Land cover and spatial heterogeneity: Place-based assessments of ecosystem services

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Introduction

These commented hypotheses try to investigate the connection between landscape structure and ecosystem services which we therefore regard specifically as landscape services (Termorshuizen & Opdam 2009). "An important characteristic of ecosystems and the service they provide is that they are not homogeneous across landscapes or seascapes, nor are they static phenomena."(Fisher et al. 2009). This spatial connection is of high relevance for almost all services, and is methodical important since both the direct evaluation and benefit transfer mostly uses area measures as proxy (Plummer 2009). The indicators for ecosystem services relate to pertinent spatial resolutions, and some examples highlight the importance of the spatial dimension (Dale & Polasky 2007). Services are usually provided within process-related landscape units as for instance watersheds (Pretty et al. 2000), specific habitats, natural units (Haase & Mannsfeld 2002), and land-use units suggesting a place-based assessment. Nevertheless, the precise allocation of cause and effect areas to the processes under investigation is often lacking. The empirical material regarding this issue is still scattered and requires a more systematical evaluation.

An outstanding advantage of the ecosystem services approach is to express under which conditions the benefits of nature are created. Preconditions for the future preservation of the services can be demonstrated. Moreover, we can ask for the beneficiary because there is a way to realize and assign a commonly accepted value to services and perhaps to support the providers.

An approved approach to assess ecosystem services starts with the determination of ecosystem services providers (ESP), and continues with the exploration under which circumstances the ESP are able to fulfill the services efficiently. But the term is ambiguous because one can regard species as well as individuals to be service providers. Most frequently, functional groups of species within the ecosystem under consideration are seen to be ESP (Kremen 2005, Le Maitre et al. 2008). This notion is particularly suitable since there is a direct relation from the ecosystem service approach to the functional perception of biodiversity, and it marks the way to specify the role of biodiversity to maintain and develop the services. Also, there is a broadening suggested to the connected habitat types by Egoh et al. (2007) which gives the possibility to comprise abiotic features such as soil properties, water supply or other place-based characteristics into the assessment. Since the danger of confusion, one could also call the according species and features as service generators.

The alternative notion is to regard the land users who facilitate the services generation by a maybe less intensive land utilization as service providers (Kosoy et al. 2008, Corbera et al. 2009). The maintenance of services and benefits (which are actually generated by ecosystems) could not be ensured without these actors who are above all affected by planning measures. Any participative, planning-related solution must include this kind of service providers also who could be perhaps the recipient of 'payments for ecosystem services' (PES) and who are able and sometimes asked for doing investments into the infrastructure needed. Particularly for service evaluation within a landscape planning or governance context, this issue has to be included.

Spatial relations

A more holistic approach is the designation of service providing units (SPU). They can be defined similar to the ESP: "Service providing units are populations that are critically important as providers of particular ecosystem services" (EASAC 2009), compare also (Kremen 2005, Luck 2007, Vanderwalle et al. 2009). These units could be seen also spatially comprising the above mentioned populations and leading to the established landscape ecological assessment methods for a wide range of landscape classification units (Burkhard & Diembeck 2006, Porter et al. 2009). In order to avoid terminological confusion, we call the spatial units as 'service providing area' (SPA) according Fisher et al. (2009). From the question: Who provides the services? - we arrive at the main issue of this paper: Where are the services generated and what are the underlying spatial structure? Since landscape units could include actors as well as populations, SPA is a promising basis to overcome the above mentioned confusion and to join several levels of a comprehensive landscape services approach. But an easy replicable and comprising framework for landscape services is still missing; therefore this paper tries to contribute some clarity at least to the spatial issues.

We build on the landscape services approach by Termorshuizen & Opdam (2009), which is featured by a local scale and by its marked planning perspective. On this basis, we try to refine it by new insights and methodical hints for the involvement of place-based assessment and structure metrics. We focus on evaluation indicators that can be used as proxy for monetarisation if needed. Particularly spatial attributes allow a specification of evaluation, even not least for benefit transfer (Plummer 2009). Service providing areas comprise ecosystems, their populations and physical components. Therefore, the best fitting spatial units are those which obviously host the ecosystems (biotopes, water bodies, soil units) or the effect areas of relating processes (floodplains, watersheds). These ecological units could be more suitable than administrative units.

In the course of continuing the spatial analysis, not only the 'source' area of a service is interesting, but also the 'sink', i.e. the question arises: Where are the benefits required? Complementary to the service providing areas, we suggest differentiating service benefit areas (SBA cp. Fisher et al. 2009). SBAs don't relate to ecosystems firstly, but to the benefited people. Therefore, according spatial units could be more likely urban areas, other settlements or administrative units, and for instances population density or the number of households are suitable as indicators.

These both area types (SPA and SBA) may be overlapped to some degree, but considerable gaps are also possible. For instance, flood protection is provided mainly in the mountains and benefits cities on the lower and middle reaches of a river. The question could be, should residents on the upper reaches pass development options to the middle and lower reaches and is there any service in return? And: Shouldn't the riverside residents move out of the floodplain instead of troubling their upstream neighbors? Fisher et al. (2009) distinguish four types of spatial relationships between SPA and SBA (Fig. 1, there called 'P' and 'B'):

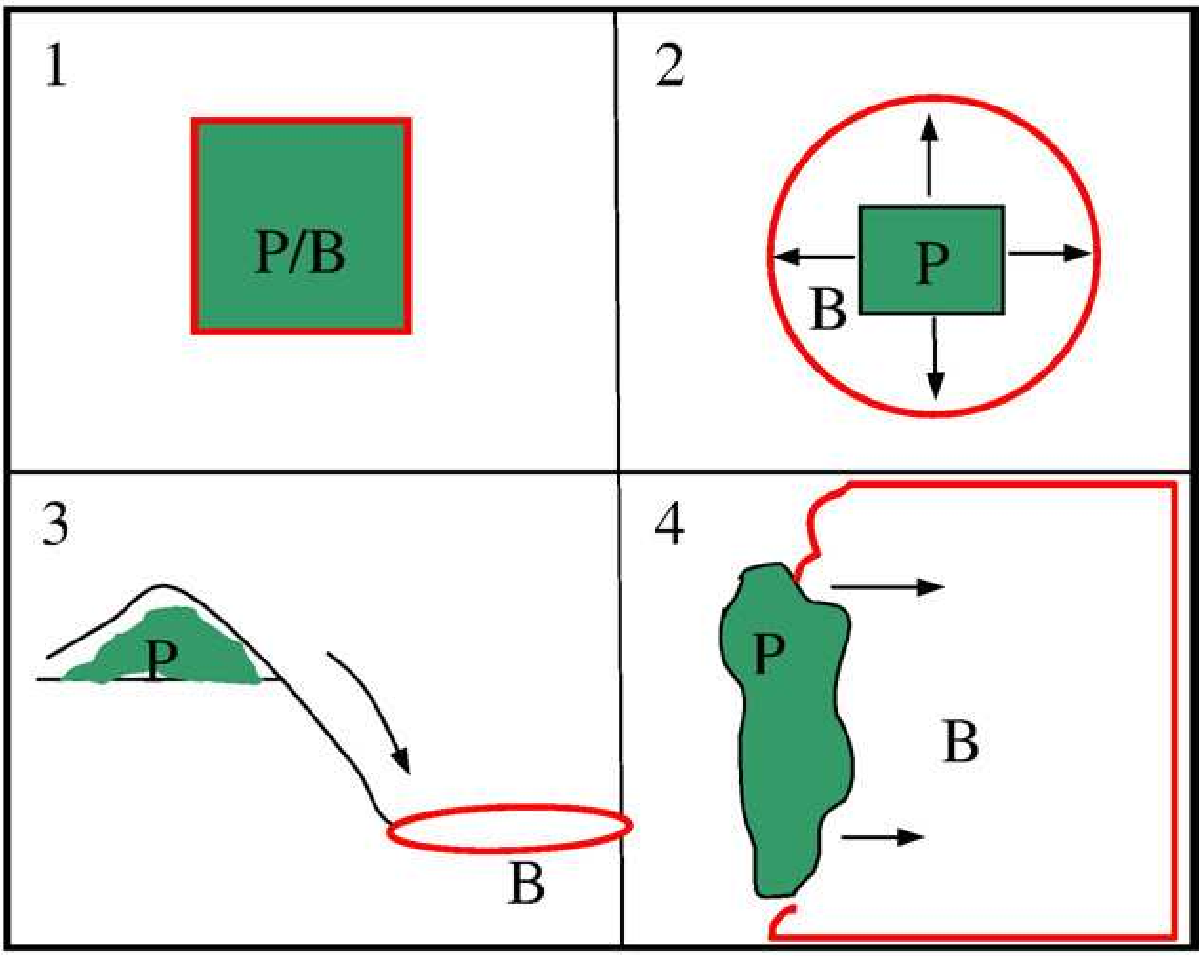

Fig. 1 Possible spatial relationships between SPA (P) and SBA (B) from Fisher et al. (2009)

1. 'in situ': SPA and SBA are identical, i.e. the service is provided and the benefits are realized in the same area.
2. 'omni directional': SBA extends SPA without any directional bias.
3. 'directional' - slope depending: SBA lies downslope (downstream) to SPA, i.e. the service is realized by gravitational processes (cold air, water, avalanche, landslide)
4. 'directional' – without strong slope dependence: SBA lies 'behind' the SPA relating to higher-ranking directional effects.

If the providing and benefit areas (SPA and SBA) don't adjoin, there must be a space between having effects onto the process variables. Regarding the example above, the course of the river, retention spaces, natural floodplains and reservoirs can change a possible flood wave critically (Fig. 2). Regarding many other services, the situation is by far not so clear like along a river. The areas as well as the involved actors have to be designated in order to treat barriers and to avoid free riders for every service. In order to have a clear spatial conception, we can name the space between: since it connect the providing and benefit areas, it should be service connecting area (SCA) whereby the different root area hints at the more diffuse shape of such a space.

Once having designated these several areas, they can be described exactly by their properties, structure, type, and criteria of geographical situation, which will be outlined below. A comprehensive characterization of SPA should at least point to:

2. a detailed analysis of the internal SPAs structure, including landscape metrics,
3. the recognition of the SPAs surrounding maybe right up to remote relationships concerning the process under consideration.

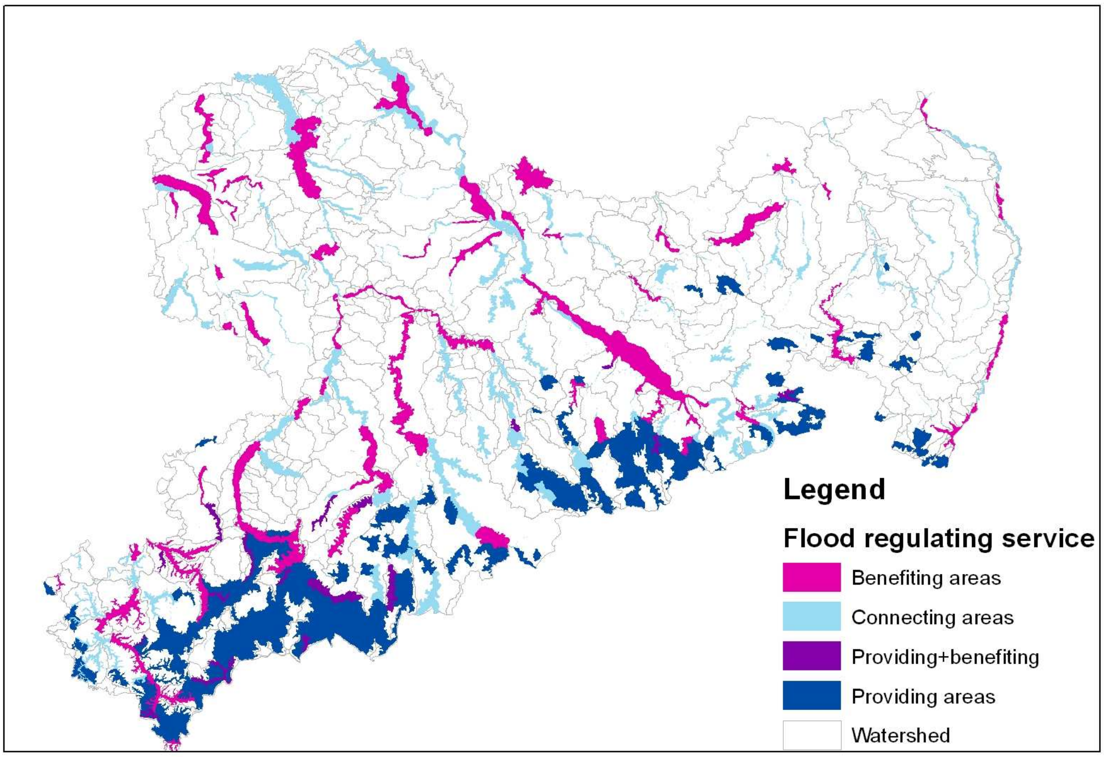

Fig. 2 Providing areas, benefiting areas and transfer areas for the flood regulating service in Saxony basing on natural units (Source: designed by the authors)

Tab 1 gives an overview about the different suitable areas for place based assessment. The main spatial feature of SPA is of course the comparison to the according SBAs and SCAs, sometimes displaying an internal or an external relationship. For the other two area types, the research focus will shift. SPA characteristics are mainly scientific: They relate to the benefit performing natural goods and – if applicable – to those processes which enable their regeneration. The analysis must also find out if investments (protective or fostering measures) are necessary to maintain the service. If so, frequency and financial support for all maintenance measures should be known as well as the regulations for them. In case the natural capital is reducible, a given replenishment rate should be determined in order to control the withdrawal accordingly (cp. Ostrom 1999).

The SBA characterization is a more social issue building a bridge from science to planning applications. Besides the nevertheless existing physical effects, above all the benefit requirements have to be analyzed there. According to the area under consideration, the claims, wishes and values of the profiting people's group give indicators for the demand of services. Notably the extent of this people's group has to be known giving a reasonable basis for the evaluation of service. Whereas thresholds among natural processes are hardly to find, thresholds for instance regarding the vulnerability of people or the withdrawal rate (see above) are critical for the assessment of several functions. Additionally, consumable resources require rules for access. The kind of access (private, common or public) to a service and the possibility of exclusion is a distinguishing variable for the marketability and the monetary evaluation of a service.

Tab. 1 Ecosystem services dependent on lateral landscape processes and the according area allocation of service (SPA) and benefit areas (SBA), service connecting area (SCA) in parentheses if not existing separately

Service	SPA	SBA	SCA
P groundwater recharge	arable[1] and wetland in a groundwater basin	built area, irrigated land in that 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
C appreciated scenery	viewsheds[2]	touristic infrastructure	(within scenery units)
C recreation activities	surface water bodies, mountains, wood	touristic lodging units	road and path network between

Even though an SCA don't exist separately due to an overlay of the other two areas, the SCA specific analysis can be useful because lateral transfer processes could be impacted by site characteristics anyway. If there is a lack between SPA and SBA, the connecting area has to be delineated. Sometimes, this is a difficult task. The main issues for the analysis of SCA are transportation and transformation processes. By differentiation of the three spatial types, a more side-specific and therefore landscape related framework for the assessment of ecosystem services are possible.

[1] Depending on climate situation, also wood and grassland may belong to the SPU.

[2] „Viewsheds are a topographic concept, delineating the area from which a particular site can be seen." Boyd & Banzhaf 2006)

Spatial units

The following spatial units are suitable as basis for ecosystem services assessment if the services are:

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

Only the first point is fully comparable to the ESP approach; all other types suggest preferring a spatial unit analysis. Also the above mentioned river example connecting to the (flood) water regulation service requires a place-based treatment whereby the physical unit equals the watershed or to some parts of it (upper part, higher order etc.) if separated into SPA, SBA and SCA. Watersheds are typical physical units, which can be delineated by current methods on the basis of DEMs and which are therefore commonly used as assessment units for water-bound services. Another possibility would be the use of regular units, e.g. grid cells. They have the advantage of comparability among each other, but also the disadvantage that they are not related to processes or administrative units. Possibly homogenous areas will be split.

Table 2 kind of spatial units correspond to selected services considered in literature

function / service*	**relation**	**relevant unit**	**examples**
P shellfish yield	SPA	yield areas	(Hoctor et al. 2000)
P biotic gross yield	SPA	Soil units	(Sandner & Mannsfeld 1992)
P water supply	SPA	Watersheds	(Cowling et al. 2003)
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	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 2009, 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 2009)

P: provisioning, R: regulating, H: habitat, C: cultural

Several spatial units are mentioned within explicit ES literature by now (Tab. 2), but mostly in general terms and without direct relation to a specific service. There are used for instance:

- Single patches, land use parcels or landscape elements are the best known spatial basis for assessment in general.
- The combined use of several indicators and data sources leads to the “smallest common geometry”, which is generated by G.I.S. overlay functions. This approach requires the highest data volume and cannot ensure a spatially logical concept due to the sheer amount of polygons. Sometimes, spatial units with a defined heterogeneity could be meaningful, particularly if biodiversity or land use patterns are the item of analysis.
- Administrative units are useful as far as according data sources have to be used, for instance social indicators or legal circumstances. The most common reason for using these units is that they are the areas of interest of a given project that may depend on the administration. Admittedly, administrative units are seldom really suitable regarding to ecosystem processes.
- Watersheds are meaningful as basis for all functions that are provided by water related landscape processes. They are used for services of 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 & Diembeck (2006) assumed a comparison of natural units with SPA were interesting, UN SEEA (2003) denoted them as preferred basis for monetary calculation, and the Department for Environment, Food and Rural Affairs (2007) for ecosystem definition.
- Landscape units are delineated not only by natural situation but also by land use are meaningful for the most functions, particularly for greater scales. They were mentioned by: Degroot (2006) as basis for conflict analysis among landscape services, by ISCU et al. (2008) as basis for biodiversity investigation, by Maass et al. (2005) as basis for sustainable studies including several (water) processes, by Metzger (2008) as components of spatial heterogeneity, by Naveh (2007) as container for total landscape ecodiversity, i.e. including cultural historical and humanmade artifacts, by UN SEEA (2003) for accounting bio(tope)diversity, and by TEEB (2009) as represents of differently intensively used landscape and as spatial frame for practical management.

“Although ecologists recognise 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).

Two main obstacles for the application of place-based assessment are:

- The delineating and classification process of units is elaborate and uncertain. Due to the fact that natural borders could be rarely found within landscape, they must be defined manually. This is not only a challenging work; also the results are seldom scientifically undisputed. Clear principles and quantitative indicators are needed for doing this.
- Although the units are heterogeneous anyway, the most assessment schemes require homogeneous units with distinct characteristics. Using data intervals, the results get improper. Instead, methods are required that can be applied to greater scales using condensed data (see next section).

Structure metrics

To overcome the second obstacle, landscape heterogeneity and structure must be exactly quantified for and considered in landscape service assessment. Comparing to function and composition analysis, landscape-based metrics of structure and composition are often the most cost-effective indicators of ecological systems. The focus on landscape structure leads to the question of what indicators are useful and necessary to supplement the landscape metrics as a way to capture key ecosystem services (Dale & Polasky 2007).

Therefore, the popular approach of landscape (structure) metrics can be used, but methods are needed that include these so-called indices for assessment. Not all services are suitable to be analyzed by landscape metrics. Only landscape services with a strong structural component should be regarded within this context. The decision can be done basing on the underlying processes and their lateral behavior (Tab. 3, based on Tab. 1).

Tab. 3 Processes and determining structure metrics of landscape services

Service	Process	Structure Metric
P groundwater recharge	above and underground water movement	roughness, surface orientation, other relief types
P fodder and fertilizer	livestock drive	pastoral paths
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
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

Selected indices in detail:

The most landscape metrics are designed to characterize service providing areas. Exceptions are mentioned. Firstly, composition measures calculating the density or proportions of several land use resp. structure elements belong to the indicators that can above all substitute more detailed data for greater scales.

- 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 with big plants relating to scenery (Adam et al. 1987), with small wet holes (Lutze et al. 2006) and with deadwood relating to habitat quality services.
- Length density is mostly applied to road and path network, to flowing waters, hedges, stone walls, and lines of trees expressed by m/km² or m/ha. A special case is the edge density, calculating the length of edges per area. For instance, the edge of wood (classes: 50, 150, 300, 500 m/km²), and of waterside length (25, 75, 150, 300 m/km²) are useful as positive criteria for the landscape scenery assessment regarding diversity (Marks et al. 1992).
- The share of natural vs. artificially appearing landscape elements, of historic vs. industrialized landscape structure as well as the share of regional typical vs. supraregional common elements and tree species are suggested as criterion for the landscape scenery assessment regarding the peculiarity (Adam et al. 1987). Additionally, the share of open space to built area within towns is a good measure for bioclimatic regulation. The degree of sealed surface and built area are in turn measures of the regulation demand within service benefit areas.
- Leaf area index (i.e. the total leaf area per ground area) is a common measure for the vitality, energy and gas exchange of vegetation stocks. Regarding ecosystem services, it is critical for air purification within urban areas. Note, not only ground level vegetation but also façade facing plants should be considered; therefore some 3-dimensional indices exist.

Configuration measures revealing shape and positional relationships of landscape elements can complete the above mentioned indices by more sophisticated geographic analyses.

- Diversity measures count the variability of phenomena (surface types, species, land use elements) in a given area. This is the most common basis for scenery assessment.
- Proximity measures (to wood, water, and nature protected areas) are proved to determine the housing quality by hedonic models (Jim & Chen 2009, Kong et al. 2007).
- Contrast measures complete the edge density by the height or potential differences of adjacent land elements. They can be good indicators for wind erosion prevention and a substitute for diversity measures regarding scenery.
- Fragmentation measures indicate scenery quality (proxy for noise load) and the possibility for animals to move across landscape. A good example is the mesh size calculated as mean size of connected habitats.
- Contrary to fragmentation, network analyses of roads and paths give insights to the accessibility of landscape, which is relevant for several utilizations. Also core area indices can help to quantify accessibility; they are beyond that useful for evaluating the habitat quality for interior species.
- A few landscape measures are developed to describe a specific function. One of them is the so-called effective hectare width calculating the ratio between length and width of acre fields, which is a good measure for the possibility to cultivate them with the least effort regarding energy and driveway.

A special kind of indices measure 3-dimensional landscape phenomena.

- The roughness of surface and vegetation retards the movement of material fluxes sometimes creating a turbulence boundary layer. Some regulation services which depend on a retardation of wind, water and snow impacts could be measured by roughness index.
- Surface orientation related to solar radiation or to the direction of mass movements gives a good measure for efficiency of energy and mass turnover. Since nearly all regulation services depend on such processes, these indices are multiple useful.
- Slope length contributes to the mass accumulation and to the acceleration of gravitational induced movements. Where these movements are desirable like regarding the fresh air supply to cities, it is a positive measure. But in most cases, for instance regarding the soil erosion, long and steep slopes define a high risk and should be subdivided therefore.
- There is for instance the number of vegetation layers as completion of vegetation diversity. The average number of storeys in built area is a very interesting index because it is a criterion for the need of bioclimatic regulation, useful for service benefit areas.
- The biotope area index in urban areas is also a 3-dimensional because vertical façade greening is included as well as the planting of roofs.

Framework for assessment

The development of a comprehensive methodology for landscape services assessment extends the scope of this paper. But a coarse framework for the implication of landscape units and structure metrics as well as some hints to apply it should be given. According to Department for Environment, Food and Rural Affairs (2007), valuation is the last stage of an often detailed assessment of the ecosystem services.

Methodical steps“

The specific issues of landscape related assessment can be captured by a framework that should be further developed cooperatively, but it might to include the following steps:

1. Determination of the spatial and temporal structure of the landscape according to the demanded services
   a) Differentiating and delineating the service protecting and service benefiting areas. If remote areas appear, the service connecting area should be included, even though the delineation gets vague.
   b) Data inquiry to the contained ecosystems, resources, structures, trends and to the time performance. The structure indices can be included here. The clear spatial delineation permits the investigation of processes not least using mass end energy balances of the most critical storage variables.
2. Determination of potential services regarding the SPA independently of actual use. Mainly area, mass and energy balances and risk estimations would be executed at this stage, which are act as proxy indicators for the later monetary evaluation.
3. Determination of actual services based on SBA according the given land use pattern. Using the proxy variables from 2, a monetary evaluation could be made if needed.
   a) Profit contribution (provisioning services)
   b) Opportunity costs (other services, in case of intervention) or
   c) Benefit transfer (other services, else)

The methodical approach should be divided regarding its renewability because renewable goods require a consideration of their renewing rate and the use reduction. According to this behavior, a further methodical division regarding the provided goods as to be public, common or private and regarding the market inclusion as commodity resp. marketable, limited/non-marketable could be meaningful. The second step is possible by alternative valuing scales, which are finally convertible into economic values. Such scales are for instance mass and energy balances, time balances (renewable vs. using time) or space-area-relationships (SAR) according to Nelson et al. (2009).

Abstract

The Ecosystem services approach is the established framework for a balanced evaluation of natural, economic and social landscape resources. It allows for identifying synergies functional (win–win situations) as well as trade-offs among various benefits resulting from ecosystem processes. Besides the contributions of biodiversity, also spatial aspects of heterogeneity and configuration play a major role for the maintaining of human wellbeing. Also cultural artifacts contribute the landscape functionality. Therefore, the more suitable term *landscape service* is increasingly used. We pursue particularly spatial aspects of that framework and ask for optimizing the trade-offs among landscape services.

Firstly, the contribution of spatial heterogeneity and landscape structure measures are distinguished as indicators for landscape services. Landscape heterogeneity is a key measure for biodiversity and contributes to several valuable functions. Likewise, habitat connectivity and other measures of landscape structure are essential criteria for the behavior of meta-populations and for the recreational value. The assessment of habitat and nature protection networks is demonstrated as an example.

Secondly, the approach of service-protecting areas should (SPA) be addressed. Complementary to the identification of ecosystem service providers (ESP) and consumers, SPAs are the areal basis for providing of services. Alike, service benefit areas (SBA) and connecting areas (SCA) for the transfer of matter, energy and organisms between them have to be investigated. Place-based assessments refer to such areas. Therefore, we show possibilities to estimate and evaluate landscape units.

Thirdly, landscape consist surely of artifacts, human activity and even social thinking. Using the landscape services approach in a wider sense, we can better address also the so-called social / cultural services because they strongly depend on memorials, structural characteristics, historical conditions end even on mental specifics which can hardly be subsumed to ecosystems. Place-based assessments are an appropriate solution for the unification of several spatial categories.

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