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National ecosystem service indicators: Measures of social–ecological sustainability

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ABSTRACT

Until present, it has been challenging to turn the concept of ecosystem services into a practical tool in the formulation of day-to-day policies on a national or regional scale. This is largely due to the overarching nature of the concept of ecosystems services (ESs) and the lack of concrete ecosystem service typologies. In this paper, we describe the foundation process of a national ecosystem service indicator framework for Finland, beginning with the selection of nationally important ESs. We also evaluate how this set of national indicators could be scaled down to regional circumstances, or integrated in the international ecosystem assessment processes. Our aim was to develop a national framework that complies both with national circumstances and with international typologies such as the Common International Classification of Ecosystem Services (CICES) and the cascade model. We developed indicators for 28 ecosystem services (10 provisioning, 12 regulating and maintenance, and 6 cultural services), a set of four indicators for every stage of the cascade model; altogether 112 indicators. We hope that the indicator framework draws attention to questions of resilience by providing information on the different aspects of ecosystem functioning that are crucial to the provisioning of ecosystem services. Furthermore, we hope to highlight the societal dependence on ecosystem services by providing indicators of both benefits and values. Besides higher-level decision-making processes, our attempt was to provide novel ecosystem service information for regional environmental managers and decision-makers, as well as the wider public interested in local issues. Integrating both ecological and socio-economic data into one platform may help to bridge the gap between science and practical decision-making resulting in more sustainable environmental management.

1. Introduction

The concept of ecosystem services (ESs) was originally formulated as a communication and educational tool to support efforts to conserve biological diversity (Daily, 1997; Gómez-Baggethun et al., 2010). As the focus of environmental management and protection has turned to the role played by species and ecosystems in securing our livelihood, the concept holds much promise in attracting wider societal interest in biodiversity. This wider interest in the function of biodiversity in supporting life and human economy can, in turn, be anticipated to increase our willingness to protect biodiversity, while severe disruptions of the provisioning of ecosystem services have been reported (e.g. MEA, 2005; TEEB, 2010).

During the early years of ecosystem service research there was a wide pluralism in the terms and concepts used (Vihervaara et al., 2010). However, initiatives such as the implementation of the Common International Classification of Ecosystem Services (CICES) and the formulation of the cascade model

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(Haines-Young and Potschin, 2010a) have attempted to unify the terms and brought some consensus amongst different fields of science.

The European Commission emphasizes the importance of accurate ecosystem service information as a basis of implementation of the EU Biodiversity Strategy for 2020 (European Commission, 2011) which is implemented, for instance, via the MAES (Mapping and Assessment of Ecosystems and their Services; especially Target 2, Action 5) working group – a procedure which aims to support national ES assessments of the member states of European Union. Time is now getting ripe for testing ecosystem service classifications in real-life situations. Examples of practical applications of the CICES classification include the Belgian national ES classification (Turkelboom et al., 2013) and the GreenFrame approach to map green infrastructure (Kopperoinen et al., 2014). National level ecosystem service indicators have already been discussed in national or regional TEEB (The Economics of Ecosystems and Biodiversity) reports but the focus of these studies has been more on the socio-economic side of ESs (e.g. Kettunen et al., 2012). The United Kingdom's national ecosystem assessment provided comprehensive ecosystem data and, by doing so, set a benchmark for future assessments (UKNEA, 2011; http://uknea.unep-wcmc.org/). Structured ES indicator frameworks have been developed for identifying ESs in decision-making processes concerning land use (van Oudenhoven et al., 2012) and, in Germany, national indicators covering both supply and demand side of ESs have also been developed (Burkhard et al., 2012; Kandziora et al., 2013; Albert et al., 2014).

Despite many advances during the three decades of active development of ecosystem service related concepts and their applications – including the rapid development of ecosystem function commodification (Kosoy and Corbera, 2010) – we are still a long way from having turned the concept of ecosystem services into a practical tool in the formulation of day-to-day policies on a national or regional scale. This is largely due to the overarching nature of the concept and the lack of concrete examples and ecosystem service typologies. In Finland, as presumably in many other countries, there is an urgent need to interpret the concept from a national point of view: What are the relevant ecosystem services in Finland? Which of them are the most important? How much do we know about them?

Our aim was to develop a national framework of ecosystem service indicators for Finland, which is built on a consideration of national circumstances and also complies with international typologies such as CICES and the cascade model. The CICES classification includes also abiotic services but at this point they are not included in our ecosystem service listing. In fact, many selected ESs involve a combination of biotic and abiotic elements (e.g. ESs related to the water cycle). We have, nevertheless, decided to start from those ESs whose provision is most obviously linked to living ecosystems. The foremost goal of the framework is to concretize the concept of ecosystem services nationally and to provide a foundation for further development. Furthermore, the indicator framework is much needed for assessing the effectiveness of biodiversity related policies, for instance when reporting to the Convention on Biological Diversity (e.g. Ahokumpu et al., 2014), as well as when monitoring the implementation of EU Biodiversity Strategy 2020. The indicators may also support science-policy platforms such as the Intergovernmental Panel on Biodiversity and Ecosystem Services IPBES (www.ipbes.net). One of the challenges for internationally comparable ecosystem assessments is that available data sets and used measures are different e.g. in European countries. The challenge is even bigger for the global biodiversity and ecosystem services assessment that is planned as a part of the IPBES process by 2018 (Objective 2; www.ipbes.net). Consistent national and European quantification systems are necessary to achieve this goal.

Besides providing ecosystem service information to higher-level decision-making processes, our attempt has been to consider the needs of regional environmental management and decision-making and the interest of the wider local public in the way we provide the information. Integrating both ecological and socio-economic data into one platform may help to bridge the gap between science and practical decision-making resulting in more sustainable environmental management.

In this paper we describe the foundation process of the national ecosystem service indicator framework for Finland, beginning with the selection of nationally important ESs and a discussion on the preferred value indicators for different ecosystem service categories. We report our ES indicators online in order to disseminate information swiftly to different target audiences at different levels of the decision-making process.

In short, our aims were to (I) describe the path of the determination and selection of nationally relevant ecosystem services, (II) provide four indicators describing each stage of the cascade model for each ecosystem service, (III) evaluate how the indicators could be applied and downscaled to regional and even local scale to be used in e.g. land use planning, and (IV) discuss their applicability in decision-making and their usefulness for the wider public. A description of indicator data sources is provided as supplementary material (Auvinen et al., 2007; Fang and Ling, 2003; Finnish Forest Research Institute, 2013a,b; Haines-Young and Potschin, 2010b; Hanski et al., 2012; Hoehn et al., 2008; Karjalainen et al., 2010; Korpela et al., 2011; Kraufvelin and Salovius, 2004; Kumpula et al., 2000; Känkänen et al., 2012; Mattila et al., 1999; Metsähallitus, 2014a; Ministry of Agriculture and Forestry, 2003, 2004, 2014a,b; Ministry of the Environment, 2014; Nowak et al., 2006; OSF, 2014a; Rassi et al., 2010; Salo, 1995; Sievänen and Neuvonen, 2011; Tike, 2014; Tyrväinen and Tuulentie, 2007). The most recent versions of the indicators themselves can be found at www.biodiversity.fi/ecosystemservices

2. Methodology

2.1. Selection of nationally important ecosystem services

Our categorization of ecosystem services (Fig. 1) began by identifying the most important ecosystem services in Finland. By the help of the CICES classification (V.4.3) we formulated approximately ten classes for each of the three ecosystem services sections; provisioning, regulating and maintenance, and cultural services (Haines-Young and Potschin, 2010a). We omitted some CICES classes that we deemed marginal for Finland such as animal based mechanical energy. All classes were given an accessible and nationally relevant title (e.g. CICES class level title 'Wild plants, algae and their outputs' was formulated as 'Berries and mushrooms'). We focused on ESs that are currently relevant in Finland while being aware that new ESs may emerge in the future.

We consulted multidisciplinary national biodiversity indicator expert groups of main ecosystem types: forests, mires, the Baltic Sea, inland waters and farmlands. These groups, each containing approximately ten members from a wide spectrum of research institutes, universities, administration, NGOs and other organizations (www.biodiversity.fi/en/about/expert-groups), have been operational since 2010. Having provided the preliminary CICES class list as an introduction into the subject we asked each expert group, which ESs are most relevant from their point of view. Once the general framework was constructed, relevant indicators chosen and a preliminary review of data availability conducted, we organized a second meeting, where all the expert groups joined.

After the expert consultations we organized a one-day stakeholder workshop for a wide national audience, including ministries,

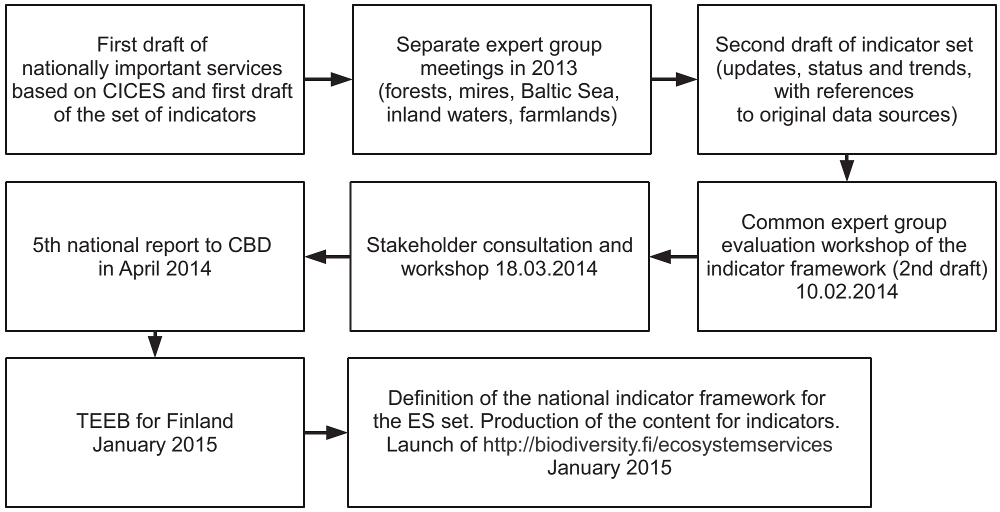

Fig. 1. Flow chart of the identification process of national ecosystem service indicators.

sectors of the economy such as agriculture, forestry, and tourism, research institutes, universities, and NGOs. In the workshop we presented the indicator framework, and asked for feedback concerning the applicability of the indicators. After this meeting the indicator framework was updated. The ES indicator work was also used in the 5th national report to CBD (Ahokumpu et al., 2014) and TEEB for Finland assessment (Jäppinen and Heliölä, 2015). The results are now reported online at www.biodiversity.fi/ecosystemservices

2.2. Applying the cascade model to ecosystem service indicators

Our ecosystem service indicator framework aims to put focus on the resilience of ecosystem processes by providing information on the different aspects of ecosystem structure and functioning that underpin the provisioning of ecosystem services. In line with steps 1 and 2 of the cascade model (Fig. 2) we aim to show the preconditions for the continued provision of each particular service. An important question here is also how much disturbance they can withstand. Are we within safe limits of ecosystem resilience? At the same time, we hope to demonstrate the societal dependence on ecosystem services by providing indicators of both benefits and values (cascade model steps 4 and 5) (see Fig. 2). Taken as a whole, the indicator chain's aim is to demonstrate the stepwise social–ecological nature of ecosystem service delivery.

Providing only one indicator on any given ES on the CICES class level (e.g. erosion control or nature tourism) would give an imbalanced picture of the phenomenon in question (Layke, 2009). By applying the cascade model, we developed four indicators for each ES representing stages of (1) structure, (2) function, (4) benefit, and (5) value of the ES flow. By doing so we hoped to balance the overall view and stress the interdependencies between the different steps in the cascade. We strived to find long-term datasets to describe the development of each cascade step indicator under each ES class. Whenever such data sets were not available we explained the processes and their outcomes in qualitative terms.

Some alterations to the original cascade model were made in an effort to increase communicability (Fig. 2). First, we did not draft indicators for the third step of the cascade since we used it as a headline for the ES in question. We believe that the delivery of ESs is sufficiently portrayed by the four indicators and that taken as a whole they represent the service itself (cascade step 3). Second, while the original cascade model has 'biophysical structures or processes' as the first step we used only 'structure'. In our interpretation processes such as net primary production, denitrification or decomposition also require structures (plants, microbes, etc.). For the sake of simplicity we decided to approach these processes from the structural point of view.

2.3. Preferred ways of valuing ecosystem services

A stakeholder workshop was organized (Fig. 1) to gather information on the preferred measures of values for all ecosystem services. The workshop included a general introduction to the topic after which the participants filled in a questionnaire. We asked the participants which of the four different value measure types – economic, social, health, and intrinsic – would they prefer and in which order with a scale from 1 to 4 (1 = least preferred, 4 = most preferred, maximum 44 points). Altogether 22 persons participated in the workshop, presenting different sectors and organizations such as forestry, agriculture, tourism, conservation, social issues, NGOs, administration and research. Full listings of preference were received from 11 participants. Although a very crude sample, these answers reflect the discussions of the workshop quite well.

3. Results

We developed indicators for 28 ecosystem services (10 provisioning, 12 regulating and maintenance, and 6 cultural services), a set of four indicators for every stage of the cascade; altogether 112 indicators (Appendix I). These were the output of the expert consultation process described in Fig. 1. Abiotic services are expected to be included in the future. In our collection the indicator titles correspond to the 'class' level of CICES. We outline factors in every ES description that are important for the ES from Finland's perspective. Three ecosystem services, berries and mushrooms (provisioning service), climate regulation (regulating service), and nature tourism (cultural service), are presented in more detail in Section 3.2 to show systematically the construction of ecosystem service indicators at the four stages of the cascade.

3.1. Classification system for national ecosystem service indicators

3.1.1. Indicators for provisioning services

In our indicator framework structural indicators (related to spatial variables) for provisioning services are described most often with area of required habitat or population of necessary organisms. Function indicators (related to spatio-temporal variables) focus on

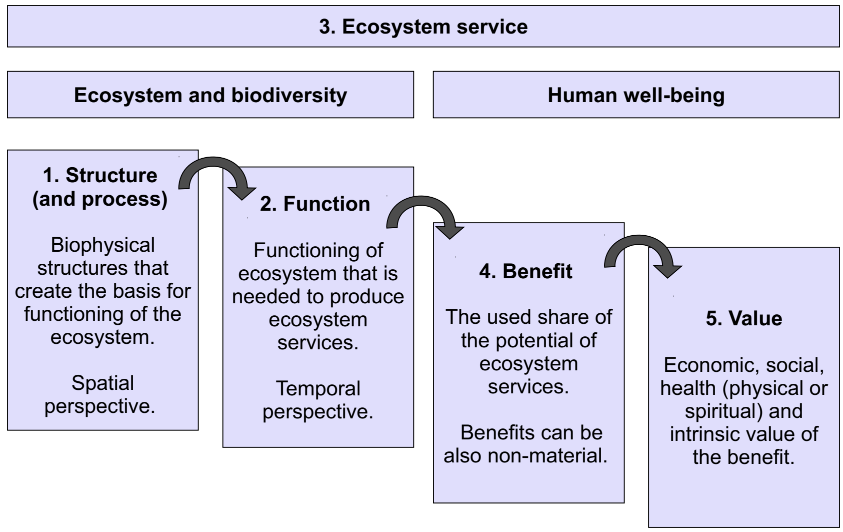

Fig. 2. Cascade model with integrated ecosystem service indicators. Step 3 of ecosystem services was moved from the middle as a headline in our framework. Adapted from Haines-Young and Potschin (2010a).

productivity, but they also consider human inputs to improve productivity by using, for example, fertilizers, supplementary feeding or different forest management practices. For example, the function indicator for clean water is the state of surface water which is maintained by the structure behind it, in this case pristine mires and undisturbed soils. For fish and crayfish the state of surface water is, nevertheless, the structure while the function indicator represents the population dynamics that result from the quality of the structure.

Benefits of provisioning services to human well-being are concrete and they are assessed as the used share of the total production. For example, for berries and mushrooms ES benefit is the amount of berries and mushrooms that are picked from the forests and mires. The values of provisioning services are assessed foremost in monetary units since most of them, if not all, have a market-value and data series exist on their trade. Provisioning services can, nevertheless, also be evaluated in terms of social, health or intrinsic values. Social value may be measured as number of jobs and health value as decreased illnesses or improved quality of life. Intrinsic value is applied in a rather loose sense. It refers, for example, to the appreciation of clean water without a clear evaluation of its usefulness to humans (i.e. that having clean water is valuable in itself).

3.1.1.1. Example: berries and mushrooms. The structure indicator of berries and mushrooms is the area of berry and mushroom habitats. For example, the cover of bilberry (*Vaccinium myrtillus*) and cowberry (*Vaccinium vitis-idaea*) has been estimated by the Finnish Forest Research Institute by using National Forest Inventory data and associated monitoring (Tonteri et al., 2013).

The function indicator includes species-wise estimates of the total production of berries and mushrooms per area unit. As above, statistics exist primarily on bilberry and cowberry. These are published annually by the Finnish Forest Research Institute. The average annual production of both bilberry and cowberry is approximately 22 kg/ha (Turtiainen et al., 2011).

The ES benefit of berries and mushrooms is the harvested share of total production. Most of the berries and mushrooms are picked for domestic use and exact amounts cannot be calculated. Survey-based data suggests that some 27 million kg of berries was collected for domestic use in 2011 while the amount of commercial picking was 8 million kg (Vaara et al., 2013). Long-term data series exist on the amount of berries and mushrooms collected for commercial markets.

The value of berries and mushrooms can be assessed in monetary units in the case of the share of harvest entering commercial markets and, to some degree, estimated also for the share of household use. Statistics on markets cover only the selling prices and not the appreciation of processed end products such as jams or canned mushrooms. Psychological and health promoting values of berries and mushrooms and their picking can be manyfold compared to the commercial value even though their measurement is challenging (Fig. 3).

3.1.2. Indicators for regulating and maintenance services

Structural indicators for regulating and maintenance services can be defined as the required habitat qualities, area of suitable habitat or required species assemblage that form the basis for these ESs. Function indicators define the function of certain ecosystem elements in a certain area per time (unit/area/time). For example the function indicator for water filtration would be expressed as ground water production or recharge rate (mm/ha/year). Numerical data do not exist for most structure and function indicators because their complex and all-inclusive nature, thus they are mainly covered qualitatively in our indicator set.

Many of the benefits of regulating and maintenance services are indirect but fundamental for human well-being. Indirect benefits are, for example, improved nutrient balance of the soil, avoided erosion, and climate regulation. Some of the benefits are more direct (air quality) and some even concrete (groundwater, viable populations). Some numeric data are available for benefit indicators such as calculations of groundwater generation (e.g. Ministry of the Environment, 2013). Many of them are, nevertheless, only rough estimations.

Value indicators of regulating and maintenance services are often expressed as avoided costs that would arise from compensating for the human-induced malfunction of the ecosystem. Many regulating and maintenance services are central for human well-being and a decline or deficiency of the service might cause adversities on many levels. For example, low level of nitrogen fixation or nutrient retention increases the need for synthetic fertilizers and thus causes expenses for farmers. Bad air quality, on the other hand, impairs human health and increases health care expenses. Also in the case of regulating and maintenance services values can be measured in non-monetary terms. For example, while some health benefits can be monetized others are best expressed as cases of avoided illnesses or bodily injuries. Many ecosystem services in

Berries and mushrooms			
Structure: **Berry and mushroom habitats (ha)** - area of suitable berry and mushroom habitats in mires and forests	Function: **Average annual production (total kg/A or kg/ha/A)** - change in annual production, trend	Benefit: **Harvest (kg)** - amount of berry and mushroom harvest entering the markets and domestic use	Value: **Value of berries and mushrooms** - sales, picking income (€), - berry and mushroom pickers (n, %), health and intrinsic values

Fig. 3. Four indicators of berries and mushrooms.

this category are necessary for life and thus elude simple monetary valuation.

3.1.2.1. Example: climate regulation. Structure indicator for the climate regulation is carbon storing habitats. There are estimations of carbon stocks in Finnish forests, mires (Asikainen et al., 2012), soils (Asikainen et al., 2012; Kortelainen et al., 2004) and inland water sediments (Kortelainen et al., 2004; Pajunen, 2004). Carbon is also absorbed in the Baltic Sea.

Function indicators for climate regulation are carbon balance and carbon sequestration rate. Finland's carbon balance and the volume of sequestration have been studied for years, but challenges remain in gaining a complete calculation. The carbon balance of mires and soils has been assessed to vary significantly and farmlands have been calculated to be a minor carbon source (OSF, 2010). During recent decades forests have functioned as carbon sinks because tree growth has exceeded loggings (Finnish Statistical Yearbook of Forestry, 1986–2013). Carbon emissions were 61 million tonnes in 2012 (OSF, 2014b), and approximately half of this is sequestered by the natural carbon sinks. Nevertheless, about 30 million tonne of carbon is released to atmosphere by Finns every year.

The benefit indicator of climate regulation is stable climate. This can be expressed indirectly by using meteorological data on the variability of climate or by evaluating damages to the society that have been caused by extreme weather events.

The values of climate regulation include avoided costs of negative climate impacts and the intrinsic value of stable climate. Research on climate change mitigation and adaptation has a fairly short history, yet some recent or ongoing research programmes already include an evaluation of costs (ENSURE, 2013; Virta et al., 2011). The economic impacts of climate change can also be evaluated by using data on insurance payments (Mills, 2005) (Fig. 4).

3.1.3. Indicators for cultural services

Structural indicators of cultural services are described most often as the quality of natural areas as experienced by people, i.e. qualities that attract people in recreation and tourism destinations or in objects of work of art, etc. Accessibility is an important quality factor related to structural indicators of cultural services. Function indicators are similar for all cultural services. According to our interpretation, the ecosystem functions that are most relevant for cultural services include natural events and phenology, such as bird migration (e.g. the mass migration of arctic breeding waterfowl across the Gulf of Finland in spring) or autumn foliage especially in Lapland. These relate to the experiences of change and/or continuity that people seek in nature. In this context, also the time scale ES function – which may vary from seasonal changes to hundreds of years (e.g. continuity of the mire landscape or eco-evolutionary maturation of cultural landscape) – need to be considered. Understandably, function indicators for cultural services will be mainly qualitative.

Benefits of cultural services are measured as numbers of visits or jobs created, or number of times that services are used. Some benefits are abstract and relate to personal experience in nature as nature affects people's identity and psychological well-being. The values of cultural services are similar to benefits, and can be economic, social, health or intrinsic values. Many of them are abstract such as knowledge, experience, identity and aesthetics, but some of them have a market-value. These include revenue from nature tourism and prices of artworks and land properties in different landscape setting (e.g. lake view). The values of scientific innovations belong to both groups; they often have a market-value, but they also generate values in the case of which the use of monetary units is sometimes impossible (e.g. health or sustainability).

3.1.3.1. Example: nature tourism. Nature tourism is built on conceptions of pure water, forests and white snow that are widely used to attract visitors to Finland. Nature tourism can have significant regional benefits, which is the case especially in Lapland (Bell et al., 2007). Numbers of visitors in tourism related facilities, e.g. over-night stays in hotels, can be used as an indirect measure to explain the area's attractiveness to nature activities (e.g. Kandziora et al., 2013).

Natural areas preferred by tourists and their accessibility are used as structure indicators. Statistics are gathered of visitors in state owned areas such as national parks (nearly 10 000 km^2), where in latest years the number of annual visits has exceeded 2 million (Metsähallitus, 2014b). In order to differentiate between recreation and nature tourism, we included only over-night stays in this indicator. From the perspective of accessibility, the limit of nature tourism could be fixed to travelling distances. Overnight stays in Finland have been studied to last five days on average and reach approximately to 300 km away from permanent home (Maes et al., 2012a,b).

The function indicator for nature tourism, as for all other cultural services, is the same: natural events and phenology. Natural events, such as seasonal changes in nature or the stability of the landscape act as attractors for nature tourism. For example, the burst of autumn foliage is one of the peak tourist seasons in Lapland (Järviluoma, 2006).

Nature tourism benefits national, regional and local economy directly and indirectly. The revenue that flows to businesses originates from organizing outdoor activities, accommodation and restaurant services. Local economic importance of nature tourism has also been studied (e.g. Huhtala et al., 2010). However, it is problematic to distinguish which services are used because of a visit to nature. The demand for these services increases employment indirectly. The visitors also value experiences, but these personally experienced values relate to recreation and its value indicators (Fig. 5).

Climate regulation			
Structure: **Carbon storing habitats (ha)** - area of carbon storing forests, mires, Baltic Sea and inland water	Function: **Carbon balance, sequestration rate** - the balance of sequestered (to plants) and released (to atmosphere) carbon	Benefit: **Climate regulation, stable climate** - stability helps foreseeing and preparing for the future - increases security	Value: **Value of climate regulation** - avoided costs of negative climate impacts (€), - intrinsic,health and social values of stable climate

Fig. 4. Four indicators describing climate regulation.

3.2. Stakeholder preferences for value indicators

According to the results of the stakeholder survey, economic value was the preferred measure of 22 out of the total of 28 ESs (Table 1). This preference was particularly pronounced in the case of five ESs: wood, crops, reared animals, water retention and nature-based tourism. All or all but one respondents felt that the benefit from these should be measured primarily in economic terms. Social value was the preferred way of measuring three ESs: nature-related heritage, landscape, and science and education. Genetic material was an interesting exception among provisioning services – most respondents stressed the intrinsic value of genetic material as much as its economic significance. Two ESs, air quality and noise reduction, received highest scores of preference for their health values.

Understandably, those ESs for which markets and economic valuation systems already exist were seen best measured in economic terms. Most of these are provisioning services. However, the social values related to two provisioning services were seen as almost equally important as their economic value. The social significance hunting (game), particularly elk, is considerable as is the significance of reindeer husbandry for the continuation of the indigenous Saami culture. In general, regulating services received also quite high scores for economic valuing. This may be slightly surprising as no markets exist for most of them. Although carbon sequestration can already be given in euro per tonne value, many respondents stressed the intrinsic value of the climate regulation.

4. Discussion

In our experience following the CICES classification helped us considerably to identify a comprehensive set of the nationally most important ESs. Involving expert and stakeholder groups was necessary to incorporate their knowledge and views on specific ESs and helped to access data from their organizations (cf. Rosenström and Kyllönen, 2007). The chosen set of ESs represents the services that are currently seen as most important in Finland. This set may change in the future and therefore requires reassessment on regular basis. One further step to be taken in the future could be to establish more transparent criteria for determining which ecosystem services are considered "most important" (cf. Jacobs et al., 2015). These could be based on any of the cascade steps: e.g. the area affected (structure), scope of processes involved (function) or magnitude of benefits and their values (e.g. harvest, monetary value or number of jobs involved). Based on our experience there is broad agreement that wood is an essential ES in Finland at present while animal-based mechanical energy is not, for example. However, there are also some borderline cases such as biological air quality maintenance which significance is not that easy to determine under the specific national circumstances.

The use of the cascade model provided a challenging but robust structure for the definition of the ES indicators themselves. By using four indicators instead of one for each ES we covered the whole ecosystem flow from ecosystem structure to values of the ES. The applicability has been noted also earlier in a regional level assessment where the cascade model was applied with available spatial datasets (Tolvanen et al., 2014). In general, the framework will help to increase understanding of the topic by presenting clearly structured and easily accessible information (incl. data sources) on the website. Despite the fact that all indicators could not be quantitatively measured, the framework offers systematic qualitative information for the purposes of different interest groups.

At the same time, building the framework revealed many remaining challenges. Long-term monitoring data are ideal for indicator purposes, but currently suitable data do not exist for all ecosystem services or they cannot be scaled up to the whole country. The latter is the case with such indicators as water filtration for which detailed information may exist from specific wetlands (e.g. Koskinen et al., 2011), but these findings cannot be generalized to the whole country. For some indicators data are collated from multiple sources, mainly from national authorities who have sectoral responsibility for monitoring, such as the Game and Fisheries Research Institute (RKTL) or the Finnish Forest Research Institute (Metla). In the case of regulating services involving large scale physical and ecological processes, such as water retention or erosion control, the drafting of comprehensive indicators would

Nature tourism			
Structure: **Preferred natural areas (ha), accessibility** - area of preferred types of nature that attract nature tourism - accessibility to these areas	Function: **Natural events, phenology** - seasonal changes of natural events or stability of landscape that attract people to nature	Benefit: **Employment (n), recreation, experience** - the employment rate in nature tourism - recreation to nature tourists	Value: **Values of nature tourism** - tourism revenue (€) - health - employment (n) (local, regional, national) - intrinsic value

Fig. 5. Four indicators describing nature-based tourism.

Table 1
Stakeholders' value preferences for ecosystem service classes in order. Four categories for values are used: economic, social, health, and intrinsic. 11 respondents arranged values to preferred order with scale from 1 to 4 (1 = least preferred, 4 = most preferred) so that the maximum value was 44 points. The ecosystem services that were not fully understood are marked in italic.

Ecosystem service	Value preference order
Provisioning services	
Berries and mushrooms	Economic (41), Social (23), Health (20), Intrinsic (5)
Game	Economic (38), Social (30), Health (13), Intrinsic (8)
Reindeer	Economic (41), Social (28), Intrinsic (13), Health (10)
Fish and crayfish	Economic (41), Social (27), Health (15), Intrinsic (10)
Crops	Economic (44), Social (17), Health (14), Intrinsic (3)
Reared animals	Economic (44), Social (17), Health (11), Intrinsic (3)
Clean water	Economic (36), Health (27), Social (17), Intrinsic (8)
Wood	Economic (44), Social (21), Health (10), Intrinsic (9)
Genetic material	Economic (32), Intrinsic (32), Health (21), Social (12)
Bioenergy	Economic (40), Social (21), Health (19), Intrinsic (7)
Regulating services	
Mediation of waste and toxins	Health (20), Economic (19), Social (18), Intrinsic (6)
Air quality	Health (34), Economic (27), Social (19), Intrinsic (9)
Water filtration	Economic (33), Health (33), Social (16), Intrinsic (11)
Nutrient retention	Economic (37), Social (22), Health (17), Intrinsic (7)
Noise reduction	Health (32), Economic (25), Social (18), Intrinsic (5)
Erosion control	Economic (39), Social (20), Intrinsic (15), Health (9)
Water retention	Economic (44), Health (12), Social (11), Intrinsic (5)
Pollination	Economic (38), Health (16), Intrinsic (16), Social (11)
Nursery habitats	Economic (25), Intrinsic (24), Social (12), Health (9)
Soil quality	Economic (35), Health (16), Intrinsic (15), Social (10)
Nitrogen uptake	Economic (42), Health (16), Intrinsic (11), Social (9)
Climate regulation	Economic (33), Intrinsic (21), Health (15), Social (14)
Cultural services	
Recreation	Economic (34), Health (29), Social (24), Intrinsic (7)
Nature tourism	Economic (43), Health (18), Social (17), Intrinsic (4)
Science education	Social (26), Economic (23), Intrinsic (23), Health (14)
Nature-related heritage	Social (34), Intrinsic (24), Economic (14), Health (13)
Landscape	Social (37), Economic (30), Intrinsic (14), Health (11)
Arts and popular culture	Economic (30), Social (27), Intrinsic (15), Health (13)

require purpose-built systemic modelling and more knowledge of the structural features necessary for the provisioning of these services (incl. the area and distribution of different types of wetlands and their ability to control water flows). One example of the challenge of upscaling is pollinator populations which have to be monitored on a very local scale if we want to use real survey data as the basis of an indicator (Alanen et al., 2011). Finding appropriate data for cultural services is still a challenge, but encouraging examples have emerged. For example, Paracchini et al. (2014) modelled successfully outdoor recreation spatially by combining recreation potential and accessibility.

In general, cost-efficient improvements that would allow for spatially explicit presentation could be achieved rather easily for some structural indicators. This lies also at the core of work related to the MAES programme. However, providing such applied data from Earth Observation (EO) raw material would require resources that were out of the scope in this exercise. In Finland, two examples of land cover products that could be used for national scale quantification of ES are CORINE land cover data provided by the Finnish Environment Institute and Multi-Source Forest Inventory data provided by the Finnish Forest Research Institute (see Appendix I: e.g. Berries and mushrooms). Recently, airborne laser scanning (ALS) data have been used for mapping spatially explicit forest structure parameters that can be related to many biodiversity and ES variables (Hill and Thomson, 2005; Vehmas et al., 2009; Vihervaara et al., 2015). In some cases spatial evaluation of ecosystem services might require more detailed information of the land cover, e.g. habitat types or land use practices. Developing remote sensing based techniques and applications is necessary if we want to detect changes in biodiversity and land cover accurately and timely.

The national ES framework and indicators presented in the Appendix I provide a novel approach also for other countries working with the issue. Although the use of the cascade model has been recommended for mapping ESs to support decision-making (Maes et al., 2012a), a comprehensive overview of all stages of the model has not, to our knowledge, been taken on a national scale elsewhere. We believe that the indicators of the national ES framework described in this paper could be used also for improving mapping and spatially explicit assessments of the ESs that are comparable with other European countries. However, the framework is still under development. Many structural indicators can be mapped quite straightforwardly using basic EO and GIS (geographic information systems) tools, but, for example, functional indicators need more elaboration to illustrate dynamic variability. Spatial presentation of ecosystem service allocation is important for understanding the overall picture.

Another challenge stems from making ESs and their indicators more commensurate. While showing ESs side by side and within a common framework has many advantages – comprehensiveness, impartiality and comparability to name but few – it also creates opportunities for oversimplification. Since an ecosystem service is, first and foremost, a utilitarian concept, the temptation soon arises to rank ESs in economic terms. This could be detected while compiling Finland's Fifth National Report to the Convention on Biological Diversity (Ahokumpu et al., 2014). The purpose of the report was to show the trends related to some of the foremost ESs in Finland. Instead of discussing emerging trends (e.g. increasing nature-based recreation) and altogether novel topics (e.g. pollination and nursery habitats) the debate in the stakeholder steering group soon turned into arguing about the economic significance of one ecosystem service over others. A purely monetary comparison of forest related ESs has already been published as a part of Finland's National Forest Programme 2015 (Ministry of Agriculture and Forestry, 2008). This is problematic not only because of the weak knowledge base related to many forest ESs such as nature tourism and recreation, but also because the comparison misses all the other ways of valuing ESs: social, health and intrinsic values. These values should be addressed early on in process of compiling ecosystem service indicators alongside with the economic ones to avoid oversimplifications (cf. Boeraeve et al., 2015; Chan et al., 2012).

Interruptions to ecosystem service provisioning flow occur in many ways. Applying the DPSIR (Driver-Pressure-State-Impact-Response) framework within the cascade model can help to point out threats to the sustainable flow of ESs (Kandziora et al., 2013). Human induced pressures, such as land-use change, cause pressures on ecosystem structures that may alter the functioning of the ecosystem and the realized benefits. Furthermore, the rate at which an ecosystem service is being used, can affect the sustainability of its provisioning. Restoration of degraded ecosystems can improve the state of many regulating services. Basing on the principles of adaptive management, these means of enhancing ESs are called "nature-based solutions" by the European Commission in the implementation of Biodiversity strategy. A further step would be to assess how such human inputs or improved management practices could be included in the set of ES indicators. The sustainability perspective will be further developed and incorporated into the indicators to ensure that the indicators are not used simplistically. A synthesis of the four indicators for one ecosystem service may also be necessary as using only one indicator would offer an insufficient information-base for making ecologically and socially sustainable decisions. By choosing the nationally most important ESs and creating, under each of them, four indicators based on the cascade model we hoped to create a matrix that could be used in further work on analyzing and assessing ESs (cf. Jacobs et al., 2015). This matrix could be applied to many situations. For example, it could be used to evaluate the environmental impacts of proposed development projects. It could also be applied to comparing the effectiveness of different forms of production; for example, to compare the ecosystem service effectiveness of conventional and organic farming. Using the matrix would go some way into making the analyses comprehensive and balanced.

5. Conclusions

In this paper we presented a comprehensive framework for national ecosystem service indicators, following the principles of the CICES framework and the cascade model. The indicators developed synthesize and visualize information from complex social–ecological systems and make it thus better accessible for decision-makers, planners and anyone interested in the theme. The set of 28 Finland's most important ecosystem services and their altogether 112 indicators – one on each four steps of the cascade (structure, function, benefit, value) – concretizes the national debate on ecosystem services. They also provide groundwork for further development. Published on the Internet at www.biodiversity.fi/ecosystemservices the indicators are open to everyone and allow for continuous reassessment and development. The indicators also support national biodiversity and ES related evaluation and, hopefully, international efforts such as MAES.

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Appendix 1. Ecosystem service indicator listing

CICES				CASCADE			
Sec.	Div.	Group	Class	1. Structure	2. Function	4. Benefit	5. Value
PROVISIONING SERVICES	Nutrition	Biomass	Berries and mushrooms	Berry and mushroom habitats (ha)	Average annual production (kg/A or kg/ha/A)	Harvest (kg)	Sales, picking income (€) berry and mushroom pickers (n, %), health and intrinsic values
			Game	Game habitats (ha)	Game population (n), wildlife richness	Game bag (kg)	Game bag (€), social, health and intrinsic values
			Reindeer	Reindeer pastures (ha)	Reindeer population (n), birth rate (%)	Culled reindeer (kg)	Sales of reindeer meat (€) employment (n), intrinsic and health values
			Fish and crayfish	State of surface waters (qualitative scale), stream fragmentation	Population dynamics of fish and crayfish	Total catch (kg)	Total catch (€), employment (n), health and intrinsic values
			Crops	Area under crop cultivation (ha)	Nutrient dynamics (kg/ha), fertilizer and pesticide use (kg/ha)	Harvest (kg)	Agricultural income (€), employment (n), health and intrinsic values
			Reared animals	Number of animals (n), area of pastures (ha)	Nutrient and energy uptake (organic vs. conventional)	Animal products (kg, l)	Agricultural income (€) employment (n), health and intrinsic values
		Water	Clean water*	Undisturbed habitats and aquifers (ha)	State of surface water and groundwater (EU classification)	Use of raw water (m^3)	Value of domestic, irrigation and process water use (€), health, social and intrinsic values
	Materials	Biomass	Wood	Managed forests (ha)	Growing stock increment, impact of management (m^3/ha)	Roundwood removals (m^3)	Roundwood trade (€) employment (n), health and intrinsic values
			Genetic material	Number of varieties (n), area of gene reserve habitats (ha)	Breeding, genetic variance, evolution	Breeding and discovery potential/benefit	Genetic variance and evolution, economic value of modified organisms (€), intrinsic, social and health values
	Energy	Biomass	Bioenergy	Area under bioenergy crops (ha)	Annual growth of biomass (tons/ha/year)	Harvest (m^3) energy content (PJ)	Produced energy (€) employment (n), health and intrinsic values
Sec.	Div.	Group	Class	1. Structure	2. Function	4. Benefit	5. Value
REGULATING AND MAINTENANCE SERVICES	Mediation of waste, toxics and other nuisances	Mediation by biota	Mediation of waste and toxins	Suitable ecosystems (ha), soil organisms	Decomposition, mediation or storage of waste by biological processes	Improvement of water and soil quality	Health value, avoided costs of waste management (€), social and intrinsic values
			Air quality	Urban green infrastructure (ha)	Retention of small particles	Improved air quality	Health values of clean air, avoided medical costs (€), social and intrinsic values
		Mediation by ecosystem	Water filtration	Undisturbed habitats and aquifers (ha)	Groundwater production (recharge rate, mm/ha/year)	Groundwater and surface water quality	Value of groundwater and surface water (€), health, social and intrinsic values
			Nutrient retention	Undisturbed habitats (ha)	Nutrient retention rate	Improved water and soil quality (qualitative scale)	Avoided costs of fertilizer use and water protection measures (€) social, health and intrinsic v.
			Noise reduction	Vegetation in urban areas (ha)	Acoustic absorption	Reduced noise level	Health values of reduced-noise environment, avoided medical costs (€), social and intrinsic v.
	Mediation of flows	Mass flows	Erosion control	Undisturbed soils (ha)	Particle retention rate	Avoided erosion, improved water quality	Avoided costs of fertilizer use (€) high quality surface water (€), intrinsic and health values
		Liquid flows	Water retention	Undrained habitats, vegetation type and cover (ha)	Detention time (per habitat type, natural vs. modified)	Flood and flow control (natural levelling of flow)	Avoided costs of flood prevention and avoided damages (€), health, social and intrinsic values
	Maintenance of physical, chemical and biological conditions	Lifecycle maintenance, habitat...	Pollination	Pollinator nesting and foraging habitats (ha)	Pollination	Increase in yield (kg/ha)	Improved production (€), health, intrinsic and social values
			Nursery habitats	Area and state of nursery habitats (n, ha)	Shelter and nutrition (measured as reproduction success)	Viable populations	Avoided costs of stock replenishment and other management measures (€), intrinsic, social and health values
		Soil formation & compos.	Soil quality	Functional diversity of soil organisms	Cycling of substances	Soil quality	Avoided costs of soil improvement (€), increased harvest (€), health, intrinsic and social value
			Nitrogen uptake	Nitrogen-fixing vegetation (ha)	Nitrogen fixation rate	Improvement of nutrient balance and soil quality	Avoided costs of fertilizer use (€) health, intrinsic and social values
		Atmospheric compostion ...	Climate regulation	Carbon-storing habitats (ha)	Carbon balance, sequestration rate	Climate regulation, stable climate	Avoided costs of negative climate impacts (€), intrinsic, health and social values of stable climate
Sec.	Div.	Group	Class	1. Structure	2. Function	4. Benefit	5. Value
CULTURAL SERVICES	Physical and intellectual interactions with biota, ecosystems and land/sescapes**	Physical and experiential interactions	Recreation	Preferred natural areas (ha), accessibility	Natural events, phenology	Experience; participation in recreational activities (n, %)	Avoided medical costs (€), health value, participation in outdoor activities (n), intrinsic value
			Nature tourism	Preferred natural areas (ha), accessibility	Natural events, phenology	Employment (n), recreation, experience	Tourism revenue (€), health value, employment (n), intrinsic value
		Intellectual and representative interactions	Science and education	Areas of particular interest (ha)	Natural events, phenology	Source of knowledge	Social, economic, intrinsic and health value of knowledge and innovations
			Nature-related heritage	Cultural heritage in natural landscapes (n)	Natural events, phenology	Cultural continuity	Social, intrinsic, economic and health values of nature-related cultural heritage.
			Landscape	Valuable/preferred landscapes (n, ha)	Natural events, phenology	Aesthetic experience	Identity and aesthetics, marketing value of landscape (€), intrinsic and health values
			Arts and popular culture	Emblematic species and landscapes (n)	Natural events, phenology	Aesthetic experience, recreation	Market value (€), identity and aesthetics, intrinsic and health values of cultural representations

* Clean water combines the CICES classes “Surface water for drinking”, “Ground water for drinking”, “Surface water for non-drinking purposes” and “Ground water for non-drinking purposes”.

** The CICES division ‘Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes (environmental settings)’ was not included here since we considered that they could mostly be considered, as intrinsic values of the other cultural services.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2015.03.041

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