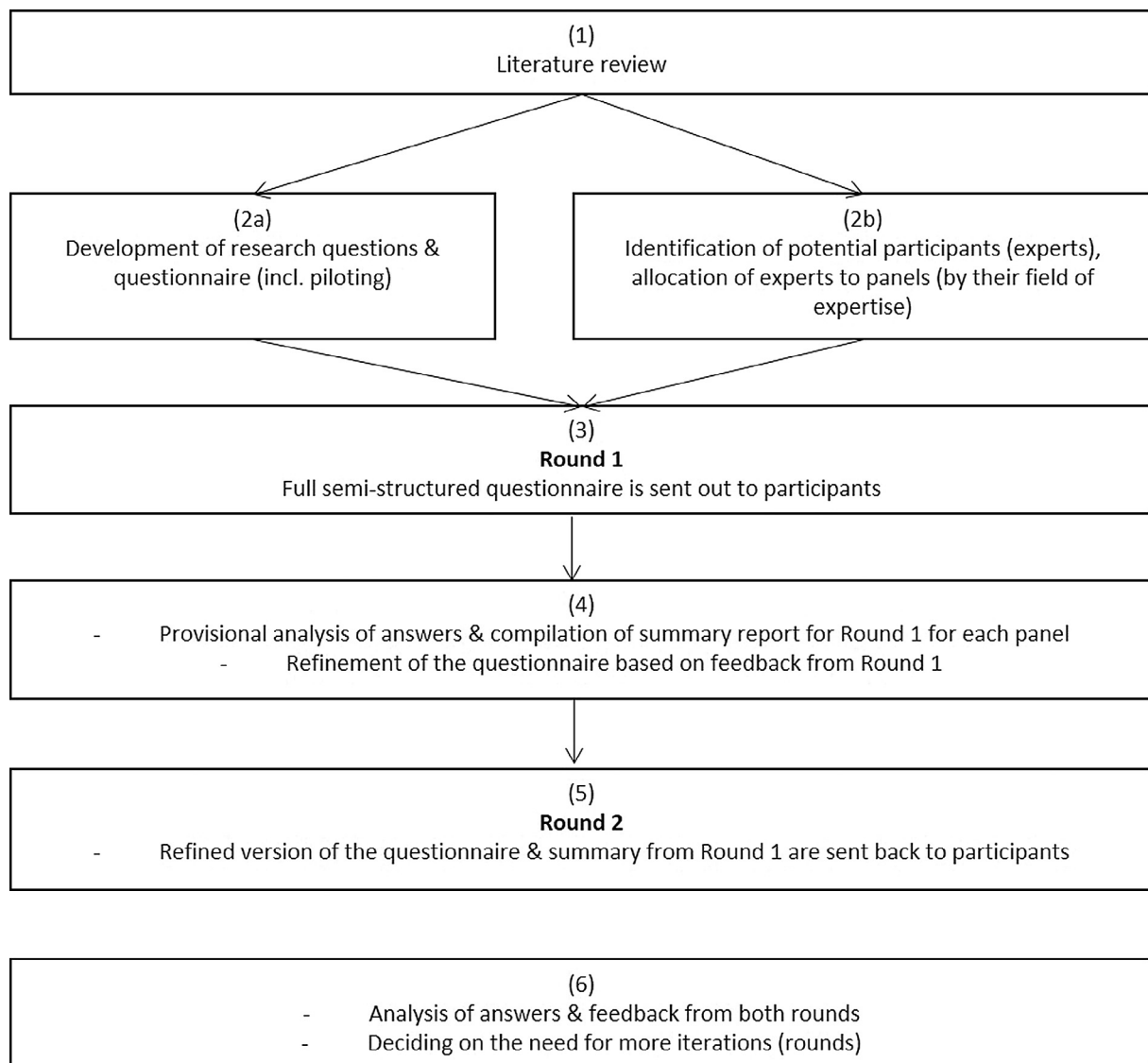


Fig. 1. Schematic diagram describing steps of the Delphi process applied in this study.

Step 1: Literature review

This study was built on a systematic review of the literature on assessment and integration of non-provisional forest ecosystem services into decision support (Filyushkina et al., 2016).

Step 2a: Questionnaire development

The focus of this study was on eliciting expert judgments about impacts of forest management on the preservation of biodiversity and habitats for two forest types in the Nordic boreal zone²: Norway spruce or Scots pine dominated forest ecosystems. In this study biodiversity preservation was regarded as a habitat supporting service according to the classification from The Economics of Ecosystems and Biodiversity (TEEB) initiative (TEEB, 2010) or “regulating and maintenance” according to the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2011).

Biological diversity, i.e. biodiversity, is defined by the Parties to the Convention on Biological Diversity (CBD): ‘the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems’ (CBD, 1992). During the pilot phase of this study participants have agreed on the following focus for preservation of biodiversity/habitat: the “long-term persistence/viability of populations of species at a landscape/regional level, including also rare or red-listed species”. The pilot study was performed with several scientists who had similar scientific profiles as the intended experts in this study, but also with scientists who had experience with creation of social science surveys. During the pilot stage feedback was elicited on the complexity of questions, need for clarifications, definitions, and re-formulations, thus allowing further improvement the questionnaire.

Two questions comprised the main body of the questionnaire:

Question 1 (Q1): “How does the potential to preserve biodiversity and habitat change between forest management alternatives?”

The classification of forest management approaches along the management intensity continuum by Duncker et al. (2012a) was used to

² We report results for one service (panel) of a bigger Delphi survey that focused on several other ecosystem services (recreation, carbon sequestration) and included the temperate Nordic zone. For those panels only one round of iteration was completed, further deliberations were not feasible due to low number of participants.

outline five management alternatives: “no management”, “close-to-nature forestry”, “continuous cover forestry”, “clear-cutting system” and “intensive forestry”. Each of the management alternatives was further divided into three stages of stand development (i.e. stand age groups). The first management alternative (no management) was represented by the following three age groups: 100 years old, 200–300 years old and older than 300 years. The other four were represented by the following three stages: establishment/young, middle-aged – and adult/mature phase (a brief explanation of management alternatives is presented in the [Supplementary materials](#)).

We also investigated individual forest characteristics (MacMillan and Marshall, 2006), in order to provide a more operational assessment that could be useful for decision-making. This led to the second question.

Question 2 (Q2) was concerned with functional relationships between forest characteristics and preservation of biodiversity. The initial list of forest characteristics was identified using findings of a systematic review outlined in Filyushkina et al. (2016) (see [Box 1](#)).

The question was split into two sub-questions:

Question 2a (Q2a): “Which forest characteristics are important for preservation of biodiversity and habitats?”

Question 2b (Q2b): “What functional form does the relationship between each of these forest characteristics and biodiversity have?”

Box 1

The initial list of forest characteristics and their definitions used in Q2.

1. Stand age – age of dominant tree species in the stand (from establishment to maturity)
 2. Stand density (from open (i.e. retention trees) to moderate (i.e. shelter-wood/selection systems) to dense (i.e. closed canopy))
 3. Variation in tree size/age within the stand (from uniform to mix of different sizes/uneven-aged)
 4. Number of canopy layers in the stand (from one to many)
 5. Presence/extent of under-storey (from none to moderate to dense)
 6. Variation in spacing between trees in the stand (from regular spaced to different sized groups of trees, patches, openings)
 7. Tree species diversity in the stand (from 1 to several to many tree species)
 8. Presence of broadleaved trees in the stand (from none to some)
 9. Amount of standing/fallen deadwood (volume from low to high)
 10. Variation in the size of individual pieces of deadwood in the stand (from all piece of the same size to a mix of different sizes)
 11. Amount of residues left from thinning and/or final harvesting (volume from low to high)
 12. Size of clear-cut (from small to large)
 13. Regeneration type (from natural to artificial)
 14. Occurrence and/or mimicking of natural disturbances (from none to some)
 15. Naturalness of forest edges – not “straight” edges (from low to high portion)

Here “functional form” refers to the algebraic form of the relationship between a dependent variable (biodiversity) and independent variables (forest characteristics). Participants could then choose from a list of possible functional forms (see [Box 2](#)) or suggest other ones.

In addition, the questionnaire contained a background section where the participants provided information on their previous experience with expert elicitation techniques and a short description of forest types and forest management alternatives. In each section, participants in the Delphi survey were provided with opportunities to provide feedback and comment on reasoning behind their answers, assumptions they made or content of the questionnaire and process itself.

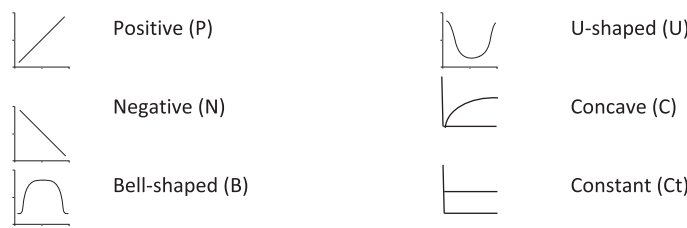
Step 2b: Identification of potential participants (experts)

Expert judgments in this study were only collected from researchers, in order to establish the current level of knowledge regarding the provision of ecosystem services from different forest management regimes. The following criteria for inclusion in the study were applied: existence of peer-reviewed publications on the preservation of biodiversity and habitat and forest management in the Nordic region and willingness to participate in the study. Initially, potential participants were identified through the literature review, professional networks, and “snowballing” technique (i.e. invited participants were asked to nominate other candidates).

Step 3: Round 1

The Delphi survey was administered via e-mail. All communication was standardized ensuring that all participants in the survey received the same information from the moderator. For Round 1, identified experts were contacted in November 2014. As it was the first contact in addition to the questionnaire the e-mail contained a short description of

Box 2 Possible functional forms of relationship between forest characteristics and biodiversity.



the Delphi process, a proposed timeline and a brief outline of aims of the survey. A reminder e-mail was sent out a week later for those who had not responded by then. Out of 25 potential participants, a total of 11 experts answered the request to participate in the study. However, five of these submitted only their feedback to the questionnaire, and in total only six returned a completed questionnaire. These six experts formed the panel in Round 1 of this Delphi study.

To reduce over-confidence bias experts were asked to report their levels of confidence in the estimates they provided in addition to their best guess estimate. In Q1 a four-step interval elicitation procedure was applied – experts were asked to provide:

- (i) upper and
- (ii) lower limits between which the estimate lies,
- (iii) best guess estimate, and
- (iv) their level of confidence in the best guess estimate (Burgman et al., 2011; Martin et al., 2012; Speirs-Bridge et al., 2010).

Step 4: Provisional analysis of Round 1 and refinement of the questionnaire for Round 2

The purpose of the provisional analysis of answers from Round 1 was to determine preliminary levels of consensus between experts and refine questions based on their feedback. At the same time, it was important to find a way to present those results from the entire panel to participants in Round 2 so that they could decide whether to adjust their individual answers (and by how much) or not.

For Q1, it was decided to present values provided by each participant graphically on one figure. Below the figure each participant was given a table containing his/her answers from Round 1 and space for new values in Round 2 should he/she decide to revise them. The four-stage elicitation technique (Speirs-Bridge et al., 2010) was replaced by a two-stage one, containing only the best guess estimate and level of confidence in best guess estimate.

For Q2, the most frequently identified relationships were presented together with a full range of answers from all participants in a tabular format. Supplementary forest characteristics suggested by participants in Round 1 were added to the list for Round 2 (see Box 3). In addition, Q2a was changed to “What is the relative contribution of these characteristics to preservation of biodiversity and habitat on a scale from 1 to 10, where 1 is the lowest?”

Box 3

The list of forest characteristics for Q2 added by participants in Round 1.

- 16. Shrub diversity in the stand (from low to high)
- 17. Degree of connectivity in the landscape (from low to some to high)
- 18. Size of individual pieces of deadwood (from small to large)
- 19. Degree of temporal and spatial continuity in the landscape (from low to high)

Step 5: Round 2

In Round 2, questionnaires were refined and tailored for each participant and e-mailed to the panel. Participants were then invited to reconsider their previous answers in the light of the group response presented to them and to revise or provide comments if they considered it appropriate. In addition, those who did not participate in Round 1

were also invited to contribute in this round.

Step 6: Analysis of results from Round 1 and 2 and decision to proceed or stop

Five participants completed both Round 1 and 2. One participant completed the questionnaire for only Round 1 and one did so for only Round 2. In order to determine whether there is a need for more iterations, results from both Round 1 and 2 were analyzed for two measures: levels of consensus and stability in answers. Levels of consensus among participants were determined using the following procedure: for Q1 and Q2a by calculating median and range (min and max) of values; and for Q2b by categorizing forest characteristics by type of relationship that was identified by at least 60% of participants. Stability in answers (i.e. consistency of responses between successive rounds) is often considered as a more important measure in determining whether more rounds are needed (Novakowski and Wellar, 2008; von der Gracht, 2012). We assessed how many answers were changed from Round 1 to Round 2 – less than 20%, this supported the decision to stop further deliberations.

3. Results

The researchers who participated in this study have investigated forest biodiversity in different parts of the Nordic boreal region: two in Finland, three in Northern Sweden and one in Norway. Each of them had studied different aspects of biodiversity and how it is affected by forest management between 10 and 28 years. Two of the participants had previously used other expert elicitation techniques in their own research, and one participant had previously participated in a Delphi exercise.

Generally, participants were willing to alter their answers after studying the summary of responses from other experts in the group from the 1st Round. Those who changed their answers were converging, i.e. moving towards their group's median estimate. Confidence levels reported by participants (data not presented) were higher for Q2 than for Q1, the latter also resulted in a higher number of comments/feedback.

(Q1): “How does the potential to preserve biodiversity and habitat

change between forest management alternatives?”

The purpose of this question was to generate trajectories that illustrate how forest management alternatives of different intensity were perceived to affect biodiversity and habitat. Figs. 2a and 2b presents aggregated group estimates of the median after 2nd round (based on individual estimates) and the range of individual answers represented by min and max values. Figs. 2a and 2b present similar trajectories for

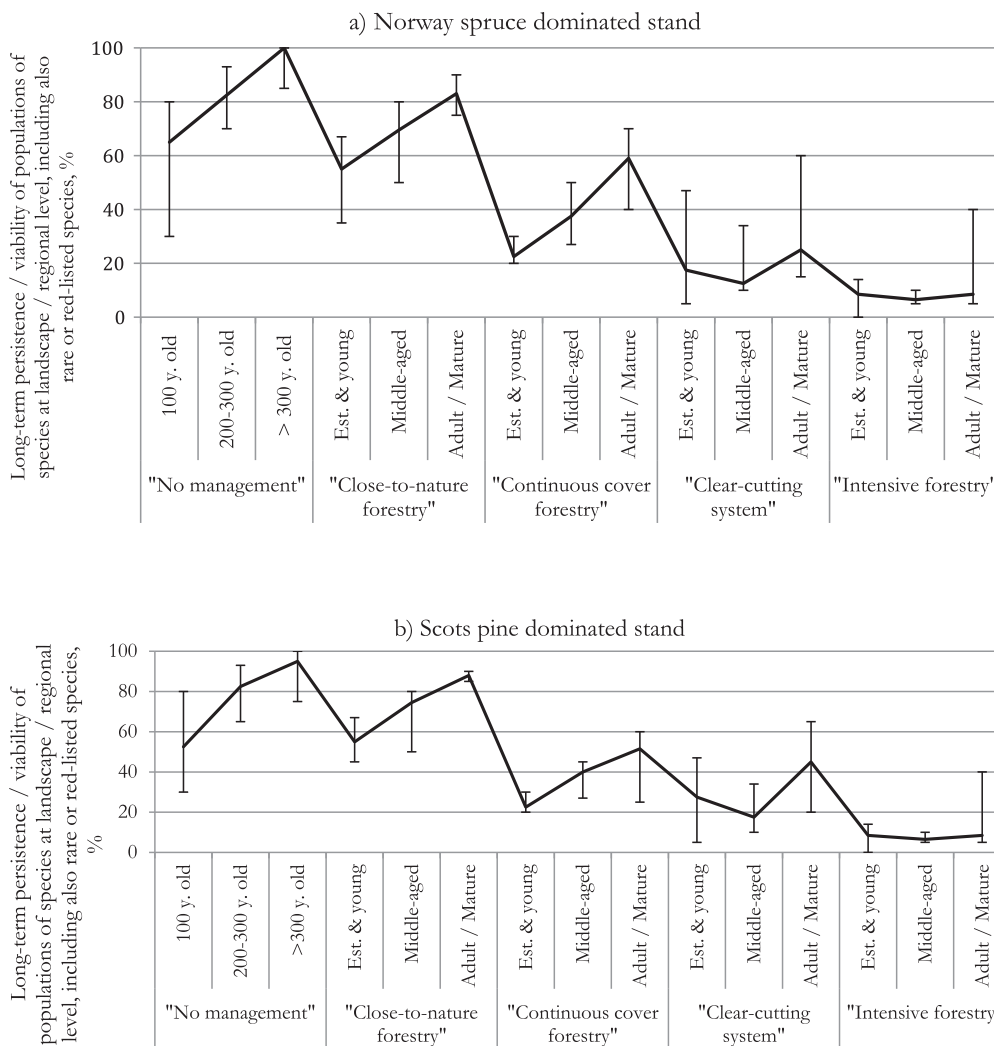


Fig. 2a. The potential to preserve biodiversity and habitat for five forest management alternatives in Norway spruce dominated stands (in %). The curve shows the group's median values and error bars indicate the max and min of the individual participants' values from the 2nd Round.

Fig. 2b. The potential to preserve biodiversity and habitat for five forest management alternatives in Scots pine dominated stands (in %). The curve shows the group's median values and error bars indicate the max and min of the individual participants' values from the 2nd Round.

Norway spruce and Scots pine dominated stands. For each large variations in the estimated values were captured. The "no management", however, seemed to have the highest potential for preservation of biodiversity and habitats, whereas "clear-cutting system" and "intensive forestry" were given substantially lower scores. Thus, an increase of management intensity is considered to negatively affect the ability to preserve biodiversity and habitat. With the exception of "intensive forestry, an increase in the potential to preserve biodiversity and habitat is observed within each forest management alternative as trees get older. However, some participants had not considered it relevant to differentiate between different stand ages as they "harbor different species and processes". The participants also reported that they found the process challenging, especially providing exact numbers given the potential range of values and a broad definition of biodiversity adopted for this study.

Levels of confidence in the estimates provided by the participants ranged from 50 to 95 %. Two forest management alternatives on the right side of the intensity continuum – "clear-cutting system" and "intensive forestry" were consistently associated with constant and higher

levels of confidence among all participants (80 %). Whereas for the other three management alternatives – "no management", "close-to-nature forestry" and "continuous-cover forestry" the levels of confidence were fluctuating.

(Q2a): "What is the relative contribution of each of the characteristics to preservation of biodiversity and habitats on a scale from 1 to 10, where 1 is the lowest?"

The experts' ranking of forest characteristics (aggregated estimates of the median as well as the min and max values reported by the individual experts) by their expected relative contribution to preservation of biodiversity and habitats resulting from experts' assessment is provided in Fig. 3. The characteristics that ranked the highest were (in descending order): stand age, amount of standing/fallen deadwood, presence of broadleaved species in the stand, degree of temporal and spatial continuity in the landscape. However, as suggested by the error bars (min and max values) a wide range of relative importance values was observed for many characteristics.

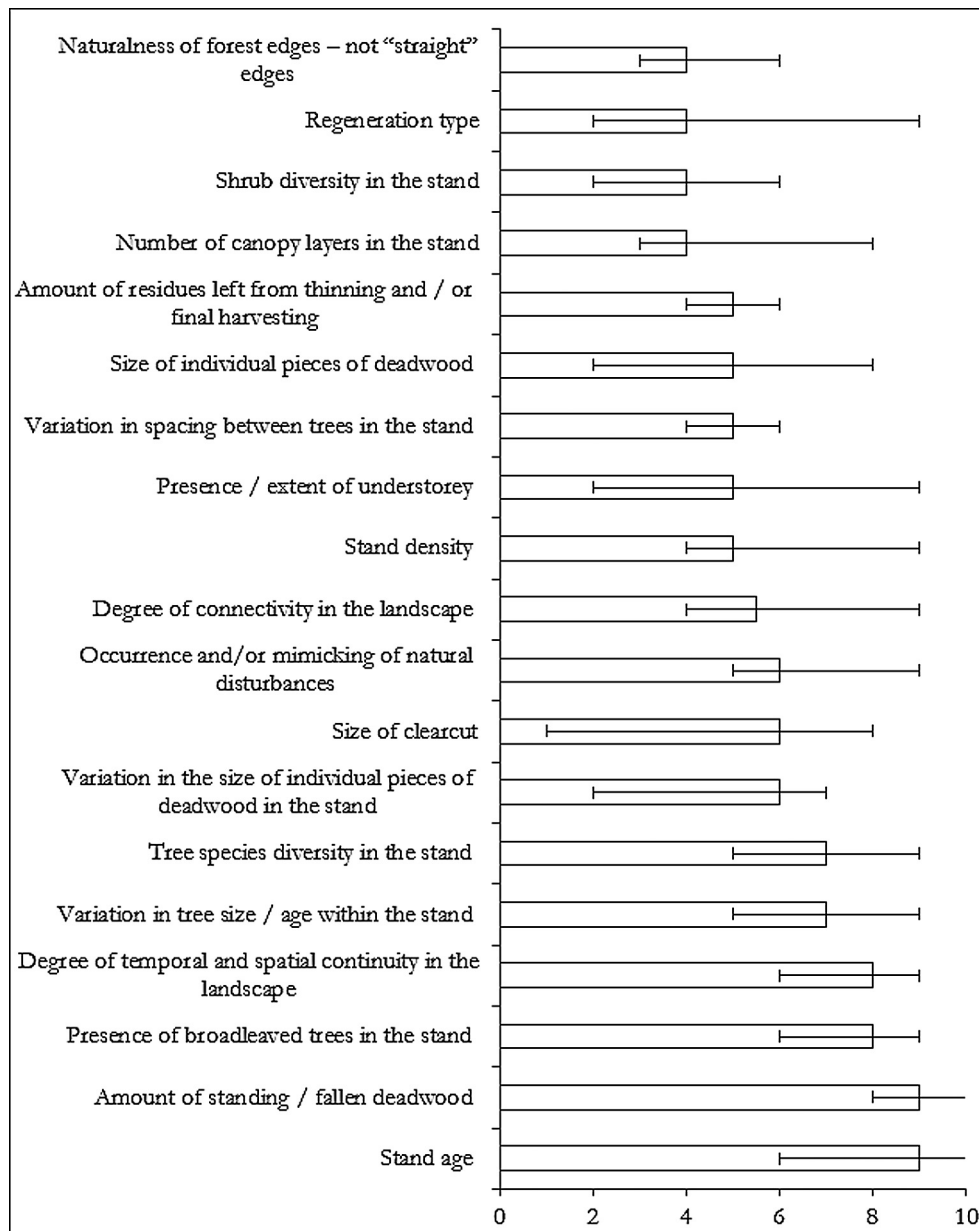


Fig. 3. The relative importance of individual forest characteristics for preservation of biodiversity and habitat in the Nordic boreal zone (on a scale from 1 to 10, where 1 is the least important). Columns show the group's median values and error bars indicate min and max of the individual participants' values.

(Q2b) “What functional form does the relationship between each of these forest characteristics and biodiversity have?”

Table 1 presents both functional forms that have been identified by a highest number of participants and other types of relationships. For almost all characteristics the participants did not agree on the same type of relationship, except for “variation in sizes of individual pieces of deadwood” and “size of clear-cutting”. Some of the participants reported lack of research experience with several of the characteristics. The majority of the relationships were reported as either positive or concave (Table 1). As the same types of functional relationships were provided for both forest types, they have been reported together. However, it was stated by participants that drainage could be an additional characteristic, which is more important in Scots pine than in Norway spruce forest.





Medium to high levels of confidence in the answers were reported for the estimates of relationships between the following eight forest 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 the 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. For the remainder of characteristics medium to low levels of confidence in the type of relationship was indicated.

4. Discussion

This study contributes to the understanding of how forest management can influence biodiversity and habitat in the boreal zone of the Nordic countries using a structured expert elicitation technique (the Delphi method). The findings from the first question of this study suggested that the two most intensive management alternatives (“clear-cutting system” and “intensive forestry”) have the strongest negative effect on biodiversity, which was supported by previous studies both in boreal and other regions (Chaudhary et al., 2016; Duncker et al., 2012b; Paillet et al., 2010). Overall diminishing ability of both Norway spruce and Scots pine stands to preserve biodiversity and habitats with an increase in management intensity has been demonstrated in this study. This is consistent with findings published in several studies on boreal

Table 1
Functional forms of relationships between forest characteristics and contribution to preservation of biodiversity and habitat.

Forest characteristics	The answer provided by the highest number of participants		Another type of relationships identified by panelists
	The type of relationship:	% of participants who chose this type of relationship	
	(C) – concave 		
	(B) – bell-shaped 		
	(P) – positive 		
	(N) – negative 		
Stand age – age of dominant tree species in the stand	C	60	P
Stand density	B	60	N
Variation in tree size/age within the stand	P	80	C
Number of canopy layers in the stand	P	80	C
Presence/extent of understorey	C	80	B
Shrub diversity in the stand	C	67	P
Variation in spacing between trees in the stand	C	67	P
Tree species diversity in the stand	P	75	C
Presence of broadleaved trees in the stand	P	75	B
Amount of standing/fallen deadwood	C	60	P
Size of individual pieces of deadwood	C	67	P
Variation in the size of individual pieces of deadwood in the stand	C	100	–
Amount of residues left from thinning and/or final harvesting	C	60	B
Size of clearcut	N	80	N
Regeneration type	N	67	P
Occurrence and/or mimicking of natural disturbances	P	80	C
Naturalness of forest edges – not “straight” edges	P	80	C
Degree of connectivity in the landscape	C/P	50	–
Degree of temporal and spatial continuity in the landscape	P	75	C

and temperate zones (e.g. Duncker et al., 2012b; Framstad et al., 2013; Gustafsson et al., 2010; Kuuluvainen et al., 2012; Martikainen et al., 2000; Paillet et al., 2010; Stenbacka et al., 2010). However, other studies showed the existence of both positive and negative correlation between biodiversity and intensity of management (Biber et al., 2015; Gossner et al., 2014), some of which has been attributed to the differences in requirements between various taxa (Gossner et al., 2014). The negative effects of forest management on biodiversity in the boreal zone are often associated with loss and fragmentation of old-growth forests in structurally simplified production forests. In this region, natural dynamics are suggested to be characterized by disturbances from recurring fires, insect outbreak, grazing or small-scale felling. Overall, in various geographical zones studies suggest that, some management might be beneficial for biodiversity (e.g. Bernes et al., 2015; Hedwall and Mikusiński, 2015; Kuuluvainen et al., 2012; Lindenmayer et al., 2006; Löf et al., 2016; Verschuyt et al., 2011). Reduced forest intervention can benefit a large range of species in boreal and temperate zones including saproxylic insects and hole-dwelling birds as well as epiphytes and fungi (Brunet et al., 2010; Friedel et al., 2006; Lassaune et al., 2011; Müller et al., 2013; Müller and Büttler, 2010; Odor et al., 2006). A certain degree of intervention is needed for maintaining biodiversity from such traditional systems as coppicing (Fartmann et al., 2013; Sebek et al., 2015).

Our findings from the second question showed that deadwood, stand age and variation in tree size in spruce and pine stands were the most important characteristics for preservation of biodiversity and habitat. These conclusions are also consistent with previously published papers (e.g. Bouget et al., 2012; Gustafsson and Perhans, 2010; Kuuluvainen et al., 2012; Siitonen, 2001; Stenbacka et al., 2010). This

suggests that to promote preservation of biodiversity and habitats, managers should focus on forest management systems that foster accumulation of deadwood in the stands, prolong rotation ages and encourage natural regeneration for increased structural diversity. This study also revealed that there is some disagreement between scientists on the functional forms of relationships between preservation of biodiversity and forest characteristics and confirm findings in previously published papers (e.g. Normander et al. 2012; Nybø et al. 2012). This indicates that the relationships between various forest characteristics and preservation of biodiversity are not well understood. Since some of these forest characteristics are often used as indicators/proxies for biodiversity, our findings also contribute to concerns regarding the strength of evidence for a number of indicators as reported by Gao et al. (2015). Thus, there is a need for more research focusing on exploring the different forms of relationships between preservation of biodiversity and various forest characteristics.

In this study, expert (researcher) opinions regarding the influence of forest management and contribution of forest characteristics on preservation of biodiversity and habitat varied. One possible reason for this variation was differences in ecological requirements of different taxa and the definition of biodiversity that was used in this study (Felton et al., 2010; Johansson et al., 2007; Martikainen et al., 2000). The experts agreed on defining preservation of biodiversity as the long-term persistence/viability of populations of species at a landscape/regional level, including also rare or red-listed species. However, if experts are focusing more on some taxa (species) than others this may contribute to differences in assessments among them. For example, lichens, fungi, and saproxylic beetles depend on forest cover continuity, deadwood and large trees. They are, thus, more likely to be negatively affected by

management of higher intensity (Paillet et al., 2010; Penttilä et al., 2004). Another possible reason for the variation in experts' opinion was the regional differences in the specific implementation of forest management alternatives, their applicability or presence of additional factors that they have considered. For example, close-to-nature forestry in boreal Sweden is not often practiced, while in Finland nature-oriented silviculture has been applied (Mielikäinen and Hynynen, 2003). Additional factors considered by the participants and recorded in the spaces for comments included: clear cut area, connectivity and distances between different types of forests, forest history ("historical contingency could be more important for today's services than current management"), ownership patterns ("random forestry" – "small-scale foresters harvesting more or less without a plan, and left for long intermittent periods of no intervention"). The range of responses could also indicate underrepresentation of certain topics (either forest management regimes or forest characteristics) in the existing research or experience of participants and thus limited knowledge about them, which has been noted in a review study by Paillet et al. (2010). In Q1 these included less intense forest management alternatives: "no management", "close-to-nature forestry" and "continuous-cover forestry". It could be that the notion 'less intense management interventions' is considered beneficial for the biodiversity.

As mentioned above this study was based on five to seven different experts. The number of experts in Delphi studies varies (from a couple of participants to hundreds). The most critical consideration is to include "all the relevant perspectives" (Novakowski and Wellar, 2008). One or two experts may be sufficient when eliciting a judgment concerning a narrow area expertise, for more complex matters the general rule of thumb is three to five participants for each perspective in order to capture various views on the matter (Linstone and Turoff, 2002; Morgan, 2014; Novakowski and Wellar, 2008). In this study, the size of the panel represented 25% of the total number of potential participants identified in the region. Examples of previous studies with similar response rates or number of participants include Uhmman et al. (2001), Eycott et al. (2011) and Curzon and Kontoleon (2016).

Methodologically, the ideal means of exploring the impacts of forest management on biodiversity and habitats would be the collection of large data sets involving empirical observations of different treatments over an extended period of time. However, this data collection method would be expensive and lengthy. The findings of this study were qualitative and based on a small but qualified panel of experts, providing a generalized assessment which is relevant for decision support as it included a broad range of forest management alternatives as well as forest characteristics, all assessed by the same group of experts. Moreover, the consistency of our findings with existing literature on biodiversity added to the reliability of the method and indicated that the Delphi method could be applied in the context of forest biodiversity and habitat preservation. Advantages of applying this technique have been frequently reported (e.g. MacMillan & Marshall 2006; Landeta 2006; McBride et al. 2012), however, the method has been relatively underused in studies on conservation and ecology (Mukherjee et al., 2015). We observed added benefits of applying the Delphi technique in the qualitative data that is collected in the process such as comments from participants, confidence as well as differences in estimates. Such information provides additional insights into the quality and extent of existing knowledge on the subject beyond what a simple literature review is capable of. In the future, this "additional" source of information could be expanded by inquiring about how long it took participants to fill out the questionnaire, or researchers they most often publish with. In addition to the identification of functional forms of relationships between forest characteristics and biodiversity (ecosystem services), such information would help determine patterns and gaps in research. This could present a more useful base for future empirical or modeling exercises as well as provide insights into forest management decision support.

In order to improve the quality of data from a Delphi survey, this

study highlighted the need for an increase in the diversity of participants involved in pre-test survey to help reveal possible misunderstandings and improve both the questions and background information. Personal contact with potential participants as well as inclusion of face-to-face interviews could increase motivation to participate and response rate, especially in the light of often complex nature of survey questions. In order to shorten the length of time used in the Delphi process as well as introduce a more interactive component, the inquiry could be administered online. For findings from a Delphi survey to be more useful for decision support it needs to be of an applied nature and focus on a specific issue from practice, which can be determined through consultation/pre-testing of the questionnaire with different groups of stakeholders (both in research and practical domains).

5. Concluding remarks

This study provided insight into the influence of different forest management and forest characteristics on preservation of biodiversity and habitat in the boreal zone of the Nordic countries using a structured expert assessment technique (Delphi method). The findings revealed that an increase in forest management intensity results in a diminishing potential to preserve biodiversity and habitat. Forest characteristics such as deadwood, increase in stand age and mixture of trees of varied sizes were considered the most important for preservation of biodiversity and habitat. As the access to research funding is becoming increasingly scarce whereas the demand for quality data for making well-informed decisions is continuing to increase, alternatives to empirical observational data collection are explored. This study suggested that the Delphi technique could play an important role in conducting novel research on complex topics with limited funding. In order to provide a more comprehensive assessment for decision support, there is a need to cover biodiversity and ecosystem services more broadly as well as conduct ecological modeling and field data collection. The findings contribute to a greater understanding on possible ways to manage forests to promote preservation of biodiversity and habitat. This could assist forest and nature managers in designing a management strategy that provides a range of benefits.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.foreco.2017.10.022>.

References

- Berg, B., Gundersen, P., Akselsson, C., 2007. Carbon sequestration rates in Swedish forest soils—a comparison of three approaches. *Silva Fenn.* 41, 541–558. <http://dx.doi.org/10.1139/X09-022>.
- Bernes, C., Jonsson, B.G., Junninen, K., Löhmus, A., Macdonald, E., Müller, J., Sandström, J., 2015. What is the impact of active management on biodiversity in boreal and temperate forests set aside for conservation or restoration? A systematic map. *Environ. Evid.* 4, 25. <http://dx.doi.org/10.1186/s13750-015-0050-7>.

- Biber, P., Borges, J., Moshhammer, R., Barreiro, S., Botequim, B., Brodrechtová, Y., Brukas, V., Chirici, G., Cordero-Debets, R., Corrigan, E., Eriksson, L., Favero, M., Galev, E., Garcia-Gonzalo, J., Hengeveld, G., Kavaliuskas, M., Marchetti, M., Marques, S., Mozgeris, G., Navrátil, R., Nieuwenhuis, M., Orazio, C., Paligorov, I., Pettenella, D., Sedmák, R., Smrček, R., Stanislavits, A., Tomé, M., Trubins, R., Tuček, J., Vizzarri, M., Wallin, L., Pretzsch, H., Sallnäs, O., 2015. How sensitive are ecosystem services in European forest landscapes to silvicultural treatment? *Forests* 6, 1666–1695. <http://dx.doi.org/10.3390/f6051666>.
- Boman, M., Jacobsen, J.B., Strange, N., Norman, J., Mattsson, L., 2010. Forest amenity values and the rotation age decision: a Nordic perspective. *Ecol. Bull.* 53, 7–20.
- Bouget, C., Lassauce, A., Jonsell, M., 2012. Effects of fuelwood harvesting on biodiversity—a review focused on the situation in Europe. *Can. J. For. Res.* 42, 1421–1432. <http://dx.doi.org/10.1139/X2012-078>.
- Brunet, J., Fritz, Ö., Richnau, G., 2010. Biodiversity in European beech forests – a review with recommendations for sustainable forest management. *Ecol. Bull.* 53, 77–94.
- Burgman, M.A., McBride, M., Ashton, R., Speirs-Bridge, A., Flander, L., Wintle, B., Fidler, R., Rumpff, L., Twardy, C., 2011. Expert status and performance. *PLoS One* 6, e22998. <http://dx.doi.org/10.1371/journal.pone.0022998>.
- Burkhard, B., Kroll, F., Müller, F., 2010. Landscapes' capacities to provide ecosystem services – a concept for land-cover based assessments. *Landsc. Online* 15, 1–22. <http://dx.doi.org/10.3097/LO.200915>.
- Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., Defries, R.S., Díaz, S., Dietz, T., Duraipah, A.K., Oteng-Yeboah, A., Pereira, H.M., Perrings, C., Reid, W.V., Sarukhan, J., Scholes, R.J., Whyte, A., 2009. Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proc. Natl. Acad. Sci. U. S. A.* 106, 1305–1312. <http://dx.doi.org/10.1073/pnas.080872106>.
- CBD, 1992. The Convention on Biological Diversity [WWW Document]. < <https://www.cbd.int/doc/legal/cbd-en.pdf> > (accessed 8.24.17).
- Chaudhary, A., Burivalova, Z., Koh, L.P., Hellweg, S., 2016. Impact of forest management on species richness: global meta-analysis and economic trade-offs. *Nat. Sci. Rep.* 6, 23954. <http://dx.doi.org/10.1038/srep23954>.
- Crance, J.H., 1987. Guidelines for using the Delphi technique to develop habitat suitability index curves. *U.S. Fish Wildl. Serv. Biol. Rep.*, 82 (10.134).
- Curzon, H.F., Kontoleon, A., 2016. From ignorance to evidence? The use of programme evaluation in conservation: evidence from a Delphi survey of conservation experts. *J. Environ. Manage.* 180, 466–475. <http://dx.doi.org/10.1016/j.jenvman.2016.05.062>.
- de Groot, R.S., Alkamade, R., Braat, L., Hein, L., Willemsen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecol. Complex.* 7, 260–272.
- Diaz-Balteiro, L., Romero, C., 2008. Making forestry decisions with multiple criteria: a review and an assessment. *For. Ecol. Manage.* 255, 3222–3241. <http://dx.doi.org/10.1016/j.foreco.2008.01.038>.
- Duncker, P.S., Barreiro, S.M., Hengeveld, G.M., Lind, T., Mason, W.L., Ambrozio, S., 2012a. Classification of forest management approaches: a new conceptual framework and its applicability to European forestry. *Ecol. Soc.* 17, 51.
- Duncker, P.S., Raulund-Rasmussen, K., Gundersen, P., Katzensteiner, K., Jong, J. De, Peter, H., 2012b. How forest management affects ecosystem services, including timber production and economic return: synergies and trade-offs. *Ecol. Soc.* 17, 50.
- Edwards, D., Jay, M., Jensen, F.S., Lucas, B., Marzano, M., Montagné, C., Peace, A., Weiss, G., 2012. Public preferences across Europe for different forest stand types as sites for recreation. *Ecol. Soc.* 17, 27. <http://dx.doi.org/10.5751/ES-04520-170126>.
- Egoh, B., Drakou, E.G., Dunbar, M.B., Maes, J., Willemsen, L., Egoh, B., Drakou, E.G., Dunbar, M.B., Maes, J., Willemsen, L., 2012. Indicators for Mapping Ecosystem Services: A Review. Publications Office of the European Union, Ispra, Luxembourg. 10.2788/41823.
- Eycott, A.E., Marzano, M., Watts, K., 2011. Filling evidence gaps with expert opinion: the use of Delphi analysis in least-cost modelling of functional connectivity. *Landsc. Urban Plan.* 103, 400–409. <http://dx.doi.org/10.1016/j.landurbplan.2011.08.014>.
- Ezeibilo, E.E., Boman, M., Mattsson, L., Lindhagen, A., Mbongo, W., 2015. Preferences and willingness to pay for close to home nature for outdoor recreation in Sweden. *J. Environ. Plan. Manag.* 58, 283–296. <http://dx.doi.org/10.1080/09640568.2013.854196>.
- Ezeibilo, E.E., Sandström, C., Ericsson, G., 2012. Browsing damage by moose in Swedish forests: assessments by hunters and foresters. *Scand. J. For. Res.* 27, 659–668.
- FAO, 2016. Food and Agricultural Organization of the United Nations. Ecosystem services [WWW Document]. < <http://www.fao.org/ecosystem-services-biodiversity/en/> > (accessed 4.24.17).
- Fartmann, T., Müller, C., Poniatowski, D., 2013. Effects of coppicing on butterfly communities of woodlands. *Biol. Conserv.* 159, 396–404. <http://dx.doi.org/10.1016/j.biocon.2012.11.024>.
- Felton, A., Lindblad, M., Brunet, J., Fritz, Ö., 2010. Replacing coniferous monocultures with mixed-species production stands: an assessment of the potential benefits for forest biodiversity in northern Europe. *For. Ecol. Manage.* 260, 939–947. <http://dx.doi.org/10.1016/j.foreco.2010.06.011>.
- Filyushkina, A., Strange, N., Löf, M., Ezeibilo, E.E., Boman, M., 2016. Non-market forest ecosystem services and decision support in Nordic countries. *Scand. J. For. Res.* 31, 99–110. <http://dx.doi.org/10.1080/02827581.2015.1079643>.
- Foley, J.A., Defries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. *Science* 309, 570–574. <http://dx.doi.org/10.1126/science.1111772>.
- Framstad, E., de Wit, H., Mäkipää, R., Larjavaara, M., Vesterdal, L., Karlton, E., 2013. Biodiversity, Carbon Storage and Dynamics of Old Northern Forests. TemaNord 2013:507. Nordic Council of Ministers. Rosendahl-Schultz Grafisk, Denmark.
- Frank, S., Fürst, C., Pietzsch, F., 2015. Cross-sectoral resource management: how forest management alternatives affect the provision of biomass and other ecosystem services. *Forests* 6, 533–560. <http://dx.doi.org/10.3390/f6030533>.
- Friedel, A., Oheimb, G.V., Dengler, J., Härdtle, W., 2006. Species diversity and species composition of epiphytic bryophytes and lichens – a comparison of managed and unmanaged beech forests in NE Germany. *Feddes Repert.* 117, 172–185. <http://dx.doi.org/10.1002/fedr.200511084>.
- Gao, T., Nielsen, A.B., Hedblom, M., Busse, A., Hedblom, M., Nielsen, A.B., Hedblom, M., 2015. Reviewing the strength of evidence of biodiversity indicators for forest ecosystems in Europe. *Ecol. Indic.* 57, 420–434. <http://dx.doi.org/10.1016/j.ecolind.2015.05.028>.
- Geneletti, D., 2007. Expert panel-based assessment of forest landscapes for land use planning. *Mt. Res. Dev.* 27, 220–223. <http://dx.doi.org/10.1659/mrd.0924>.
- Gobbi, M., Riservato, E., Bragalanti, N., Lencioni, V., 2012. An expert-based approach to invertebrate conservation: identification of priority areas in central-eastern Alps. *J. Nat. Conserv.* 20, 274–279. <http://dx.doi.org/10.1016/j.jnc.2012.05.003>.
- Gossner, M.M., Schall, P., Ammer, C., Ammer, U., Engel, K., Schubert, H., Simon, U., Tutschick, H., Weisser, W.W., 2014. Forest management intensity measures as alternative to stand properties for quantifying effects on biodiversity. *Ecosphere* 5, art113. 10.1890/es14-00177.1.
- Gustafsson, D., Kouki, J., Sverdrup-Thygeson, A., 2010. Tree retention as a conservation measure in clear-cut forests of northern Europe: a review of ecological consequences. *Scand. J. For. Res.* 25, 295–308. <http://dx.doi.org/10.1080/02827581.2010.497495>.
- Gustafsson, L., Perhans, K., 2010. Biodiversity conservation in Swedish Forests: ways forward for a 30-year-old multi-scaled approach. *Ambio* 39, 546–554. <http://dx.doi.org/10.1007/s13280-010-0071-y>.
- Haines-Young, R., Potschin, M., 2011. Common International Classification of Ecosystem Services (CICES): 2011 Update [WWW Document]. < <http://unstats.un.org/unsd/envaccounting/seeaLES/egm/Issue8a.pdf> > .
- Harrison, P.A., Berry, P.M., Simpson, G., Haslett, J.R., Blicharska, M., Bucur, M., Dunford, R., Egoh, B., Garcia-Llorente, M., Geamănă, N., Geertsema, W., Lommelen, E., Meiresonne, L., Turkelboom, F., 2014. Linkages between biodiversity attributes and ecosystem services: a systematic review. *Ecosyst. Serv.* 9, 191–203.
- Hasson, F., Keeney, S., 2011. Enhancing rigour in the Delphi technique research. *Technol. Forecast. Soc. Change* 78, 1695–1704. <http://dx.doi.org/10.1016/j.techfore.2011.04.005>.
- Hedwall, P.-O., Mikusiński, G., 2015. Structural changes in protected forests in Sweden: implications for conservation functionality. *Can. J. For. Res.* 45, 1215–1224. <http://dx.doi.org/10.1139/cjfr-2014-0470>.
- Hytönen, M., 1995. Multiple-use Forestry in the Nordic Countries. Metla, Finnish Forest Research Institute, Helsinki Research Centre, Jyväskylä.
- Johansson, T., Hjältén, J., Gibb, H., Hilszczanski, J., Stenlid, J., Ball, J.P., Alinvi, O., Danell, K., 2007. Variable response of different functional groups of saproxylic beetles to substrate manipulation and forest management: implications for conservation strategies. *For. Ecol. Manage.* 242, 496–510. <http://dx.doi.org/10.1016/j.foreco.2007.01.062>.
- Jolson, M., Rossow, G., 1971. The Delphi process in marketing decision making. *J. Mark. Res.* 8, 443–448.
- Kangas, J., Alho, J., 1998. Analyzing consistency of experts' judgments-case of assessing forest biodiversity. *For. Sci.* 44, 610–617.
- Kettunen, M., Vihervaara, P., 2013. Socio-economic Importance of Ecosystem Services in the Nordic Countries—Synthesis in the Context of The Economics of Ecosystems and Biodiversity (TEEB) [WWW Document]. < http://www.teebweb.org/wp-content/uploads/2013/03/TEEB_Nordic_-_technical_summary.pdf > (accessed 3.18.17).
- Kriström, B., Boman, M., 2001. Valuing the multiple functions of forests. In: Palo, M., Uusi-Vuori, J., Mery, G. (Eds.), *World Forests, Markets and Policies*. Kluwer Academic Publishers, Dordrecht, pp. 149–158.
- Kuuluvainen, T., Tahvonen, O., Aakala, T., 2012. Even-aged and uneven-aged forest management in boreal Fennoscandia: a review. *Ambio* 41, 720–737. <http://dx.doi.org/10.1007/s13280-012-0289-y>.
- Kynn, M., 2008. The “heuristics and biases” bias in expert elicitation. *J. R. Stat. Soc. Ser. A Stat. Soc.* 171, 239–264. <http://dx.doi.org/10.1111/j.1467-985X.2007.00499.x>.
- Landeta, J., 2006. Current validity of the Delphi method in social sciences. *Technol. Forecast. Soc. Change* 73, 467–482. <http://dx.doi.org/10.1016/j.techfore.2005.09.002>.
- Lassauce, A., Paillet, Y., Jactel, H., Bouget, C., 2011. Deadwood as a surrogate for forest biodiversity: meta-analysis of correlations between deadwood volume and species richness of saproxylic organisms. *Ecol. Indic.* 11, 1027–1039. <http://dx.doi.org/10.1016/j.ecolind.2011.02.004>.
- Layke, C., Mapendembe, A., Brown, C., Walpole, M., Winn, J., 2012. Indicators from the global and sub-global millennium ecosystem assessments: an analysis and next steps. *Ecol. Indic.* 17, 77–87. <http://dx.doi.org/10.1016/j.ecolind.2011.04.025>.
- Lindenmayer, D.B., Franklin, J.F., Fischer, J., 2006. General management principles and a checklist of strategies to guide forest biodiversity conservation. *Biol. Conserv.* 131, 433–445. <http://dx.doi.org/10.1016/j.biocon.2006.02.019>.
- Linstone, H.A., Turoff, M., 2002. The Delphi Method. Techniques and Applications [WWW Document]. < <https://pdfs.semanticscholar.org/8634/72a67f5bdc67e4782306efd883fca23e3a3d.pdf> > (accessed 3.6.17).
- Löf, M., Brunet, J., Filyushkina, A., Lindblad, M., Skovsgaard, J.P., Felton, A., 2016. Management of oak forests: striking a balance between timber production, biodiversity and cultural services. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* 12, 59–73. <http://dx.doi.org/10.1080/21513732.2015.1120780>.
- MacMillan, D.C., Marshall, K., 2006. The Delphi process - an expert-based approach to ecological modelling in data-poor environments. *Anim. Conserv.* 9, 11–19. <http://dx.doi.org/10.1111/j.1469-1795.2005.00001.x>.
- Martikainen, P., Siitonen, J., Punttilä, P., 2000. Species richness of Coleoptera in mature managed and old-growth boreal forests in southern Finland. *Biol. Conserv.* 94,

- 199–209.
- Martin, T.G., Burgman, M.A., Fidler, F., Kuhnert, P.M., Low-Choy, S., McBride, M., Mengersen, K., 2012. Eliciting expert knowledge in conservation science. *Conserv. Biol.* 26, 29–38. <http://dx.doi.org/10.1111/j.1523-1739.2011.01806.x>.
- McBride, M.F., Garnett, S.T., Szabo, J.K., Burbidge, A.H., Butchart, S.H.M., Christidis, L., Dutton, G., Ford, H.A., Loyn, R.H., Watson, D.M., Burgman, M.A., 2012. Structured elicitation of expert judgments for threatened species assessment: a case study on a continental scale using email. *Methods Ecol. Evol.* 3, 906–920. <http://dx.doi.org/10.1111/j.2041-210X.2012.00221.x>.
- Mendoza, G.A., Martins, H., 2006. Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. *For. Ecol. Manage.* 230, 1–22.
- Mielikäinen, K., Hynynen, J., 2003. Silvicultural management in maintaining biodiversity and resistance of forests in Europe—boreal zone: case Finland. *J. Environ. Manage.* 67, 47–54. [http://dx.doi.org/10.1016/S0301-4797\(02\)00187-1](http://dx.doi.org/10.1016/S0301-4797(02)00187-1).
- Morgan, M.G., 2014. Use (and abuse) of expert elicitation in support of decision making for public policy. *Proc. Natl. Acad. Sci. U. S. A.* 111, 7176–7184. <http://dx.doi.org/10.1073/pnas.1319946111>.
- Mukherjee, N., Hugé, J., Sutherland, W.J., McNeill, J., Van Opstal, M., Dahdouh-Guebas, F., Koedam, N., 2015. The Delphi technique in ecology and biological conservation: applications and guidelines. *Methods Ecol. Evol.* 6, 1097–1109. <http://dx.doi.org/10.1111/2041-210X.12387>.
- Müller, J., Brunet, J., Brin, A., Bouget, C., Brustel, H., Bussler, H., Förster, B., Isacson, G., Köhler, F., Lachat, T., Gossner, M.M., 2013. Implications from large-scale spatial diversity patterns of saproxylic beetles for the conservation of European Beech forests. *Insect Conserv. Divers.* 6, 162–169. <http://dx.doi.org/10.1111/j.1752-4598.2012.00200.x>.
- Müller, J., Büttler, R., 2010. A review of habitat thresholds for dead wood: a baseline for management recommendations in European forests. *Eur. J. For. Res.* 129, 981–992. <http://dx.doi.org/10.1007/s10342-010-0400-5>.
- Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., Chan, K.M., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H., Shaw, M., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Front. Ecol. Environ.* 7, 4–11.
- Norman, J., Ellingson, L., Boman, M., Mattsson, L., 2010. The value of forests for outdoor recreation in southern Sweden: are broadleaved trees important? *Ecol. Bull.* 53 – Broadleaved For. South. Sweden Manag. Mult. goals. 21–31.
- Normander, B., Levin, G., Auvinen, A.P., Bratli, H., Stabbertorp, O., Hedblom, M., Glimskär, A., Gudmundsson, G.A., 2012. Indicator framework for measuring quantity and quality of biodiversity – exemplified in the Nordic countries. *Ecol. Indic.* 13, 104–116. <http://dx.doi.org/10.1016/j.ecolind.2011.05.017>.
- Novakowski, N., Wellar, B., 2008. Using the Delphi technique in normative planning research: methodological design considerations. *Environ. Plan.* 40, 1485–1500. <http://dx.doi.org/10.1068/a39267>.
- Nybø, S., Certain, G., Skarpaas, O., 2012. The Norwegian Nature Index – state and trends of biodiversity in Norway. *Nor. Geogr. Tidsskr. - Nor. J. Geogr.* 66, 241–249. <http://dx.doi.org/10.1080/00291951.2012.743168>.
- Odor, P., Heilmann-Clausen, J., Christensen, M., Aude, E., van Dort, K.W., Piltaver, A., Siller, I., Veerkamp, M.T., Walley, R., Standovář, T., van Hees, A.F.M., Kosec, J., Matošec, N., Kraigher, H., Grebenc, T., 2006. Diversity of dead wood inhabiting fungi and bryophytes in semi-natural beech forests in Europe. *Biol. Conserv.* 131, 58–71. <http://dx.doi.org/10.1016/j.biocon.2006.02.004>.
- Oliver, I., 2002. An expert panel-based approach to the assessment of vegetation condition within the context of biodiversity conservation Stage 1: the identification of condition indicators. *Ecol. Indic.* 2, 223–237.
- Orsi, F., Geneletti, D., Newton, A.C., 2011. Towards a common set of criteria and indicators to identify forest restoration priorities: an expert panel-based approach. *Ecol. Indic.* 11, 337–347. <http://dx.doi.org/10.1016/j.ecolind.2010.06.001>.
- Paillet, Y., Bergès, L., Hjaltn, J., Odor, P., Avon, C., Bernhardt-Römermann, M., Bijlsma, R.-J., De Bruyn, L., Fuhr, M., Grandin, U., Kanka, R., Lundin, L., Luque, S., Magura, T., Matesanz, S., Mészáros, I., Sebasti, M.-T., Schmidt, W., Standovář, T., Tóthmérész, B., Uotila, A., Valladares, F., Vellak, K., Virtanen, R., 2010. Biodiversity differences between managed and unmanaged forests: meta-analysis of species richness in Europe. *Conserv. Biol.* 24, 101–112. <http://dx.doi.org/10.1111/j.1523-1739.2009.01399.x>.
- Penttilä, R., Siitonen, J., Kuusinen, M., 2004. Polypore diversity in managed and old-growth boreal *Picea abies* forests in southern Finland. *Biol. Conserv.* 117, 271–283. <http://dx.doi.org/10.1016/j.biocon.2003.12.007>.
- Raudsepp-Hearne, C., Peterson, G.D., Bennett, E.M., 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proc. Natl. Acad. Sci. U. S. A.* 107, 5242–5247. <http://dx.doi.org/10.1073/pnas.0907284107>.
- Rubino, M.J., Hess, G.R., 2003. Planning open spaces for wildlife 2: modeling and verifying focal species habitat. *Landsc. Urban Plan.* 64, 89–104. [http://dx.doi.org/10.1016/S0169-2046\(02\)00203-7](http://dx.doi.org/10.1016/S0169-2046(02)00203-7).
- Scolozzi, R., Morri, E., Santolini, R., 2012. Delphi-based change assessment in ecosystem service values to support strategic spatial planning in Italian landscapes. *Ecol. Indic.* 21, 134–144.
- Sebek, P., Bace, R., Bartos, M., Benes, J., Chlumska, Z., Dolezal, J., Dvorsky, M., Kovar, J., Machac, O., Mikatova, B., Perlik, M., Platek, M., Polakova, S., Skorpik, M., Stejskal, R., Svoboda, M., Trnka, F., Vlasin, M., Zapletal, M., Cizek, L., 2015. Does a minimal intervention approach threaten the biodiversity of protected areas? A multi-taxa short-term response to intervention in temperate oak-dominated forests. *For. Ecol. Manage.* 358, 80–89. <http://dx.doi.org/10.1016/j.foreco.2015.09.008>.
- Segura, M., Ray, D., Maroto, C., 2014. Decision support systems for forest management: A comparative analysis and assessment. *Comput. Electron. Agric.* 101, 55–67. <http://dx.doi.org/10.1016/j.compag.2013.12.005>.
- Siitonen, J., 2001. Forest management, coarse woody debris and saproxylic organisms: fennoscandian boreal forests as an example. *Ecol. Bull.* 10–41.
- Speirs-Bridge, A., Fidler, F., McBride, M., Flander, L., Cumming, G., Burgman, M., 2010. Reducing overconfidence in the interval judgments of experts. *Risk Anal.* 30, 512–523. <http://dx.doi.org/10.1111/j.1539-6924.2009.01337.x>.
- Spiecker, H., 2003. Silvicultural management in maintaining biodiversity and resistance of forests in Europe—temperate zone. *J. Environ. Manage.* 67, 55–65. [http://dx.doi.org/10.1016/S0301-4797\(02\)00188-3](http://dx.doi.org/10.1016/S0301-4797(02)00188-3).
- Stenbacka, F., Hjaltn, J., Hilszczański, J., Dynesius, M., 2010. Saproxylic and non-saproxylic beetle assemblages in boreal spruce forests of different age and forestry intensity. *Ecol. Appl.* 20, 2310–2321.
- Strand, J., Carson, R.T., Navrud, S., Ortiz-Bobea, A., Vincent, J.R., 2017. Using the Delphi method to value protection of the Amazon rainforest. *Ecol. Econ.* 131, 475–484. <http://dx.doi.org/10.1016/j.ecolecon.2016.09.028>.
- TEEB, 2010. The Economics of Ecosystems and Biodiversity: Mainstreaming the economics of nature: a synthesis of the approach, conclusions and recommendations of TEEB [WWW Document]. < <http://www.unep.org/pdf/LinkClick.pdf> > (accessed 6. 13.17).
- Torrás, O., Saura, S., 2008. Effects of silvicultural treatments on forest biodiversity indicators in the Mediterranean. *For. Ecol. Manage.* 255, 3322–3330. <http://dx.doi.org/10.1016/j.foreco.2008.02.013>.
- Trivino, M., Pohjanmies, T., Mazziotto, A., Juutinen, A., Podkopaev, D., Le Tortorec, E., Monkkonen, M., 2016. Optimizing management to enhance multifunctionality in a boreal forest landscape. *J. Appl. Ecol.* <http://dx.doi.org/10.1111/1365-2664.12790>.
- Tversky, A., Kahneman, D., 1974. Judgment under Uncertainty: Heuristics and Biases. *Science* (80-). 185, 1124–1131. <http://dx.doi.org/10.1126/science.185.4157.1124>.
- Uhmman, T., Kenkel, N.C., Baydack, R.K., 2001. Development of a habitat suitability index model for burrowing owls in the eastern Canadian prairies. *J. Raptor Res.* 35, 378–384.
- van Oudenhoven, A.P.E., Petz, K., Alkemade, R., Hein, L., de Groot, R.S., 2012. Framework for systematic indicator selection to assess effects of land management on ecosystem services. *Ecol. Indic.* 21, 110–122. <http://dx.doi.org/10.1016/j.ecolind.2012.01.012>.
- Verschuur, J., Riffell, S., Miller, D., Wigley, T.B., 2011. Biodiversity response to intensive biomass production from forest thinning in North American forests – a meta-analysis. *For. Ecol. Manage.* 261, 221–232. <http://dx.doi.org/10.1016/j.foreco.2010.10.010>.
- von der Gracht, H.A., 2012. Consensus measurement in Delphi studies. *Technol. Forecast. Soc. Change* 79, 1525–1536. <http://dx.doi.org/10.1016/j.techfore.2012.04.013>.
- Waldron, K., Lussier, J., Thiffault, N., Bujold, F., Ruel, J., 2016. The Delphi method as an alternative to standard committee meetings to identify ecological issues for forest ecosystem-based management: a case study. *For. Chron.* 92, 453–464.