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Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making

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ABSTRACT

Despite the growing body of literature on ecosystem services, still many challenges remain to structurally integrate ecosystem services in landscape planning, management and design. This paper therefore aims to provide an overview of the challenges involved in applying ecosystem service assessment and valuation to environmental management and discuss some solutions to come to a comprehensive and practical framework.

First the issue of defining and classifying ecosystem services is discussed followed by approaches to quantify and value ecosystem services. The main part of the paper is focussed on the question how to analyze trade-offs involved in land cover and land use change, including spatial analysis and dynamic modelling tools. Issues of scale are addressed, as well as the question how to determine the total economic value of different management states.

Finally, developments and challenges regarding the inclusion of ecosystem services in integrative landscape planning and decision-making tools are discussed.

It is concluded that the ecosystem service approach and ecosystem service valuation efforts have changed the terms of discussion on nature conservation, natural resource management, and other areas of public policy. It is now widely recognized that nature conservation and conservation management strategies do not necessarily pose a trade-off between the "environment" and "development". Investments in conservation, restoration and sustainable ecosystem use are increasingly seen as a "win-win situation" which generates substantial ecological, social and economic benefits.

1. Introduction

There is a growing interest in the science of ecosystem and landscape functions and services and especially since the release of the Millennium Ecosystem Assessment (MA, 2005) the number of publications has increased strongly (Fisher et al., 2009). However, many issues still remain to be resolved to fully integrate the concept of (ecosystem) services into everyday landscape planning, management and decision-making.

At the landscape level, the main challenge is how to decide on the optimal allocation and management of the many different land use options. Landscape functions (and services) have become an important concept in policy making, as decision makers have to deal with an explicit demand for landscape services from a broad range of stakeholders (FAO, 1999; OECD, 2001; Hollander, 2004; Wilson, 2004; Bills and Gross, 2005; Hein et al., 2006). However, landscape services are still lacking in most policy support tools (Pinto-Correia et al., 2006; Vejre et al., 2007), and current landscape models mostly deal with either land cover patterns (Geertman and Stillwell, 2004; Verburg et al., 2004) or are strongly sector-oriented (Heilig, 2003; Meyer and Grabaum, 2008).

In the literature many challenges and obstacles are described that still need to be addressed, some of the most mentioned are listed in Box 1.

A substantial research effort is currently deployed, nationally and internationally on ecosystem services (e.g. TEEB, EEA/MA 2015, DIVERSITAS, QUEST, RUBICODE, SENSOR—see for an inventory and hyperlinks: www.naturevaluation.org).

Most of these research programs, however, are targeted at one or a few aspects of the above listed questions. A coherent and integrated approach to come to practical application of the concept of ecosystem and landscape functions in planning, management and decision-making is still lacking (ICSU et al., 2008).

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Box 1. Main research questions in need to be resolved in order to better integrate ecosystem services in landscape planning, management and decision-making (*).

a. *Understanding and quantifying how ecosystems provide services*

(1) What is the state-of-the art regarding the typology of ecosystem services?
(2) How can the relationship between landscape and ecosystem characteristics and their associated functions and services be quantified?
(3) What are the main indicators and benchmark-values for measuring the capacity of an ecosystem to provide services (and what are maximum sustainable use levels)?
(4) How can ecosystem/landscape functions and services be spatially defined (mapped) and visualized?
(5) How can relationships between ecosystem and landscape character and services, and their relevant dynamic interactions, be modelled?
(6) What is the effect of (changes in) dynamic conditions (temporal and spatial) of landscape functions on services, in terms of sustainability and resilience? Are there possible critical thresholds?

b. *Valuing ecosystem services*

(7) What are the most appropriate economic and social valuation methods for ecosystem and landscape services, including the role and perceptions of stakeholders?
(8) How to make economic and social valuation of landscape and ecosystem services consistent and comparable?
(9) What is the influence of scaling-issues on the economic value of ecosystem and landscape services to society?
(10) How can standardized indicators (benchmark-values) help to determine the value of ecosystem services and how can aggregation steps be dealt with?
(11) How can values (ecological, social and economic) be mapped to facilitate the use of ecosystem services in (spatial) landscape planning and design?

c. *Use of ecosystem services in trade-off analysis and decision making*

(12) How can all the costs and benefits (ecological, socio-cultural and economic) of changes in ecosystem services and values of all stakeholders (in time and space), be taken into account properly in discounting and cost-effectiveness issues?
(13) How can analytical and participatory methods be combined to enable effective participatory policy and decision making dialogues?
(14) How can spatial and dynamic ecosystem services modelling be linked to participatory trade-off assessment methods to optimize multi-functional use of the ''green and blue space''?
(15) How can landscape design-alternatives be visualized and made accessible for decision-making, e.g. through expert systems and other decision and policy support tools?

d. *Use of ecosystem services in Planning and Management*

(16) How to incorporate resilience of landscape functions, and thresholds of service-use, into methods for landscape planning, design and management of 'green and blue space'?
(17) What are the main bottlenecks in data availability and reliability with regard to ecosystem services management and how can they be overcome?
(18) What is the relationship between ecosystem management state and the provision of ecosystem services (both on individual services and the total mix of ecosystem services)?

e. *Financing sustainable use of ecosystem services*

(19) What is the adequacy of current financing methods for investing in ecosystem and landscape services? How can they be improved (and linked to valuation-outcomes)?
(20) How to communicate ecosystem and landscape services, and their social and economic importance, to all stakeholders.

Source (among others): ICSU et al. (2008), MA (2003, 2005), EC (2008), Verburg et al. (2009).
*Note that the terms functions and services are used both in relation to ecosystems and landscapes; in the view of the authors of this paper there is not a principle difference between ecosystem and landscape functions or services but mainly a matter of scale. But this is still subject of debate.

A research program that aims to tackle these questions in an integrated manner was started in 2006 by Wageningen University and Research Centre (WUR) under the name of SELS (=Speerpunt Ecosystem & Landscape Services) which has developed a coherent framework linking ecosystem and landscape character to services (Theme 1), values (Theme 2), trade-off instruments (Theme 3), planning tools (Theme 4) and financing mechanisms (Theme 5) (see Fig. 1 and www.ecosystemservices.nl).

The following sections of this paper will give a very brief state-of-the-art of ecosystem service assessment and discuss the main challenges and opportunities for improving both the science and practical applications.

2. Developing a conceptual framework for ecosystem service assessment

This section mainly addresses research question 1 (see Box 1): "What is the state-of-the art regarding the typology of ecosystem services?" The concept of ecosystem services dates back at least to the 1970s but gained momentum in the scientific literature in the 1990s (e.g. De Groot, 1992; Costanza et al., 1997; Daily, 1997). The concept was mainstreamed by the Millennium Ecosystem Assessment (MA, 2003, 2005) which distinguished provisioning, regulating, cultural and supporting services (see Table 1) and since then efforts to put the concept into practice have increased strongly (e.g. Daily and Matson, 2008; Tallis et al., 2008). Yet, there is still much debate about how best to define the distinction between ecosystem functions and services, and how to classify the services in order to make them quantifiable in a consistent manner (e.g. Wallace, 2007; Fisher et al., 2009). One of the follow-up activities of the Millennium Ecosystem Assessment is the TEEB-project (The Economics of Ecosystems and Biodiversity (European Communities, 2008)[1]) and consensus is growing to use the following framework for linking ecosystems to human wellbeing (Fig. 2).

As the figure depicts, ecosystem services are generated by ecosystem functions which in turn are underpinned by biophysical

[1] Following the G8 countries meeting in Potsdam in March 2007, the German government proposed a study on 'The Economics of Ecosystems & Biodiversity to address some the challenges in ecosystem services research and implementation. TEEB will analyze the global economic benefit of biological diversity, the costs of the loss of biodiversity and the failure to take protective measures versus the costs of effective conservation and sustainable use. TEEB will facilitate the development of cost-effective policy responses, notably by preparing a 'valuation toolkit', and the final results will be presented at CBD COP-10 in 2010.

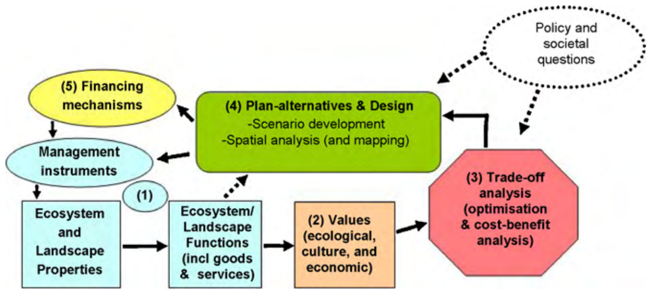

Fig. 1. Framework for integrated assessment of ecosystem and landscape services. (1)–(5): Themes addressed in the research program on Ecosystem and Landscape Services, Wageningen University (www.ecosystemservices.nl): (1) Understanding and quantifying how ecosystems provide services. (2) Valuing ecosystem services. (3) Use of ecosystem services in trade-off analysis and decision making. (4) Use of ecosystem services in Planning and Management. (5)Financing sustainable use of ecosystem services.

structures and processes called "supporting services" by the Millennium Ecosystem Assessment (MA, 2005) (see Table 1 for details). Ecosystem functions are thus intermediate between ecosystem processes and services and can be defined as the "capacity of ecosystems to provide goods and services that satisfy human needs, directly and indirectly" (De Groot, 1992). Actual use of a good or service provides benefits (nutrition, health, pleasure, etc.) which in turn can be valued in economic terms and monetary terms. Although the overall structure of this "cascade" is generally accepted, the distinction between "function", "service" and "benefit" is still debated. Balmford et al. (2008), for example, use the terms "Core Ecosystem Process (e.g. production, decomposition, nutrient & water cycling), "Beneficial Ecosystem Process" (e.g. biomass prod., pollination, biological control, habitat and waste assimilation), and "Benefit" (e.g. food, fresh water, raw materials, energy and wellbeing).

Other discussion points are the place of biodiversity in the framework, how to distinguish ecosystem from landscape functions and services, how to value services provided from natural versus cultivated systems (e.g. fish from the ocean versus fish from aquaculture), and the notion of Land Use Function (Perez-Soba et al., 2008) or "Land Function" (Bakker and Veldkamp, 2008; Verburg et al., 2009) which combines functions, services and benefits.

3. Quantifying the capacity of ecosystems and landscapes to provide goods and services

The quantitative relationship between biodiversity, ecosystem components and processes and services is still poorly understood. The specific nature of interdependencies between the structure and diversity of biotic communities and the functioning of ecosystems remains one of the most important unresolved questions in ecology (ICSU et al., 2008). Criteria and indicators are needed to comprehensively describe the interaction between the ecological processes and components of an ecosystem and their services (see Table 1 for examples).

Two main types of indicators are needed: (1) state indicators describing what ecosystem process or component is providing the service and how much (e.g. total biomass or leaf area index) and (2) performance indicators describing how much of the service can potentially be used in a sustainable way (e.g. maximum sustainable harvest of biomass or the effect of LAI on air-quality).

In Box 1, there are several main questions ("challenges") listed regarding quantifying the relationship between ecosystem components and processes and services (questions 2, 3, and 6). These questions are explicitly addressed by the TEEB-II project (TEEB, 2008). Other interesting initiatives are the RUBICODE-project which introduced the concept of Service Providing Unit (SPU) to make the link between ecosystem character and service more explicit and Ruijgrok (2006), made a thorough attempt to design a list of benchmark-values for the main ecosystem-types and their services in the Netherlands.

4. Valuing ecosystem services

The importance ("value") of ecosystems and their services can be expressed in different ways. Basically, there are three value-domains ecological, socio-cultural and economic (MA, 2003).

The ecological value encompasses the health state of a system, measured with ecological indicators such as diversity and integrity, while socio-cultural values include the importance people give to, for example, the cultural identity and the degree to which that is related to ecosystem services.

Economic literature recognizes two broad kinds of values: use values and non-use value. Use values encompass direct consumptive use values such as the value of timber, fish or other resources that ecosystems provide, and direct, non-consumptive use values such as those related to recreation and aesthetic appreciation. Indirect use values relate to the services provided by nature such as air- and water-purification, erosion prevention and pollination of crops. Non-use value is the importance attributed to an aspect of the environment in addition to, or irrespective of its use values. In essence, it can be understood as the value attributed to the simple existence of the "object" (i.e. its existence value) sometimes also referred to as "insurance value" or "glue" value (Turner et al., 2003). A type of value in between use and non use is the notion of option value: the value we place on keeping the option open to use ecosystem services in the future, either within our own life time, or for future generations (in the latter case this is called bequest value).

The sum total of use and non-use values associated with a resource or an aspect of the environment is called Total Economic Value (TEV).

If we are interested in economic values only, the measurement unit will usually be money (see Box 2) whereby it is important to realize that economic and esp. monetary valuation will always capture only part of the "true" or total value (which should also include ecological and socio-cultural values) of an ecosystem or service. Table 2 gives an overview of the many analytical and participatory techniques available to value (i.e. measure preferences for) ecosystem services.

A number of ways exist to translate economic and some socio-cultural values of ecosystem services into monetary values. Market prices (marginal values) exist for many ecosystem services, especially the provisioning services such as timber and non-timber forest products. Values of other services are often also expressed through the market but in an indirect way which can be measured through, for example, (avoided) damage cost methods (for regulating services), and hedonic pricing and travel cost methods for some cultural services such as aesthetically pleasing landscapes. Contingent valuation (i.e. measuring preferences based on questionnaires) and benefit transfer (i.e. using data from comparable studies) provide yet other alternatives. See also Table 2 for an overview.

Each of these methods has their advantages and disadvantages (De Groot, 2006) and although the knowledge base on the monetary value of individual services is improving, there are still large data gaps and there is still a need for better frameworks, models and data-bases to calculate the TEV of entire ecosystems and the bundle of services they provide, as expressed through Question 7–11 in Box 1 (see also Section 5).

Table 1
Potential indicators for determining (sustainable) use of ecosystem services.

	Services comments and examples	Ecological process and/or component providing the service (or influencing its availability) = functions	State indicator (how much of the service is present)	Performance indicator (how much can be used/provided in sustainable way)
Provisioning				
1	*Food*	Presence of edible plants and animals	Total or average stock in kg/ha	Net Productivity (in kcal/ha/year or other unit)
2	*Water*	Presence of water reservoirs	Total amount of water (m^3/ha)	Max sust. water-extraction (m^3/ha/year)
3	*Fiber & Fuel & other raw materials*	Presence of species or abiotic components with potential use for timber, fuel or raw material	Total biomass (kg/ha)	Net productivity (kg/ha/year)
4	*Genetic Materials*: genes for resistance to plant pathogens	Presence of species with (potentially) useful genetic material	Total "gene bank" value (e.g. number of species & sub-species)	Maximum sustainable harvest
5	*Biochemical products and medicinal resources*	Presence of species or abiotic components with potentially useful chemicals and/or medicinal use	Total amount of useful substances that can be extracted (kg/ha)	Maximum sustainable harvest (in unit mass/area/time)
6	*Ornamental species and/or resources*	Presence of species or abiotic resources with ornamental use	Total biomass (kg/ha)	Maximum sustainable harvest
Regulating				
7	*Air quality regulation*: (e.g. capturing dust particles)	Capacity of ecosystems to extract aerosols & chemicals from the atmosphere	Leaf area index NOx-fixation, etc.	Amount of aerosols or chemicals "extracted"—effect on air quality
8	*Climate Regulation*	Influence of ecosystems on local and global climate through land-cover and biologically-mediated processes	Greenhouse gas-balance (esp. C-sequestration); Land cover characteristics, etc.	Quantity of Greenhouse gases, etc. fixed and/or emitted → effect on climate parameters
9	*Natural Hazard mitigation*	Role of forests in dampening extreme events (e.g. protection against flood damage)	Water-storage (buffer) capacity in m^3	Reduction of flood-danger and prevented damage to infrastructure
10	*Water regulation*	Role of forests in water infiltration and gradual release of water	Water retention capacity in soils, etc. or at the surface	Quantity of water retention and influence of hydro-logical regime (e.g. irrigation)
11	*Waste treatment*	Role of biota and abiotic processes in removal or breakdown of organic matter, xenic nutrients and compounds	Denitrification (kg N/ha/y); Immobilization in plants and soil	Max amount of chemicals that can be recycled or immobilized on a sustainable basis.
12	*Erosion protection*	Role of vegetation and biota in soil retention	Vegetation cover Root-matrix	Amount of soil retained or sediment captured
13	*Soil formation and regeneration*	Role of natural processes in soil formation and regeneration	E.g. bio-turbation	Amount of topsoil (re)generated per ha/year
14	*Pollination*	Abundance and effectiveness of pollinators	Number & impact of pollinating species	Dependence of crops on natural pollination
15	*Biological Regulation*	Control of pest populations through trophic relations	Number & impact of pest-control species	Reduction of human diseases, live-stock pests, etc.
Habitat or supporting				
16	*Nursery habitat*	Importance of ecosystems to provide breeding, feeding or resting habitat for transient species	Number of transient species & individuals (esp. with commercial value)	Dependence of other ecosystems (or "economies") on nursery service
17	*Genepool protection*	Maintenance of a given ecological balance and evolutionary processes	Natural biodiversity (esp. endemic species); Habitat integrity (irt min. critical size)	"Ecological Value" (i.e. difference between actual and potential biodiversity value)
Cultural & amenity				
18	*Aesthetic*: appreciation of natural scenery (other than through deliberate recreational activities)	Aesthetic quality of the landscape, based on e.g. structural diversity, "greenness", tranquility	Number/area of landscape features with stated appreciation	Expressed aesthetic value, e.g.: Number of houses bordering natural areas # users of "scenic routes"
19	*Recreational*: opportunities for tourism and recreational activities	Landscape-features Attractive wildlife	Number/area of landscape & wildlife features with stated recreational value	Maximum sustainable number of people & facilities Actual use
20	*Inspiration for culture, art and design*	Landscape features or species with inspirational value to human arts, etc.	Number/area of Landscape features or species with inspirational value	#books, paintings, etc. using ecosystems as inspiration
21	*Cultural heritage and identity*: sense of place and belonging	Culturally important landscape features or species	Number/area of culturally important landscape features or species	Number of people "using" forests for cultural heritage and identity
22	*Spiritual & religious inspiration*	Landscape features or species with spiritual & religious value	Presence of Landscape features or species with spiritual value	Number of people who attach spiritual or religious significance to ecosystems

Table 1 (*Continued*)

	Services comments and examples	Ecological process and/or component providing the service (or influencing its availability) = functions	State indicator (how much of the service is present)	Performance indicator (how much can be used/provided in sustainable way)
23	*Education & science* opportunities for formal and informal education & training	Features with special educational and scientific value/interest	Presence of features with special educational and scientific value/interest	Number of classes visiting Number of scientific studies, etc.

(1) The main difference with the MEA is that supporting (of Habitat) services are limited to the nursery and genepool function and that biodiversity is not recognized as a separate service.
Source: adapted from MA (2005) (1, and De Groot, 2006).

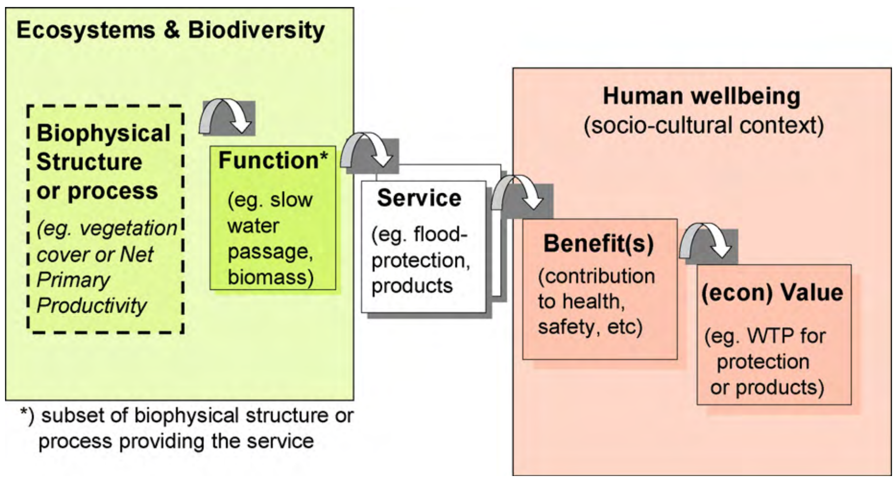

Fig. 2. Framework for linking ecosystems to human wellbeing (adapted from Haines-Young and Potschin, in press).

5. Linking ecosystem management states to the total bundle of ecosystem services

Most ecosystems on earth have been converted to another type of land cover which can be characterized by its management, or land use type (see Fig. 3). Management systems differ in their way people extract goods, in the level of production, in the intended and unintended provision of services and in the level and quality of biodiversity (see Table 3). Land use and management influence the system properties, processes and components that are the basis of service provision. A change in land use or management will therefore cause a change in service supply, not only for specific services but for the complete bundle of services provided by that (eco)system.

Box 2. Modelling ecosystem services and environmental change: IMAGE and GLOBIO.

The IMAGE 2.4 framework of models, including the GLOBIO model provides a global methodology to do so. The framework describes simultaneous changes in climate, pollution, land use and biodiversity expected from changes in socio-economic developments derived from prognoses on demography and economic growth (MNP, 2006; Alkemade et al., 2009).
GLOBIO3 describes biodiversity as the remaining Mean Species Abundance (MSA) of original species, relative to their abundance in pristine or primary vegetation, which are assumed to be not disturbed by human activities for a prolonged period. MSA is similar to the Biodiversity Integrity Index (Majer and Beeston, 1996), the Biodiversity Intactness Index (Scholes and Biggs, 2005), and the Living Planet Index (LPI, Loh et al., 2005).

To make better decisions regarding trade-offs involved in land cover and land use change, a systematic account of the relationships between ecosystem management and the ecosystem services and values that it generates, is needed. Empirical information on the quantitative relationship between land use and ecosystem management and the provision of ecosystem services at the local and regional scale is, however, still scarce and "to date, there appear to be no examples of complete landscape-scale assessments of the quantity, quality and value of an entire bundle of ecosystem services under alternative management regimes" (ICSU et al., 2008, p. 37).

Increased research effort is needed on quantifying the capacity of various land-cover types, and associated manage-

Table 2
Economic and non-economic techniques available to value biodiversity.

Economic techniques	Non-economic techniques
Market price approaches	Consultative methods:
Market cost approaches	Questionnaires
Replacement costs approaches	In-depth interviews
Damage cost avoided approaches	Deliberative and participatory approaches:
Production function approaches	Focus groups, in-depth groups
Revealed preference methods	Citizen juries
Travel cost method	Health-based valuation approaches
Hedonic pricing method	Q-methodology
Stated preference methods	Delphi surveys
Choice modelling	Rapid rural appraisal
Contingent valuation	Participatory rural appraisal
Participatory approaches to valuation	Participatory action research
Deliberative valuation	Methods for reviewing information:
Mediated modelling	Systematic reviews
Benefits transfer	

Source: Christie et al. (2008).

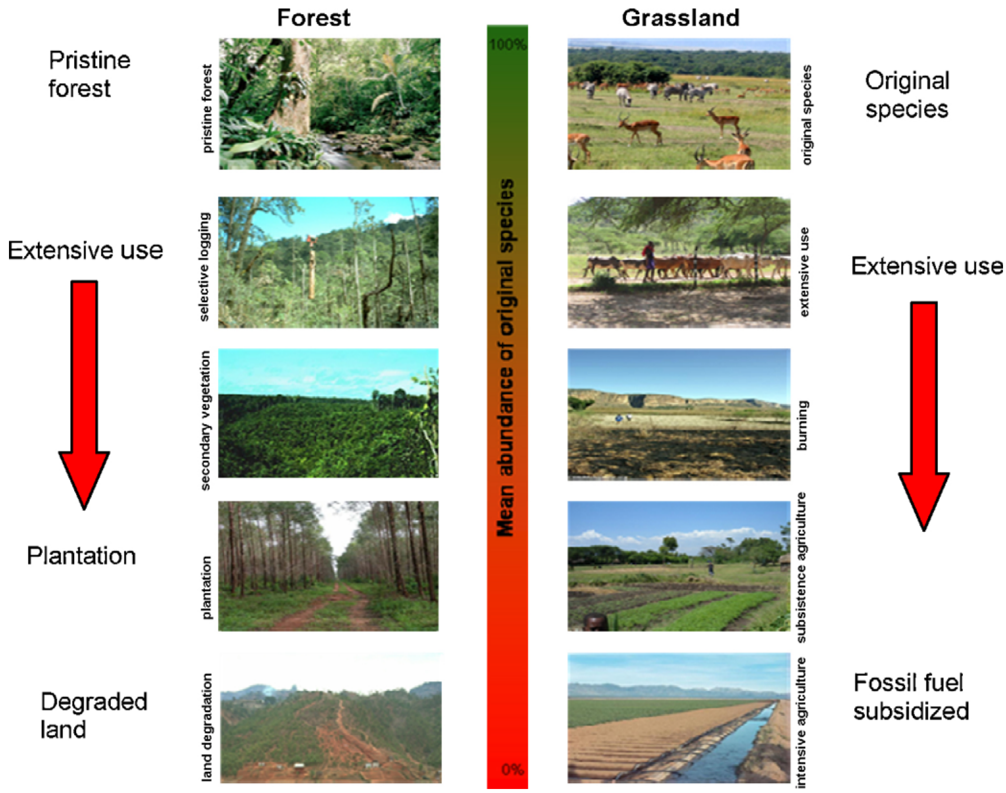

Fig. 3. Transition phases between natural and human-dominated (eco)systems.Source: CBD (2004) and MNP (2006).

ment intensities to provide a range (bundle) of ecosystem services (see Fig. 4).

Table 3 makes a start with developing a typology of management states for the main ecosystem and land use types to analyze the degree of service-provision by each management state, ranging from natural (i.e. un-managed) to an intensively managed or completely converted system. It should be realized that the boundaries between different management states are often not clear and there are many gradients in moving from one management state to another.

Increasingly, studies are showing that multi-functional use of natural and semi-natural ecosystems and landscapes is not only ecologically more sustainable, and socio-culturally preferable but frequently also economically more beneficial than converted systems. Balmford et al. (2002) demonstrated that tropical forests, wetlands, mangroves and coral reefs can provide greater benefits when intact rather than when converted into intensive economic use. More recently, Naidoo and Adamowicz (2005) have shown that conserving biodiversity of African Rainforests exceed its costs (see also Turner et al., 2003).

However, most of these services are still neglected in land use planning and decision-making. As a consequence, highly productive, multi-functional landscapes continue to be converted into more simple, often single-function land use types, such as croplands, or are turned into wastelands, such as eroded land after clear-cut logging. This approach only provides short-term economic profit to a few at the expense of the long-term wellbeing of many.

An important remaining challenge is therefore to investigate the relationship between ecosystem management and the provision of the total bundle of ecosystem services and analyze the impact of changes in management state on ecosystem services and possible (critical) thresholds.

6. Assessing the trade-offs involved in land cover and land change on ecosystem services

Once the relationship between landscape/ecosystem properties and services is known (Section 5), the consequences of land cover, land use change and ecosystem management decisions on ecosystem services can be analyzed. This analysis should focus on the impacts on individual ecosystem services as well as effects on the total bundle of ecosystem services, and their values, provided at the local and regional scale (Fig. 4).

Several instruments are available to analyze the implications of land use and management changes, including mapping and visualizing ecosystems services (Section 6.1, Question 4 and 10)), modelling changes in ecosystem services (6.2, Question 12) and integrated cost-benefit analysis (6.4, Question 14). For the application of all these instruments, taking proper account of scaling issues is essential (e.g. services are provided locally but the benefits accrue at different scales, ranging from local (e.g. food) to global (e.g. carbon sequestration). For proper valuation, and trade-off analysis, all scales, and associated stakeholders, should be taken into account (see Section 6.3, Question 8).

6.1. *Mapping & visualizing impact of land use change on ecosystem services*

Land management decisions typically relate to spatially oriented questions; how and where can we change the landscape in order to enhance the provision of one or more landscape services? In order to make adequate choices regarding land management, information on the spatial distribution of landscape functions and services is needed (Question 4, Box 1). Current maps of the landscape normally only include land cover or land cover related land uses. Spatial information on landscape functions is

Table 3
Main management states and related use of services for the main ecosystem (biome) types.

Ecosystem	Management state (and some examples of types of use and services)				
	Wild/ un-managed[a]	Sustainably managed[b]	Degraded[c]	Intensively managed[d]	Developed[e]
Open ocean		Sust. Fishery Gas-regulation Transport?	Over-fished Polluted	Conventional Fishery, intensive harvesting	Permanent Human infrastructure, intensive cultivation and artificial service-provision
Coral Reefs		Sust. fishery Res harvest Eco-tourism	Dynamite fishing Mining div. damages	Conventional Fishery/ Intensive tourism	
Estuaries, Sea-grass, Shelfsea		Sust. fishery Res harvest Eco-tourism	Over-fished Polluted	Conventional Fishery, Aquaculture Intensive tourism	
Coastal Wetlands (Tidal Marsh/Man-groves)		Sust. fishery Res harvest Eco-tourism	Over-fished Polluted, drained	Conventional Fishery, Aquaculture Intensive tourism	
Inland Wetlands (Floodplains & swamps)		Sust. fishery Res harvest Eco-tourism	Over-fished Polluted, drained	Conventional Fishery, Aquaculture Intensive tourism	
Lakes/Rivers		Sust. fishery Res harvest Eco-tourism	Over-fished Polluted, drained	Conventional Fishery, Aquaculture Intensive tourism	
Tropical Forest		Selective Logging + NTFP	Clearcut + burning Secondary re-growth	Plantations, Agro-forestry, Agriculture	
Temperate Forest		Selective Logging, + NTFP	Clearcut + Secondary re-growth	Plantations, Agro-forestry, Agriculture	
Shrub/heathland (Maquis, etc.)		Ext. resource harvesting & grazing	Clearcut, burning	Intensive harvesting, Int. grazing, Agro-forestry Agriculture	
Grass/Rangeland (Savanna)		Sust. grazing Eco-tourism	Over-grazed	Int. Grazing, Agro-forestry. Agriculture	
Tundra		Grazing	Over-grazed	Intensive Grazing	
Desert (cold/hot)		Some resource harvesting	Over-harvested	(irrigation) Agriculture	
Other					

[a] Wild/un-managed ecosystems: although human influence (in terms of pollution) has reached almost every corner of the planet (except maybe some deep sea environments), there are still many regions that are un-managed and still in a more-or-less natural/wild state. Also wildlife reserves, with no or very little human activity allowed, would fall under this category. Uses of these systems are mainly related to habitat and regulating services.
[b] Sustainably, extensively managed: the use of resources and services is limited to the natural productivity and carrying capacity of the system and the original species composition is largely kept intact. Other than harvesting activities and some "minor" infrastructure to allow use of the services there is no manipulation of the original system.
[c] Degraded: the system is currently under high pressure from pollution and/or physical or biological disturbance, or was previously used "Intensively" or "Developed" but has been abandoned and is now recovering (to the extend that is possible).
[d] Intensively managed: this category can be defined as use (management) that heavily depends on external inputs of energy and/or resources but which still uses the original substrate as the main basis of production. The original ecosystem has been (partly) converted into another type of land-cover), or is under high pressure from human manipulation to increase natural productivity, harvest resources and/or utilize its services whereby some of the original ecosystem structure and/or species composition still remains (e.g. agro-forestry in terrestrial ecosystems or aquaculture in aquatic ecosystems).
[e] Developed: the "developed" state is defined as the (more or less) complete conversion of the original ecosystem to support permanent human infrastructure and/or cultivation systems and involves a structural change of the original substrate and/or ecosystem.

scarce as only some landscape functions relate to directly observable landscape features (e.g. forest cover provides timber production). Information on the spatial distribution of landscape functions that do not relate to one single land cover type, i.e. that can not be directly observed, need to come from additional intensive field observations or cartographic work. For example, the recreational function of a landscape or ecosystem is not only defined by the land cover of a specific location (e.g. natural area) but depends also on accessibility properties (e.g. distance to roads) and characteristics of the surrounding landscape. To facilitate decision making, maps of landscape functions should (besides visualizing the location of landscape function) also show the spatial heterogeneity in the quantity and quality of services provision (Troy and Wilson, 2006; Meyer and Grabaum, 2008). Spatial heterogeneity in service provision is a result of differences in biophysical and socio-economic conditions at different scale levels (Wiggering et al., 2006; Syrbe et al., 2007).

6.1.1. Mapping approaches

In Table 1 we presented an overview of indicators that can be used to assess the location and quantity of the (potentially) provided landscape services. These indicators, representing biophysical and social properties of the landscape, can be used to map the presence of landscape functions and their capacity to provide goods and services. Key in mapping approaches are therefore the quantification of relations between landscape properties/spatial indicators, landscape functions and services supply.

Empirical analyses on landscape function presence or service supply and landscape properties can be used as spatial indicator selection and quantification method. Factual knowledge on the location and amount of service supply (e.g. biodiversity observations, crop yields, level of aesthetics) is in this case linked to variables describing spatial landscape properties (see e.g. Alessa et al., 2008; Willemen et al., 2008). For example, biodiversity observations can be included regression methods to statistically test the explanatory power of a broad range of spatial variables. A pre-selection of these spatial variables can be made based on expert and process knowledge. Once the spatial variables have been selected, the quantified relation between process indicators and service supply can subsequently be used to map service supply for a larger region (See example Fig. 5).

Empirical mapping approaches are by definition data-driven and therefore require an extensive spatial dataset covering the full

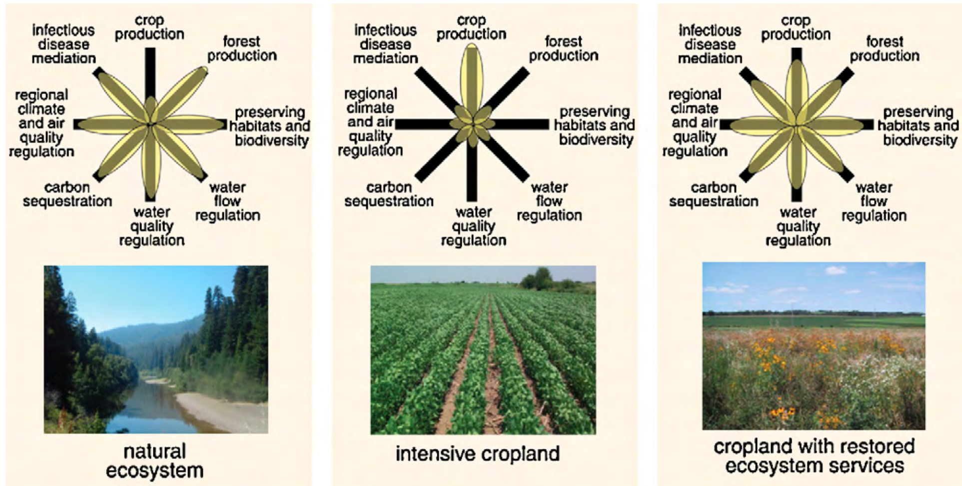

Fig. 4. Impact of land use change on bundles of ecosystem services.Source: Foley et al. (2005).

area of interest. Complete data coverage could be a problem of large areas (e.g. global level). Additionally, in large areas regional differences in service provision indicators can complicate the empirical mapping method (Verburg and Chen, 2000). This makes the empirical mapping method mainly suitable for regional studies.

When no suitable observation data on service supply is available, spatial requirements and quantified relations derived from literature or process models can be used to map landscape functions. Several studies combined spatial datasets to map a range of landscape functions or their supplied services (e.g. Haines-Young et al., 2006; Chan et al., 2006; Naidoo and Ricketts, 2006; Gimona and Van der Horst, 2007; Egoh et al., 2008; Meyer and Grabaum, 2008; Kienast et al., in press).

Landscape service mapping based on literature or models make best use of available knowledge and underlying theories. A drawback of this approach is that they are based on general assumptions not on site specific quantified relations.

Other studies have mapped landscape service to directly link service supply to land cover or complete ecosystems using general assumptions from literature reviews. This approach is mostly seen in studies aiming to quantify the economic value for the area of interest (e.g. Naidoo and Ricketts, 2006; Troy and Wilson, 2006). As in this approach the complex spatial heterogeneity of service provision is not included, this a relative quick way to map landscape services.

6.1.2. Relevance for land management

The results of approaches to visualize landscape function are two-fold. First, relations between service provision and spatial process indicators are identified and quantified and second, the spatial distribution of landscape functions is made explicit.

Policy makers can use this information to design spatial policies and (ex-ante) evaluate the effect of their land use strategies on the capacity of the landscape to provide goods and services (Bockstael et al., 1995). This is a complex task as most landscapes provide more than one service at the same time, i.e. they are multi-functional, leading to possible trade-off in their decision making. Within such multifunctional landscapes, interactions between landscape functions may occur (Sattler et al., 2006; Groot et al., 2007; Van Huylenbroeck et al., 2007). Detailed knowledge on landscape function indicators makes it possible to identify conflicting or synergizing landscape functions; two landscape functions might have equal or opposite spatial requirements (Willemen et al., 2010). Subsequently, by overlaying the different landscape function maps with the locations at which multi-functionality can lead to synergies or conflicts can be identified. Especially for areas with high pressure on land resources, good management of interacting functions promotes sustainable land use (Chan et al., 2006; Egoh et al., 2008).

6.1.3. Remaining challenges

Remaining challenges regarding mapping landscape functions include the development of guidelines for selecting the most appropriate mapping approach. These selections could be based on the properties of the landscape functions to be mapped and the purpose of use of the landscape service maps (Willemen et al., 2008). Additionally, appropriate visualization techniques need to be defined. Traditional 2-d maps are not suitable for representing multiple services at a single location or the spatial and temporal services supply changes. Dynamic visualization alternatives need to be explored to allow for representing changing bundles of services in space and time.

Mapping exercise can also help to make decisions on minimal service supply. In principle, all landscapes are multifunctional but only some functions will supply enough services to be of interest for decision making (e.g. desert vegetation also captures CO_2, but this amount can be neglected compared to other locations). How to define this minimal supply benefiting society?

Finally, for communication purpose mapping and visualization is very important and further development are needed to explore (internet-based) tools to visualize ecosystem services, e.g. "MyPlaceToBe (see www.ecosystemservices.nl) and the use of Google Earth (e.g. www.consvalmap.org—Conservation International (USA).

6.2. Modelling impact of land use change on ecosystem services

Globally, several models exist to assess the impacts of economic and environmental factors on natural resources, including the provisioning of goods and services, e.g. IMAGE-GLOBIO (MNP, 2006), GUMBO (Boumans et al., 2002) and MIMES (www.uvm.edu/giee/mimes). Most of these models, however, usually focus only on a few Ecosystem Goods and Services (EGS) and neglect the effects of management strategies and biodiversity on combined EGS (Fig. 4).

Some regional (dynamic) models have been developed to simulate the impacts of land use change and management on EGS (Portela and Rademacher, 2001; Guo et al., 2000). The InVEST model aims at spatially explicit modelling of multiple services, biodiversity and trade-offs (Nelson et al., 2009). Other authors use

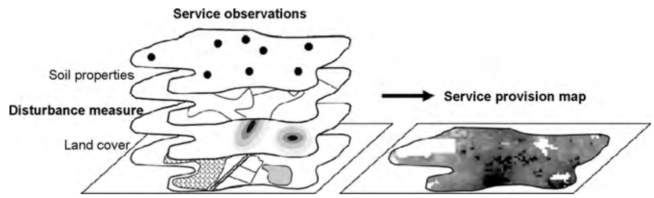

Fig. 5. An example of mapping of service provision using empirically derived relations between service observations and landscape properties.

GIS techniques to relate biodiversity, land use change and EGS at regional levels (Metzger et al., 2006; Chan et al., 2006; Egoh et al., 2008), and ARIES (Villa et al., 2007).

Braat and ten Brink (2008) suggest a simplified set of relationships between the levels of ecosystem services and the degree of loss of biodiversity related to different management systems (see Fig. 6 for an example).

The relationships in Fig. 6 are tentative and specific situations will have specific versions of these generalized curves. Both the shape of these curves and the magnitude of the different corresponding ecosystem service levels determine the shape of the overall ESL (Ecosystem Service Level) curve and whether an overall optimum can be reached. Research is started to analyze, and quantify these relationships for the four main types of ecosystem services.

Provisioning (P): By definition, there is no provisioning service in a pristine ecosystem. In order to harvest naturally produced goods such as fish and timber we need to at least temporarily disturb the ecosystem. With increasing intensity of use, the production of goods and their benefits can only increase by adding human inputs such as fertilizer, water, pest control and labor. To maximize yield, usually of only one service, ecosystems are reduced to a substrate for production of biomass or other single use purposes. The most extreme types of land use are built up areas and areas covered by concrete or asphalt, where production of natural ecosystem goods approaches zero.

Regulating (R): Many regulating services (climate change buffering by carbon sequestration, flood regulation, pollination) perform optimal in “intact” ecosystems. The degree of regulating services provided by converted systems depends largely on the type of service. In general, regulating services are believed to decrease with increased use intensity.

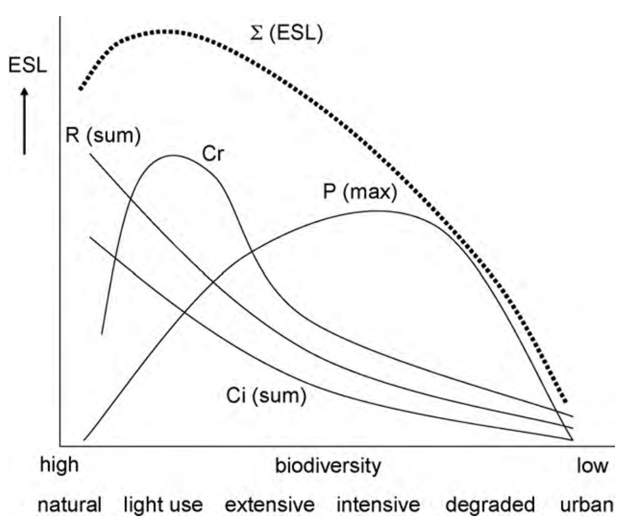

Fig. 6. Generalized functional relationships between the levels of ecosystem services provision (*Y*-axis) and the degree of loss of biodiversity related to different land use intensities (*X*-axis). Adapted from Braat et al. (2008).

Cultural—recreation (Cr): Recreational benefits are classified as part of the Cultural services in the MA. A crucial feature in the valuation of the recreational services of ecosystems is accessibility. The graph therefore displays an increase from inaccessible pristine systems to higher values in accessible lightly used systems and a subsequent drop in value towards the more intensely used and degraded systems.

Cultural—information (Ci): Most of the other cultural ecosystem services and their values are a function of the information content which is considered to decrease with the degree of conversion.

A vertical summation of the ecosystem service levels, and implicitly their economic and social values, per management system points at the trade-offs included in land use conversions. The challenge in regional policy making and planning now is to optimize the spatial pattern of land-use types and the management of the flows of benefits in view of social and economic objectives. To this end, it is necessary to quantify the relationships between management systems and the ecosystem services they provide to give substance to the generalized conceptual model. More detail in both the provided services and the management systems are required to build a model that can be used in policy making and planning. Once having these relationships, the modelling of ecosystem services is simplified to estimating the possible changes from one management system into another (see Box. 2).

The approach described here neglects the dynamic nature of ecosystems as the relationships between management systems and services are assumed to be static in time. This might not hold for longer time spans. A major challenge for future research remains the inclusion of dynamic processes into the model, including possible regime shifts of ecosystems. For policy making and planning, information on the level of sustainability (i.e. the use of desired ecosystem services, without long-term decline of biodiversity and maintaining the use the ecosystem in the future; CBD, 2004) of management systems can be an important criterion.

6.3. *Issue of scales (in time and space)*

Scales refer to the physical dimension, in space or time, of phenomena or observations (O'Neill and King, 1998). Scales can be defined by the extent and resolution: extent refers to the size of a dimension, for example, the size of the study area or the duration of time under consideration, whereas resolution refers to the precision used in measurement. There is increasing awareness of the importance of spatial and temporal scales for the analysis and valuation of ecosystem services (e.g. De Groot et al., 2002; MA, 2003). The importance of scales has been widely recognized in both economics and ecology. However, to date, few ecosystem valuation studies have explicitly considered the implications of scales for the analysis and valuation of ecosystem services. Below, the two key scales relating to economic and ecological scales are discussed, followed by an analysis of their implications for ecosystem management and a description of remaining challenges in ecosystem services research and management.

(a) *Economic scales*

In economics, scales (in time and space) have been considered in a variety of ways, see e.g. Van den Bergh (1996) for an overview. Distances to urban centers have been widely used as an explanatory variable for economic activity (see e.g. Van Kooten, 1993) and, in more recent work, spatial dimensions have been included in economic optimization models for resource harvesting (e.g. Sanchirico and Wilen, 2005). The importance of temporal dimensions is reflected, for instance, in the large literature on discount rates (e.g. Howarth and Norgaard, 1993; Khanna and

Chapman, 1996) and, for instance, with regard to drivers for economic change at different temporal scales (e.g. Dasgupta, 1996). Ecosystem services can be supplied to society at a range of institutional scales, ranging from households to the national state to the global community (O'Riordan et al., 1998; Berkes and Folke, 1998; Peterson, 2000). For instance, households may directly depend upon ecosystem services for their income (e.g. fishermen, ecotourism operators). Government agencies at different levels are involved in managing ecosystems, and in regulating the access to ecosystem services. They may also receive income from specific ecosystem services (e.g. park entrance fees).

(b) *Ecological scales*

According to its original definition, ecosystems can be defined at a wide range of spatial scales (Tansley, 1935). These range from the level of a small lake up to the boreal forest ecosystem spanning several thousands of kilometres. A number of specific ecological scales are generally distinguished in ecology ranging from the individual plant, via ecosystems and landscapes, to biomes and the global system (Holling, 1992; Levin, 1992). Commonly, ecological processes operate at specific spatial and temporal scales (Limburg et al., 2002; Holling et al., 2002). Ecological and institutional boundaries seldom coincide, and stakeholders in ecosystem services often cut across a range of institutional zones and scales (Cash and Moser, 1998).

The supply of ecosystem services depends on the functioning of ecosystems, which, in turn, is driven by ecological processes operating across a range of scales (MA, 2003; Hein et al., 2006). Nevertheless, often, a specific ecological scale can be identified at which an ecosystem service is generated (see Table 4). For instance, a local forest patch may provide pollination service to nearby cropland. The supply of the hydrological service depends on a range of ecological processes that operate, in particular, at the scale of the watershed. At the global scale, ecosystems may provide a carbon sink or support the conservation of biodiversity. Analyses of the dynamics of ecosystem services supply requires consideration of drivers and processes at scales relevant for the ecosystem services at stake.

(c) *Implications for management and payments for ecosystem services schemes*

Hence, scales of ecosystem services are crucial to environmental management (e.g. Balmford et al., 2002; Hein et al., 2006). A main issue is that stakeholders managing an ecosystem usually benefit from only part of the ecosystem services provided by that ecosystem. This relates to the positive externalities provided by ecosystems, for instance, at the scale of the watershed, upstream forest users influence downstream water supply – and forest degradation may lead to increased flood risk or sedimentation. Also ecosystem services such as air filtration or carbon sequestration are public goods and not commonly considered in decision making by managers of ecosystem providing the service (e.g. Balmford and Whitten, 2003; Powe and Willis, 2004).

In these cases, there is economic rationale for setting up payment mechanisms from stakeholders benefitting to stakeholders carrying the (opportunity) costs of managing or maintaining an ecosystem, in the form of payment for ecosystem services (PES) projects. These payment mechanisms may also be implemented at different scales, e.g. within a watershed or through the CDM mechanisms supporting reforestation for carbon capture. Key issues in this respect are (i) defining appropriate (effort or impact-related) indicators to measure the supply of the service and (ii) setting up a transparent and cost-effective payment mechanism, in which transaction costs are minimized.

6.3.1. *Remaining challenges*

In dealing with scales in relation to ecosystem services analysis, a number of issues remain. First, modelling ecosystem services supply as a function of processes and management interventions requires multi-scale approaches that are able to incorporate drivers that function across a range of scales. These processes range from the global scale (e.g. climate change) to the micro-level (e.g. denitrification). Incorporating management variables into a decision model that reflect management options across these scales is important in defining 'optimal' ecosystem management approaches, but highly complex in terms of modelling (e.g. Levin, 1992; Limburg et al., 2002). Second, there is need to incorporate complex ecosystem dynamics in ecosystem management models, with the thresholds and state variables of the models also present at a range of scales (see e.g. Scheffer et al., 2001 for an overview, or Hein, 2006 for a case study). Thirdly, economic drivers need to be modelled at the appropriate institutional scales, and the integration of ecological and economic drivers and scales requires further effort, also in view of the different modelling paradigms applied in ecology and economics (e.g. Van den Bergh, 1996; Turner et al., 2003).

6.4. *Valuing trade-offs in ecosystem services due to land cover and land use change*

In order to make well-informed decisions about trade-offs between different management states, ALL costs and benefits should be taken into account, including ecological, socio-cultural and economic values and perceptions. Or, as it is formulated in Question 15 (Box 1): how can evaluation methods of plan-

Table 4
Most relevant ecological scales for the regulation services.

Ecological scale	Dimensions	Regulation services
Global	$>1{,}000{,}000\,km^2$	Carbon sequestration Climate regulation through regulation of albedo, temperature and rainfall patterns
Biome—landscape	$10{,}000–1000{,}000\,km^2$	Regulation of the timing and volume of river and ground water flows Protection against floods by coastal or riparian ecosystems Regulation of erosion and sedimentation Regulation of species reproduction (nursery service)
Ecosystem	$1–10{,}000\,km^2$	Breakdown of excess nutrients and pollution Pollination (for most plants) Regulation of pests and pathogens Protection against storms
Plot plant	$<1\,km^2$	Protection against noise and dust Control of run-off Biological nitrogen fixation (BNF)

Note that some services may be relevant at more than one scale. Based upon Hufschmidt et al. (1983), De Groot (1992), Kramer et al. (1995) and Van Beukering et al. (2003).

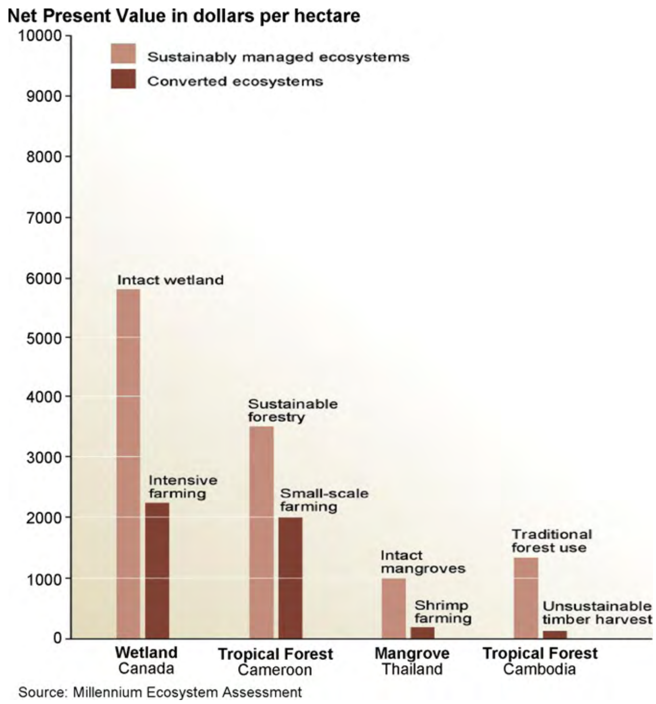

Fig. 7. Integrated Cost-Benefit Analysis of management alternatives for wetland and forest ecosystems.Source: Balmford et al. (2002).

alternatives for use of land and landscape services be improved (notably the neglect of ecosystem services and values in conventional Cost Benefit Analysis (CBA))? One problem is that classical CBA is limited to a financial analysis of those effects that can be expressed in marginal (market) values and as literature has shown, more than 80% of the values of ecosystem services are not (yet) captured in markets (e.g. Costanza et al., 1997; De Groot et al., 2002). New techniques are therefore needed, and being developed, to expand CBA with environmental and social indicators some of which can be translated into monetary terms (Social-CBA, or Integrated-CBA).

Although these techniques are still in the early stages of development, results quite consistently show that when all factors are taken into account properly, multi-functional sustainable use is usually economically more beneficial than conversion into singe-function use (Balmford et al., 2002; Turner et al., 2003 (see Fig. 7)).

Another approach is the development of Multi-Criteria Decision Analysis (MCDA)-techniques, with explicit involvement of the main stakeholders in the trade-off analysis (Henkens et al., 2007).

7. Integrated landscape planning, policy and financing instruments

With all the building blocks in place, an important remaining key question is how all the analytical and participatory assessment methods can be combined to enable effective planning and decision making.

7.1. Integrative, participatory landscape planning and design

Ideally, spatial and dynamic ecosystem services modelling should be linked to participatory trade-off assessment methods to optimize multi-functional use of the "green and blue space".

An important tool that is currently being developed by the Ecoinformatics Laboratory of the University of Vermont, together with Earth Economics, and Conservation International (and support from the US-NSF), is an artificial intelligence technology designed for rapid ecosystem service assessment and valuation called ARIES (Villa et al., 2007).

Within the Wageningen University Research Program on Ecosystem Services (SELS) several researchers are looking at ways to incorporate landscape functions more structurally into methods for target setting, design and negotiation in spatial planning processes. Another interesting development is the use of Baysian Belief Networks (BBN) to determine Total Utility Value of (changes in) Land Use Functions (Haines-Young, 2000).

7.2. Interactive communication tools and data bases

Knowledge about ecosystem and landscape services and values should be clearly communicated, and made easily accessible to policy makers, (other) stakeholders, and the general public. For this, internet is an ideal medium and several interesting applications are being developed, such as the ARIES-project mentioned above, a Google-earth based application developed by Conservation International to visualize ecosystem services and values (www.consvalmap.org).

To facilitate planning, design and decision-making, large amounts of data on ecosystem services (ands their values) are needed which can come from both meta-analysis and new empirical data. In both cases, data bases are essential which should be made accessible through internet to enable easy storage and retrieval of the data.

Some existing initiatives include the Ecosystem Service Database (ESD-www.esd.uvm.edu) of the Gund Inst. for Ecological Economics, USA, and work done in the Netherlands by the Platform for Nature Valuation & Financing (NV&F) which has a data base that includes over 200 case studies (www.naturevaluation.org). Ideally, these data bases should be linked to expert systems, such as ARIES (www.eartheconomics.org) to analyze the implications of changes in (ecosystem) management for the provision (and values) of ecosystem services (see Section 5), and visualization tools (see Section 6.1).

7.3. Financing instruments

Finally, in order to achieve more sustainable, long term planning and management of natural and semi-natural landscapes, proper financing instruments are essential. Also in this field much progress is being made (Jack et al., 2008) but still some questions remain about the adequacy of current financing methods for investing in ecosystem and landscape services. These include: Under what conditions are which payment or financing schemes feasible? How can, and should they be linked to valuation-outcomes? How can transaction costs be kept low? And what is the influence of scales? What costs should be included? Who should pay for these costs? How to involve beneficiaries into payments for ecosystem and landscape services? How to structurally promote the implementation of financing instruments (for example by bringing together the supply and demand of services)?

8. Conclusions

Although consensus on a coherent and integrated approach to ecosystem service assessment and valuation is still lacking, and empirical data is still scarce, efforts to fill these gaps have changed the terms of discussion on nature conservation, natural resource management, and other areas of public policy. It is now widely recognized that nature conservation and conservation management strategies do not necessarily pose a trade-off between the "environment" and "development" but that investments in conservation, restoration and sustainable ecosystem use generate substantial ecological, social and economic benefits.

Several issues follow from the recognition of the potential of the 'ecosystem service approach' to transform priorities of environmental management and related policy making. Some of these pertain to the practices and protocols of the ecosystem service approach itself.

Although much has been achieved, there is a need to develop widely shared definitions of key concepts and typologies (of services, benefits, values), so that lesson learning and accumulation of results can be facilitated and fostered. For the same reasons, it is important to develop ecosystem services measurement and reporting practices and standards for ecological socio-cultural and economic values which are robustly based on an underlying conceptual framework and which are widely shared among the practitioners of the ecosystem service approach to ensure comparability and transferability.

To achieve this kind of integrated approach presents many challenges both at the levels of theory and methods, as were highlighted in this paper.

Although much remains to be done, the many ongoing projects and initiatives mentioned in this paper provide reason for optimism that the concept of Ecosystem Services will soon become mainstream in environmental planning and management at all levels of decision-making. To facilitate this process, recently the Ecosystem Services Partnership (ESP: www.es-partnership.org) has been launched to provide a platform for communication on research and practical implementation of the 'ecosystem services approach'.

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