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Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics

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ABSTRACT

The ecosystem services approach is an established framework for the balanced evaluation of ecological, economic and social landscape resources. It promotes functional synergies (win–win situations) as well as trade-offs among various benefits resulting from ecosystem processes. Spatial aspects of heterogeneity and configuration play a major role in maintaining biodiversity and ecosystem services and hence in human wellbeing. Cultural artifacts also contribute to landscape functionality. Because of the underlying areal aspects, an additional term, landscape service has been proposed and is increasingly used (Termorshuizen and Opdam, 2009). We take a particular interest in spatial aspects of this framework and the optimization of trade-offs between landscape services.

Firstly, spatial heterogeneity is assessed by means of landscape metrics computed as indicators for landscape services. Landscape heterogeneity is a key measure of biodiversity and contributes to several valuable functions. Habitat connectivity and other measures of landscape structure are also essential criteria for the behavior of metapopulations and for recreational value.

Secondly, service providing areas (SPAs) are discussed as the areal basis for service provision. Similarly, service benefiting areas (SBAs) and connecting areas (SCAs) for the transfer of matter, energy and organisms between them are investigated. Place-based assessment addresses such areas. We thus show possibilities for estimating and evaluating landscape units.

Thirdly, the landscape consists of the natural environment, artifacts from past human use, current human activity and even social thinking. The landscape services approach in a wider sense allows us to take social/cultural services better into account because they depend strongly on heritage assets, structural characteristics, historical conditions end even cultural specifics; which can hardly be subsumed to ecosystems. Place-based assessment is an appropriate solution for combining several spatial categories.

1. Introduction

Fisher et al. (2009) point out that ecosystem services are “not homogeneous across landscapes or seascapes, nor are they static phenomena.” This is highly relevant for almost all services. It is also methodologically important because both direct evaluation and benefit transfer tend to use area measures as proxies (Plummer, 2009). But the concept developed by de Groot et al. (2002) does not describe how spatial relations are taken into account in the valuation process (Blaschke, 2005). Indicators for ecosystem services should relate to pertinent spatial resolutions. Dale and Polasky (2007) give examples highlighting the importance of the spatial dimension. Services are usually provided within process-related landscape units such as watersheds (Pretty et al., 2000), specific habitats, or natural units (Haase and Mannsfeld, 2002). These land-use units suggest place-based assessment. Nevertheless, cause and effect areas are frequently imprecisely allocated to the processes investigated. The empirical data on these spatial issues is widely dispersed and require more systematic evaluation. Costanza (2008) has developed a sound concept for classifying ecosystem services according to spatial characteristics, which opens the door to the more structure-dependent indicators and methods we describe below. Anderson et al. (2009) conclude that “there are few studies on which to base conclusions about the spatial relationships between habitats important for different ecosystem services and benefits for biodiversity”. Generally, such data are scarce, and so spatial correlations between ecosystem services have often been assumed rather than demonstrated (e.g. Troy and Wilson, 2006; Turner et al., 2007). Notable examples of attempts to estimate the relevant spatial relationships include the study by Chan et al. (2006).

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This paper investigates the spatial characteristics of ecosystem services and how they relate to quantified measures of landscape structure. We enhance our knowledge about the underlying processes with tried and tested methods, units and indicators from the literature. An outstanding advantage of the ecosystem services approach is that it shows the conditions under which nature creates benefits. But the areas that provide services can in many cases differ from those that benefit from these services. If it were possible to assign a generally accepted value to services, it would be easier to identify beneficiaries and perhaps support providers (Wunder, 2006). Once the appropriate units have been established, landscape structure can be precisely quantified. So-called landscape metrics offer great potential for place-based ecosystem service assessment, which has hardly been employed to date. The most promising landscape metrics are therefore collected and their process-related use explained.

The landscape services approach is referred to as such because of this spatial perspective (Termorshuizen and Opdam, 2009) on a local scale with a marked planning perspective. We seek to refine it on the basis of new insights and methodological proposals for including place-based assessment and structure metrics. In particular, spatial attributes allow more specific evaluation, not least for benefit transfer (Plummer, 2009). The main issues addressed by the paper are, first, where services are generated and what the underlying spatial structures are and, second, who benefits from services and how they relate to the providing area. We consider the term ecosystem service as a synonym for landscape service in general, but we use the latter if we highlight spatial relationships.

2. Spatial characteristics of ecosystem services

2.1. Providing, benefiting and connecting areas

Brauman et al. (2007) ask "What is the spatial relationship between ecosystem service supply and consumption? They outline "As human population densities increase, there is often a spatial mismatch between the places where humans use ecosystem services and the location of ecosystems that produce them. Because of this, feedbacks to ensure the continued provision of services may not exist. Moreover, risk of impairment is greatest in areas where land conversion happens most rapidly, often the same places where people depend most directly on ecosystem services. Some ecosystem services are transportable, whereas others are not. Identification of key ecosystem service source areas would aid in ensuring continued delivery." Examination of the spatial relationships between scientifically assessed and local priorities can identify hotspots of value alignment and conflict. Where conflict exists, the method could be used to help participants understand other stakeholders' perspectives and to negotiate alternative resource management futures which provide for multiple ecosystem services, whilst limiting harm to others (Raymond et al., 2009).

A first approach to considering area characteristics is suggested by Egoh et al. (2007), who extend the species approach of Kremen (2005) and Le Maitre et al. (2008) to connected habitat types. This allows abiotic features such as soil property, water supply, and other place-based characteristics to be included in assessment. The second main issue is the sometimes varying allocation of supply and demand for the services.

2.1.1. Service providing areas

Shifting the focus from ecosystems and species to the diversity of habitat mosaics and consequently to the structure of whole landscapes, this paper examines where services are generated and what the underlying spatial structures. Following Fisher et al. (2009), we call the spatial units that are the source of landscape services 'service providing areas' (SPAs). These units are also defined in terms of the above-mentioned species and populations approaches, providing the methodological basis for assessing a wide range of landscape classification units (Burkhard and Diembeck, 2006; Porter et al., 2009). Since landscape units can include land use stakeholders as well as wildlife populations, the SPA is a promising basis for combining several levels into a comprehensive landscape services approach.

2.1.2. Service beneficiaries and benefiting areas

In spatial analysis, not only the 'source' area of a service is of interest but also the 'demand'. Where are benefits required? We propose distinguishing service benefiting areas (SBAs) as the complement to service providing areas (cf. Fisher et al., 2009). Benefiting areas may be far distant from the relevant SPAs, raising the question whether a service can be supplied to those demanding it. But the structural characteristics of a benefiting area must be such that the area can take advantage of a service. For instance, the building stock must allow fresh air from the surroundings to circulate, and surface sealing must be minimized to maintain bio-climatic functions (Rößler, 2010).

2.1.3. Service connecting areas

If providing and benefiting areas (SPAs and SBAs) are not contiguous, the intervening space affects process variables. For example, a river course, retention spaces, natural floodplains, and reservoirs can have a critical effect on any flood wave (Fig. 3). The situation is not as clear for many other services. For every service, areas and actors have to be identified in order to handle barriers and to avoid free riders. A complete and clear landscape services framework requires the intervening space to be taken into account. Connecting providing and benefiting areas, it can be referred to as a service connecting area (SCA). Artificial solutions for connecting providing and benefiting areas should be taken into account, for example the long-distance piping of drinking water to towns or densely settled areas. Most important, however, are natural processes such as the infiltration of water in karst regions (SPA) and long-distance underground transport (SCA), so that springs and water consumption (SBA) are far distant from the area of origin. The same is true for the creation of fresh, cool air in forested or open land (SPA) and its transport downhill along hollows and valleys (SCA) to settlements (SBA). It is particularly important to consider the relief and height of surface objects for such processes within the SCA (Wende et al., 2010).

2.1.4. Positional relations of SPA, SCA and SBA

SPA and SBA may overlap to some degree, but gaps are also possible. For instance, flood protection is provided mainly in the mountains and benefits cities on the middle and lower reaches of a river. Fisher et al. (2009) distinguish four types of spatial relationship between SPA and SBA (Fig. 1).

Of course, this is true only as long as interconnections are embedded in the same scale. Otherwise we can find scale trade-offs, meaning, for instance, that service provision is local and benefits global or vice versa (Fig. 2). Divergences between service provision and benefit can cause trade-offs associated with market failure and social imbalances (Ring et al., 2010). Besides temporal and interpersonal trade-offs, spatial trade-offs in a given scale or across scales need to be addressed here.

The classification by Costanza (2008) is quite similar: the classes 'in situ', 'local proximal' and 'directional flow related' correspond to the first three classes above. The 'user movement' class of Costanza (2008) draws attention to the necessity of differentiating supply and demand structures. Costanza's first class 'global non proximal' points to the issue of scale dependency. The four cases of Fisher

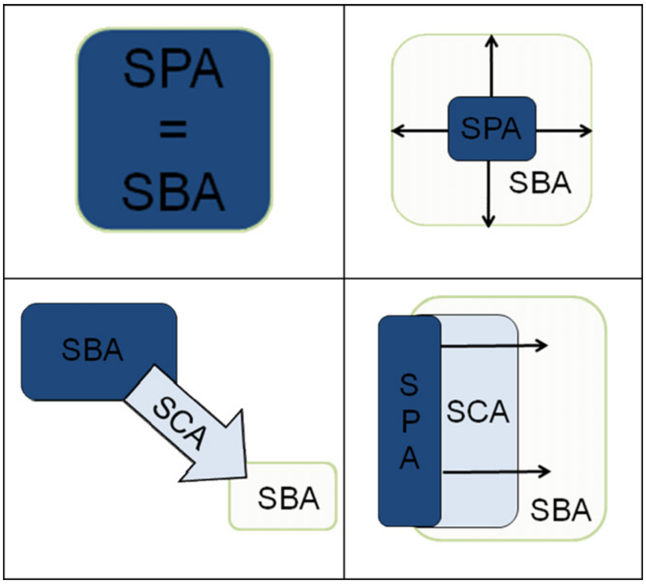

Fig. 1. Possible spatial relationships between service providing area (SPA) and service benefiting area (SBA) (according to Fisher et al., 2009): upper left: 'in situ': SPA and SBA are identical, i.e. the service is provided and benefits realized in the same area. Upper right: 'omni directional': SBA extends SPA without any directional bias. Lower left: 'directional' – slope dependent: SBA lies downslope (downstream) from SPA, i.e. the service is realized by gravitational processes (cold air, water, avalanche, landslide). Lower right: 'directional' – without strong slope dependence: SBA lies 'behind' the SPA relating to higher-ranking directional effects.

et al. (2009) thus have to be complemented by the 'scale transfer' variant in Fig. 2.

2.2. Spatial units as valuation reference

Delineating the areas mentioned above could prove difficult and complex. The use of known spatial units with existing (digital) borders is therefore to be recommended. Various types of unit can usefully represent SPAs, SBAs, and SCAs.

Service providing areas (SPAs) comprise ecosystems, their populations and physical components. Hence, the most appropriate spatial units are those that obviously host the ecosystems (biotopes, water bodies, soil units) or the effect areas of related processes (floodplains, watersheds). Such ecological units could be more suitable than administrative units. Preferable indicators for characterizing SPAs are natural parameters or landscape metrics.

Service benefiting areas (SBAs), in contrast, do not relate primarily to ecosystems but to beneficiaries. Spatial units for SBAs are accordingly more likely to be urban areas, rural settlements, administrative and/or planning units. We need different indicators to describe the characteristics of SBAs regarding the vulnerabilities,

Fig. 2. Scale divergence between service providing area (SPA) and service benefit area (SBA), regarding the preservation of a given type of rainforest as an example. *Map source*: www.nature-escapes-kuala-lumpur.com.

needs and demands of the people concerned. For instance, population density or the number of households and other demographic measures are to be considered as indicators for SBAs (cf. Section 2.3). Depending on different characteristics of landscape services, the following spatial units are suitable as basis for assessment. If the services are:

1. generated by specific ecosystems or populations: suitable habitats,
2. based on selected resources: natural unit with the given resource,
3. dependent on certain site characteristics: land unit with similar spatial relations,
4. reproduced by a physical process: physical unit as effect area of that process, contingent on land use practices: landscape unit with selected land use composition,
5. rooted in history and culture: cultural heritage landscape (elements).

The example cited above of the river and connecting (flood) water regulation services requires place-based treatment where the physical unit is the watershed or certain parts of it (upper part, higher order, etc.) if divided into SPA, SBA and SCA. Watersheds are typical physical units that can be delineated by current methods on the basis of digital elevation models (DEM) and which are therefore frequently used as assessment units for water-bound services.

A number of spatial units are mentioned in the literature on ecosystem services (see also Table 3), but mostly in general terms and without any direct relation to a specific service. The following can be said:

- Single patches, land use parcels or landscape elements are the most widely used spatial basis for assessment in general.
- The combined use of several indicators and data sources leads to the "smallest common geometry" generated by GIS (Geographical Information System) overlay functions. This approach requires high data volumes and cannot ensure a spatially logical concept due to the sheer number of polygons. Sometimes, spatial units with a defined heterogeneity could be useful, particularly if biodiversity or land use patterns are the subject of analysis.
- Administrative units are useful as far as corresponding data sources have to be used, for instance social indicators, legal and planning regulations. These units are mostly predefined by the areas of interest of a given project. Admittedly, administrative units are seldom really suitable with regard to ecosystem processes.
- Watersheds are useful as the basis for all functions provided by water-related landscape processes. They are used for such services as habitat evaluation, scenic beauty, flood prevention, and water purification.
- Natural units should be used as long as mainly natural characteristics (soil, surface, climate, geological, vegetation) determine a service or if the available data relate to them. Burkhard and Diembeck (2006) propose a comparison of natural units with SPA, the United Nations Statistic Divison (UN SEEA, 2003) gives them as the preferred basis for monetary calculation, and the Department for Environment, Food and Rural Affairs (2007) for ecosystem definition.
- Landscape units delineated not only by natural situation but also by land use are useful for most functions, particularly on a larger scale. They are mentioned by de Groot (2006) as the basis for conflict analysis among landscape services, by ISCU et al. (2008) as the basis for biodiversity investigation, Maass et al. (2005) as the basis for sustainable studies including several (water) processes, Metzger (2008) as components of spatial heterogeneity, Naveh (2007) as container for total landscape ecodiversity, i.e.

Table 1
Landscape services dependent on lateral landscape processes and the corresponding area allocation of service areas (SPAs) and benefit areas (SBAs); service connecting areas (SCA) in parentheses if not discrete.

Service[a]	SPA	SBA	SCA
P groundwater recharge	Arable[b] and wetland in a groundwater basin	Built area, irrigated land in the basin	Pollution risk area in that catchment
P fodder and fertilizer	Pastures	Farms, stables	Pastoral paths
R protection against snowdrift, storm	Roadside wood, hedges, groves	Traffic area	(Road edges)
R erosion prevention—by wind—by water	Wood, hedges, groves around and between acre fields	Acre fields	(Field edges)
R flood prevention (compare Fig. 1)	Flood originating area	Built area within the floodplain	Floodplain upstream of built area
R climate regulation (cold/fresh air)	Open spaces uphill around a city	The city downhill	Depth contours and slopes around a city
R noise reduction	Roadside wood, hedges, groves	Residential and recreation area	(Along the noise source)
R avalanche and landslide prevention	Wood uphill a housing or recreation area	Housing/rec. Area near steep slopes	(Along the slope)
R pollination	Nesting habitats	Crops	Foraging area
R pest control	Nesting habitats	Crops	Foraging area
R stream water purification	Surface water bodies	Housing or recreation area	Water catchment
H habitat value	Sub-habitats for foraging, hunting, hibernating	Nesting habitats	Ecological networks
C appreciated scenery	Viewsheds[c]	Touristic infrastructure	(Within scenery units)
C recreation activities	Surface water bodies, mountains, wood	Touristic lodging units	Road and path network between

[a] P = providing services, R = regulating services, H = habitat services, C = cultural services.
[b] Depending on climate situation, also wood and grassland may belong to the SPU.
[c] "Viewsheds are a topographic concept, delineating the area from which a particular site can be seen." (Boyd and Banzhaf, 2006).

including cultural historical and humanmade artifacts, UN SEEA (2003) for accounting bio(tope)diversity, and, finally, as representative units of landscape used with varying intensity and as the spatial frame for practical management TEEB (2009).

It should, however, be noted that in nearly every case the delineation of spatial units simplifies reality, as the following statement shows: "Although ecologists recognize landscape units such as forests and lakes as ecosystems, they also accept that ecosystems are not self-contained: they have porous boundaries and both organisms and materials move between systems, often with important ecological consequences" (EASAC, 2009, p. 7). Against this background, two main obstacles to the place-based assessment can be identified:

- The process of delineating and classifying units is elaborate and uncertain. Since natural borders are rarely found within landscape, they must be defined manually. This is not only a challenging task; the results are also seldom scientifically undisputed. Clear principles and quantitative indicators are needed for the purpose.
- Although the units are in any case heterogeneous, most assessment schemes require homogeneous units with distinct characteristics. Data intervals can lead to incorrect results. Instead, methods are required that can work with greater scales using condensed data (see next section).

However, every ecological model is a simplification of the real world. For assessing landscape services, we propose to adapt units to the processes under consideration as well as possible. If we have to evaluate trade-offs, it may be meaningful to use the same spatial reporting unit for several services even though that spatial unit does not match ecological areas perfectly.

2.3. *Characterization of processes and assessment*

Once service providing, benefitting, and connecting areas have been designated, they can be described in terms of their properties, structure, type, and geography, which will be outlined below. Table 1 gives an overview of the areas suitable for place-based assessment.

2.3.1. *Service providing areas*

SPA characteristics are mainly natural and biophysical. They supply goods and services and enable underlying processes to regenerate. Analysis must also establish whether investment (protective or fostering measures) is needed to maintain the service. If so, the frequency of and financial support for all maintenance measures have to be ascertained, as well as the regulatory situation. Where natural capital is subject to depletion, a given replenishment rate should be determined to monitor withdrawal (cp. Ostrom, 1999).

The comprehensive characterization of SPA should at least point to:

1. a site classification as basis for evaluating benefits and benefit transfer (bt),
2. a detailed characterization of internal SPAs structure by means of landscape metrics,
3. an investigation of neighboring SPAs in relation to the process under consideration.

2.3.2. *Service benefiting areas*

SBA assessment is more of a social issue, bridging science and planning. Benefit requirements first have to be analyzed together with existing physical effects. Beneficiary claims, wishes and values in the area are to be represented by demand indicators. The extent of the beneficiary group needs to be established as a reasonable basis for evaluating services. Whereas thresholds are difficult to ascertain for natural processes, those for human vulnerability or withdrawal rates (see above) are crucial for assessing a number of functions. Consumable resources also require access rules. The kind of access (private, common or public) to a service and the possibility of exclusion is a distinguishing variable for the marketability and monetary evaluation of a service.

SBAs therefore have to be characterized in the first place in terms of beneficiary structures. Both socio-economic and physical data are required. Depending on the type of service, analysis should consider at least:

1. access to the desired service and exposure to more or less regulated natural hazards,
2. demand and consumption of environmental goods,

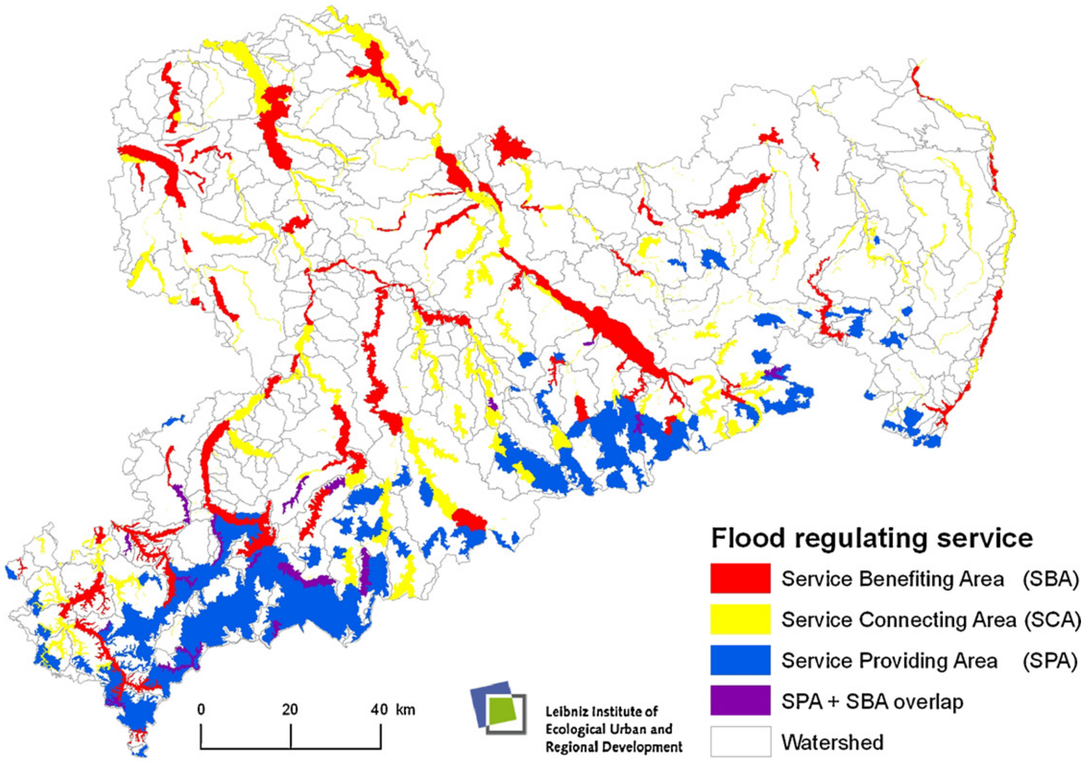

Fig. 3. Service providing areas (SPA), service benefiting areas (SBA) and service connecting areas (SCA) for the flood regulating service in Saxony (Germany) basing on natural units.
Source: Designed by the authors basing on Syrbe (2002).

3. vulnerability to environmental risks and to the depletion of resources,
4. regularities of allocation, acquisition power and precaution issues.

2.3.3. Service connecting areas

Even where an SCA does not exist independently because it is overlaid by the other two areas, specific analysis of the SCA can be useful, since lateral transfer processes could be impacted by site characteristics. If something is lacking between SPA and SBA, the connecting area has to be delineated. This can prove difficult. The main issues in SCA analysis are transportation and transformation processes. Differentiation of the three spatial types permits a more side-specific and therefore landscape related framework for assessing landscape services.

Useful attributes of a service connecting area are indicators of the areal and functional connections between SPA and SBA and of possible third-party access (Fig. 3).

Based on the tried and tested methods of landscape assessment developed by the authors and the German Academy of Landscape research (DAL) panel of experts "Geoecological Mapping and Capacities of Nature" (Bastian and Schreiber, 1999; Zepp and Müller, 1999; Marks et al., 1992), Table 1 shows how services that depend strongly on lateral processes relate to the best matching spatial units for providing, benefiting and connecting. This selection is incomplete and is designed to illustrate the proposed spatial principle. The services are ordered according to TEEB (2010), which is the most recent, internationally coordinated classification.

2.4. Characterizing spatial units by measuring landscape structure

To assess landscape services, landscape heterogeneity and structure must be quantified. In comparison to the function analysis and model approaches, so-called landscape metrics – landscape-based metrics of biotope, surface and land use structure – are often the most cost-effective indicators of ecological systems. The question is which indicators are useful and necessary for capturing key services (Dale and Polasky, 2007). Adequate methods for using landscape metrics in assessing landscape services are also needed. This is a growing field of research: "Beyond the investigation of species presence, abundance or dispersal, the usefulness of landscape metrics for the understanding of interactions between landscape balance and land use at various levels of scale is increasingly investigated, namely addressing processes of soil erosion, groundwater recharge, surface runoff of material into river and lakes, using remotely sensed data and complex GIS-based models (Thierfelder, 1998; Wrbka, 1998; Zhang et al., 1998)" (Blaschke, 2005).

Not all services are suitable for analysis by landscape metrics. Only landscape services with a strong structural component should be regarded as falling under this category. A decision can be based on the underlying processes and their lateral behavior as shown in Table 2 (based on Table 1).

Most landscape (structure) metrics are designed to characterize service providing areas, but there are exceptions. The following groups can be identified:

- Generally, *composition measures* calculating the density or proportions of several land use or structure elements are among the indicators that can substitute more detailed data for greater scales. *Configuration measures* revealing the shape and positional relationships of landscape elements can complement the indices mentioned below by more sophisticated geographic analyses.
- *Point density* measures are calculated by the number of discrete landscape elements of specific types per area. The measure is used with different element types, for instance large plants in relation

Table 2
Processes and determining structural metrics of landscape services.

Service[a]	Process	Structure metric
P groundwater recharge	Above and underground water movement	Roughness, surface orientation, other relief types
P fodder and fertilizer	Livestock drive	Livestock drive ways
R protection against snowdrift, storm	Wind retarding	Roughness, edge contrast
R erosion prevention	Wind/water retarding and water infiltration	Edge density and contrast, mesh size, slope length
R flood prevention	Runoff, retarding, retention, infiltration	Roughness, stream characteristics
R climate regulation (cold/fresh air)	Gravitational air movement, air purification/renewal	Slope length, edge contrast, roughness, leaf area index
R avalanche and landslide prevention	Retarding of snow and mud movement	Slope length, edge contrast, roughness
R pollination	Animal movement	Biotope density
R pest control	Animal movement	Biotope density
R stream water purification	Microbial activity and chemical oxidation	Stream characteristics
H housing quality	Visual composition	Proximity to wood, water, nature
H habitat value	Sub-habitat composition	Diversity, effective mesh size
C appreciated scenery	Visual composition, observer psychology	Diversity, edge density, proximity to sights and nature
C recreation activities	Visitor movement	Road and path network, accessibility of landscape

[a] P = providing services, R = regulating services, H = habitat services, C = cultural services.

to scenery (Adam et al., 1987), small wet holes (Lutze et al., 2006), and deadwood in relation to habitat quality services.

- *Length density* is mostly applied to road and path networks, flowing waters, hedges, stone walls, and lines of trees expressed in terms of m/km^2 or m/ha (Luck, 2007b). A special case is edge density, calculating the length of edges per area. For instance, the edge of wood and of waterside length are useful positive criteria for landscape scenery assessment with respect to diversity (Marks et al., 1992).
- *Edge contrast* measures complement edge density by the height of or potential differences between adjacent land elements. They can be good indicators for wind erosion prevention and a substitute for diversity measures in relation to scenery. The best known effects are on population dynamics and invasions (Watling and Orrock, 2010).
- The *share of* natural vs. artificial landscape elements, of historic vs. industrialized landscape structures, as well as the share of regionally typical vs. supraregional common elements and tree species are suggested as criteria for landscape scenery assessment as regards distinctive character (Adam et al., 1987). The ratio of open space to built area in towns is a good measure for bioclimatic regulation (Gómez et al., 2001). The proportion of sealed surface and built area are in turn measures of regulation demand in service benefiting areas, e.g. regarding flooding risk (Helbron et al., 2009).
- *Diversity* measures calculate the variability of phenomena (surface types, species, land use elements) in a given area. This is the most common basis for scenery assessment (Jessel, 2006; Fry et al., 2009).
- *Shape and shape complexity* give insight into potential situations in a patch or patch mosaic and their origins. Conclusions can be drawn on the naturalness of processes forming the mosaic, allowing these measures to be used above all for habitat services and scenic quality (Moser et al., 2002).
- *Fragmentation* measures indicate scenery quality (proxy for noise load) and the possibility for animals to move across landscape. A good example is mesh size, calculated as the mean size of connected habitats (Jaeger, 2000; Moser et al., 2007).
- Contrary to fragmentation, *network analyses* of roads and paths give insight into the accessibility of landscape, which is relevant for several utilizations (SBA). *Core area* indices and several *patch size* indices can also help quantify accessibility; they are, moreover, useful in evaluating habitat quality for interior species (Bastin et al., 2002; Wolf and Meyer, 2010).
- *Proximity* measures (to wood, water, and to nature protected areas) are used to determine housing quality by means of hedonic models (Kong et al., 2007; Jim and Chen, 2009) but also to buffer and maintain sensible habitat qualities (Bastin et al., 2002).

A special kind of indices measure 3-dimensional landscape phenomena. Such indices include the true surface of objects in calculating landscape metrics. This can be the relief or the surface of vegetation or artefacts.

- The *roughness* of surface and vegetation retards the movement of material fluxes, sometimes creating a turbulence boundary layer. Some regulation services which depend on the retardation of wind, water and snow impacts can be measured by the roughness index, for instance water infiltration into soil as a component of erosion (Le Maitre et al., 2008; EASAC, 2009, Nelson et al., 2009), which can be increased by soil invertebrates (Flury et al., 1994; Lavelle et al., 2006).
- *Slope length* contributes to the mass accumulation and acceleration of gravitationally induced movements. Where these movements are desirable, in supplying fresh air to cities, it is a positive measure. But in most cases, for instance soil erosion, long and steep slopes define a high risk and should therefore be subdivided (Syrbe, 2002).
- The *number of vegetation layers* complements vegetation diversity (Marks et al., 1992). In contrast, the average number of storeys in the built area could be a criterion of the need for bioclimatic regulation, useful for service benefiting areas.
- The *biotope area index* in urban areas is also 3-dimensional because vertical façade greening is included as well as roof planting (Lakes, 2006).
- The *density of summits* completes measures relief diversity for scenic beauty in lowlands (Syrbe, 2002).
- *Lacunarity or leakiness* is interesting because it can characterize service connecting areas (SCAs), particularly with regard to their ability to retain or leak processes like flood prevention or cold air movement (McIntyre and Wiens, 2000; Bastin et al., 2002; Ludwig et al., 2002; Hoechstetter et al., 2011).

3. Evaluation of services using landscape metrics

3.1. Evaluation methods

Many tried and tested methods use landscape units or landscape metrics for assessment, and many are also useful in the landscape services framework. Our review of methods focuses on the literature dealing with the connection between landscape structure and landscape planning, avoiding regular modeling approaches, which may require a number of structural parameters, as well. We can give only a rough overview, which nevertheless shows the range of methods available, as well as their implementation in classical approaches. Since some approaches utilizing landscape metrics are

Table 3
Selected services with corresponding spatial units considered in literature.

Function/service[a]	Relation	Relevant unit	Examples
P shellfish yield	SPA	Yield areas	Hoctor et al. (2000)
P biotic gross yield	SPA	Soil units	Sandner and Mannsfeld (1992)
P water supply	SPA	Watersheds	Cowling et al. (2003)
P flood prevention	SPA	Watersheds	Nelson et al. (2009) (app.)
P water supply	SPA	Groundwater recharge areas	Röder (1992), Hoctor et al. (2000)
R erosion prevention	SP/BA	Natural units	Syrbe (2002)
R flood prevention R flood regulation	SPA	Natural units	Röder (2002)
R water purification	SPA	River sections	Horn (1999)
R water purification	SPA	Natural units	Röder (2002)
R air purification	SPA	Land use units-complexes	Marks et al. (1992)
R favorable climate	SPA	Natural units	Röder (2002)
H habitat value	SP/BA	Watersheds	EPA (2011), Golubiewski (2008)
H biotope value	SPA	Biotopes; natural units	Kaule (1991), Kias (1990), Grebe (1992), Bastian (1991), Bastian (2002)
C scenic beauty	SPA	Selected rivers	Hoctor et al. (2000)
C scenic beauty	SPA	Biotope/land use complexes	Adam et al. (1987)
C scenic beauty	SPA	Natural units, scenery units	Syrbe (2002), Syrbe et al. (2007)
C scenic beauty and recreation	SPA	Watersheds	EPA (2011)

[a] P: provisioning, R: regulating, H: habitat, C: cultural.

already mentioned in Section 2.4, useful methods based on geographical units are listed in Table 3.

3.2. Framework for assessment

The development of a comprehensive methodology for landscape services assessment goes beyond the scope of this paper. But a rough framework for including landscape units and structure metrics as well as some indications on application are needed. According to the DEFRA (2007), valuation is the last stage of an often detailed assessment.

The specific issues of landscape-related assessment can be captured by a framework that should be developed in cooperation but might include the following methodological steps:

1. Determination of the spatial and temporal structure of the landscape depending on the services demanded:
   (a) Differentiating and delineating service providing areas (SPAs) and service benefiting areas (SBAs). If remote areas appear, the service connecting area (SCA) should be included, even though delineation becomes vague.
   (b) Data inquiry on ecosystems, resources, structures, trends and time performance. Structure indices can be included here. Clear spatial delineation permits the investigation of ecological processes.
2. Determination of potential services regarding the SPA independently of actual use. Area, mass and energy balances and risk estimations would mainly be made at this stage, which serve as proxy indicators for later monetary evaluation.
3. Determination of actual services based on SBAs according to the given land use pattern. Using the proxy variables from 2, a monetary evaluation can be made if needed.

The methodological approach should be subdivided with regard to renewability because renewable goods require consideration of their renewal rate and use reduction. Depending on this behavior, a further methodological subdivision could be useful dealing with the goods provided, whether public, common or private, and with market inclusion as commodity or as marketable, limited/non-marketable good. The second step is permitted by alternative valuing scales, finally convertible into economic values. Such scales include mass and energy balances, time balances (renewable vs. using time) or space–area relationships (Nelson et al., 2009).

4. Discussion

An appropriate approach to assessing ecosystem services starts by determining ecosystem services providers (ESP), and goes on to explore the circumstances under which ESPs are able to provide the services efficiently. But the term is ambiguous because both species groups and individuals can be regarded as service providers. Most frequently, functional groups of species in the ecosystem under consideration are seen as an ESP (Kremen, 2005; Le Maitre et al., 2008). This notion is particularly suitable since there is a direct relationship between the ecosystem service approach and the functional perception of biodiversity, and it points the way to specifying the role of biodiversity in maintaining and developing services. The alternative notion is to regard land users who facilitate service generation by perhaps less intensive land utilization as service providers (Kosoy et al., 2008; Corbera et al., 2009).

A more holistic approach is the designation of service providing units (SPUs) by Luck et al. (2003). They define SPUs in relation to ESPs: "Service providing units are populations that are critically important as providers of particular ecosystem services" (EASAC, 2009, see also Kremen, 2005; Luck, 2007a; Vandewalle et al., 2009). Kontogianni et al. (2010) also use the SPU conception with a spatial and a population (number) approach depending on the service under consideration. Even though the term ". . . unit" suggests a spatial consideration, and many applicable areas are called units (see Table 3), we call them ". . . areas" to avoid confusion between the two concepts.

Spatial considerations are important not only for the estimation and evaluation of ecosystem services but also for their maintenance. A good knowledge of the spatial structure necessary for a service can help considerably in avoiding degradation through the loss of species or habitats (EFTEC, 2005). The maintenance of services and benefits (which are actually generated by ecosystems) cannot be ensured without actors, who are above all affected by planning measures. Any participative, planning-related solution must include this kind of service provider, who may be the recipient of 'payments for ecosystem services' (PESs) and who are able and sometimes requested to investment in the infrastructure needed. This issue needs to be addressed in particular for service evaluation in the landscape planning or governance context. It is of outstanding significance for the world's poor. Structural measures in benefiting areas housing people with low purchasing power and high social vulnerability must be sophisticated enough to take account of their specific sensitivity. Whereas the well-off can buy clean water, use air conditioning, and afford stable architecture for their houses, the poor are much more exposed to environmental hazards such as water pollution and scarcity, urban warming, landslides, and floods. Frequently, the most vulnerable population groups are obliged to live in structurally exposed suburbs. Only the differentiated consideration of both environmental exposition and social sensitivity can provide a clear and realistic view of the situation.

The framework of ecosystem services is especially useful for a broad range of services of all types (P, R, C, see tables). This can help avoid the classical types of trade-off between them, namely temporal, spatial, and interpersonal (Ring et al., 2010). Our approach is designed to provide methodological improvements, especially for spatial trade-offs, but the two other categories can also be addressed, e.g. interpersonal trade-offs by the quantitative and structural description of beneficiaries.

Ecosystem services are increasingly being assessed on the basis of quantitative models. Physical or ecological models use their own sets of parameters and modeling areas. Of course, each model represents a necessary simplification of its object. But progress in knowledge about spatial connections need not be lost even though certain models give fast and exact results. Suitable parameters and areas need to be selected; the paper shows the wide ranging experience in this field.

5. Conclusions

The spatial arrangements of functional units, habitats, landscape elements and land use constraints significantly influence the generation of ecosystem services and the benefits they offer humanity. Obviously, these spatial arrangements have to be considered in assessing ecosystem services. What is more, they are a key element in rendering assessment processes manageable. Landscape ecology offers tried and tested methods and techniques. Landscape metrics can be used to quantify landscape structure and relate it to ecological processes. At the same time, it is a cost effective method for appraising ecosystem services on the landscape scale; the term "ecosystem services" should therefore be enlarged to "landscape services". This is justified by the strong reference to spatial characteristics and the more integrative approach, which includes neighboring processes.

This approach can visualize the spatial connections of such processes in the landscape. It is important for people to realize that the services on which they depend are the result of complex processes in different, sometimes far distant areas. This insight is hopefully another stepping stone towards the more sustainable use of nature. Landscape metrics make the assessment of such services easier and more exact. Some can be evaluated one-dimensionally using a proxy indicator for the amount of benefit accruing to the people affected. But given the complexity of modern landscapes, it is perhaps not necessary to give simple values for all services and in all cases. Cultural services, in particular, such as scenic beauty, ethic values, or educational values can therefore be described multidimensionally or qualitatively. Landscape metrics can also provide indications for qualitative comparison and for sustainable use thresholds.

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