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ECOSYSTEM SERVICES – CLASSIFICATION AND DIFFERENT APPROACHES AT VARIOUS LEVELS OF BIOSPHERE ORGANISATION – A LITERATURE REVIEW

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Abstract

In the literature on the subject, evaluation of ecosystem services (ES) is regarded as a one of the important scientific problems of nature protection, environmental economics and ecology. ES are the benefits that people obtain from ecosystems. The concept of ecosystem services is generally defined as a set of products and functions of ecosystems that benefit society. The present paper contains definitions of the most common concepts found in the literature, i.e. ecosystem services, the drivers behind these services, trade-offs and synergies, and interactions between different categories of services.

Key words

ecosystem services • ecological and spatial scale • management • land use • biodiversity

Introduction

Since the late 1960s, evaluations of ecosystem services (ES) have accounted for the largest amount of scientific literature in the fields of nature protection, environmental economics and ecology (Limburg et al. 2002; Costanza 2008; Rosin et al. 2011). It was primarily ecologists and geographers who began to pay increasing attention to the importance of environmental influences on the functioning of societies (e.g. de Groot et al. 2002). Humans need the resources and functions performed by nature, such as agricultural produce, clean water and clean air, control of the climate and the flow of elements, etc. Historically, scientific interest in ecosystem services was initially oriented towards analysing their spatial differentiation; later the focus shifted to the socio-economic aspects of ES (Costanza et al. 1997; Foley et al. 2005; Spangenberg & Settele 2010). There have also been attempts to show the degree of interest on the part of stakeholders and decision-makers, i.e. people, communities, institutions, organisations and administrative bodies.

A prominent role in the creation and promotion of the idea of ecosystem services has been played by the American scientist Robert Costanza, an expert in ecological economics and sustainable development. His papers of 1997 and 2008 are of fundamental importance in the theoretical ordering and classification of ES.

The aim of this article is to shed light on the concept of ecosystem services and methods of valuing ES (in the relevant literature) that can potentially be used in decision making on ecosystem management. The concept of ecosystem services may be very useful in providing a guide for our response to human activities, which takes into account and quantifies trade-offs between society and nature and increases welfare. Any classification of ecosystem services ought to account for ecosystem characteristics, human interests and decisions directly related to the need for a specific service.

The amount of information about the ecological and socio-economic value of goods and services provided by natural and semi-natural ecosystems has been growing quite rapidly. A framework for comparable ecological-economic analyses of ecosystem services can only be developed if the principles of comprehensive assessment of the functioning of ecosystems, goods and services are standardised. This challenge prompts the development of models of typologies and classifications used in evaluating ecosystem goods and services.

As is usual in such cases, classification-oriented analyses of ecosystem services have been motivated by expediency. For example, effective action for nature conservation requires other solutions than just legal regulations, and, in particular, all sorts of prohibitions. A key factor that may influence the effectiveness of nature conservation efforts, and which is also economically important, is broad public awareness and recognition of natural values. Ecosystem services are an example of making use of these values (Rosin et al. 2011). These authors, like many others, state that all natural goods and processes that make it possible to obtain many different benefits (e.g. wild fruit, pollination, pest control) are ecosystem services. This term has been used to refer to anything obtained from ecosystems (Kremen et al. 2002; Moser et al. 2011).

Definitions of basic concepts

Many terms related to ecosystem services are not defined or explained by their users. The present paper thus contains definitions of the most common concepts found in the literature, i.e. ecosystem services, the drivers behind these services, trade-offs and synergies, and interactions between different categories of service.

Ecosystem services are the benefits that people obtain from ecosystems (Millennium Ecosystem Assessment 2003). This definition accounts for ecosystem services provided by grossly intact ecosystems which include, for example, aesthetic values, as well as those supplied by ecosystems intensively managed for agriculture, recreation and other purposes, including intensively managed agroecosystems, aquatic cultures or mangrove forests. The concept of ecosystem services is generally defined as a set of products (e.g. timber, forest fruit, game animals) and functions of ecosystems (e.g. purification of water and air, production of oxygen, recreational sites) from which society benefits (Costanza et al. 1997; Solon 2008). Ecosystem services may be regarded as an applied concept as there are numerous examples of an effective implementation of this concept for practical purposes (Daily & Matson 2008; Mizgajski & Stępniewska 2009), particularly the so-called *Payment for Ecosystem Services* (PES). For example, a large French manufacturer of mineral water, alarmed by high levels of nitrate pollution in the water resulting from intensive agriculture, opted for extra payments to farmers in return for employing more sustainable farming practices so that stable income levels could be ensured (TEEB 2008). In Poland, as in many other European countries, one of the biggest PES schemes, though not referred to as such to date, is taking place within EU programmes for the development of rural areas and in particular those concerned with agriculture and environment. The growing awareness of the benefits that ecosystems supply to society makes the concept of ES worth promoting and developing (Foley et al. 2005). Solon (2008) extends the scope of the ES concept to include the entire landscape and understands ES as the set of products and functions of an ecosystem (landscape), which are useful to human society.

The simplest and most commonly adopted division of ES distinguishes four basic categories: (1) **provisioning services**, including, among others, providing food and water; (2) **regulating services**, such as flood control, drought control, prevention of soil degradation, and disease control; (3) **supporting services**, including soil formation and nutrient cycling; and (4) **cultural services**: recreational, spiritual and religious values, and other intangible assets (Millennium Ecosystem Assessment 2003, 2005).

A **driver** is a factor that influences one or more ecosystem services and is modifiable by human activity (e.g. Bennett et al. 2009).

Trade-offs describe a situation when the value of one of two services increases and the value of the other decreases. This may be caused by a simultaneous response to the same driver or may be the result of interaction between the services. For instance, water quality and agricultural produce are the best known trade-off due to their differing responses to an additional supply of nutrients to an agricultural landscape (Carpenter et al. 1998).

Synergies are situations where two services simultaneously decrease or increase in value. These changes may be mediated by a shared driver or by interaction between the services. An example can be the synergy between algae grazing by fish and recreation in the marine protected zone of the coral reef. These areas support more fish, which graze on algae more intensely, at the same time protecting the corals. This also supports recreation (Hughes et al. 2007).

Interactions between ecosystem services: are situations where one service directly influences another one. Interactions can be unidirectional (the supply of service A influences the levels of service B, but there is no effect in the other direction) or bidirectional (when the supply of service A influences the levels of service B, which in turn influences the supply of service A). They can be positive (the supply of service A raises the levels of service B) or negative (the supply of service A inhibits the supply of service B) (Bennett et al. 2009).

Selected classifications of ecosystem services – functions and ranking scales

Our review of the literature covers many studies investigating the scales applied to ES evaluation. This line of research has basically focused on the ecological scale of production of ecosystem services and the spatial measure of their effects and reception by stakeholders. The assumption of a spatial ecological scale of the effects of ecosystem services has been investigated at four levels of ecological systems (with their corresponding spatial measures): 1) global level, 2) biome and landscape level, 3) ecosystem level, and 4) the level of a single study plot and organism (e.g. a plant species), see Table 1 (Hein et al. 2006).

The classifications of ecosystem services cited by Costanza et al. (1997) and Costanza (2008) include two in particular: one related to spatial characteristics and one related to ecosystem functions (Tab. 2 and Tab. 3). Table 2 classifies the 18 ecosystem services into five categories according to their spatial characteristics. For example carbon storage, as an ES, does not depend on proximity and belongs to the first category (global – non proximal). Disturbance Regulation/Storm protection, as an ES, depends on proximity and authors included it in the second category (local proximal). Nutrient regulation, as an ES, belongs to the third category (directional, flow-related, from the point of production to the point of use). Food production, as an ES, belongs to the fourth category (in situ/ point of use). Finally, Costanza (2008), for example, includes cultural services in the fifth category (user movement related to the flow of people to unique natural features).

Table 3 illustrates ecosystem services as benefits that humans derive from the functioning of ecosystems and this table identifies 17 ecosystem services and ecosystem functions corresponding to each of these. Among the 17 examples we can find a connection between the retention of soil within an ecosystem as a function derived benefit of erosion control and sediment retention as an ecosystem service (Costanza et al. 1997).

Table 1. Most relevant ecological scales for regulation services – note that some services may be relevant at more than one scale (according to Hein et al. 2006).

Ecological scale	Dimensions (km^2)	Regulation services
Global	>1,000,000	carbon sequestration climate regulation through regulation of albedo, temperature and rainfall patterns regulation of the timing and volume of river and ground water flows
Biome (landscape)	10,000-1,000,000	flood protection provided by coastal or riparian ecosystems regulation of erosion and sedimentation regulation of species reproduction (nursery service) breakdown of excess nutrients and pollution
Ecosystem	1-10,000	pollination (for most plants) regulation of pests and pathogens protection against storms protection against noise and dust
Plot (plant)	<1	control of run-off biological nitrogen fixation (BNF)

Source: Hufschmidt et al. (1983), de Groot (1992), Kramer et al. (1995) and van Beukering et al. (2003).

Table 2. Ecosystem services classified according to spatial characteristics.

Services	Under Climate regulation and Proximity
1. Global – non proximal (does not depend on proximity)	carbon sequestration (NEP) carbon storage cultural/Existence value
2. Local proximal (depends on proximity)	disturbance regulation/storm protection waste treatment pollination biological control habitat /refugia
3. Directional flow – related: flow from point of production to point of use	water regulation/flood protection water supply sediment regulation/erosion control nutrient regulation
4. In situ (point of use)	soil formation food production/non-timber forest products raw materials
5. User movement related: flow of people to unique natural features	genetic resources recreation potential cultural/aesthetic

Source: according to Costanza (2008).

Table 3. Ecosystem services, the benefits humans derive from ecosystem functions.

Ecosystem services	Ecosystem functions
Gas regulation	regulation of atmospheric chemical composition
Climate regulation	regulation of global temperature, precipitation, and other biologically mediated climatic processes at global, regional or local levels
Disturbance regulation	capacitance, damping and integrity of ecosystem response to environmental fluctuations
Water regulation	regulation of hydrological flows
Water supply	storage and retention of water
Erosion control and sediment retention	retention of soil within an ecosystem
Soil formation	soil formation processes
Nutrient cycling	storage, internal cycling, processing, and acquisition of nutrients
Waste treatment	recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds
Pollination	movement of floral gametes
Biological control	trophic-dynamic regulations of populations
Refugia	habitat for resident and transient populations
Food production	that portion of gross primary production extractable as food
Raw materials	that portion of gross primary production extractable as raw materials
Genetic resources	sources of unique biological materials and products
Recreation	providing opportunities for recreational activities
Cultural	providing opportunities for non-commercial uses

Source: according to Costanza et al. (1997).

As stated above, a given measure of the value of ES depends on the scale of research. Obviously, a global valuation of ecosystem services is not feasible as different services are of different importance locally (Spangenberg & Settele 2010). By way of example, Swift et al. (2004) point to the substantial differences between the limited temporal and spatial scales used, of necessity, in studies of agricultural ecosystems, while Limburg et al. (2002) describe the diversification of measurements by type of ecosystem service and spatio-temporal scale in research on aquatic and terrestrial ecosystems (Tab. 4). Using the criterion of the temporal and spatial scale of service production, the authors list ecosystem components or the levels of their aggregation associated with a given service. Limburg et al. (2002) emphasise that it is often very difficult to determine the scale of production and provision of a given ecosystem service. For example, the service related to nutrient mineralisation is mostly generated by soil-, water- or sediment-dwelling microorganisms. Plants and animals make use of these nutrients regardless of the scale of time or geographical space. Nevertheless, the authors believe that using the scale criterion for classifying ecosystem services aids in understanding and evaluating ES.

Most ecosystem services are based on benefits to biodiversity. Another important group are those resulting from ecological processes. Many examples of measurements of the efficiency of various ecosystem services found in world literature use biodiversity as their basis (e.g. Kremen 2005). Ecosystem services are often discussed with regard to their potential application to the planning of the protection of naturally valuable areas (Egoh et al. 2007). It needs to be underlined that the scope of evaluation and use of ES should be as broad as possible to include both anthropogenically altered and intact habitats. The scope of analysis of the quality and quantity of services should undoubtedly follow from the specific characteristics of a given spatial unit, their use pattern and the requirements of the party who has ordered specific research. Cultural services should not be left out either. The elementary ecosystem services that, according to Egoh (2007), can be used for the protection of naturally valuable ecosystems are listed in Table 5. The author classified them into three categories of ecosystem services: regulatory (i.e. carbon sequestration), supporting (i.e. soils), provision (i.e. forest production) and cultural (i.e. recreation).

An example of a classification where nine regulating and four supporting services are derived from biodiversity is that by Kremen (2005). For each type of service the author named the ES-providers, efficiency measures and examples included in references (Tab. 6). For example Balvanera et al.

Table 4. Examples of the generation of ecosystem services (ES) at different scales for terrestrial and aquatic ecosystems.

Scale in time or space (day) (m)	Terrestrial ecosystem	Example of ES	Scale at which ES is valued	Aquatic ecosystem	Example of ES	Scale at which ES is valued
10^{-6}–10^{-5}	soil microbes	nutrient remineralisation, denitrification	regional/global	bacteria	nutrient uptake and production of organic matter	local/regional
10^{-3}–10^{-1}	within-plant processes, soil communities	photosynthetic production, mechanical working of soil	regional/global	plankton	trophic transfer of energy and nutrients	local/regional
10^{0}–10^{1}	whole plant	wood, leaf, sap, and fruit production	local	water column and/or sediments, small streams	provision of habitat	local
10^{2}–10^{4}	forest stand/ landscape	microclimate regulation, water filtration	local/regional	lakes, rivers, bays	fish and plant production	local/regional
$\geq 10^{5}$	regional/global	heat/water/gas exchange with atmosphere	regional/global	ocean basins, major rivers and lakes	nutrient regulation CO_2 regulation	global

Source: according to Limburg et al. (2002).

Table 5. Ecosystem services identified in 16 conservation assessments (see Methods for details on how these were identified)

Ecosystem service	Method of identification	References
Regulatory		
Carbon sequestration	NDVI (Normalised Differential Vegetation Index) Unclear	Faith et al. (2001); Nagendra (2001); Phua & Minowa (2005)
Water production	Catchments gathering water for use by humans living downstream	Cowling et al. (2003)
	Vegetation, soil and slope	Gou & Gan (2002)
	Rivers, lakes, dams	Arriaza et al. (2004)
	Aquifer recharge areas	Hoctor et al. (2000)
Flood prevention	Environmental variables[a]	Phua & Minowa (2005)
Drought prevention	Environmental variables[a]	Phua & Minowa (2005)
Erosion control	Slope	Kremen et al. (1999)
Supporting		
Productive	Soil types	Cantu et al. (2004)
Soils	Local knowledge	Nagendra (2001)
Provisioning		
Shell fish production	Harvesting areas	Hoctor et al. (2000)
Economically useful products	Economically useful plants Timber, rice, grass, vegetation type	Nagendra (2001); Coppolillo et al. (2004); Polasky et al. (2005);
Forest production	Eco forestry potential	Kremen et al. (1999); Faith et al. (2001); Faith & Walker (2002)
Cultural		
Aesthetic value	Environmental variables[a] and mixed forest	Bojorquez-Tapia et al. (1995); Natori et al. (2005)
	Outstanding scenic features and landscape quality	Cowling et al. (2003)
	Scenic rivers	Hoctor et al. (2000)
	Landscape quality	Arriaza et al. (2004)
	Photos and environmental variables[a]	Mendel & Kirkpatrick (1999)
Cultural value	Valued species	Coppolillo et al. (2004); Phua & Minowa (2005)
Ecotourism	Accessibility, expert knowledge	Kremen et al. (1999); Cowling et al. (2003);
Environmental education	Vegetation types, accessibility	Bojorquez-Tapia et al. (1995)
Recreation	Expert knowledge	Cowling et al. (2003); Kurttila & Timo (2003)

[a] – Environmental variables refer to any combination of slope, elevation, rainfall, soil depth, geology and topology.
Source: according to Egoh (2007).

(2005) treats carbon storage as a regulating service and tree species as an ES, provider with a biomass accumulation rate as an efficiency measure. Another example of a regulating service is the crop pollination provided by bee species (or the bee community) measured by pollen deposition per visit, seed or fruit set with and without bees (Kremen 2005). Balser and Firestone (2005) estimated nutrient cycling as one of the supporting services provided by soil microorganisms measured by the rate of processes. It should also be emphasised that the values of the same ecosystem services differ when they are described for units of different spatial scales like those mentioned above. It is important to define the spatial scale of influence of a given service, from local to regional to global. Results for biocoenoses differ significantly from those obtained for the landscape scale. It is thus necessary to find aspects of research shared by the two approaches. Kremen (2005) lists the following four

Table 6. Examples of efficiency measures for different ecosystem services identified from the literature; services are classified as regulating or supporting according to the Millennium Ecosystem Assessment (2003).

Service classification	Service	Ecosystem service provider	Efficiency measure(s)	References
Regulating	carbon storage (per capita)	tree species (per capita)	biomass accumulation rate	Balvanera et al. (2005)
	crop pollination	bee species (per capita) or community	pollen deposition per visit; seed or fruit set with and without bees	Kremen et al. (2002); Klein et al. (2003)
	crop pollination	bee species (per capita)	ratio of pollen deposition to removal	Thomson & Goodell (2001)
	disease control	vertebrate host species (per capita)	disease dilution rate	Ostfeld & LoGiudice (2003)
	leaf litter decomposition in streams	stream invertebrate species (per capita)	leaf-shredding process rate	Jonsson et al. (2002)
	pest control	insect parasitoid species	parasitism rate	Kruess & Tscharntke (1994)
	dung burial	dung beetle species (per capita)	burial rate	Larsen et al. (2005)
	water flow regulation	forest habitat	water flow rate	Guo et al. (2000)
	invasion resistance	herbaceous community	invader biomass m^{-2}, change in resident biomass/unit invader	Zavaleta & Hulvey (2004)
Supporting	bioturbation	benthic marine invertebrate species (per capita)	bioturbation potential index	Solan et al. (2004)
	nutrient cycling, mineralisation	soil microbial community/ functional groups	process rates	Balser et al. (2001)
	above-ground net primary productivity	herbaceous community	biomass accumulation rate	Reviewed in Schmid et al. (2001)
	mineralisation and decomposition	herbaceous community	N leaching or retention; decomposition rate; microbial biomass, etc.	Reviewed in Schmid et al. (2001)

Source: Kremen (2005).

common planes of research: 1) identification of the most important ES and their providers, 2) determination of the various aspects of biocoenosis structure that influence the landscape and stabilise its functions or compensate for the consequences of non-random events (e.g. extinction or other disturbances), 3) the evaluation of key environmental factors influencing ecosystem services, 4) the determination of the spatio-temporal scale of activity of the provider and ecosystem services.

As has been indicated, the concept of ecosystem services has been used in ecological research. Abiotic factors, such as sunlight, precipitation, or nutrients, taken into account in ecosystem function studies, are the causative force behind many ecosystem services. They may be conceptualised as a three-level structure involving intermediate services, final services and benefits there from. This approach is supposed to lead ultimately to an economic valuation of services. Some examples of relationships between abiotic inputs, intermediate services, final services and benefits are presented in Table 7 (Fisher & Turner 2008). The authors show, as an illustration, the relationship between sunlight, rainfall, nutrients (as abiotic inputs), soil formation (as an intermediate service), water regulation (as a final service) and water for irrigation, drinking water and electricity from hydropower (as a benefit).

Costanza (2008) also introduced another division of ecosystem services involving two economic concepts, namely, excludability and rivalness. The author presented these two opposing characteristics in a matrix embracing four categories of goods

Table 7. Illustrative example of relationships between some intermediate services, final services and benefits.

Abiotic inputs	Intermediate services	Final services	Benefits
Sunlight, rainfall nutrients, etc.	soil formation primary productivity nutrient cycling	water regulation	water for irrigation drinking water electricity from hydro-power
	photosynthesis pollination pest regulation	primary productivity	food timber non-timber products

Source: according to Fisher and Turner (2008).

and services (Tab. 8). The author suggests that goods and services are excludable when, for example, they are privately owned (the use of such goods and services may be banned until payment is effected). At the same time, the exclusion of goods and services is not possible when they are public (for example, fishing in the open ocean or the aesthetic value of forests). The same "philosophy" applies to rivalness. Costanza (2008) uses the following example of goods derived from services "if I eat the tomato or the fish you cannot eat it". Conversely, as regards goods ensuing, for example, from a "well-regulated climate", if I benefit from them, "you can also do the same". The author notes that excludability is in most cases a function of service supply (i.e. to what degree can producers exclude users), while rivalness is a function of demand (to what extent do the goods produced depend on other users) and it seems more of a characteristic of the goods and services themselves.

Rudolf S. de Groot of Wageningen University & Research Centre, a leading theoretician of ecosystem services, presented a tentative classification and some definitions of ecosystem services for use in spatial planning, landscape management and design (de Groot et al. 2002, 2010). The classification comprises 23 ecosystem services combined into 4 basic groups: 1) provisioning, 2) regulating, 3) habitat or supporting, 4) cultural and amenity. He also listed the ecological processes responsible for the provision of particular services and indicators describing the efficiency of particular ecosystem services and key indicators of their continuing provision (Tab. 9).

Table 8. EcoServices classified according to rivalness and excludability.

ES	Excludable	Non-Excludable
Rival	Market Goods and Services (most provisioning services)	Open Access Resources (some provisioning services)
No-rival	Congestible Services (some recreation services)	Public Goods and Services (most regulatory and cultural services)

Source: according to Costanza (2008).

Table 9. Potential indicators for determining (sustainable) use of ecosystem services

Services, comments and examples	Ecological process and/or components providing the service (or influencing its availability) = function	State indicator (how much of the service is present)	Performance indicator (how much can be used/provided in a sustainable way)
Provisioning			
1. Food	presence of edible plants and animals	total or average stock (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^3ha/year)
3. Fiber & Fuel & other raw materials	presence of species or abiotic components with potential use for timber, fuel or raw materials	total biomass (kg/ha)	net productivity (kg/ha/year)

Services, comments and examples	Ecological process and/or components providing the service (or influencing its availability) = function	State indicator (how much of the service is present)	Performance indicator (how much can be used/provided in a sustainable way)
4. Genetic Materials: genes for resistance to plant pathogens	presence of species with (potentially) useful material	total „gene bank" value (e.g. number of species and 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 and 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 effect emitted – effect on climate parameters
9. Natural hazard mitigation	role of forests in dampening extreme events (e.g. protection against flood damage)	water-storage (buffering) capacity in m^3	reduction of flood-danger and damage to infrastructure prevented
10. Water regulation	role of forests in water infiltration and gradual release of water	eater retention capacity in soils, etc. or at the surface	quantity of water retention and influence of hydrological 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); immobilisation in plants and soil	max amount of chemicals that can be recycled or immobilised 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. bioturbation	amount of topsoil (re) generated per ha/year
14. Pollination	abundance and effectiveness of pollinators	number and impact of pollinating species	dependence of crops on natural pollination
15. Biological Regulation	control of pest populations through trophic relations	number and impact of pest-control species	reduction of human diseases, livestock pests, etc.
Habitat or supporting			
16. Nursery habitat	importance of ecosystem to provide breeding, feeding or resting habitat for transient species	number of transient species and 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 (inc. 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", tranquillity	number /area of landscape features with stated appreciation	expressed aesthetic value, e.g.: number of houses bordering natural areas or users of "scenic routes"

Services, comments and examples	Ecological process and/or components providing the service (or influencing its availability) = function	State indicator (how much of the service is present)	Performance indicator (how much can be used/provided in a sustainable way)
19. Recreational: opportunities for tourism and recreational activities	landscape features, attractive wildlife	number/area of landscape and wildlife features with stated recreational value	maximum sustainable number of people and 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	number of 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 and religious inspiration	landscape features or species with spiritual and religious value	presence of landscape features or species with spiritual value	number of people who attach spiritual or religious significance to ecosystems
23. Education and science opportunities for formal and informal education and 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.

Source: according to de Groot et al. (2010).

Inspiration may come from the example of application of ecosystem services to the analysis of the functioning of riparian ecosystems presented by Soman et al. (2007). Based on research by de Groot (1992), the authors linked services to ecosystem functions, grouped into four elementary types: 1) regulation, 2) habitat, 3) production, and 4) information (Tab. 10). Regulation functions refer to the capacities of natural and semi-natural ecosystems and regulate basic ecological and life-supporting processes by biogeochemical cycles (e.g. carbon cycling) and other biological processes (e.g. photosynthesis). Habitat functions safeguard the physical needs of man, fauna and flora (e.g. living space for plants and animals; habitats for biocoenoses with rare, threatened and endangered species; and the provision of travel corridors for migration). Information functions supply cognitive and recreational possibilities, especially those derived from natural ecosystems. Production functions are ecosystem goods produced naturally without human involvement; however, humans must expend time and energy to obtain them (e.g. collecting mushrooms and berries).

Table 10. Riparian Ecosystem Function and Services.

Number	Ecosystem Function	Ecosystem Services	References
1. Regulation Function			
1.1	gas regulation	Role of riparian ecosystem in biogeochemical cycles. Provides clean breathable air.	Wilson et al. (2005)
1.2	climate regulation	Influence of land cover and biologically-mediated process on climate. Influence terrestrial and stream temperature, human health, recreation and crop productivity. Thermal refuge for aquatic species.	Collier (1995); Wegner (1999); Woodall (1985); Wilson et al. (2005); de Groot et al. (2002), Cunjak (1996); Waters (1995)
1.3	disturbance prevention	Influence of ecosystem structure on dampening environmental disturbances such as flood attenuation, ice damage control, stream bank stabilisation, maintaining channel morphology. Biological control mechanisms.	Postal & Carpenter (1997); Fischer & Fischenich (2000); Platts (1981); Wegner (1999); Williams (1983); de Groot et al. (2002)
1.4	water regulation	Role of riparian cover in regulating runoff and stream flow. Infiltration and maintenance of stream flow.	Williams (1986); Lowrance et al. (1984)
1.5	water supply	Filtering, retention, and storage of fresh water. Riparian buffers filter sediments, nutrients, pathogens, pesticides, and toxics in runoff. Infiltration of surface water that helps maintain base flow. Water supply and ground water recharge.	Fischer & Fischenich (2000); Waters (1995); Chase (1995); Hartung & Kress (1977); Peterjohn & Correll (1984)

Number	Ecosystem Function	Ecosystem Services	References
1.6	soil retention	Role of vegetation root matrix and soil biota in soil retention. Reduce soil erosion and sediment control.	Waters (1995); Castelle et al. (1994)
1.7	soil formation	Weathering of rock, accumulation of organic matter. Maintenance of topsoil and soil fertility.	de Groot (1992)
1.8	nutrient regulation	Storage and recycling of nutrients such as N and P and organic matter. Contribution of organic matter to stream from adjacent vegetation.	Barling & Moore (1994); de Groot (1992)
1.9	waste treatment	Role of riparian vegetation and biota in removal or breakdown of xenic nutrients and compounds. Storage and recycling of human waste.	Castelle et al. (1994); de Groot (1992)
1.10	pollination	Role of biota in pollination.	de Groot (1992)
2. Habitat (Carrier) functions			
2.1	refugium function	Suitable living space for wild animals and plants. Woody debris in the stream provides habitat and shelter for aquatic organisms. Terrestrial riparian ecosystem provides habitats for amphibians, mammals and birds. Habitat for natural communities, rare threatened and endangered species. Provide travel corridors for migration and dispersal.	Chase (1995); Verry et al. (2000); Allan (1995); Wenger (1991, 2002); Kaufman (1992); Keller et al. (1993); Naiman & Rogers (1997); Hammond (2002)
2.2	nursery functions	Suitable reproduction habitat for aquatic organisms and amphibians.	Semlitsch (1998); de Groot (1992)
3. Production Function			
3.1	food	Conversion of solar energy into edible plants and animals.	de Groot (1992); Wilson et al. (2005)
3.2	raw materials	Conversion of solar energy into biomass for human construction and other uses. Genetic materials.	de Groot (1992); Wilson et al. (2005)
4. Information Function			
4.1.	aesthetic information	Attractive landscape features. Clear and clean water enhances sensory and recreational qualities.	de Groot (1992); Wilson et al. (2005)
4.2	recreation	Water quality for recreation, boating, swimming.	de Groot (1992); Wilson et al. (2005)
4.3	science and education	Variety in nature with scientific and educational value.	de Groot (1992); Wilson et al. (2005)

Source: according to Soman et al. (2007).

Diversity of ecosystem services and correlations between them

Turner et al. (2010) state that at the basis of the theory and practice of ES is the need to understand the economic value of nature, and the role of nature's services is becoming increasingly important in shaping local, national and global policies and decision making. This trend should be regarded as connected to the evidently spatial nature of ecosystem services and the ensuing benefits.

Contemporary research mandates the simultaneous study of multiple ecosystem services and other issues, such as emerging trade-offs, local support policies, or use in spatial planning and management. Lavorel et al. (2011), on the basis of a study conducted in grassland ecosystems of the French Alps, propose a new approach to the study of ecosystem services, consisting of the development of a spatial model of ES combining plant traits and abiotic environmental characteristics to identify *hot* and *cold spots* for the provision of ecosystem services. The authors suggest that this approach will make it possible to specify the determinants of ES distribution (Fig. 1). The analysis began by studying the traits of the plant community in the landscape. The aim is to understand the ecological mechanism underlying the provision of services. The recognition of various functions of plants and ecosystem services translates into the identification of existing trade-offs or synergies between services. A sustainable approach to the management of species and grassland ecosystem functions has a twofold goal of protecting both

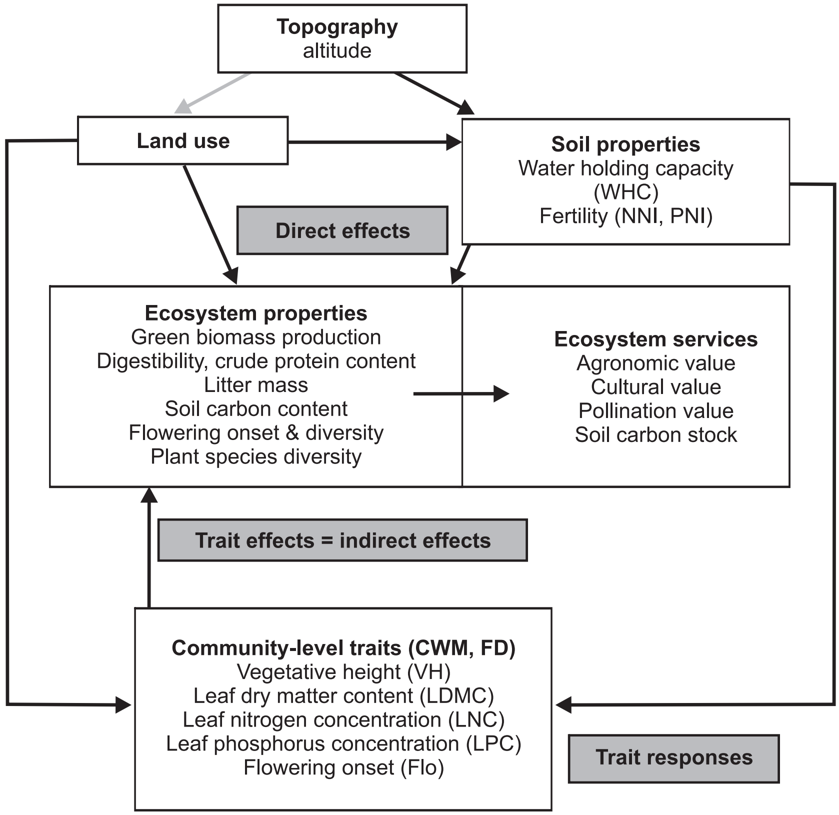

Figure 1. Conceptual framework for analysis of ecosystem properties underlying ecosystem services.

Source: according to Lavorel et al. (2011).

biodiversity and locally important ecosystem services. It should take into account correlations as well as antagonisms between different plant traits (Lavorel et al. 2011). The height of vegetative parts of plants and leaf dry matter are traits "responding" to various forms of land use and abiotic factors, and are therefore good indicators of changes in ecosystem properties that can be used as characteristic measures of ES. The two traits listed above (vegetative height and leaf biomass) may serve to identify both suggestions for agriculture and hot and cold spots for the presence of a particular ecosystem service. Traditional agriculture, based on natural fertilisers and summer grazing, is a hot spot as the service (food production and quality) is combined with the specific and functional diversity of a given spatial unit, especially the ecosystem and landscape.

Land use patterns, biodiversity and ecosystem services are closely related to each other. Many animal and plant species, which provide ecosystem services are associated with rural areas and depend substantially on traditional extensive land management practices. This is the underlying cause of differences between Western, Central and Eastern Europe with regard to services provided by agrocoenoses. In the opinion of many authors, intensively managed agroecosystems provide fewer ecosystem services compared to natural agroecosystems (e.g. Rosin et al. 2011). It is all the more relevant as the changes in agriculture are so immense, especially in Western European countries, that they have led to the fragmentation and loss of semi-natural habitats (boundary strips and woods in fields, hedges) and, as a result, to the creation of large monocultures. Consequently, the population sizes of numerous plant and animal species providing ecosystem services have been considerably reduced. The first step towards rational application of the concept of ES in Central and Eastern Europe is to recognise the differences between natural and artificial agricultural production systems. The prevailing principle is that high biodiversity has a beneficial effect on agricultural produce and quality of life.

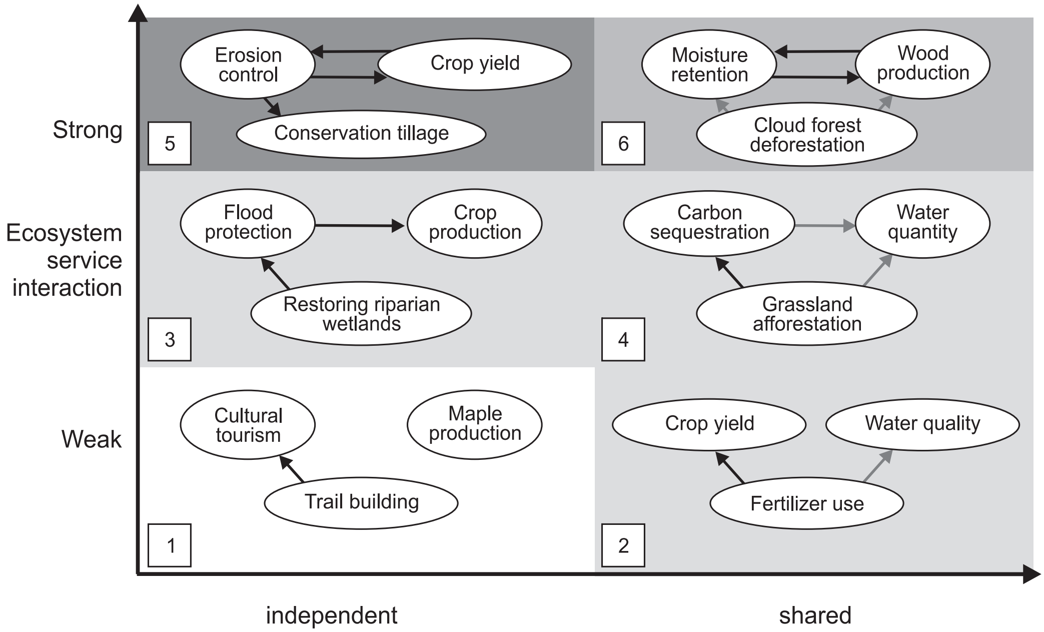

Figure 2. Impact of driver on multiple ES.

Source: according to Bennett et al. (2009).

Bennett et al. (2009) note that an abundance of ecosystem services at different levels of organisation of nature gives rise to a number of relationships between these services. This is due to the action of drivers, which significantly modify particular services. The authors point out that before commencing ES research, whether on an ecosystem or landscape scale, the researchers need to develop a model of relationships and action relations between relevant services and their drivers. The use of an ecosystem/landscape will frequently lead to increased production of one type of service and a major decline in the production of another (Bennett et al. 2009). A sample model of interactions between various ecosystem services and causative factors (drivers) developed by these authors is presented in Figure 2 (where black and grey arrows indicate positive and negative effects, respectively).

In the left lower corner of Figure 2 (Sector 1), a driver (trail building) has a positive effect on cultural tourism (Service A). This service, in turn, has no effect on, say, the production of maple syrup (Service B). In Sector 2, the driver (fertiliser use) has an effect on both services, but the services do not influence one another. In the example provided, fertilisation has a positive effect on crop yield, and a negative one on water quality. It may also be supposed that a particular driver has both negative and positive effects on both services. In Sectors 3 and 4, there is a unidirectional relationship between services, i.e. the amount of Service A influences the provision of Service B, but not vice versa. Sectors 5 and 6 show bidirectional relations between services. The provision of Ecosystem Service A influences the supply of Service B, and Service B has an effect on Service A. There can be positive and negative relations.

The essence of relationships between ecosystem services and drivers and the resultant trade-offs or synergies are exemplified in Table 11 (Bennett at al. 2009). For example using a fertiliser (driver) positively influences crop production (service A) but negatively affects water quality (service B) creating a trade-off between them. Another such example is connected with afforestation (driver) which positively influences carbon sequestration (service A) but negatively affects quantity of water (service B) creating a trade-off (conflict) between the two services mentioned. Table 11 also demonstrates synergies among services. For example restoration of riparian vegetation (driver) positively influences flood control (service A) and in the same way crop production (service B), creating synergy between both services. The same is connected with the wetland restoration (driver), flood control (service A) and water quality (service B). As we can see from the drivers and relationships among multiple services, this illustrates a number of cases where it is possible to observe trade-offs or synergies between two services (A and B) – Table 11.

Environmental Services (PES). PES programmes aim to allocate some part of the benefits from ecosystem services (such as clean water) to entrepreneurs who work with these services as an encouragement to promote these services (Pagiola et al. 2005).

Table 11. Examples of ecosystem service relationships.

Sector	Driver	Service A	Service B	Shared driver	Response type	Interaction type	Synergy/ trade-off	References
1	Trail building	cultural tourism	agricultural production	no	–	none	none	Brscic (2006)
2	Fertiliser use	crop production	water quality	yes	opposite	none	trade-off	Carpenter et al. (1998)
2	Wolf reintroduction	nature tourism	floodplain maintenance	yes	similar	none	synergy	Wolf et al. (2007)
3	Restoring riparian vegetation	flood control	crop production	no	–	unidirectional, positive	synergy	Kramer et al. (1997)
3	Maintaining forest patches close to coffee plantations	pollination	crop production	no	–	unidirectional, positive	synergy	Ricketts et al. (2008)
4	Wetland restoration	flood control	water quality	yes	similar	unidirectional, positive	synergy	Zedler (2003)
4	Afforestation	carbon sequestration	water quantity	yes	opposite	unidirectional, negative	trade-off	Engel et al. (2005)
4	Marine protected area development	regulation of algae growth	tourism	yes	similar	unidirectional, positive	synergy	Huges et al. (2005)
5	Dry spells	C sequestration/ soil organic matter	crop yield	no	–	bidirectional, positive	synergy	Enfors et al. (2008)
5	Pesticide spraying	wood production	pest control	no	–	bidirectional, negative	trade-off	Clark et al. (1979)
6	Cloud forest land clearance	moisture retention	carbon sequestration and tree growth	yes	similar	bidirectional, positive	synergy	del Val et al. (2006)

Source: according to Bennett et al. 2009.

Summing up

The set of services that should be evaluated and taken into account in further work and whose ultimate area of application is nature conservation, ought to depend on the roles these services play in the ecosystem/landscape and on their specific features. The specificity of services provided by a spatial unit should not be undervalued as recent years have brought evidence that it is advantageous to pay for ecosystem services in order to protect them. This is known as Payments for

The special physical and geographic properties and spatial scale of a given unit together with its intended and actual use impoase a requirement to find the ecosystem services best suited to this unit. In an agricultural landscape, besides food production, examples of good ecosystem services may include those listed by Rosin et al. (2011):
- pollination and pollinators,
- weeds and invasive plants,
- ecotourism on agricultural land, including bird watching,

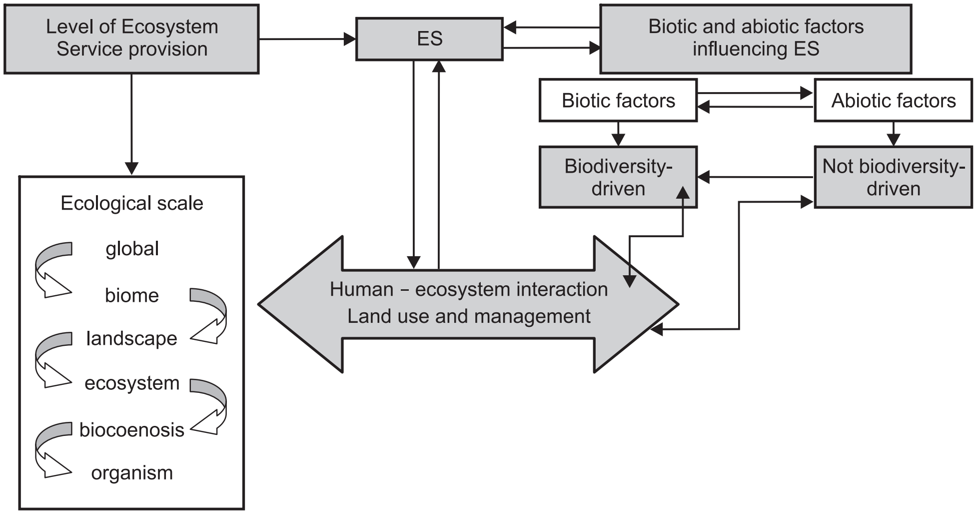

Figure 3. Connection between provision of ES and biotic/abiotic factors at different spatial scales.

– biological control/quantitative relations between harmful and beneficial organisms (unfortunately, the current, actual and potential level of biological control viewed as an ecosystem service remains unknown, and therefore – importantly – the value of such services is probably very much underrated).

Even though this article only briefly touches upon the economic aspects and the valuation of ecosystem services, it should be emphasised that ES are connected with the entire economic and ecological system. Ecosystems and economic systems ought to be analysed with regard to human preferences. Importantly, the "humanist" approach to nature has been gaining popularity. The evaluation of ecosystem services necessarily involves making a choice between the value of ES, the consumption of raw materials, and the prevention of drastic changes to the ecosystem.

Planning ES research should combine elements of approaches adopted by widely understood natural and social sciences. The scope and methodology of ES research always depends on the specific characteristics of the area where services are to be quantified and evaluated and it should also account for recipient expectations.

With regard to the ecological scale of provision of ecosystem services at different levels of nature organization and in different spatial scales, two fundamental determinants, namely the magnitude and quality of these services, need to be taken into account. These two determinants are in turn dependent on human activity related to land use patterns and space management and on biotic factors secondary to biodiversity, as well as on all abiotic factors that integrate the functions of an ecosystem, landscape, biocoenosis, etc. In view of the above considerations, and particularly the connections between the provision of ecosystem services and biotic/abiotic factors in various spatial scales, we present a scheme that can be used at the preliminary stage of planning research, especially ecological research, on ecosystem services (Fig. 3). In the first step, everyone who plans, or has to do an evaluation of specific ecosystem services, and has a down-to-earth approach to ecosystem services problems, should draw up a list of ES essential for nature and a society of research units. These chosen ES play a vital role in the economic life of society and in a fundamental way provide another one specific service.

Accordingly, the quantification of ecosystem services requires a qualitative and quantitative assessment of both abiotic and biotic (biodiversity-driven) factors influencing a given service. It is also necessary to determine the value of interactions between selected factors characteristic of a given natural unit and the recognition of the effect of these interactions on the ecosystem service.

Editors' note:
Unless otherwise stated, the sources of tables and figures are the author(s), on the basis of their own research.

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