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Title: Exploring operational ecosystem service definitions: the case of boreal forests

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Abstract

Despite the widespread use of the concept of ecosystem services, there is still much uncertainty over the precise understanding of basic terms such as ‘ecosystem services’, ‘benefits’ and ‘values’. This paper examines alternative ways of defining and classifying ecosystem services by using the specific example of boreal forests in Finland. We find the notion of final ecosystem goods and services (FEGS) operable, and suggest using it in economic valuation and other priority setting contexts, as well as in the selection of indicators. However, in the context of awareness raising it might be more effective to retain the well-established terminology of the Millennium Ecosystem Assessment. Our analysis shows that the cascade model (Potschin and Haines-Young 2011) is helpful in distinguishing between ecosystem structures, processes, services, benefits and values by making the sequence of links visible. Johnston and Russell’s (2011) operational mechanism for determining FEGSs proves also instrumental in separating intermediate (e.g. carbon sequestration) and final ecosystem services (e.g. reduction of atmospheric carbon). However, we find their definition of importance, which is based on willingness to pay, too narrow. Furthermore, we favour the CICES approach, which defines ecosystem services as the direct contributions that ecosystems—whether natural or semi-natural—make to human well-being.

1. Introduction

The concept of ecosystem services has been received enthusiastically by the research community and recently also by policy makers (e.g. Primmer and Furman 2012, Hauck et al. 2013). Despite the definitions provided by the Millennium Ecosystem Assessment (MA 2005) and other studies (e.g. Fisher et al. 2009, Harrington et al. 2010), there is still much uncertainty over the precise understanding of what is meant by ecosystem services, and the basic terms such as ‘ecosystem services’, ‘functions’, ‘benefits’ and ‘values’ are often used with different meanings from one study to another (Ojea et al. 2012, Chan et al. 2012). Some researchers argue that ecosystem services are ecosystem attributes such as clean water, which lead to benefits such as angling or other recreational activities (e.g. Fisher et al. 2009, Nahlik et al. 2012, Johnston and Russell 2011), while others equate ecosystem services to the benefits, e.g. recreational activities, that humans derive from ecosystems (e.g. MA 2005, Tallis et al. 2011, Bateman et al., 2011). Yet for other authors, ecosystem services are the ecological processes or functions such as nitrogen removal from surface water (MA 2005, Tallis and Polasky 2011, Maes et al. 2012), which contribute to clean water. Due to these inconsistencies, researchers often measure and map different biophysical outcomes and different benefits as ecosystem services. Lacking clarity also makes communication of the importance of “ecosystem services” to managers and the public more difficult. Making the concept practicable for researchers, as well as understandable for the public, decision-makers and managers, requires a clear and precise way of naming and categorizing ecosystem services and linking them to underpinning ecological structures and processes (Tallis et al. 2011, Lamarque et al. 2011).

The most influential attempt to create an ecosystem service typology is by the MA (2005), which classified ecosystem services as supporting, regulating, provisioning and cultural services. The MA has been highly effective in stimulating discussion on ecosystem services and bringing the concept into broader environmental planning and policy making arenas. However, the MA categories of ecosystem services are not operable as such because they do not distinguish between intermediate ecosystem processes and the services that are directly consumed or enjoyed by people (Boyd and Banzhaf 2007, Fisher and Turner 2008). For instance, if we calculate the value of the regulating service 'nitrogen removal' on the basis of the value of clean drinking water, and sum it up with the value of the provisioning service 'drinking water', we double-count the contribution of the nitrogen removal service.

In order to provide an analytic distinction between intermediate and final services, Boyd and Banzhaf (2007) have introduced the notion of Final Ecosystem Goods and Services (FEGS) defined as "components of nature, directly enjoyed, consumed, or used to yield human well-being". These are thus ecosystem services proper [sensu strictu]. The notion of FEGS is adopted by Fisher et al. (2009), Nahlik et al. (2012) and the Common International Classification of Ecosystem Services (CICES; see www.cices.eu), which defines final ecosystem services as the contributions that ecosystems make to human well-being: "These services are final in that they are the outputs of ecosystems (whether natural, semi-natural or highly modified) that most directly affect the well-being of people. A fundamental characteristic is that they retain a connection to the underlying ecosystem functions, processes and structures that generate them (Haines-Young and Potschin 2013)". Benefits are defined by CICES as final outputs from ecosystems that have been turned into products or experiences that are not functionally connected to the systems from which they were derived (Haines-Young and Potschin 2013).

A further attempt to define final ecosystem services is Johnston's and Russell's (2011) operational mechanism for determining whether a biophysical feature, quantity, or quality represents a final ecosystem service for beneficiaries. Their set of rules to distinguish final services stipulates that for a biophysical outcome to serve as an ecosystem service, a beneficiary should be willing to pay for an increase in the outcome, assuming that all ecosystem outputs and conditions are held constant. Johnston and Russell (2011) illustrate these conditions with an example of nutrient removal in a riparian buffer that leads to an increase in water clarity in a neighboring lake. Nutrient removal is not a final ecosystem service for lakeside homeowners because it does not influence their welfare if other ecosystem conditions, including water clarity, remain the same. The final service is water clarity because homeowners are willing to pay for increased water clarity, even with no other changes in ecosystem condition. Johnston and Russell (2011) also maintain that biophysical outcomes that count as ecosystem services must represent the output of an ecological system prior to any combination with human labour, capital or technology, and that in cases where an ecosystem outcome simultaneously represents both a final service to a beneficiary and an intermediate service to another beneficiary, only the benefits of final services should be counted and aggregated. In the above example, water clarity can be a final service for lakeside homeowners and an intermediate service for recreational anglers, assuming that it increases the catch. In this case we should calculate both the benefits for lakeside owners as well as the benefits for anglers.

To illustrate the ways in which underlying ecological structures, processes and functions—the intermediate services—are linked to ecosystem services, Potschin and Haines-Young (2011) have introduced the cascade model (Figure 1), which has also been adopted in The Economics of Ecosystems and Biodiversity (TEEB) study (2010, 2011). The cascade model seeks to articulate the 'production chain' that underlies ecosystem services and emphasizes the fact that services exist only in relation to people's needs; the benefits from ecosystem services and their value to different beneficiaries depend on the social contexts in which the services are used. The ecological structures in the cascade model refer to the composition and distribution of the system´s components; the processes refer to any change or reaction which occurs within ecosystems, either physical, chemical or biological, and functions denote the capacity of an ecosystem to provide services (Potschin and Haines Young 2011)[1].

Chan et al. (2012) have tackled the problem of conflation of services, benefits and values in ecosystem service frameworks particularly in the context of cultural ecosystem services. They view benefits as valued goods and experiences at the level at which people can most easily relate ecosystems to themselves, and services as the ecosystem processes underpinning benefits, at the level at which ecosystem properties and dynamics might be considered in planning and management. They also provide a detailed typology of different types of values including e.g. market-mediated and non-market mediated, self-oriented and other oriented, and individualistic and group values.

Despite these conceptual developments, it is still commonplace in ecosystem service research to simply list all services with no systematic distinctions between intermediate and final services for different beneficiaries (Johnston and Russell 2011, see e.g. Raymond et al. 2009, Casado-Arzuaga et al. 2013). In this paper, we examine alternative ways of defining and classifying ecosystem services by using a specific example of boreal forests in Finland, and discuss the implications of different definitions for different purposes such as valuation, priority setting and awareness-raising. We apply Johnston and Russell's (2011) operational mechanism for determining whether a biophysical feature, quantity or quality represents a final ecosystem service for beneficiaries, and compare that with the classification outputs derived from alternative definitions, including the MA and CICES. We also draw on the cascade model in order to visualize the flow of multiple ecosystem services from a specific social-ecological system, in this case boreal forests.

The purpose of the paper is to propose an operational definition for the concept of ecosystem services as well as related concepts of benefits and values for different decision contexts, and to assess the use

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[1] While the term ”functions” is used in several different meanings within the environmental sciences in general and in the context of ecosystem services specifically (see Jax 2005), Potschin and Haines Young (2011) as well as several other authors (e.g. De Groot et al. 2002) define ”functions” as the capacity of an ecosystem to provide services or sometimes as “the subset of interactions between biophysical structures, biodiversity and ecosystem processes that underpin the capacity of an ecosystem to provide services” (TEEB 2010, p. xxxiii)

of the cascade model in illustrating the sequence of linkages between ecosystem structures and processes at one end, and benefits and values, at the other. In this way, we hope to contribute to a consistent ecosystem service typology that facilitates comparative studies and enables repeatable quantification and valuation of ecosystem services.

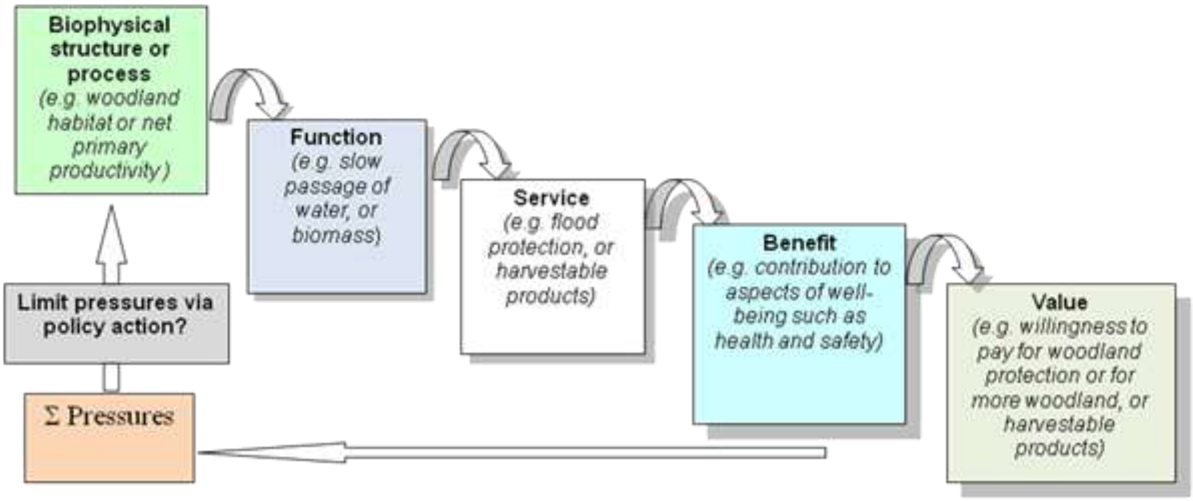

Figure 1.The ecosystem service cascade model (Potschin and Haines-Young, 2011)

2. Materials and Methods

The social-ecological system that is the focus of this study is boreal forest (taiga) ecosystems in Finland. Finland is completely encompassed within the continental coniferous-mixed forest zone with cold, wet winters (McKnight et al. 2000). The forests are intensively managed with native species and rather long (50-80 years) rotation times. However, the forests are growing faster than they are harvested, resulting in an increase in the total amount of wood biomass (Finnish Forest Research Institute 2013). About half of the forest land area consists of mixed stands with a mosaic character. This results from the varied topography and growing conditions as well as a diverse forest ownership structure: close to a million private persons own 60% of Finnish forests. The forests are also important habitats for endangered species, 36% of which depend on forests, particularly on old-growth and fertile forests in Southern Finland, which are under the most severe threat (Rassi et al. 2010).

In order to identify forest ecosystem services, existing literature on forest ecosystem services in Finland (Matero et al. 2003, Vihervaara et al. 2010, Kettunen et al. 2012) was reviewed. For cultural services we also drew on literature from similar boreal zones in the USA and Canada (Clement & Cheng 2011; van Riper et al. 2012; Sherrouse et al. 2014) because cultural services are not extensively covered in articles specific to Finnish forests. Three tables were created from the review in which cultural services (Table 1), regulating services (Table 2) and provisioning services (Table 3) are listed and compared with the MA and CICES categories.

These tables were then used to select cultural, regulating and provisioning ecosystem services that we found to be most relevant and useful in illustrating the range of services provided by Finnish boreal forest social-ecological systems. For instance, the service of erosion prevention was omitted because it is important in dry steep terrains and human-dominated social-ecological systems, but not in boreal forests in Finland. These categories were then fitted to the cascade model (Figures 2, 3 and 4), which we modified to agree with the proposed definitions (the changes are justified in the discussion section). We employed Johnston and Russell's (2011) operational set of rules, as well as CICES definitions, to locate the list of services under the cascade model categories 'benefits' and '(final) ecosystem services'. We then selected a few ecosystem services to illustrate the links between these categories and the biophysical structures and processes underlying them. Here, we drew on basic ecological literature as well as the work by de Bello et al. (2010) on functional traits which underlie ecosystem services, Harrison et al. (2014) on linkages between biotic attributes and services, and Luck et al. (2009) on service providing units. The latter is defined as the collection of organisms and their characteristics necessary to deliver a given ecosystem service at the level required by service beneficiaries. Similarly, discussion of the category 'values' drew on the work by Chan et al. (2012). Finally, we combined elements from Figures 2 to 4 into a single cascade model (Figure 5) to illustrate the linkages between different types of services.

3. Classifying ecosystem services from boreal forest social-ecological systems

3.1 *Cultural services*

Cultural ecosystem services are defined by the MA (2005) as the "non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences". However, in our cascade model (Figure 2), we regarded the different types of cultural ecosystem services listed in Table 1 not as services but benefits. Here we followed CICES, which defines benefits as "direct or indirect outputs from ecosystems that have been turned into products or experiences that are no longer functionally connected to the systems from which they were derived"[2] (Haines-Young and Potschin 2013). For instance, the satisfaction that people derive from beautiful forest landscapes resides in the minds of people observing and enjoying them, not in the landscape itself. This logic is actually also applied by the MA, which terms the cultural services listed in Table 1 as non-material *benefits* that people obtain from ecosystems. It is also consistent with the operational set of rules by Johnston and Russell (2011), who regard attributes such as presence of structural habitats for wildlife viewing opportunities as a final ecosystem service, and the recreational experience from these as

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[2] On the other hand, CICES states that cultural services—not benefits—"cover all the non-material, and normally non-consumptive, outputs of ecosystems that affect physical and mental states of people" (Haines Young and Potschin 2013, p. ii). This is somewhat inconsistent because recreation can be defined simultaneously as a cultural service (non-material ecosystem output that affects physical and mental states of people) and a benefit (a direct or indirect output from ecosystems that has been turned into an experience like recreation).

a benefit. In a similar way, Nahlik et al. (2012) maintain that birds are an ecosystem service and bird watching an ecosystem benefit that is appreciated by ornithologists, amateur bird watchers as well as ordinary people who enjoy seeing and listening to birds. Chan et al. (2012), too, term the MA cultural service categories (see Table 1) as benefits[3].

Boreal forests are important destinations for recreational users such as hikers, bird watchers, hunters and anglers, and recently several eco-tourism enterprises have been set up to observe and photograph bears, wolfs and wolverines (Peltola et al., 2013). Walking and cycling while enjoying the landscape are the most popular outdoor hobbies in Finland, and 60% of Finnish people consider spending time in recreational houses close to nature as a preferred recreational activity (Sievänen and Neuvonen 2011). Part of the recreational experience is achieving a state of peacefulness, calm and restfulness, and having a sense of connection to nature and seasonal changes. The scenic beauty of forests are enjoyed by recreational users as well as visitors and the local population, and forests have inspired artists such as the national romantic painters and composers in the 19th century, who helped to shape Finnish national identity as an independent nation, which derives its strength from a close connection to nature. Consequently, forest landscapes and heritage sites such as ancient forest routes are an important part of Finnish cultural heritage. Outdoor recreation and other forest based activities also provide opportunities for shared experiences and thereby enhance social relations. For instance, in rural communities moose hunting is an important social activity and contributes to a sense of community and social cohesion (Peltola et al., 2013). In Finnish Upper Lapland, old-growth forests have an important role for indigenous Sami culture, which is based on free-grazing reindeer herding especially in old-growth forests. Activities around herding are important in maintaining the Sami language, sense of place, and traditional knowledge, and hence the forests are vital in maintaining cultural diversity (Forbes et al. 2006). Sami people regard some landscape features as sacred, and also other people can attach religious or spiritual meanings to forests.

Many people also attach value to knowing that forests exist now (*existence value*) and into the future (*future/inheritance/bequest value*). Biodiversity is linked to existence and bequest value because people appreciate nature for emblematic individual species (such as the endangered flying squirrel) as well as for species and/or habitat richness and ecological integrity (Burkhard et al. 2012), and want to preserve nature for future generations. However, it does not seem logical to consider values as benefits. In particular, it is contradictory to place value to intrinsic value, which, by definition, resides in the object itself, independent of an external valuator (Partridge 1986). On the other hand, we miss an important aspect if we only focus on direct benefits, such as recreation, and ignore the ethical and moral reasons for why people want to protect nature. We attempted to solve this problem by naming the attributes that people assign value to as ‘preserving nature for its own sake’ and ‘preserving nature for future

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[3] However, they have partly retained the MA categories and list e.g. ‘outdoor recreation’ and ‘education and research’ as ecosystem service categories and ‘activity’ and ‘knowledge’ as benefit categories. In our view, outdoor recreation (benefit) is a subcategory of activity and the underlying ecosystem service is landscapes or ecosystem attributes such as clean water which enable outdoor recreational activities.

generations'. Another solution would be to use the term 'nature and biodiversity' as a proxy for the qualities that are bearers of different values (existence, intrinsic, etc.).

As stated above, the final ecosystem services that give rise to cultural benefits are attributes such as presence of structural habitats or individual species in forests. Some cultural benefits such as berry picking or the social interaction around hunts can be linked to distinct units, or Ecosystem Service Providers[4] (Kremen 2005), such as berries or game animals (the FEGS), and these can be traced back to intermediate services (biomass production) and the underlying processes such as decomposition and nutrient uptake, and the biotic and abiotic attributes that lie beneath them (e.g. species richness and soil qualities). In a similar way, species abundance and richness can be linked with species-based recreation (Harrison et al. 2014). However, for the more intangible cultural benefits such as aesthetic experiences it is difficult to pinpoint a single biotic or abiotic element of the ecosystem that is the 'carrier' of the service; instead, the intangible benefits are created by landscapes, which consist of abiotic elements such as cliffs, lakes and rivers as well as biotic elements: bird song or the smell of pine forest on a hot summer day. According to a systematic review by Harrison et al. (2014), the specific Ecosystem Service Providers most often associated with landscape aesthetics were single or two or more communities or habitats as well as landscape diversity (or complexity). Gee and Burkhard (2010), too, have used landscape and place as ecosystem units to which aesthetic and other cultural values are ascribed, and Plieninger et al. (2013) use the term *sites* of aesthetic value and *sites* of spiritual or religious meaning for cultural services. Consequently, we considered physical landscapes, such as the mosaic of different types of forests, or uniqueness of a forest type that provides habitats for certain forest species as FEGSs. In Figure 2, we illustrate this by the box forest landscape, which comprises of the ecological structure and processes creating landscapes.

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[4] Ecosystem Service Providers are the component populations, functional groups or communities that contribute to ecosystem service provision (Harrington et al. 2010).

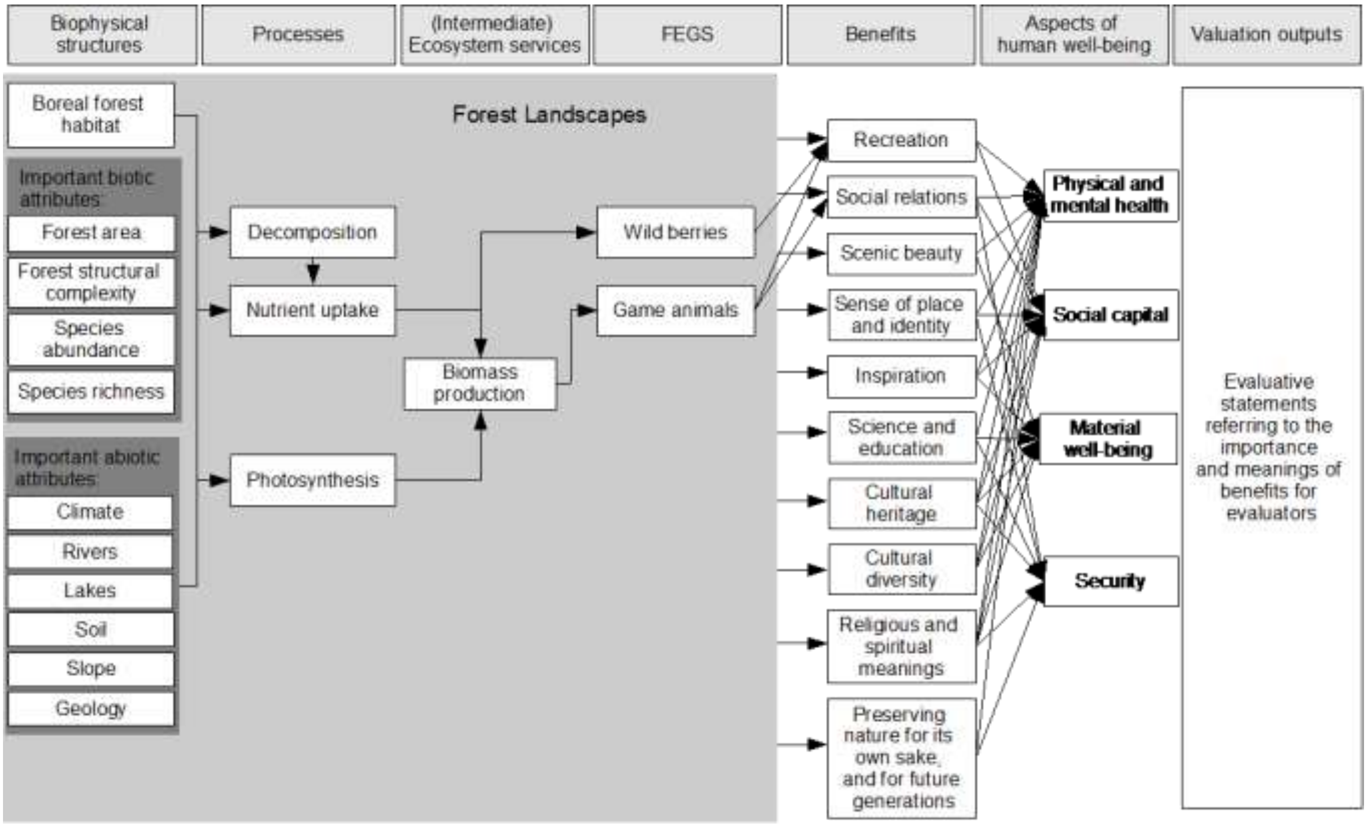

Figure 2. The cascade model for the cultural benefits of boreal forest ecosystems and some examples of the underlying services (final and intermediate). The links between benefits and aspects of human well-being are indicative. The grey shaded area represents forest landscapes, which links as a whole to the benefits.

We added the category human well-being to Figure 2 because we think that moving directly from benefits to values, which are often evaluated in monetary terms, overlooks central considerations in societal decision-making. For instance, if we estimate the value of recreation on the basis of willingness to pay for these activities, we miss the positive impacts on physical and mental health. Exposure to natural environments has been found to promote stress recovery and to stimulate positive feelings and creativity (Tyrväinen et al. 2014). Natural environments, including forests, have also been found to improve physical health by providing opportunities for physical exercise, such as hiking and orienteering and by muffling noise and improving air quality (Korpela et al. 2014). Some studies have considered well-being aspects such as mental well-being and health (e.g. Kettunen et al. 2012) or therapeutic values (Clement and Cheng 2011, van Riper et al 2012, Sherrouse et al. 2014) as cultural services. However, these well-being effects are usually mediated by recreational or other types of benefits and hence considering them as benefits (or services) leads to double-counting.

3.2 Regulating services

Regulating ecosystem services are defined by the MA (2005) as the “the benefits obtained from the regulation of ecosystem processes, including, for example, the regulation of climate, water, and some human diseases". The regulating ecosystem services listed by the MA and CICES and provided by Finnish boreal forests are given in Table 2.

The key regulating services of boreal forests are carbon sequestration, water flow regulation and water purification, which are discussed in more detail below. In addition, boreal forests can regulate air quality by filtering air borne particles. They also can regulate micro climate, e.g. by mitigating strong winds; this is particularly important in the vicinity of residential areas where heating costs can be 10-20% lower in forest sheltered sites than in open sites (Matero et al. 2003). Landslides and avalanches are not key problems in flat and humid Finland, but forests play an important role in pest control as well as providing habitats, particularly forest edges, for pollinators (Matero et al. 2003).

We applied the cascade model diagram to three regulating services to illustrate the full production chain from biophysical structures and ecological functions to benefits and values: carbon sequestration, water flow regulation and water purification (Figure 3). Forest ecosystems play an important role in regulating the global climate, acting as a carbon sink and reducing the amount of greenhouse gases in the air (Obersteiner et al., 2010). Finnish forests sequester carbon, as the annual increment exceeds removals due to timber extraction (see provisioning services section) (Finnish Forest Research Institute 2013). Carbon is also stored in the forest soil, but forestry operations release some of this carbon, the amount being dependent on the type of operation (Vanhala et al., 2013).

According to the review by Harrison et al. (2014) the service of reducing atmospheric carbon (also sometimes referred to as climate regulation or atmospheric regulation) is predominately provided by entire communities and habitats, particularly forests and woodlands, so the relevant biophysical structure in Figure 3 is defined as the boreal forest itself. Harrison et al. (2014) also identify a wide range of biotic and abiotic attributes associated with the ecosystem structure that are important for reduction of atmospheric carbon. The most important are the tree species themselves, particularly the stand age, species population diversity, species richness and tree size. For example, larger carbon storage was found in older tree species because of the longer time period over which they have sequestered carbon and because their size increases with age (e.g. Hantanaka et al., 2011). In addition, forest structural complexity, area, litter volume and soil organisms were also cited as important parts of the overall biophysical structure. For instance, Liski et al. (2002) found that litter input was the main factor influencing soil carbon storage in Finland. However, evidence of the direction of relationships between the different biotic attributes and carbon sequestration is complex and sometimes conflicting (Harrison et al. 2014). A range of abiotic factors were also identified by Harrison et al. (2014) as influencing carbon sequestration, such as those related to the soil (including nutrient availability), weather (including water availability) and topography.

These components of the boreal forest habitat affect carbon sequestration, some directly and some through other ecological processes such as photosynthesis, nutrient uptake, and soil formation and retention. In some studies, the ecological process of carbon sequestration is regarded as an ecosystem service (e.g. Vihervaara et al. 2010). However, according to Johnston and Russell's rigorous test, carbon sequestration is an intermediate service because beneficiaries are not willing to pay for increases in carbon sequestration as such, assuming that other ecosystem outputs and conditions, such as carbon dioxide in the atmosphere, are held constant. So, it is the alleviation of climate change that beneficiaries - basically the whole of humankind - are interested in, not the capacity of forest biomass to store carbon. The economic value of carbon sequestration can be calculated on the basis of carbon emissions mitigation costs and avoided damage costs of climate change (Stern 2007)[5] . Despite high uncertainty there are a number of conventions for assigning a monetary value to an avoided tonne of CO_2 emissions, which are frequently employed in ecosystem service valuation studies.

Forest ecosystems are also part of the water regulation system by retaining runoff (Palviainen et al., 2014), and, hence, contribute towards flood control. The final ecosystem service here is flood control, but another final ecosystem service which has an opposing relationship with the same ecosystem functions is the volume of water supply, i.e. the more runoff that is infiltrated and retained, the better the flood control service but the worse the supply of water (Harrison et al. 2014). However, in Finland there is seldom a shortage of water and, therefore, there is no major trade-off between flood control and water availability. Furthermore, forest soils - humus layer and root system - can retain soil particles (Vauramo and Setälä, 2011) and, hence, play a role in water purification where forested soils, especially esker formations, which effectively filter rain and snowmelt waters leading to good availability and quality of groundwater, are the final ecosystem service. Forest soils and vegetation also have the ability to prevent nutrients from leaching to water bodies, further contributing to good quality surface water bodies through water purification (Palviainen et al. 2014).

Similarly to the service of climate regulation, Harrison et al. (2014) find that both water flow regulation and water purification are predominately provided by entire communities and habitats (in 68 and 82% of papers reviewed, respectively), so the relevant biophysical structure in Figure 3 is also defined as the boreal forest. Specific biotic attributes found to be important were: forest area, structural complexity, stand age and tree size for water flow regulation; and habitat area, structural complexity and species richness for water purification. Notable abiotic attributes were the weather (particularly precipitation, snow and evaporation), the soil and topography (particularly slope). All these components of the boreal forest habitat affect the capacity of forest vegetation and soils to infiltrate and retain flood water, which is an important ecosystem process for both services. In addition, nutrient uptake by vegetation and the physio-chemical retention of soil particles are critical processes for water purification.

The beneficiaries are individuals and communities that use the groundwater sources and surface water bodies for drinking and household water, and in the case of flood control, homeowners and municipalities as well as farmers whose properties and fields are protected from rising water levels. This can be valued in terms of the avoided costs of water treatment and property damage from flooding, as

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[5] According to the Stern Review, one percent of global GDP per annum is required to be invested to avoid the worst effects of climate change.

well as the commercial value of drinking water and the security value for human well-being of a safe environment with plentiful, good quality water. There are obvious overlaps with the cultural services of recreation and aesthetic enjoyment as good quality water bodies lead to improved water clarity (e.g. absence of algae blooming) and viable fish stocks, both of which are final ecosystem services, e.g. for lakeside home owners and recreational anglers who experience the benefit of swimming in clean water, enjoying beautiful views and being able to catch fish from the lake. This is analogous to Johnston and Russell's (2011, 2246) example of nutrient removal in riparian buffers: homeowners would not be willing to pay for increased nutrient removal if all ecosystem conditions such as water clarity would remain the same, but they would be willing to pay for increased water clarity.

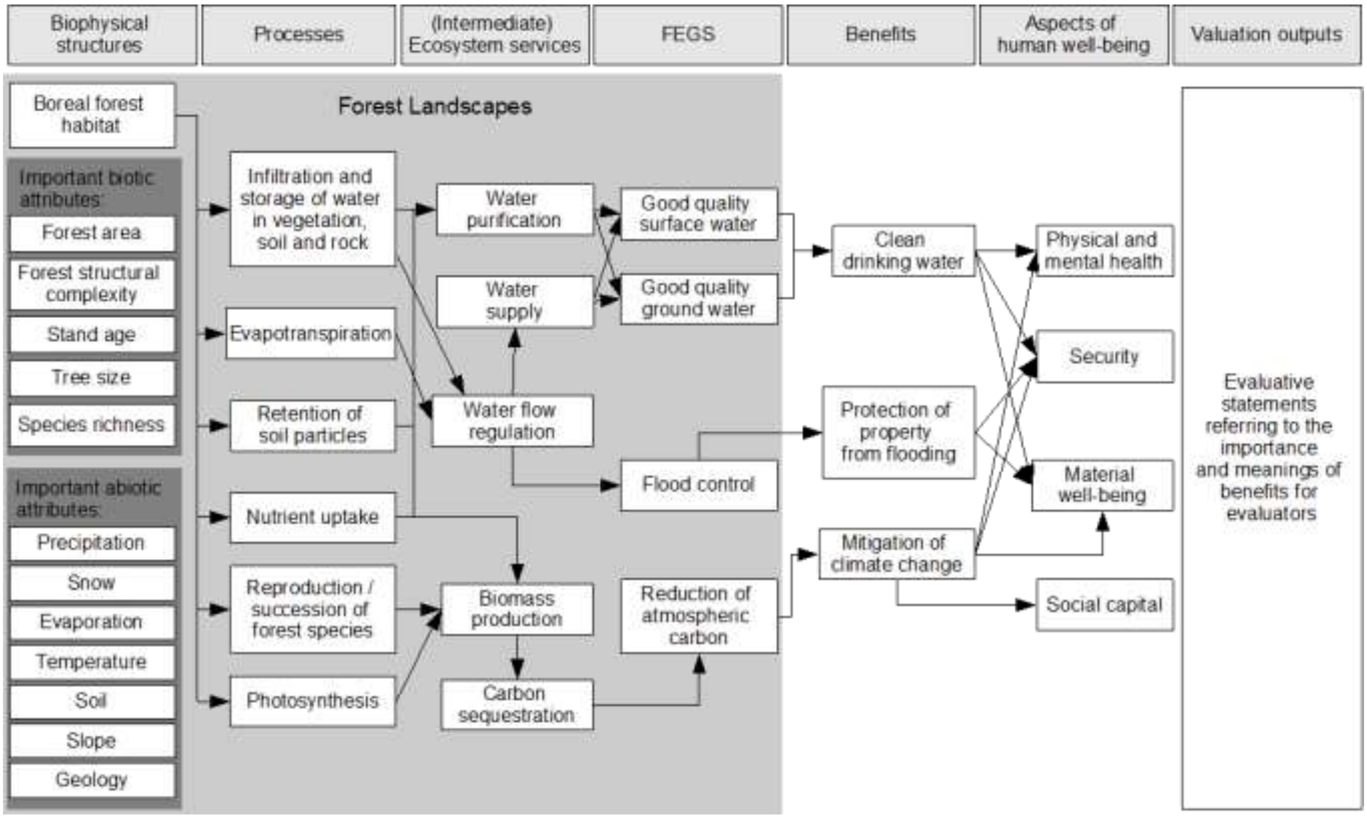

Figure 3. The cascade model for the services of good quality surface and ground water, flood control and reduction of atmospheric carbon.

3.3 *Provisioning services*

Provisioning services consist of all the products obtained from ecosystems (MA 2005). The provisioning service categories by the MA and the CICES, relevant for forest ecosystems, are presented in Table 3. The table also lists provisioning services that are identified in the context of boreal forests in Finland and Nordic Countries (Matero et al. 2003, Vihervaara et al. 2010, Kettunen et al. 2012).

The most economically valuable provisioning services delivered by Finnish forests are timber and fibre for pulp production. Timber and fibre can be considered as FEGSs because they are directly used by a beneficiary (e.g. cut down for processing or for firewood) and timber—(i.e. the trees)—retain a clear connection to the underlying ecosystem functions, processes and structures that generate them (see Figure 4). The ‘production boundary’ is exceeded when biomass is extracted for commercial or domestic use by cutting trees down, and storing and transporting them for production processes. These stages involve input of human labour and capital, and hence the value of timber and timber products do not only derive from ecosystems. Rather, they are commodities, the value of which is determined in the market. However, the production boundary is not clear-cut because human input such as sowing, planting seedlings, fertilizing and tending young stands are common practices in commercial forestry.

Another fibre related provisioning FEGS is harvesting residue (branches, stumps and other residual biomass left behind after forestry operations), which has become an important source of biofuel due to the EU renewable energy targets (Directive 2009/28/EC). Wood-based energy is mostly used in large scale district heating and combined heat and power plants. The use of fire wood for household heating is also very common in Finland where around 60% of households use firewood for heating (Kettunen et al. 2012).

Further provisioning services are wild berries, game, mushrooms and herbs. The most important berries are lingonberries (*Vaccinium vitis-idaea*) and blueberries (*Vaccinium myrtillus*), which are picked for household use as well as commercially. Eurasian elk is the most important big game species, while artic hares and grouse species are typical smaller game species in Finland. Semi-domestic reindeer herding is a traditional form of animal husbandry in northern parts of the boreal forests of Lapland and in Arctic regions, practiced especially by indigenous Sami people. Forests also provide a range of decorative materials such as lichen and Christmas trees, and around 20 plants are currently collected from the wild for commercial medicinal purposes in Finland (Kettunen et al. 2012). There is also growing interest in research related to biotechnological applications based on Nordic genetic resources, and there are increasing markets for forest products such as birch sap in the food, drink and cosmetics industries (Kettunen et al. 2012).

The intermediate ecosystem services, which give rise to the FEGS such as timber and berries, include biomass production and pollination (Figure 4). Insect pollination is vital particularly for provisioning of lingonberries and blueberries while coniferous trees are pollinated by wind. Biomass production is dependent on ecosystem processes, such as primary production, nutrient uptake and decomposition of organic material, and structural biotic and abiotic elements, such as species richness, tree size, evaporation and soil nutrient balance. For instance, nitrogen is a growth limiting factor in dry pine forests (*Pinus sylverstris*) where decomposition of organic material is slow, and therefore decomposers (e.g. microbes, fungi and nematodes) play a central role in the nutrient cycle (Matero et al 2003). *Nostoc* cyanobacteria, which live on the surface of moss (*Pleurozium schreberi*), are the most important absorbers of atmospheric nitrogen in boreal forests (De Luca et al. 2002). In the ecosystem service literature, primary productivity is frequently linked to species richness and species abundance (Harrison et al. 2014). However, some studies have also observed negative relationship with species richness and timber production (Harrison et al. 2014).

The benefits from fibre and timber, as well as biofuels, include forest owner income, forest industry revenue and forest sector employment. The forest sector, including forestry and forest industries, generates 20% of Finland's export revenue and employs 2.8% of the employees in Finland, around 70 000 people (Finnish Statistical Yearbook of Forestry 2012). The forest sector also has led to the creation of other industries and economic activity in Finland, such as manufacturing of paper and other fibre-based products as well as bioenergy refining and forestry machinery. The beneficiaries of berries, mushroom and game are either people who are interested in the catch or yield, or people who are interested in the recreational aspect of berry picking or hunting; being out in the wild and enjoying the exercise and excitement of the hunt (see section on cultural services). Similarly, free grazing reindeer herding is a source of livelihood and income but at the same time, it is the foundation of the Sami pastoralist culture and tradition (Forbes et al. 2006).

It is relatively straightforward to estimate the economic value of some provisioning services. For instance, the value of berries sold in market places and directly to households or restaurants was estimated to be 3.4 million EUR in 2000, and the value of berries collected for household use was evaluated to be 54 million EUR (Kettunen et al. 2012). However, these figures do not cover the non-material values such as the recreational value of berry picking. Furthermore, economic valuation of fibre and timber, as well as biomass for biofuels, is not as straightforward as it seems at first sight. . A simple approach is to account for the forest owner net income ‘at the farm gate’. Further down the forest product value chain we have to make stronger assumptions. If we assume that capital in the forest processing industry cannot be reinvested, nor forestry processing labour reemployed in other sectors, we could also include the value-added by the forest products industry revenue and forest sector employment income. If forestry sector capital and employment are partly mobile, it becomes more difficult to account for different man-made inputs to the forest sector value chain, and its importance in the economy at large. Furthermore, as Chan et al. (2012) point out, the value of a job to a person transcends its contribution to the overall economy. This is especially the case in rural areas where forestry related jobs play an important role in regional development and sustaining living countryside.

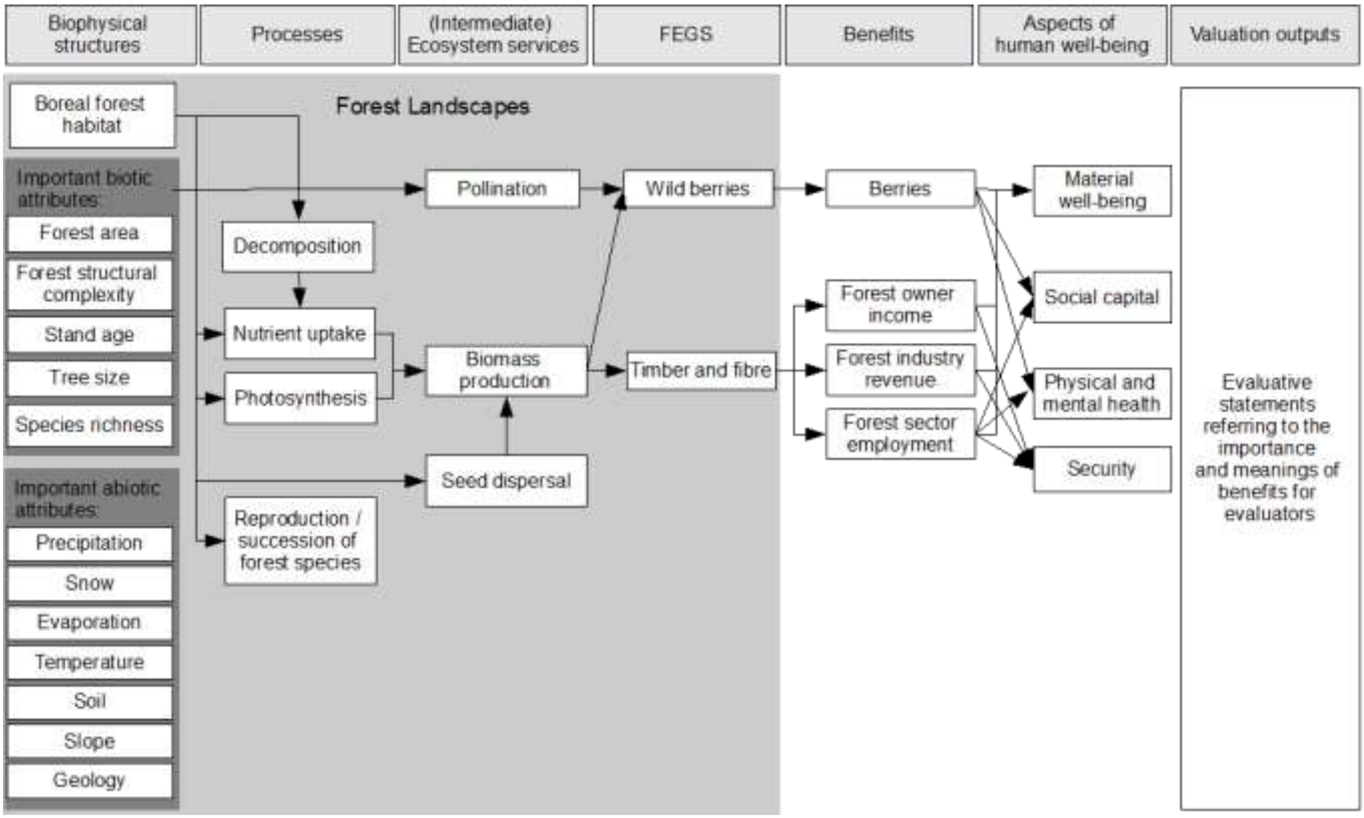

Figure 4. The cascade model for the provisioning services of wild berries, and timbre and fibre, and some examples of the underlying services (final and intermediate).

3.4 Linkages between services

Ecosystems are characterized by complex interactions between biotic and abiotic elements, and hence the same ecosystem structures and processes can mediate the delivery of multiple services. Harrison et al. (2014) observe several positive linkages between ecosystem service providers such as habitats and populations and ecosystem services, and they also identified some negative linkages. For example, vegetation, especially trees, can have a negative impact on water provision by sucking water out of the system while simultaneously having positive impacts on atmospheric regulation and landscape aesthetics. Furthermore, several benefits (e.g. nutrition and social capital) can be experienced together by some stakeholders in a given activity such as indigenous subsistence fishing, which include material benefits as well as socio-cultural benefits (Klain et al. 2014).

In Figure 5 we have combined elements from each cascade model (Figures 2-4) to illustrate the interrelationships between the services. In our model, good surface water quality, which depends on water purification and water supply through water flow regulation, provides clean drinking water (provisioning benefits) as well as opportunities for recreational activities such as swimming and angling (cultural benefits). It is important to note that due to the cross-sectoral interactions, forest management practices can have far-reaching impacts on the services of other social-ecological systems such as rivers, lakes and estuaries (Dunford et al. 2015). Biomass production also has multiple functions in supplying timber, sequestering atmospheric carbon and hence contributing to climate change mitigation, and taking up nutrients and hence aiding water purification. Furthermore, material services related to berry picking and hunting have important non-material dimensions such as providing outdoor recreational and related aesthetic experiences. In valuation exercises it is important to distinguish the economic or subsistence value of the harvest (provisioning service) from the recreational aspect of hunting or berry picking. A further challenge is that several cultural benefits are often experienced together in a given activity and hence it might be difficult to separate these for valuation purposes (Gee and Burkhard 2010, Klain et al. 2014). For example, the aesthetic qualities of forests influence the berry picking experience as well as other recreational activities.

The combined model serves as a starting point before undertaking more detailed analyses of cause-and-effect relationships using more sophisticated approaches such as state-and-transition models (Bestelmeyer et al., 2009; Lopez et al. 2010) and Bayesian Belief Networks (Landuyt et al., 2013) within the DPSIR framework (de Groot et al. 2010). A further possibility for more fine-grained analysis is to create separate cascades for different beneficiaries and examine the relationships between them. In such analysis, the systemic understanding of the ecosystem service approach should be maintained.

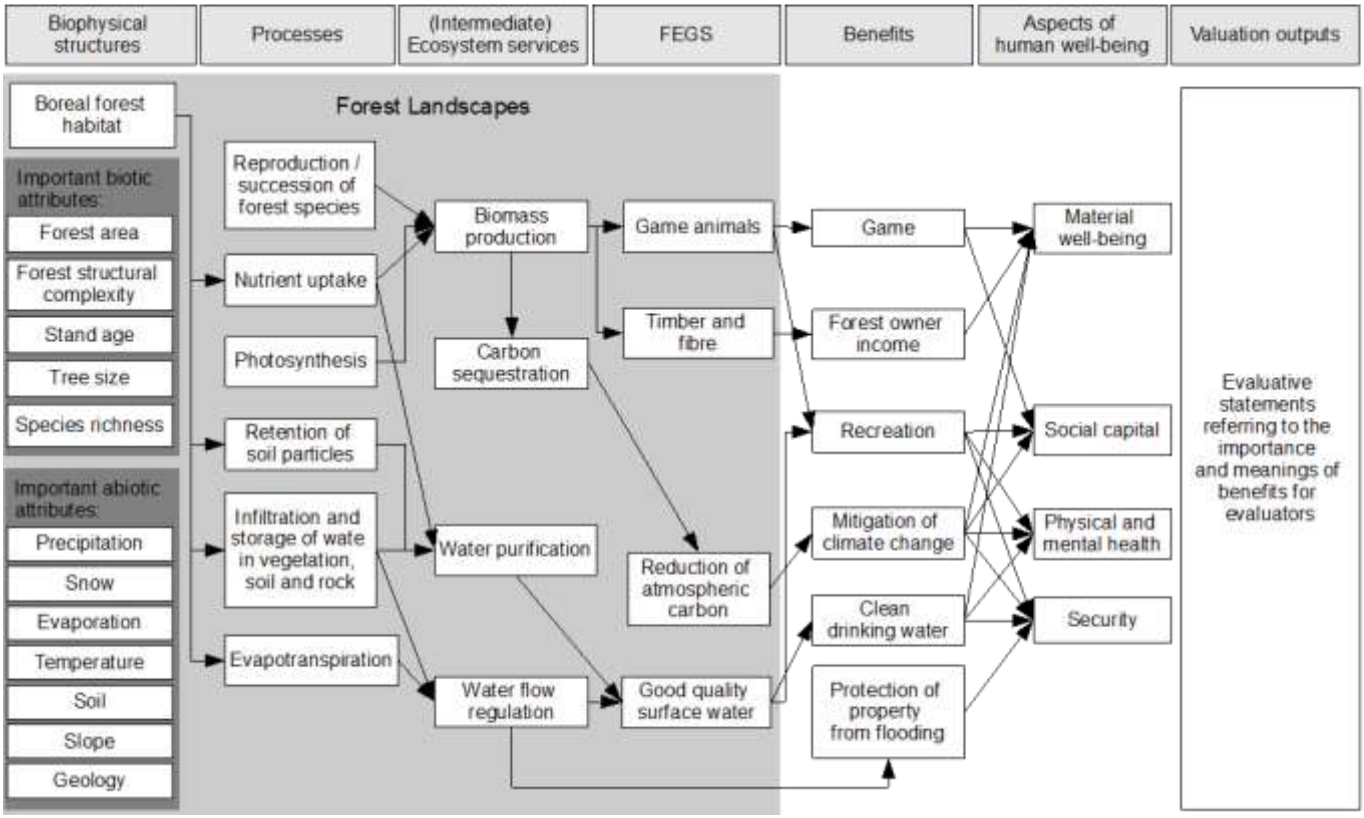

Figure 5. Combination of some elements in Figures 2-4 to highlight the interactions between cultural, regulating and provisioning services.

4. Discussion

In order to ground the somewhat abstract debates on ecosystem service definitions, we have examined different conceptualizations in a concrete example of boreal forest ecosystems and proposed a typology, which builds on CICES as well as the literature that it draws upon (Boyd and Banzhaf 2007, Fisher et al. 2009, Nahlik et al. 2012). We subscribe to the notion of final ecosystem good and services (FEGS), defined as “outputs of ecosystems (whether natural, semi-natural or highly modified) that most directly affect the well-being of people and that retain a direct connection to the underlying ecosystem functions, processes and structures that generate them” (Haines-Young and Potschin 2013). Following this characterization, we have defined timber, good quality surface water and forest landscapes, as well as other ecosystem services, to name a few, as FEGS. We also adopt the CICES definition of benefits as “direct or indirect outputs from ecosystems that have been turned into products or experiences that are no longer functionally connected to the systems from which they were derived” (Haines-Young and Potschin 2013). Examples of benefits in our model are forest owner income, potable water and recreation activities.

However, as Gómez-Baggethun and Barton (2013) have pointed out, the applicability of different valuation methods—and also conceptual tools—depend on the policy contexts in which the result are used. The notion of FEGS brings operational clarity *for valuation studies* in the context of priority setting (e.g. choosing between alternative policy options), where it is important to define explicitly the output to be valued and to distinguish between intermediate and final services in order to avoid double counting. This is particularly crucial in monetary valuation studies, which seek to provide exact estimates. It is important also in non-monetary priority setting processes such as Multi Criteria Decision Analysis processes, where the evaluation criteria should not be ambiguous or overlapping.

Analytical clarity is important also in selecting ecosystem service indicators for the purpose of monitoring the state of the environment. Some indicators such as water quality measures reflect changes in the actual environment while some indicators such as number of national park visitors or recreational anglers are influenced by changes in the habits, behaviour and lifestyles of people. Therefore, it is important to distinguish between benefit indicators, which reflect changes both in the supply (e.g. availability of green areas) as well as demand (e.g. the number of people visiting these areas), and FEGS indicators which reflect changes in ecosystem service provision (supply).

The requirements for precision are less stringent in the context of awareness-raising where the aim is to draw attention to the fact that nature provides a wide range of services such as pollination, water purification or flood control, which often go unnoticed. In this context, it is useful to use the term ‘ecosystem services’ also for the intermediate services, or ecosystem functions, to retain the well-established terminology of the MA. It might be confusing particularly for wider audiences to refer to pollination, for example, which is widely understood as an ecosystem service *par excellence*, as an ecosystem function or process. To that end, we find it necessary to add a category, which we name ‘(intermediate) ecosystem services’, denoting the processes involving biotic features of the environment that produce FEGS and benefits. In awareness-raising context, it is also important to allow for multiple perspectives and therefore a too rigid framework can be constraining.

At the same time, our analysis shows that ecosystem functions are hard to distinguish, which is why we have dropped the category ‘function’ from our model. In the original cascade model (see Figure 1), harvestable products such as timber are ‘services’, biomass is a ‘function’ and ‘woodland habitat or net primary production’ are grouped together as ‘biophysical structures and processes’. However, we find it analytically clearer to separate structures (i.e. biotic and abiotic attributes, which constitute the biophysical structure) and processes (i.e. interactions between these attributes) (see Harrington et al. 2010), which in our model are ‘boreal forest habitats’ (structure) and ‘decomposition’ and ‘nutrient uptake’ (processes). Together with the new category ‘intermediate services’ the model would have become very complex, and the category ‘functions’ somewhat superfluous. Furthermore, as Jax (2005, 2015) states, the term ‘function’ is used with several different meanings within the environmental sciences, and these ambiguities do not serve operational clarity. Again we must be clear that operational clarity required is defined by the decision context in which we are operating. For example, in the context of experimental ecosystem accounting, Schröter et al.(2014) use physical indicators of ecosystem function which they term “capacity” , distinguished from “flow” which represent “ecosystem services” as they are actually utilized.

"The cascade model has sometimes been perceived as defining values quite narrowly as mainly referring to the economic value of the benefits. Potschin and Haines-Young (2011) in their graph of the cascade, for instance, provide as the main example illustrating value "willingness to pay for ...". However, as Chan et al. (2012) have pointed out, values are the preferences, principles and virtues that we (up)hold as individuals or groups, and draw upon when making evaluative statements and preference orderings of services or benefits, that is, producing valuation outputs (e.g. economic value of clean water). The conceptual conflations result from the fact that researchers have not always separated the value of an object (e.g. value of biodiversity or individual species) from human values (e.g. egocentric values or market values), which determine the value ascribed to an object. Therefore, in our analysis we have redefined the category ‘values’ as ‘valuation outputs’, which are “evaluative statements referring to the importance and meanings of benefits for evaluators” (see Klain et al. 2014)[6]. The ecosystem service framework can capture non-anthropocentric values because valuators—people—can assign value to non-human objects irrespective of their instrumental value (Jax et al. 2013). However, it is fully anthropogenic because it assumes a conscious valuator and hence rules out intrinsic value in a strict sense[7] (Davidson 2013).

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[6] Klain et al. (2014) define values as “preferences, principles and virtues that are evaluative statements referring to both benefits and services”. However, this definition equates values with evaluative statements whereas Chan et al. (2012) point out that values are ubiquitous and pertain to human preferences, principles and virtues, upon which people draw when reaching valuation outputs. Furthermore, we find that services will be valuated through the benefits they create; mentioning both benefits and services will reintroduce the risk of double-counting.

[7] Intrinsic value refers to value that resides in the object in itself, independent of an external valuator (Partridge 1986)

We have also added a category ‘human well-being’ to the Cascade Model to illustrate the fact that ecosystem services contribute to several aspects of personal and social functioning such as mental and physical health or good social relations that need to be considered in valuation; they are the underlying reasons why certain services are important. The concept of human well-being, which is prominent in the MA framework, is not an explicit category in many frameworks (neither in the cascade model nor in de Groot et al. 2002 and Chan et al. 2012). The TEEB sees human well-being as providing the context for including benefits and values into the framework and defines it (following the MA) principally in terms of a list of its assumed components, namely: “A context- and situation-dependent state, comprising basic material for a good life, freedom and choice, health and bodily well-being, good social relations, security, peace of mind, and spiritual experience” (TEEB 2010, p. xxxv). A useful and more generic definition taken from an intense debate about human well-being in philosophy and development research is the understanding of human well-being as a state that is “intrinsically and not just instrumentally valuable” (or good) for a person or a societal group (Alexandrova 2012, p. 697). The aspects listed in our model are just examples of human well-being dimensions (see e.g. Polishchuk and Rauschmayer 2012, Summers et al. 2012). Further research is needed to specify the links between ecosystem services and human well-being.

We find the set of operational questions by Johnston and Russell (2011) helpful for identifying final ecosystem services and hence bringing operational clarity to ecosystem service classification in the boreal forest example. However, our cascade example also draws attention to some problems with Johnston and Russell’s (2011) set of rules. The first rule stipulates that for biophysical outcome h to serve as an ecosystem service for beneficiary j, changes in h must influence the welfare of beneficiary j, so that fully informed, rational beneficiary j would be willing to pay for increases in h rather than go without. Changes in forest landscape influence the welfare of multiple beneficiaries but not all of them are necessarily willing to pay for the benefits. It is easy to calculate willingness to pay for ecotourism and it is also relatively straightforward to estimate people’s willingness to pay for recreational activities on the basis of similar commercial services. However, most people do not conceive, for instance, spiritual experiences and sense of place and identity in monetary terms, and can be offended about the idea that deeply held beliefs or moral and cultural values were treated as commodities (Gomez-Baggethun and Ruiz-Peres 2011). The problems with monetizing ecosystem services are discussed widely (see e.g. Jax et al. 2013) and alternative ways of assessing the importance of ecosystem services are explored (e.g. Vatn 2009, Spangenberg and Settele 2010, Chan et al. 2012). The rule can be modified by adding “willing to pay, *or otherwise assign value*, for increases in h”.

The second rule of Johnston and Russell (2011) stipulates that for biophysical outcome h to serve as an ecosystem service for beneficiary j, h must represent the output of an ecological system prior to any combination with human labour, capital or technology. This rule basically excludes landscapes such as nature parks with man-made structures like paths and resting places, which makes the landscape more accessible. Separating the value of the landscape, the actual ecosystem, from the built infrastructure in valuation studies can be very difficult. Furthermore, cultural services such as cultural landscapes are the outcome of complex and dynamic relationships between ecosystems and humans (Fagerholm et al. 2012). The second condition also rules out timber because timber production often, though not necessarily, involves silvicultural activities. Given the widespread human influence on ecosystems, we opt for the CICES approach, which defines ecosystem services as the direct contributions that ecosystems—whether natural or semi-natural—make to human well-being. As environmental historian William Cronon (1991, p. 19) stated, "Just as our own lives continue to be embedded in a web of natural relationships, nothing in nature remains untouched by the web of human relationships that constitute our common history".

5. Concluding remarks

The starting point of this paper was the conceptual confusion related to the terms 'ecosystem services', 'benefits', 'functions' and 'values' and their inter-relationship. We explored alternative definitions and conceptualizations in the context of a concrete example—boreal forest ecosystems in Finland—in order to propose an operational typology of ecosystem services.

We found the notion of FEGS operable, particularly in priority setting contexts where it is important to define explicitly the outputs to be valued to avoid double counting. In our model, FEGSs are good quality surface water, timber and fibre, game and wild berries, reduction of atmospheric carbon, and forest landscapes. These are ecosystem outputs that retain a direct connection to the underlying processes and structures that generate them, and are valued by beneficiaries even if all ecosystem output and conditions are held constant.

The benefits in this case are products and experiences linked to the FEGS such as potable water, forest owner income and a range of cultural benefits such as recreation, scenic beauty and sense of place and identity. The MA and several studies following it regard these latter categories as cultural ecosystem services. However, based on our analysis, we find it important to distinguish between ecosystem attributes (e.g. landscapes) that give rise to human experiences, and the experiences (e.g. recreation and appreciation of scenic beauty) themselves. The latter are dependent on the social context in which they are used and are subject to change, like landscape preferences.

We found the cascade model category 'functions' analytically ambiguous for application in the boreal forest example . Instead, we added a category 'intermediate ecosystem services' to denote services such as biomass production, carbon sequestration and pollination, which underpin the provision of FEGS. Furthermore, pollination and carbon sequestration are widely regarded as ecosystem services *par excellence*, and therefore we wanted to retain the term (intermediate) ecosystem services for awareness raising purposes. We also divided the category 'biophysical structure or process' into 'biophysical structures' and 'processes' to separate the ecosystem service providers and their biotic and abiotic attributes, which constitute the biophysical structure, from the ecological processes, which represent the interactions between these attributes.

We also renamed the category ‘values’ as ‘valuation outputs’, and followed Klain et al. (2014) by defining them as ‘evaluative statements referring to the importance and meaning of benefits for evaluators‘, and not simply ‘willingness to pay’. Here, we agree with Chan et al. (2012) that there is not a straightforward link between the flow of ecosystem services and their (monetary) value as ‘production function’ approaches to ecosystem services seem to assume; instead, people attach importance and meaning to ecosystem services depending on their value systems, and monetary units are just one expression of value, namely commercial or exchange value. Finally, we added the category ‘aspects of human well-being’ to serve as a reminder of the underlying reasons of why ecosystem services are valuable. In this sense our conceptual framework recognizes conceptual plurality of different research traditions. Disaggregating ‘ecosystem services’ into different categories with a determined causal structure also means that the framework is challenging as a tool for public awareness-raising. Our discussion has illustrated how ‘operational’ definitions of ecosystem services depend on the context in which the framework and definitions are meant to operate.

This desk-study exercise, which was based on document analysis and previous case study examples, could be developed further by identifying beneficiaries and the benefits they derive from ecosystem services in a real-life case study focused on a certain time and place, and allowing the beneficiaries themselves to identify the ecosystem attributes from which they benefit (see e.g. Landers and Nahlik 2013). This would create a more nuanced understanding of the various ways in which people make use and benefit from forest ecosystems.

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Table 1. Cultural ecosystem services listed by different sources.

MA	**CICES V4.3**	**Coniferous forests elsewhere** (Clement & Cheng 2011; van Riper et al. 2012; Sherrouse et al. 2014)	**Boreal forests in Finland** (Vihervaara et al. 2011[1], Kettunen et al. 2012)
Cultural diversity: diversity of ecosystems is one factor contributing to the diversity of cultures			Local and Sami culture[1]
Spiritual services: recognizing that many religions attach spiritual and religious values to ecosystems or their components	Sacred and/or religious	**Spiritual**: I value these Forests because they are sacred, religious, or spiritually special place to me or because I feel reverence and special respect for nature there	Cultural and spiritual values, identity and experience[2]
Knowledge systems, traditional and formal: appreciating that ecosystems influence the types of knowledge systems developed by different cultures	Scientific		
Educational values: understanding that ecosystems and their components and processes provide the basis for both formal and informal education in many societies	Educational	**Learning:** I value these Forests because we can learn about the environment through scientific observation and experimentation	Education and research (information for) (i.e. cognitive development)[2]
Inspiration: In a sense that ecosystems provide a rich source of inspiration for art, folklore, national symbols, architecture, and advertising	Symbolic, entertainment		Art, design and culture[2]
Aesthetic values: many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, scenic drives, and the selection of housing locations	Aesthetic	**Aesthetic:** I value these Forests because I enjoy the scenery, sights, sounds, smells etc.	Aesthetic landscape[1], aesthetic values and information[2]
Social relations: in the sense that ecosystems influence the types of social relations that are established in particular cultures			
Sense of place and identity: ecosystems as a central pillar of the 'sense of place' that is			Cultural and spiritual values, identity and experience: Nordic values and identity,

associated with recognized features of their environment			Sami culture's values and identity[2]
Cultural heritage values: understanding that many societies place high value on the maintenance of either historically important landscapes ('cultural landscapes') or culturally significant sites	Heritage, cultural	**Cultural**: I value these Forests because they are a place for me to continue and pass down the wisdom and knowledge, traditions and way of life of my ancestors	
		Historic: I value these Forests because they have places and things of natural and human history that matter to me, others and the nation	
Recreation and ecotourism: recognizing that people often choose where to spend their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area	Experiential and physical use of plants, animals and land-/seascapes in different environmental setting	**Recreation**: I value these Forests because they provide a place for my favorite outdoor recreation activities	Recreation[1,2] and tourism[2] : outdoor activities (hiking, running, skiing etc.), hunting, fishing, berry and mushroom picking
		Therapeutic: I value these Forests because they make me feel better, physically and/or mentally	Mental wellbeing and health: stress and related problems and illnesses (reduction of)[2]
		Biodiversity: I value these Forests because they provide a variety of fish, wildlife, plant life, etc.	
	Existence	**Intrinsic:** I value these Forests in and of themselves, whether people are present or not	Intrinsic value of nature and biodiversity[1]
	Bequest	**Future**: I value these Forests because they allow future generations to know and experience the Forests as they are now	

Table 2. Regulating services listed by different sources.

MA	**CICES V4.3**	**Boreal Forest in Nordic countries (Kettunen et al. 2014)**	**Boreal forests in Finland (Matero et al. (2003)[1]; Vihervaara et al. (2010)[2]**
Air quality maintenance Ecosystems both contribute chemicals to and extract chemicals from the atmosphere, influencing many aspects of air quality.	**Bio-remediation by micro-organisms, algae, plants, and animals** **Ventilation and transpiration** **Dilution by atmosphere, freshwater and marine ecosystems** **Filtration/sequestration/ storage/accumulation by micro-organisms, algae, plants, and animals, and ecosystems** **Mediation of smell/noise/visual impacts**	**Air quality regulation**	**Air quality[1]** Filtration of air borne particles
Climate regulation Ecosystems influence climate both locally and globally. For example, at a local scale, changes in land cover can affect both temperature and precipitation. At the global scale, ecosystems play an important role in climate by either sequestering or emitting greenhouse gases.	**Global climate regulation by reduction of greenhouse gas concentrations** **Micro and regional climate regulation**	**Climate: carbon storage and sequestration** **Climate: climate patterns (local and regional)**	**Climate regulation** (mitigation of climate change**)** [1] **Local and regional climate regulation[1,2]** **Carbon sequestration and storage[2]**
Water regulation The timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes in land cover, including, in particular, alterations that change the water storage potential of the system, such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.	**Hydrological cycle and water flow maintenance** **Flood protection**	**Water and water flow: drainage and stabilization of water flow, drought mitigation, irrigation, aquifer recharge**	**Water regulation (**hydropower production**)[1]** **Flood prevention[1,2]**
Erosion control Vegetative cover plays an important role in soil retention and the prevention of landslides.	**Mass stabilization and control of erosion rates** **Buffering and attenuation of mass flows**	**Erosion**	**Soil retention/erosion prevention[1]** **Erosion prevention[2]**
Water purification and waste treatment Ecosystems can be a source of impurities in fresh water but also can help to filter out and decompose organic wastes introduced into inland waters and coastal and marine ecosystems.	**Dilution by atmosphere, freshwater and marine ecosystems** **Bio-remediation by micro-organisms, algae, plants, and animals** **Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals, and by ecosystems**	**Water purification and waste treatment**	**Water availability[1]** Drinking water and industrial use of water **Nutrient sequestration[2]** **Waste treatment[1]** Organisms ability to remove and dissolve harmful nutrients and compounds (recycling of organic waste, absorbing nitrogen and phosphorous fallout)
	Water conditions: Chemical condition of freshwaters and salt waters		

Regulation of human diseases Changes in ecosystems can directly change the abundance of human pathogens, such as cholera, and can alter the abundance of disease vectors, such as mosquitoes.	**Disease control**	**Biological control: disease and pathogen control**	
Biological control Ecosystem changes affect the prevalence of crop and livestock pests and diseases.	**Pest control**	**Biological control: Pest control**	**Biological control**[1] Regulation of pest populations
Pollination Ecosystem changes affect the distribution, abundance, and effectiveness of pollinators.	**Pollination and seed dispersal** **Maintaining nursery populations and habitats**	**Pollination**	**Pollination**[1,2]
Storm protection The presence of coastal ecosystems such as mangroves and coral reefs can dramatically reduce the damage caused by hurricanes or large waves.	**Storm protection**	**Natural hazards: storm protection, avalanche prevention, mud flows/floods**	**Storm protection**[1] **Prevention of avalanches**[1]
		Soil fertility (maintenance of)	
	Weathering processes		
	Decomposition and fixing processes		

Table 3. Provisioning services listed by different sources.

MA	**CICES V4.3**[1]	**Boreal Forest in Nordic countries (Kettunen et al. 2014)**	**Matero et al. (2003)**[1]**; Vihervaara et al. (2010)**[2]
Food and fibre. This includes the vast range of food products derived from plants, animals, and microbes, as well as materials such as wood, jute, hemp, silk, and many other products derived from ecosystems	**Reared animals and their outputs** **Wild plants, algae and their outputs** **Wild animals and their outputs** **Fibres and other materials from plants, algae and animals for direct use or processing**	**Reindeer herding, fishing (fresh waters), game, berries (non-cultivated), mushroom (non-cultivated), timber and fibre for pulp production**	**Nutrition**[1] Transformation of solar energy to edible plants and animals **Food**[2] (Reindeer, Game, Berries and mushrooms) **Fodder**[2] (lichen) **Wood**[2] (Material for pulp and sawmills, firewood)
Fuel. Wood, dung, and other biological materials serve as sources of energy.	**Plant-based resources** **Animal-based resources**	**Energy: fuel wood and other bioenergy**	**(Raw) materials**[1] Transformation of solar energy to biomass (e.g. timber, energy wood, fodder) **Energy**[2] (Falling waste and hydropower potential)
Genetic resources. This includes the genes and genetic information used for animal and plant breeding and biotechnology.	**Genetic materials from all biota**	**Genetic resources**	**Genetic resources**[1,2] Genetic material evolution of organisms
Biochemicals, natural medicines, and pharmaceuticals. Many medicines, biocides, food additives such as alginates, and biological materials are derived from ecosystems.	**Plant-based resources**	**Medicinal products, natural food supplements and "health/super" foods, cosmetics, biochemicals/ pharmaceuticals, non-medicinal biochemicals**	**Natural medicines**[1,2] Diversity of chemical compounds
Ornamental resources. Animal products, such as skins and shells, and flowers are used as ornaments, although the value of these resources is often culturally determined. This is an example of linkages between the categories of ecosystem services.	**Plant-based resources**	**Ornamental resources: traditional handicraft, fashion and jewellery, natural dyes and colorants, decorative plants**	**Ornamental resources**[1] Elements that have ornamental value
Fresh water. Fresh water is another example of linkages between categories - in this case, between provisioning and regulating services.	**Surface water for drinking** **Ground water for drinking** **Surface water for non-drinking purposes** **Ground water for non-drinking purposes**	**Fresh water: drinking and potable water, water for other types of human consumption**	**Drinking water**[2]

[1] Non-forest related provisioning services such as plants and algae from in-situ aquaculture are removed from the table