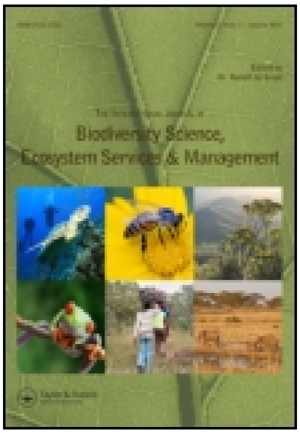

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Space and time aspects of ecosystem services, using the example of the EU Water Framework Directive

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Space and time aspects of ecosystem services, using the example of the EU Water Framework Directive

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Within the concept of ecosystem services (ES), space and time approaches, with their physical and socio-economic dimensions, play an important role. Among the space aspects, the configuration (e.g. size, shape) and composition (pattern) of ecosystems, but also the spatial positions of service providing areas, service connecting areas and service benefiting areas are of great relevance. Ecosystem changes, and also differences between supply and demand (or use) of ES, are typical time-related aspects. Scale issues concern both the space and time dimensions. A scheme in the form of a guideline or a checklist is proposed, which helps to consider, systemize and improve space and time aspects in methodological frameworks and in special investigations. Space and time aspects of ES and the application of the scheme are exemplified on the European Union Water Framework Directive. The introduction of this directive as a political instrument has led to significant improvements of the ecological state of surface waters and the groundwater, and the ES they supply, not least due to the appropriate, exemplary consideration of space and time aspects.

Keywords: Elbe River; nutrient loads; reference units; river basin; scale; supply and demand

Introduction

Ecosystems are related to tangible spaces and manifest themselves in several scales. They are by no means static but are as a rule subject to sometimes rapid change. Ecosystem services (ES) are, in the definition used here, the actually used or demanded contributions of nature to human benefit and human well-being (Grunewald and Bastian 2010; Bastian et al. 2011). Not only ecosystems and the supply of ES but also human demands for benefits are heterogeneous in space, and evolve through time depending on social and economic structures of society, as well as on their development. Thus, both the factual and the value levels are concerned. According to Fisher et al. (2009), we should note that these spatial–temporal dynamics are characteristics that can help to understand and classify ES.

Critical voices have addressed the issue of the insufficient consideration of these issues in prevalent ES concepts. For instance, de Groot et al. (2002, 2010) and the Millennium Ecosystem Assessment (MA; 2003) notice that although there is an increasing awareness of the importance of spatial and temporal scales for the analysis and evaluation of ES, and the role of scales has been widely recognized in both economics and ecology, to date, few ecosystem evaluation studies have explicitly considered the implications of scales for the analysis and evaluation of ES. The arrangement patterns and spatial relationships of ecosystems are hardly ever taken into account (Blaschke 2006), and 'spatial and temporal dimensions of ecosystem service production, use, and value are not well understood' (The Economics of Ecosystems and Biodiversity 2010). If the space–time dimensions of the ES concept are not well understood, the conclusion is inevitable that nature and its services cannot be integrated adequately into political decision-making processes, especially those involving distribution options.

Various main research questions need to be resolved in order to better integrate ES into landscape planning, management and decision-making, as identified by de Groot et al. (2010), who calls for a focus on such aspects as: 'How can ecosystem/landscape functions and services be spatially defined (mapped) and visualized?', and 'What is the influence of scaling-issues on the economic value of ecosystem and landscape services to society?' Following The Economics of Ecosystems and Biodiversity (2010), studies of ES should 'be spatial and time explicit'. But what does that mean? How can it be operationalized? We also have to take into account the different space–time approaches in ecology, in economy and in social issues. How can we deal with the different terminology and defective compatibility? There are further questions, for example, to what extent specific methods are necessary for analyses and evaluations in the particular scales? How can spatial approaches in the areas of nature and society be harmonized? How can we define clear space and time relations, especially with regard to distribution options?

This study takes up some of these questions, and seeks to identify and to describe the space and time aspects of ES. As an example for these reflections, we will use the European Union (EU) Water Framework Directive (WFD;

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2000), with special reference to the Elbe River basin, and we present a scheme to check given conceptual and/or methodological ES frameworks and studies with respect to the consideration of important space and time aspects.

Theoretical fundamentals

Aspects of space

The term 'space' is used and considered very important and constitutive in a wide range of scientific disciplines, for example, philosophy, mathematics and physics, but also history, medicine, theology, archaeology, education science and sociology. Of course, this term is especially important for the interdisciplinary and multidisciplinary spatial sciences, especially for geography, environmental sciences, urban development and architecture, spatial planning, traffic sciences and also sociology and economics (cf. Müller 2005). According to Blotevogel (1995) we understand 'space' as a

(1) tangible physical space (pattern of different areas and cubes), which can be described objectively;
(2) the natural human environment (e.g. landscape); and
(3) social space (social construction of reality, spaces of collective actions, areas of spatial allocations).

The spatial relations of ES are manifold. This applies to the supply aspects (for the areas where ES are supplied or maintained), but also for the areas where human needs or demands for ES arise, and where they have to be satisfied.

(a) Spatial aspects of ES properties and supply

The generation of ES requires ecosystems with specific (including spatial) characteristics. To be able to supply ES, special *areal requirements* (minimum areas – see Table 1) of the ecosystems concerned are necessary. For example, animal populations need, for their stability and their survival – specific minimum areas of appropriate quality; or a forest must have a size of several hectares to be able to influence the microclimate in the vicinity; or a body of groundwater must have a minimum size or rate of groundwater recharge in order to be able to supply usable amounts of drinking water. Sometimes only single parts of ecosystems, single (organism) species, individuals or parts of them (roots or leafs of plants) are responsible for ES generation. We refer to the concepts of functional traits (Lavorel et al. 1997; De Bello et al. 2010) and Ecosystem Service Providers (ESP – introduced by Kremen (2005)). ESP encompass the levels of population, functional group and community (Luck et al. 2009), and they may contribute to service provision to a different degree in different places (De Bello et al. 2010). A stronger spatial relationship is posited in the service providing unit (SPU) concept, introduced by Luck et al. (2003, cf. Harrington et al. 2010). An SPU is 'the collection of organisms and their characteristics necessary to deliver a given ecosystem service at the level required by service beneficiaries.' The respective areas of an SPU as well as the areas related to the beneficiaries should be considered as a spatial basis for the ES evaluation. The characteristics of such units, their classification, size, spatial and temporal scales, and their origin (How to derive appropriate units if they are not available, yet?) are important questions that need specific analyses.

Frequently, a specific *spatial composition* or pattern of several ecosystems is necessary to generate ES. Composition aspects are also manifested in the spatial congruence or divergence of ES (e.g. Anderson et al. 2009), or in mutual influences. There can be spatial concordance among different services. Some ES co-vary positively: for example maintaining soil quality may promote nutrient cycling and primary production, enhance carbon storage and hence climate regulation, help regulate water flows and water quality, and improve most provisioning services, notably food, fibre and other chemicals (Ring et al. 2010). Other services co-vary negatively. Thus, an increase in provisioning services may impair many regulating services. For example, the provision of agricultural crops may reduce biodiversity. Earthworms may be damaged by the application of biocides (e.g. containing copper). However, these animals support infiltration and water storage capacity of the soils through increased vertical macro- and coarse pores (worm tubes) (Sieker 2007).

Multiple ES can be interconnected and interlinked in 'bundles' (MA 2005). Willemen (2010) refers to interactions between landscape functions (or ES), which can be categorized into three classes:

(1) Conflicts: the combination of several landscape functions reduces the provision of services to society of a particular landscape function;
(2) Synergies: the combination of functions enhances a particular function; or
(3) Compatibility: landscape functions co-exist without reducing or enhancing one another.

Whether different ES co-vary positively or negatively often depend on the *configuration* (e.g. spatial structures, shape) of the ecosystems or landscape elements involved at a specific scale. Productive land uses require compensation areas for the maintenance of key ecosystem providers. By contrast, sensible ecosystems need buffers to shelter them from harmful side effects. Where there is not enough space for all desired functions in a landscape to operate equally, complex structures and sophisticated sequences of different ecosystems might nonetheless be able to maintain the majority of them. In practice, mainly at local levels rather than at regional scales, we are familiar with structural environmental quality standards, such as buffer stripes, habitat connection, wildlife corridors and SCA concepts, as described below. A well-known example is the zoning within large protected areas (national parks, biosphere reserves), where the core zone (wilderness) should

Table 1. General checklist of space and time issues related to ES.

Position	Issue	Criteria (examples)
1. Space aspects		
1.1	*Areal requirements*	Minimum area (for the supply of ES) with a special quality (structure, abiotic characteristics, biodiversity)
1.2	*Spatial composition*	Completeness of required partial habitats of animals, land-cover diversity, patch richness, a set of ESP
1.3	*Spatial configuration*	Shape, core areas, buffers, land-use gradients, proximity, mesh size
1.4	General: *functional connection*	Supply–transfer–demand relations, ecological interdependencies (e.g. habitat networks, river–floodplain relations)
2. Time aspects		
2.1	*Time requirements*	Minimal process time, regeneration time (of ecosystems and ES)
2.2	*Temporal sequences*	Natural oscillation, land-use time pattern and interferences, adequate order of ES use (from one area/ecosystem various ES can be used but if this use is organized in a sophisticated manner, benefits can be enhanced and damages are avoided), storage capacity for ES
2.3	*Time lags*	Differences between supply and demand, precaution measures, risks, option values, inter-generational time lags (the present generation benefits, the next pays for environmental damages)
3. Scale and dimension		
3.1	*Suitable dimension*	Compatibility of scale and measures, reference units, areal and temporal resolution
3.2	*Transition*	Consideration of upper/lower scale effects (up-scaling, down-scaling), analysis of transition risks, transfer offsets

be buffered by a managed, near natural zone, which in turn provides a gradient to the more intensively used areas (e.g. farmland) outside the protected area.

(b) Spatial aspects of ES providers and ES beneficiaries (functional connections)

In spatial analyses of ES, not only the ‘source’ area of a service is interesting, but also the ‘demand’, that is the areas where the benefits are required and realized. Hence, we need to address both providers and beneficiaries of ES: Who provides the ES? For whom are they provided, or who benefits from them? Within which spatial position is the ES generated and supplied, and where is it used (where are providers and beneficiaries located)?

There are often distinct spatial differences between areas where ES are generated (service providing areas, SPA) and areas which benefit from the ES (service benefiting areas, SBA). If providing and benefiting areas (SPA and SBA) do not adjoin, there will necessarily be a space between them, the so-called service connecting area (SCA) (Fisher et al. 2009; Syrbe and Walz Forthcoming). For instance, flood protection is provided mainly in the mountains (by water storage reservoirs), and benefits the cities along the middle and lower stretches of a river. In between, the river course can alter a flood wave. The SCA should be identified to support the transmission from the SPA to the SBA, for instance by avoiding or removing barriers (e.g. in water streams or in biotope networks). Thus, a natural floodplain, which is connected with the river and not separated by dams, can be regarded as an SCA, too. It can contribute to flood mitigation in favour of downstream settlements. The identification of service providers and beneficiaries helps to avoid free riders or at least to reduce their effect on ES consumption.

Fisher et al. (2009) proposed a classification scheme that describes relationships between service provision and benefiting (i.e. where and by whom benefits are realized):

(1) both the service provision and benefit occur at the same location (e.g. soil formation, provision of raw materials);
(2) the service is provided omnidirectionally and benefits the surrounding landscape (e.g. pollination, carbon sequestration);
(3) specific directional benefits: for example down slope units benefit from services provided in uphill areas in mountains or the service provision unit could be coastal wetlands providing storm and flood protection to a coastline.
An additional case could be added to these classes as the counterpart to (2):
(4) the service is provided in large (hardly limited) areas and benefits small, discrete locations (e.g. a settlement).

The cases described in (2) and (4) necessarily lead to scale transfers (cf. Section 2.3).

According to such spatial characteristics, Costanza (2008) groups ES into five categories. For example, services like carbon sequestration are classified as ‘global: non-proximal’, since the spatial location of carbon sequestration does not matter. Nowadays, due to carbon trades, spatial scales in CO_2 storage area are becoming more crucial and need to be considered on a finer scale. When one pays for CO_2 storage, for example by planting trees, he would like to know where the trees are planted and how much carbon will be sequestrated. 'Local proximal' services, on the other hand, are dependent on the spatial proximity of the ecosystem to the human beneficiaries. For example, 'storm protection' requires that the ecosystem doing the protecting be proximal to the human settlements being protected. 'Directional flow-related' services are dependent on the flow from upstream to downstream, as is the cases of water supply and water regulation. Other services are 'in situ (point of use)' (e.g. soil formation) or 'user movement related: flow of people to unique natural feature' (e.g. recreational potential).

We should also consider spatial cost/benefit relationships, such as spatial 'benefits here–costs there' trade-offs, where a service is provided in one location for the benefit of another. This creates a relation between the ES provider (the person/or group responsible for an ES or environmental responsibility) and the ES beneficiary, or between winner/s and loser/s (Ring et al. 2010). A special problem results from the WFD planning and ES assessment in transboundary catchment areas: the heterogeneous data. From both methodical and practical (expense!) points of view, the data homogenization is difficult but there are several attempts to find solutions (e.g. Gedrange et al. 2011).

Aspects of time

Ecosystems need not only special time spans for their regeneration, they are also subject to natural fluctuations and trends, which can alter their functionality and capacity (to supply ES) periodically, episodically or permanently. The MA (2005) predicts a worsening of many ES. Land use (intensification) is or will be a major reason for this (European Academies Science Advisory Council 2009). Increasingly, changes in ecosystems and the ES they supply are caused by humans. The knowledge of time-dependent changes of ES are of great practical importance, since it helps to evaluate the practical consequences of impacts, plans and policies for humans and societies either ex-post or ex-ante (scenarios and prognoses). Not only ecosystems or ecological properties can change, so too can economic values and the values that different stakeholders attach to the services. For example, infrastructure and transportation costs can change, which leads to new spatial and economic relationships between service providers and beneficiaries. Methods are needed to reveal natural fluctuations or changes of ecosystems in more detail in order to be able to better adapt impacts caused by human utilizations.

Systematically, the following time aspects are especially important:

(1) the minimum *time requirements* for the generation of the particular ES, that is how much time is needed regarding the underlying ecological processes as well as management and land-use activities in order to ensure a sufficient recovering of the concerned ecosystems;
(2) sophisticated *temporal sequences* in the utilization of ES to enhance benefits and to avoid risks and damages (e.g. crop rotations, fodder harvest from grasslands after meadow birds have finished breeding, use of the nutrient regulation capacity of soils at appropriate times – disposal of liquid manure only in the vegetation period, not on bare soils);
(3) the temporal differences between supply and demand or use of goods and services, so-called *time lags* (e.g. between water sampling from the water bodies and water consumption, or between water accumulation in the mountains and the crisis situation in the valley) (e.g. Grunewald and Scheithauer 2007).

Functional traits (or SPU, ESP – Section 2.1) may contribute to services provision to a different degree, not only in different places, but also at different times (De Bello et al. 2010).

To consider the capacity of ecosystems to supply ES sustainably is a basic issue for the development of the ES concept, and also needs to be fundamentally implemented in its methodology. Thus, it is also crucial to adjust the sequence of different land uses in an intelligent manner, to minimize impacts. For instance, crop rotation can influence flood regulation. A tight crop rotation, adapted intercrops or conservative cultivation can close critical bare fallow periods to reduce erosion and surface runoff.

One of the most important issues refers to the sometimes huge differences between the periods in which natural developments occur and the time frames of social processes (public awareness, political opinion-making, parliamentary terms, human lifetimes).

Ring et al. (2010) highlight the question of temporal trade-offs: benefits now–costs later. Such trade-offs represent the central tenet of sustainable development, stipulating that it ' . . . meet the needs of the present generation without compromising the needs of future generations . . . '. Therefore, even the inter-generational *time lags* need to be addressed.

Time differences between the supply of ES on the one hand and the use of goods and services on the other can usefully be expressed by the concept of natural potentials. The concept of natural potentials (see Neef 1966; Haase 1978; Mannsfeld 1979; Bastian and Steinhardt 2002; Burkhard et al. 2009; Grunewald and Bastian 2010; Bastian et al. 2011) aims to display the service capacities of an area as a field of options available to society for use, and also to take into account such categories as risks, carrying capacity and the capacity to handle stress (increasingly summarized today in the term 'resilience'), which limit or may even exclude certain intended uses. Analogously, for example de Groot et al. (2002) and Willemen (2010) use the term 'capacity' and define 'ecosystem functions' (and 'landscape functions') as 'the capacity of natural processes and components to provide goods and services which directly and/or indirectly satisfy human needs', and the MA (2005) refers to 'the capacity of the natural system to sustain the flow of economic, ecological, social, and cultural benefits in the future.'

The approach of (natural) potentials constitutes an important basis for land-use and landscape planning. Interesting questions relevant for planning purposes are, for example 'Where are land use opportunities not realized, yet?' and 'When and where are land uses that are not adequate to the potential of nature (carrying capacity, resilience)?' Therefore, we need knowledge about potentials, which are available but still barely used, so that it can be applied to improve land use and develop resources. Regarding the carrying capacity of ecosystems, and particularly the potential time response, we can define the systemic limit before it is reached.

Scale and dimension

The scale dependence of ES is an additional but rather poorly investigated aspect (MA 2003; Hein et al. 2006). Recent research emphasizes that both the manner in which we are dissecting our reality and the scale of investigation influence the results significantly (cp. Blaschke 2006). Ecological structures and processes as well as ES manifest themselves at different scales and in quite different manners at the local, the regional and the global scale (Figure 1).

According to its original definition, ecosystems can be defined at a wide range of spatial scales (Tansley 1935), from the level of a small ephemeral sunlit spot on the forest floor up to a whole forest ecosystem spanning several thousands of kilometres and persisting for decades or centuries (Forman and Godron 1986). The supply of ES depends on the functioning of ecosystems, which is in turn driven by ecological processes operating across a range of scales (MA 2003; Hein et al. 2006). Hence, ES depend on several scale issues. Often, specific ES are generated and supplied at particular scales (Hein et al. 2006, cf. Costanza 2008 in Section 2.1). The spatial variability of ES at different scales is very important (de Groot et al. 2010).

As an example, carbon sequestration and climate regulation are related more to the global scale – notwithstanding the fact that the global balance will be improved by a multitude of local measures. On the other hand, protection against floods by coastal or riparian ecosystems as well as regulation of erosion and sedimentation requires various scales. Pollination (for most plants) and regulation of pests and pathogens refer to the ecosystem level or the local scale (Hein et al. 2006).

According to various scale levels, scale-dependent process variables and magnitudes require scale-adapted methods of analysis and evaluation, which have already been addressed by dimension theory (Neef 1963). Using this, the approaches developed at the local and regional scales can be transferred (adapted, applied and checked) to the supra-regional or even to the global context (bottom-up strategy). But the reverse approach (top-down), too, is possible. For example, the results of the MA (2005) (global scale) need to be underpinned by case studies at the local to regional levels (Neßhöver et al. 2007). Due to the fact that the combination and processing of data from quite different temporal and spatial scales and the transition from one scale to another can cause problems concerning the expressiveness and interpretation of data and information (Neef 1963), the choice of a *suitable dimension* is a main essential for any conceptual and/or methodological ES framework.

It is necessary to distinguish between scales related to socio-economic and ecological issues. Ecological and

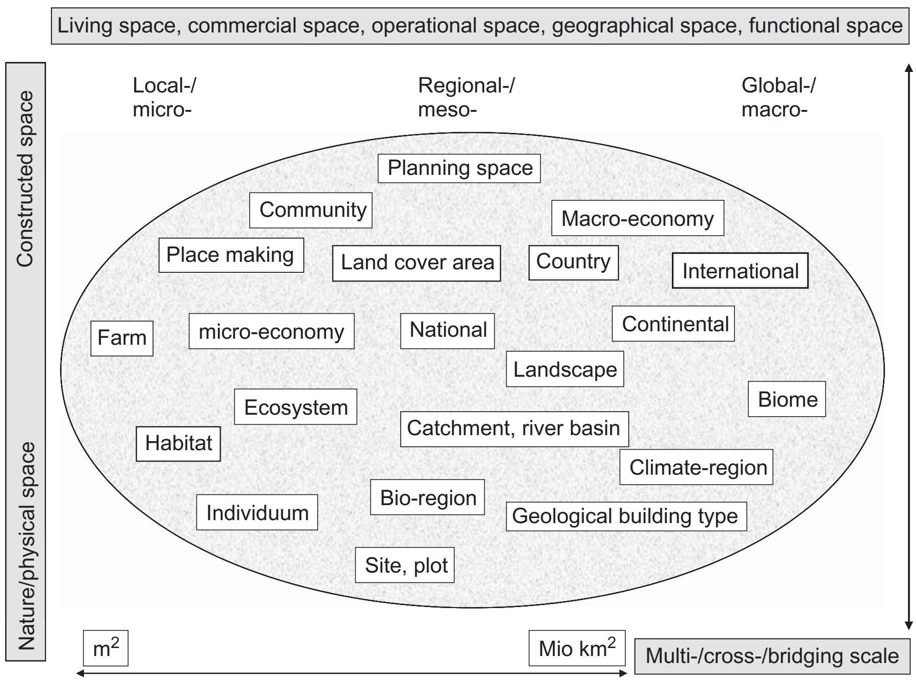

Figure 1. Selected spatially relevant phenomena reflecting different scales.

institutional boundaries seldom coincide, and stakeholders in ES often cut across a range of institutional zones and scales (de Groot et al. 2010). Services generated at a particular ecological level can be provided to stakeholders at a range of institutional scales, from the individual and household to the local/municipal, state/provincial, national and international/global community levels, and stakeholders at a particular institutional scale can receive ES generated at a range of ecological scales (Hein et al. 2006; de Groot et al. 2010).

- The fact that ES are generated and supplied at various spatial scales has a strong impact on the value that various stakeholders attach to the services, as the scale at which the ES is supplied determines which stakeholders may benefit from it and what their interests will be.
- Spatial trade-offs in terms of the local costs and regional or global benefits and vice versa (e.g. of water purification, carbon sequestration, biodiversity conservation), so-called spatial externalities (Ring et al. 2010), are also a question of scale. The costs of conserving ecosystems and biodiversity fall mostly on local land users and communities, whereas the beneficiaries of conservation are found not only at the local level but also far beyond it, at the national and global scales as well.
- There are also various scales at which decisions on natural resources and ES are made. The identification of scales and stakeholders allows an analysis of potential conflicts in environmental management, in particular between local stakeholders and those at larger scales. Considering scale issues in ecosystem management can be important as a basis for establishing compensation payments to local stakeholders who face opportunity costs of ecosystem conservation, and they provide insight into the appropriate institutional scales for decision-making on ecosystem management (Hein et al. 2006).

There is a strong need to examine the various scales at which ES are generated and used, and, subsequently, how the supply of ES affects the interests of stakeholders at various scales (Tacconi 2000; MA 2003; Turner et al. 2003; Hein et al. 2006). Hence, the possible *scale transitions* of ES and the relevant traits need to be examined carefully.

Scale trade-offs are very difficult to manage, because they include, in both space and time, shifts of costs and benefits transcending levels of magnitude – small- and large scale, as well as short- and long term. Threats on biodiversity and climate, deforestation and desertification do not imply only transfers of costs from one area to other regions or continents, but also likely transfers to later periods and future generations. That problem can render ecosystem payment systems as well as immediate political reactions difficult or even impossible. Regarding time scales, it is very important that 'analyses of the dynamics of ES supply require consideration of drivers and processes at scales relevant for the ES at stake' (de Groot et al. 2010). Due to the scale trade-off problem, the transfer of ES assessments over the different scales needs to analyse the specific units and scales of SPA and SBA (see Section 2.1).

Scale issues lead to the question of reference units. Adequate spatial reference units are necessary for the sampling, analysis and assignment of data, as well as for the assessment and modelling of ES (Bastian et al. 2006). The reference units should be related to scales that are ecologically reasonable and policy relevant, and they should express the complexity of facts and relationships. Examples for ecological units are ecosystems, watersheds, landscapes and geo-chores (Haase and Mannsfeld 2002; Bastian et al. 2006; Blaschke 2006). For example, the supply of the hydrological service depends on a range of ecological processes that operate, in particular, at the scale of the watershed (de Groot et al. 2010). Examples for socio-economic reference units are administrative units (municipality, district, state, country) and land-use units. The mismatch of administrative/socio-economic and ecological units and data is a crucial problem (e.g. population statistics on administrative units not matching catchment boundaries), which needs special attention.

Ecological reference units can be used for benefit transfers (e.g. Plummer 2009): Ecological data and analyses from a particular reference unit can be transferred to a certain degree to ecologically similar and therefore comparable units (including the capacity to supply goods and services).

Control scheme for ES space and time considerations

In order to check and improve the given methodological ES frameworks and studies concerning the consideration of important space and time aspects, we propose the following checklist (Table 1). It can help avoid overlooking or missing important aspects, and it provides a guideline for the quality control of ES assessments as well as for the analysis of the aspects taken into consideration. The relevant issues (space, time and scale aspects) have been described above (Sections 2.1–2.3: The relevant key words are in italics). We explicitly intend to introduce the checklist even into fields that have not been affected by the ES concept to date. The scheme is demonstrated by the example of the EU WFD (WFD 2000), which addresses many space and time aspects (see Section 3.4). In fact, it does not mention the ES concept and terminology, but implicitly aims to maintain and improve several ES.

Case study: EU Water Framework Directive and ES

WFD – contents

The application of the EU WFD (WFD 2000) implies consideration for the ES concept (e.g. Grossmann et al. 2010) and many space and time aspects, as we seek to demonstrate below, using the example of the Elbe River management plan (Table 2). The WFD is a directive designed to harmonize the legal framework of water policy in the EU. It also aims at a stronger orientation of the water policy towards a sustainable and environment-friendly use of waters. Due to the quite heterogeneous natural conditions within the EU, the WFD is confined to establishing general quality goals, and to indicating methods for meeting those goals and achieving favourable water quality.

The core of this directive is the establishment of environmental goals for the WFD including sustainable land use (long-term sustainable water management based on a high level of protection for the aquatic environment), and also the optimization of ES (e.g. human health protection, economic consequences).

The 'translation' of the normative regulations in the WFD into numerical class limits of a 'favourable state' applies scientific methods. Socio-economic aspects are also taken into consideration by the WFD in the form of 'exceptions' from the goals, and of cost-efficiency analyses.

The goals of the WFD imply mainly the following benefits, reflecting a whole bundle of ES:

- Human health protection by water-related utilizations, for example bathing-water quality, drinking-water quality
- Lower costs for water purification
- Maintenance of water supply
- Improvement of life quality by increasing the recreation value of surface waters
- Coping with conflicts and regional damages through the balance of interests among different social groups.

The precautionary principle, information and transparency shall be considered consequently. The WFD contains mechanisms to assure that socio-economic effects are considered in decision-making processes and that cost-effective options are preferred. The implementation of the environmental goals, however, can cause additional costs but it can be profitable for some beneficiaries (e.g. landscape management companies), and – in the long run – for the whole society. According to the particular watershed, the goals depend on the difference between the actual and the target state as well as on the choice of instruments and management measures. Space–time approaches play a decisive role.

Selected spatial and scale aspects of the WFD

The spatial orientation towards river basins is decisive. Until recently, the water body management in Germany was organized predominantly according to political borders and administrative units. At first, the water policy in Great Britain and in France was oriented on watershed units. This gave the impulse for a European regulation. As the watersheds of many large European rivers (Meuse, Rhine, Elbe, Oder, Danube) exceed state borders, a common European regulation suggested itself. The similar situation applies to the groundwater bodies, which are also independent of political borders.

The international Elbe River basin unit contains 146,828 km^2 water, and it is divided into 10 coordination units. The Czech Republic is responsible for five coordination units (Upper and Middle BohemianLabe/Elbe, Upper Vltava/Moldau, Berounka, Lower Vltava/Moldau, Ohře/Eger), while Germany is responsible for the other five coordination units (Mulde-Elbe-BlackElster, Saale, Havel, Middle Elbe/Elde, Tidal Elbe). Except for the coordination unit Lower Vltava/Moldau, minor parts of the coordination units with Czech responsibility are situated in Germany (Ohře/Eger and Lower Bohemian Labe/Elbe, Berounka, Upper Vltava/Moldau) and in Austria (Upper Vltava/Moldau) and Poland (Upper and Middle Bohemian Elbe). The International Commission for the Protection of the Elbe River has the role of a supra-national coordination agency (e.g. water monitoring, supra-regional goals and strategies).

Management plans for large-scale river basin units, for example the plan for the Elbe watershed in Germany, contain, specifically for these large dimensions, strongly aggregated statements. They refer to such questions as: 'Who provides the ES and who pays for them?' They also consider the specific spatial categories for ecological analyses, for planning and for decision-making.

Table 2. Scheme of spatial levels in the Elbe River management plan.

Scale	Physical level	Institutional level	↑	↓
Macro	Total catchment area, watershed-related coordination units	International Commission for the Protection of the Elbe River, countries/states		
Meso	Partial catchment areas, coordination and planning units	States, counties, catchment areas, area-specific panels	Analyses, provision, processing, evaluation	Requirements, strategies, structures
Micro	Small catchment areas, study areas, surface waters and groundwater bodies	Districts, municipalities, working groups and commodity teams, clearing meetings		

As EFTEC (2010) noticed, 'the spatial analysis of the management plans

- helps better organise locally specific data on water bodies and provides a consistent basis for accounting for the context-specific nature of economic values, in particular in terms of spatial variation,
- allows better representation of the impacts of WFD implementation (e.g. in identifying the location of improvements in environmental quality),
- provides a basis for assessing spatial variation in economic values. This implies that more robust estimates of aggregate costs and benefits can be obtained, and additionally, that the distributional impacts can also be examined'.

The real planning and implementation of measures take place at the regional and local levels within meso- and micro-scale spatial sub-units. For this purpose, combined top-down and bottom-up approaches are necessary: Supra-regional environmental goals and needs must be down-scaled to regional and local action targets. By contrast, the measures must be aggregated according to the related river basin units and coordination units. After EFTEC (2010) a key aspect of the WFD implementation is concerned with the spatial and geographic aspects of water bodies. It is necessary to understand how the impacts of measures may vary over spatial scales. These effects will not only have an impact on the direct benefits related to the water bodies themselves but can also have indirect beneficial or detrimental impacts elsewhere. In the case of water quality, and in particular rivers, most of the relationships between ES production areas and benefit areas are 'directional' in a downstream direction (rather than 'in situ'). In some cases the beneficial effects can be spatially very remote from the area of a targeted intervention. For example, reducing diffuse pollution may enhance terrestrial biodiversity, soil quality and erosion control, in addition to the water quality benefits downstream (EFTEC 2010) (Tables 1 and 4 – 3.2: *scale transition*). Accordingly, for management purposes (assessments of the state, targeting) the Elbe River basin has been divided into 61 planning units, ranging in size from 300 to 5600 km^2, 3896 surface water bodies and 327 groundwater bodies. The institutional levels and the information levels, including the accuracy of data, should be referenced to these scales (Tables 1 and 4 – 3.1: *suitable dimension*).

The chemical, biological and ecological quality of waters depend on a variety of influences. In order to assess them and to take action, an integrated approach and a broad database are the key necessities. The WFD prescribes consistent and therefore comparable criteria for the provision and updating of these data. For example, Article 10 of the WFD prescribes that the loads from point sources (especially industrial wastes and from sewage purification works) and diffuse sources (especially from agricultural land) should be considered together.

This is based on spatially specific analyses and documentations of loads (main sources). Typical questions are Which waters (surface waters, groundwater) are polluted by nutrients (N, P) and to which extent? What is the contribution of parts of catchment areas or of countries/states to the eutrophication of the North Sea and what are the specific potentials for reducing these loads? Such spatially relevant distribution options were traded off in the framework of the Elbe River Basin Agency (Flussgebietsgemeinschaft Elbe 2009). It is obvious that the efforts to reduce N can and should be especially high in the German states of Schleswig-Holstein and Saxony, while the potentials to reduce P are especially high in Thuringia, Schleswig-Holstein, Saxony-Anhalt and Saxony (Tables 3 and 4 – 1.4: *functional connection*).

This supra-regional distribution of nutrient reductions must be further underpinned in the water basin sub-units. In terms of spatial aspects, that means, for example whether agro-environmental payments, for example for intermediate crops, or soil protection against erosion, are provided for all arable fields, or are concentrated on focus areas. Analyses of efficiency and acceptance are necessary

Table 3. Expected reductions of nutrient loads of the Elbe River for the protection of the North Sea in tributary rivers, by country/state.

	Nitrogen		Phosphorus	
Country/state	%	tons/annum	%	tons/annum
Czech Republic	5	≈3120	7	≈150
Brandenburg, Berlin	0.8	≈47	1.5	≈8
Bavaria	3.5–7.5	≈195	2–5	≈3
Hamburg	10	≈85	10	≈3
Mecklenburg-Western Pomerania	19	≈400	5	≈5
Lower Saxony	2.7	≈270	2.7	≈12
Schleswig-Holstein	16.6	≈1650	18.7	≈70
Saxony	10–11	≈2740	11–13	≈75
Saxony-Anhalt	3.9	≈625	13.4	≈60
Thuringia	5	≈600	23.6	≈80

Note: Reference year is 2006; measurements between 2009 and 2015, nutrient inputs into primary flowing waters, as per Flussgebietsgemeinschaft Elbe (2009).

Table 4. Checklist of space and time issues, exemplified by WFD (2000).

Position	Issue	Implementation in WFD (examples)	ES – example: groundwater recharge
1. Space			
1.1	*Areal requirements*	Minimum sizes of standing waters (50 ha) and catchments (of flowing waters: 10 km^2) in the WFD monitoring and reporting taken into account; catchment alignment instead of administrative units	Areas and state of groundwater bodies
1.2	*Spatial composition*	Combined consideration of surface and groundwater, management of entire catchments	Patterns of aquifers and infiltration areas; distribution of groundwater recharge (supply) and groundwater extraction (demand)
1.3	*Spatial configuration*	Configuration issues only partially implemented with mappings of the waters' structure; fish migration ability considered; confined to big- and medium-sized water bodies (i.e. two-thirds of streams are not considered in terms of their structure)	Spatial structure and shape of landscape elements (e.g. infiltration areas)
1.4	General: *functional connection*	Orientation towards human health, quality of life, joint consideration of biological, chemical and ecological quality	Maps of groundwater protection; spatial allocation of measures, benefits and payments
2. Time aspects			
2.1	*Time requirements*	Differentiating management measures by graduated time periods	Time aspects of groundwater recharge and flows, monitoring (water-level gauge)
2.2	*Temporal sequences*	Targets in accordance with ecological processes are differentiated according to specific time periods; flexible management priorities	Natural conditions can vary (precipitation necessary for water infiltration, crop rotation), trends (e.g. climate change)
2.3	*Time lags*	Strict application of the precautionary principle, (flood) risk minimization	For example, the establishment of water protection areas
3. Scale and dimension			
3.1	*Suitable dimension*	Combined top-down and bottom-up approach, planning and management regional, but measures local	Hierarchy of catchment areas
3.2	*Transition*	Partly considered: effects on climate protection goals	Many local measures can affect groundwater recharge regionally (or regarding the whole water body)

for this (Grunewald and Naumann Forthcoming). It is also necessary to make arrangements for cooperative efforts and to negotiate solutions between the land users (farmers) and the beneficiaries of ES (here, society as a whole).

Time aspects of the WFD

The WFD outlines several time limits, for the legal implementation of the directive itself, the analyses, the monitoring programme, the management plans and the specific programmes (timetables) for the measures. Moreover, and importantly, it is established until when a 'favourable state' of the water(s) has to be reached.

Time aspects are especially considered with respect to the practical implementation of the WFD. The clear requirements for ES providers and beneficiaries correspond to the time spans for the realization of measures, for example for reducing nutrient loads, or the reporting obligation of the countries/states (see Table 4 – 2.1: *time requirements*). The concrete, super-ordinate timetable with milestones is obligatory for all parties concerned, from the transformation of the WFD into national legislation in 2003, until the achievement of the 'good ecological state in river basins' in 2015, with the possibility of extending this time limit until 2021 or 2027 (WFD 2000).

It must be considered that waters need time to reach such goals after development measures (time span until results of the measures are achieved). The *temporal sequence* (Table 4 – 2.2) of requirements refers to the duration of natural processes, as well as to the *adequate order of measures and the* time needed to accomplish management measures. In fact, WFD aims at a 'good ecological state' of all waters by 2015. But the directive also allows exceptions: extensions of time or reduced environmental targets, if they cannot be achieved in time for objective reasons. The exceptions are designed to avoid excessively high costs of management measures. Without valid cost calculations, it is difficult to justify exceptions. As for the practical implementation of the WFD, the countries (in Germany also states) are responsible. All countries interpret the directive independently, but they have implemented working groups to harmonize the national regulations to a certain extent.

The WFD puts an end to previous *time lags*, it contributes to ensuring water-related ecosystem potentials for the future. The precautionary principle is already implemented, since the WFD ensures water reasonable quality. But even economic time lags (i.e. the next generation has to pay for our success now) will be avoided.

Until 2010, the member states of the EU have the obligation to implement an appropriate water fee policy, with incentives for water users to use the resources economically. The various water users (industry, households, agriculture, etc.) are to contribute adequately to cover the costs of water ES, including costs related to the environment and the resources (Article 9 WFD). The evaluation of financial disproportions (cost excessiveness) also needs the balancing of costs and benefits, that is typical core aspects of the ES approach are considered. The WFD also prescribes that until 2010, the water supply was to be organized in such a way that all costs were covered (the cost-covering principle). The question is 'Who pays?' Formerly, the general public has paid for the protection of drinking water. Now, the waste producer has to pay, but the principle of solidarity is applied. It must be noted that to date, these regulations and obligations have been only partially implemented.

Control scheme for ES space and time considerations in the WFD

The checklist for space and time aspects (Table 1) is completed and exemplified by means of relevant aspects of the EU WFD. Table 4 shows that the directive meets most of the space and time issues concerned, for example, the size of catchments and the differentiation of measures in terms of space and time. On the other hand, the table also reveals possible lacks, such as the incomplete consideration of spatial configuration, or of scale transition aspects.

Discussion and conclusion

ES demonstrate a wide range of space-, time- and scale-dependent relations. Not only the ecological aspects are concerned, but also socio-economic and cultural ones, in respect both to the analysis and evaluation steps and the supply and demand perspectives. Often, space and scale effects are related mainly to ecological phenomena. According to our concept of space, we have tried to widen this perspective and to include socio-economic aspects as well. This is in line with the UK National Ecosystem Assessment (2011), which notes that institutional mechanisms linking across spatial scales (from small- to large scale in terms of area) would 'provide opportunities for stakeholder engagement and greater collaboration between actors, and for the involvement of local groups and non-governmental organisations.'

There are still various open questions concerning space, time and scale relationships in ES assessments. Some of the questions raised in Section 1of this article could be solved and discussed by reference to the example of the EU WFD, for example, spatial configuration and composition (patterns), reference units, concordance of physical and socio-economic space concepts, the spatial position of services providers and service beneficiaries, SCAs, the role of temporal sequences (of land uses, supply and demand) and time lags (precautionary principle, intergenerational lags), the shift from one scale to another, and practical consequences resulting from these factors.

In order to take space, time and scale effects into consideration adequately, a checklist is useful, which we have developed and tested successfully using the example of the WFD. Such a checklist can be applied to all frameworks and studies where ES are to be assessed. This checklist is a flexible scheme that can be modified according to the particular situation.

Space, time and scale aspects of ES are of great practical interest, for example, for land-use and landscape management, for spatial planning, regional development and financial policies (balancing of costs and benefits arising from ES). After EFTEC (2010) spatial analysis improves the economic valuation, and it can help to 'target' policies (e.g. maximize aggregate benefits given a resource budget, or to redistribute benefits to disadvantaged groups). The example of the WFD reveals the practical relevance in many ways, for example, the choice of relevant reference units, the spatial and temporal distribution of costs and benefits, time frames for reaching particular goals with consideration for ecological preconditions (e.g. the regeneration capacity of waters) and also of economic scales (economic carrying capacity, payments over adequately great time periods). The WFD takes ecological periods into account (development, seasonality, regeneration, matter transfers), and it gives a clear orientation in terms of time horizons, which is important for users and other stakeholders. In the WFD, such issues are better addressed than – for instance – in the EU Habitats Directive and other regulations.

The testing of the checklist on other practical applications and its qualification can contribute to the improvement of the ES concept and to raise its practical applicability as well as its acceptance by stakeholders and society. The consideration for space, time and scale aspects should not lead to a negligence of other important aspects, such as the ecological fundamentals, functional relations or special economic and socio-cultural issues. The checklist could be extended to include these aspects. Also, legal and ethical issues and problems of economic evaluation (e.g. fairness and balance between costs and benefits) should be accomplished, but that goes beyond the scope of this article.

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