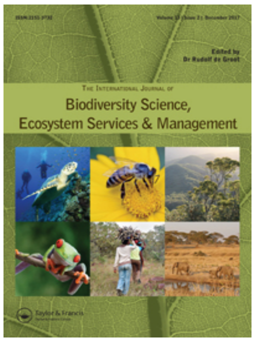

International Journal of Biodiversity Science, Ecosystem Services & Management

ISSN: 2151-3732 (Print) 2151-3740 (Online) Journal homepage: www.tandfonline.com/journals/tbsm21

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To cite this article: Ralf-Uwe Syrbe & Karsten Grunewald (2017) Ecosystem service supply and demand – the challenge to balance spatial mismatches, International Journal of Biodiversity Science, Ecosystem Services & Management, 13:2, 148-161, DOI: 10.1080/21513732.2017.1407362

To link to this article: https://doi.org/10.1080/21513732.2017.1407362

Published online: 05 Dec 2017.

INTERNATIONAL JOURNAL OF BIODIVERSITY SCIENCE, ECOSYSTEM SERVICES & MANAGEMENT, 2017
VOL. 13, NO. 2, 148–161
https://doi.org/10.1080/21513732.2017.1407362

Ecosystem service supply and demand – the challenge to balance spatial mismatches

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ABSTRACT

Ecosystem services (ESs) are influenced by use intensity. Arising disparities between supply and demand are often depending on spatial relationships. We propose to classify the spatial relations into six cases with regard to the relocation of resources to the affected groups of people. Based on these six cases, the paper also identifies the human contributions to service supply and transfer. The classification distinguishes between 'local' (supply and demand in the same area), 'proximity' (close natural transfer), 'process' (distant transfer by natural processes), 'access' (users can get to the ecosystem), 'commodity' (supply contributed and transfer carried out by market players), and 'global'. For the several cases, specific scientific methods and different policy approaches are applicable. A crucial issue is how to deal with the actors who enable, maintain, and restrict ESs. Thus, considerations about landscape maintenance, conservation support, and private solutions are necessary. The contribution suggests a framework to analyse and improve the relationships concerned by uncovering mismatches between supply and demand. We use selected indicators to compare supply and demand in these relations. Four examples show the capability of the approach to limit the overuse of ecosystems and to maintain the according ESs.

ARTICLE HISTORY
Received 23 February 2017
Accepted 14 November 2017

EDITED BY
Christine Fürst

KEYWORDS
spatial flow; transfer type; providing area; benefitting area; connection area; resources

Introduction

Ecosystems contribute to human welfare through a supply of natural goods, a control of material and energy flows towards a reduction in natural hazards, and by opportunities of cultural experiences in connection with nature and landscape (Bastian et al. 2014b). Behind them are a variety of other (not directly used) natural functions, which support the preservation of essential resources. Thereby, contributions are made for safety, fulfilment of essential natural resources, maintenance of health, good social relationships, and the freedom of choice (MEA 2005).

The imbalance between socially driven economic growth on the one hand and the naturally limited availability of resources on the other poses one of the biggest challenges of our time: the overuse of resources and the associated losses of natural processes providing the essentials of our life (WBGU 2011). The problem is that very few of these resources or usage limits are publicly known or used in a sustainable manner. To overcome this problem, ecosystem services (ESs) are defined as the contributions of ecosystems to human well-being (De Groot et al. 2002). These contributions to well-being are not only luxury goods but also the basic requirements for survival (water, air, food, heating). The concept of ES is an approach that shall analyse and describe not only the diversity and relationships between functions and processes in the natural environment but also their relevance to society. An additional reason to consider the ES framework is that the social perspective and economic tools allow potential market failures to be overcome (Nelson et al. 2009).

Fisher et al. (2009) have refined the challenge to govern ES through a fourfold differentiation: Firstly, ecosystem goods and services can be subdivided into excludable and non-excludable ones. Secondly, they can either be categorized as 'rivalling' or 'non-rivalling' depending on whether they are consumable or not. As the case may, be they should be managed accordingly. Many environmental goods are non-excludable, such as climate regulation, air quality, safety against disasters, or (partly) scenic quality. But if it were impossible to exclude specific ecosystem users, then primarily profit-oriented players would be encouraged to use them without maintaining these assets in the same way as others (cf. Ostrom 1990). Those who use and care are at risk of being knocked out of the competition due to higher costs and less income. If only irresponsible market players are able to survive in the long run, it is much more difficult for society and policy to maintain the environmental goods and to ensure the welfare of mankind (cf. Hardin 1968).

If politicians try to counteract this effect, they need public support and instruments to do this. Possible instruments were for instance an updated agricultural policy that not only promotes ecological cultivation

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but also omits the funding of industrial cropping or an exhaustive consumer information policy that would not facilitate unethical practices by an oversize of privacy. New arguments and control tools for policy, planning, and economic decision-making processes can be provided (Grunewald and Bastian 2015). Because ecosystem goods and services are also considered economically, there is new hope that adverse market mechanisms can be corrected. Besides socio-economic issues (ownership, maintenance, prices), the spatial connections and in particular the access for people to the benefits of ecosystems are crucial for a fair use of ES and for protecting the goods of nature against overuse and impairment.

Recently, several promising approaches have been developed to highlight and analyse the spatial relationships between service-providing areas (SPA), service-benefiting areas (SBA) as well as the space in between. Ruhl et al. (2007) described patterns of service transmission, of which four different types have been identified by Fisher et al. (2009). Syrbe and Walz (2012) expanded the scheme by adding the service connecting area (SCA) between SPA and SBA. Particularly, the spatial flows of ES have been modelled by Bagstad et al. (2013) using a multi-agent simulation system (SPANS) based on the ARIES modelling platform (Villa et al. 2011). The SPANS algorithm is made to describe the routing of one particular ES provided in one location and used in another. Bagstad et al. (2013) have developed a generic framework describing possible sinks, depletions, and other kinds of obstacles affecting the spatial flow between the locations of provision and use, which are thus particular features of the above-mentioned SCA. Because individual flows have to be captured, such a model is data intensive and requires in-depth knowledge and may not be applicable for mapping and even monitoring a whole country. Serna-Chavez et al. (2014) developed a more general approach and applied it even on a global level. They defined a benefit flow indicator measuring the spatial flow area in relation to the whole SBA and developed possible configurations for different services. Unfortunately, the use of the term ‘ecosystem services flow’ has been ambiguous, referring as well to spatial transfer as the actual use of provided services without regard to spatial routing like in the Mapping and Assessment of Ecosystems and their Services (MAES) documents (Bagstad et al. 2013; Burkhard et al. 2014).

The authors were faced with the task of quantifying ESs nationwide in the framework of the EU biodiversity strategy (EU 2011), as it has to be done in nearly all European countries. Indicators have been developed that describe the most relevant services or even particular characteristics of such services (Grunewald et al. 2016). It can be useful to characterize and map ES by indicators that express potential, supply, flow, demand, and human impact as well as the conditions of ecosystems (Wolff et al. 2015; Syrbe et al. 2017). Of course, it is possible to work through the list of ESs very systematically such as Jäppinen and Heliölä (2015) did for Finland calculating indicators for structure, function, benefit, and value for each ES. Since the underlying processes and relationships are quite different, some of these aspects can be more or less useful to quantify. A very huge number of indicators may make it difficult to efficiently use this information in policy and planning. Therefore, the decision for Germany was made to carefully select only a subset from all possible cases and most of all to confront supply and demand indicators as far as meaningful. The hypothesis is that this confrontation of supply and demand can uncover imbalances and thus unsustainable use of natural resources.

But one can expect that only a plain confrontation of supply and demand will not totally solve the problem. Besides the above-mentioned spatial relations, also the various access alternatives to the ecosystems and the transfer of goods and benefits should be included in the consideration. The latter depends on natural processes or on human activities and is strongly scale dependent. Therefore, it must be assumed that political measures and socio-economic approaches to govern ES in a sustainable way can be derived more specifically if these relationships are considered. Therefore, the authors took up the approaches from Ruhl et al. (2007), Fisher et al. (2009), Syrbe and Walz (2012), and Bagstad et al. (2013) and distinguished also transfer connections. We pursued the question if a clear distinction of the arising cases can improve the possible conclusions for a fruitful governance of natural resources and a fair ESs’ use. Led by a respectively extended scheme, recently calculated indicators should be confronted and scrutinized if the differentiated view can offer helpful insights.

The paper displays indicators of ESs from several data sources, which have been calculated and mapped nationwide and can be included in the German national reporting for the EU biodiversity strategy as a selection of the entire indicator set (Grunewald et al. 2016; Grunewald, Syrbe, et al. 2017). The purpose of this paper is to check the new scheme using specific examples and to highlight the specific supply-demand connections. Therefore, it shall propose indicators and ideas that are useful for analysing, in particular, the spatial link between supply and demand sides of ESs and for overcoming the respective challenges. A nationwide and spatially precise monitoring of different environmental aspects highlights emerging problems and provides starting points for possible planning and political corrections. By means of proper calculating and mapping indicators for supply and demand, decision makers, planners and private activists can be enabled to protect resources and regulate the ES use (Fisher et al. 2009).

ES supply versus ES demand

The ES concept is initially a construct reflecting the value of nature and the reasons for using it carefully. Since the majority of ecosystems are used, most services involve human impact. Thus, their mapping and assessment should consider such impact or the effects of maintenance. Since one of the essential motivations of the ES concept is to safeguard biodiversity, each indicator has to be double-checked regarding what it means for careful use and preservation of biodiversity (EU 2011; Grunewald et al. 2016). People are seldom aware of their need for natural goods, processes, and potential that ensure their welfare today or in the future. By contrast, from a socio-economic point of view, services exist only with respect to a demand of a beneficiary. So we need to distinguish at least the supply and demand side of service provision, and even regarding all the above-mentioned considerations we may have to add the aspects of ecosystem conditions, potential, impact, and flows (Villamagna et al. 2013; Burkhard et al. 2014; Albert et al. 2015; Jones et al. 2016). Demand cannot be captured merely by the willingness to pay for ES, since people with low financial power even depend on ES more than the rich (TEEB 2010). A question of environmental justice is to ensure ES for all people in need. That is, ecosystems must be protected from exploitation by primarily profit-oriented players. Therefore, a sound analysis of demand and perhaps endangered supply of ES – together with the need for maintenance or protection of ecosystems – will be crucial for the future of our world.

The ES framework bridges the variously interconnected ecosystem and socio-economic system, considers the mutual impact and intrinsic subsystems (cf. Syrbe et al. 2017). It considers the stock of natural assets as a starting point for the flow of material, energy, information, and organisms as a result of both ecosystem potential and human co-production in terms of land use. Another feature on the ecosystem side is its potential, often also called 'capacity', which is important as a guarantee to regenerate goods and ensure services in the long run. When usage exceeds naturally limited potential, the ecosystem can be harmed, causing less ES supply or quality of life due to environmental damage.

Social demand covers both the purchasing power to get desired benefits as well as the essential needs of all people, which are difficult to monetize. Corresponding maps can help to uncover risks for ecosystem health, unsustainable use of potential, harmful impact to landscape, vulnerable assets, impaired flow as well as mismatches between supply and demand in order to provide indications for improving the environmental situation and maintaining biodiversity. Additionally, there are interdependencies between services called trade-offs (affecting each other) and synergies (facilitating), which can be recognized using maps and indicators. Dependencies among users caused by 'rivalry' and 'excludability' (see Fisher et al. 2009) can only be considered depending on a particular ES.

For a political and economic application, it may even be required to state ES in monetary terms. But the first key challenge is to measure the various items correctly in order to value them fairly. The ES assessment methodology is very diverse, i.e. depending on the chosen approach, different results may be obtained (Haines-Young and Potschin 2009; Grunewald and Bastian 2015). Maps and numerical comparisons between supply and demand can help to recognize spatial mismatches, to identify endangered environmental goods, and to uncover the need for sound maintenance of the affected ecosystems.

ES transfer from providing to benefiting areas

Supply and demand are seldom realized at the same point. The ecosystems that generate services are located in the SPA. By contrast, the demand comes from people who want to benefit from services. If it is possible to designate particular areas for the service use, we call them SBA. However, in some cases, the beneficiaries are dispersed very widely or even worldwide. It can be difficult to clearly decide where the SBA actually is (Fisher et al. 2009; Syrbe and Walz 2012).

The possible supply and demand indicators in the following examples underline that there is rarely a clear spatial point-to-point relation between supply and demand. ESs exist only if there is any kind of transfer of goods and services to a beneficiary. Several possibilities exist, systematically depicted in Figure 1. This scheme is based on the classification of Fisher et al. (2009), expanded by the SPA-SBA-SCA connections by Syrbe and Walz (2012) and comprises the five cases of 'spatial service flow' given by Serna-Chavez et al. (2014). For each case of transfer and for each scale level, an individual collection of supply, demand, and perhaps flow indicators is necessary; likewise, the mapping and monitoring approach has to be adapted. But the question is, are there suitable factors dependent on the types of transfer?

Depending on the relations of service transfer between provision and benefit (Figure 1), there are specific approaches to configure indicators of supply and demand and to derivate possible methods to govern ES.

(1) The first case, 'ES local', concerns services that provide benefits mainly at the area where they

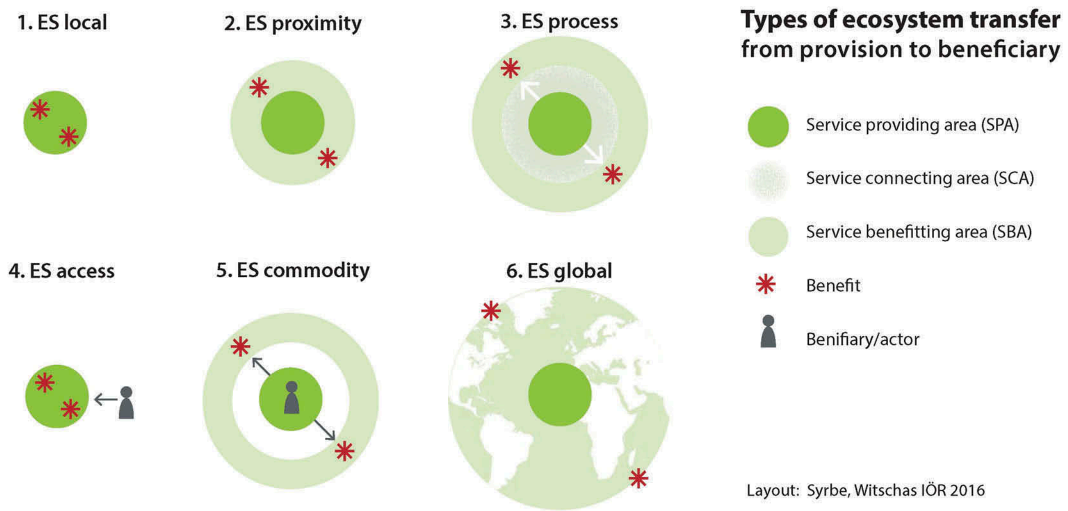

Figure 1. Types of ecosystem service transfer from provision to beneficiary, own draft based on Fisher et al. (2009), Syrbe and Walz (2012), and Serna-Chavez et al. (2014).

are generated. One can assume that governance must deal mainly with the real plots where supply and demand arise, but our first example suggests that this case is hardly that simple.

(2) For the second case, 'ES proximity', benefit is not derived at the same point as its origin; therefore, the distance is crucial. ES generation and transfer depend on proximity between SPA and SBA and trends towards zero for long distances. The distances are fixed by ecological laws and can hardly be levered out by management measures.

(3) The third case, 'ES process', arises where movements reach the beneficiary (or potential victims) by natural processes even at a greater distance. Here, a spatial analysis can give insights into the interspace, the so-called SCA (Syrbe and Walz 2012), whose characteristics control the effects as it can be analysed, e.g. using the model of Villa et al. (2011). Since this SCA has different owners as well, corresponding management must govern and negotiate the interests and behaviour of several, sometimes distant, stakeholders. Artificial processes have been separated from this case (to case 5) because they often lack physical landscape structures and are more dependent on market mechanisms.

(4) The fourth case 'ES access' means that a user can get to an ecosystem and enjoy the ES there if he or she can reach it. Therefore, the user needs a way to get there and must be allowed to access it. This applies to most cultural ES and is exemplified by urban recreation below. The respective governance approach deals mainly with the access possibilities or restrictions, but must also include a balance of interests between users who seek access and residents who should maintain the ES without economic drawback.

(5) The fifth case, 'ES commodity', is much more complex because the goods of an ecosystem can only render benefits if an actor carries goods (timber, meat, fruit, etc.) to the final consumer. The benefit has to be shared (income for the actor and final use by consumers). Since the actors not only organize the transport but also shape and maintain (or damage) the ecosystem, it is worth focusing the ES analysis on the first steps of valorization. Since transport and sale depend rarely on landscape structures (SCA), this case is separate from case 3.

(6) The sixth case, 'ES global', is relevant when the benefit of a service is global and cannot be restricted spatially. For planning and political issues, it is interesting how a global ES can be safeguarded even without direct SPA-SBA connections. The clause 'think globally, act locally' is not randomly connected with the selected example.

Typically, carbon sequestration can be discussed here, just as all other greenhouse gas emissions regarding their climate change effects. Though there is actually a worldwide demand area, it can be nevertheless meaningful to analyse spatial transfer effects here. But above all it is a case of mutual commitment that each one contributes to a common goal as much as possible and shares the expense. Maps and indicators can offer solutions if they show how much can possibly be done (regarding ecosystem potential) versus how much incentive there is to use this potential.

Examples of supply and demand indicators

Like the other European countries, Germany shall assess and map ES on its territory and include the results in a national report to the European Commission (EU 2011). Therefore, by order of the German, the politically most relevant ES have been selected and calculated as a set of (quantitative) indicators (Ifuplan, ETH-Zürich, Universität Bayreuth 2014; Grunewald, Syrbe, et al. 2017), which should fit into the EU-wide indicator schemes (Maes et al. 2013, 2014). In most cases, there is a main indicator that captures the essential service of a certain class, supplemented by several auxiliary indicators that show special aspects or the relation between supply and demand. Though not all indicators have been finally coordinated with federal government yet, we demonstrate – through only four instructive examples of the groups providing, regulating, and cultural ES – how supply and demand can be quantified and compared as a contribution to sustainable handling of limited environmental resources.

Regulating indicators for preventing water soil erosion

Soil erosion can be regarded as a dysfunction, i.e. an adverse natural process. But there is little erosion in many natural ecosystems of Central Europe due to the vegetation cover breaking the precipitation energy, reducing the rain by interception and transpiration, absorbing water into a well-rooted and loose soil, and retarding run-off with unevenness and obstacles. These effects are reduced by humans through agricultural, mining, or building practices, causing so-called damage erosion. The remaining demand for avoidance of erosion arises on arable fields, where steep slope degree, high precipitation, and lack of vegetation cover pose a risk of high soil loss if a rainstorm should occur. Syrbe et al. (2016) modelled the erosion rate using an adapted USLE (Wischmeier and Smith 1978; Schwertmann et al. 1990) for all non-developed areas of Germany. One purpose was to estimate erosion rates for all open areas in order to get an idea of the services of ecosystems outside of agricultural fields. However, these erosion rates can also be seen as unmet demand. In this sense, full demand is the hypothetical amount of soil that would get lost if the entire country was without vegetation cover. This hypothetical amount has also been considered in the model, but only as an auxiliary variable to calculate the avoided soil loss as difference of both. Thus, the maps indicate the share of actual versus avoided erosion and allow an understanding of the effects of used ecosystems. Maps and indicators shall show us a call for action and what success we had (or missed) regarding the protection of soils. Unfortunately, even the soil map is the weakest point in calculation since the only nationwide coherent geodata set is the soil overview map applied here at 1: 1 Million. The model considers plant cover (due to the cultivated crops) and the structure of agricultural land, i.e. whether there are landscape elements hindering the run-off on plain fields.

The two maps (Figure 2) show that the highest service supply is not in general under forests, grasslands, and near-nature vegetation, but rather in intense textured parts of the country. These are, in part, the areas with the highest demand, i.e., if agriculture and mining occur there. For instance, on the right-hand map of the service supply, it is not only the German mountains that stand out due to their red and orange colours resp. dark grey that mark high values of erosion prevention in the Alps and low range mountains (for instance Harz, Black Forest), but also the foothills close to the mentioned areas, which show significant supply and demand and are mostly hilly and intensively used by agriculture. A

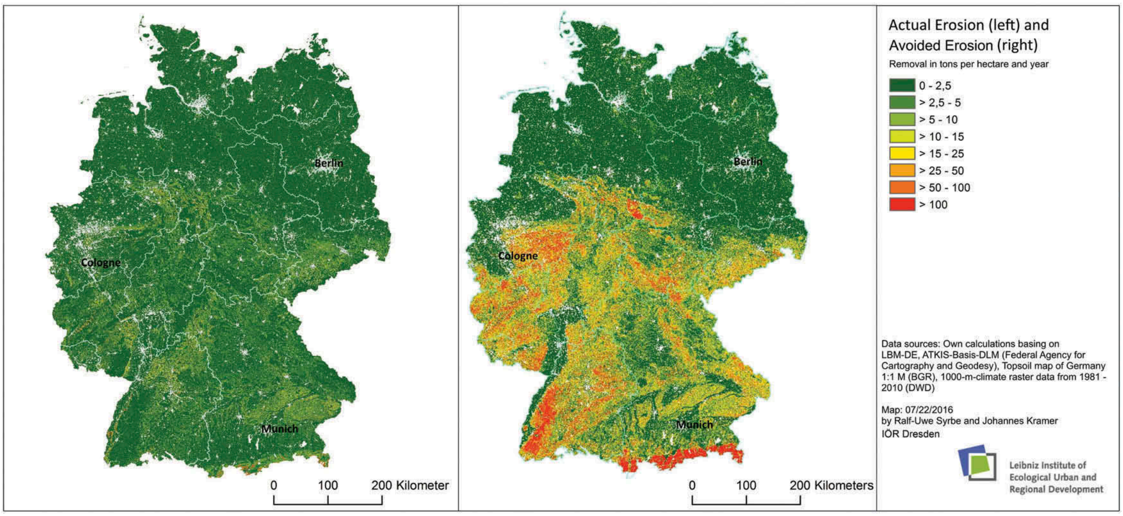

Figure 2. Recent soil erosion (left, unmet demand) and avoided soil erosion (right, supply).

comparison with the results by Syrbe et al. (2016) shows that the avoided erosion in Germany is 10 times more than the residual actual erosion. The fertile loess uplands with their many small valleys show considerable erosion prevention as well as soil loss today. The latter area is yellow-orange (resp. light grey) not only in the right-hand map, but also in the one on the left. Particularly here, erosion needs to be reduced by diverse landscape structure, high share of permanent crops, intelligent crop rotation, organic farming, and at least conservative soil tillage. These factors are partly regarded in the model, so that some progress will be proven. But in fact, there is a negative trend (rising erosion rates and shrinking avoidance) due to the intensification of energy crop production in Germany between 2009 and 2012.

The soil erosion example seems to combine relationships of the two cases, case 1 ('ES local') and case 2 ('ES proximity'), in Figure 1 because the initial split-off effect of precipitation and run-off formation takes place locally, just where the protective effect of vegetation is required. But since run-off accumulates over a slope, the proximity of protective landscape elements can prevent too much removal. Soil erosion can be prevented locally by near-natural land cover. On arable fields, the cultivators are capable of and responsible for considering the erosion problem and shaping the basic conditions. Erosion-preventing landscape elements can decelerate run-off and have the most positive impact if they are situated at the best possible places regarding the underlying physical process (e.g. in depth lines or crossing steep slopes). Also, off-site effects of slurry seal coating (on streets and railways) or nutrient entries into valuable habitats depend on proximity to the erosion area due to the declining transport capability of run-off at the slope toe. Planning solutions and governance should, therefore, concentrate on the field in question and regard the flow connections and landscape elements within a catchment. We all benefit from food safety due to fertile soils, clean waterbodies, and clean streets, but the first benefit arises locally in the fields that are threatened by erosion and must be protected by an adapted agricultural advice and policy.

The case 'ES proximity' means that the spatial relations do not reach very far. Therefore, the supply and demand areas must be close together to govern the service, also barriers shaping the connections have to be considered. This is a strong argument for highly structural diversity. The denser near-natural elements exist in intensively used landscapes the closer such SPA elements are situated to acre fields consisting the SBA here. As a consequence, the ecosystem monitoring will take up also the landscape element density as a future proxy indicator for more than one ES to encourage farmers, planners, and politicians to act accordingly.

Regulating indicator for flood protection

Admittedly, mountain areas with high precipitation and steep slopes can contribute primarily to flood protection. But secondary, the valleys and floodplains are also able to mitigate high water, providing a retention area or at least decelerating the flood peak. Dikes and other flood protection facilities are made to protect particular fields, settlements, or streets, but similarly, they reduce the retention area for the downstream valley. Today, valleys and floodplains in Central Europe are built up to a high degree, so that very little area is left for this ES. The left-hand side of Figure 3 shows the supply of remaining retention area along the largest rivers in the German federal state of Bavaria, calculated by and explained in Walz et al. (2017). These data are available for all federal states, but unfortunately, no smaller river valleys and lowlands are covered by this data set. Only in the mountains and far from agglomerations are there green (resp. bright) areas (in the left map), where the majority of the natural meadows have been left free. Comparing it with demand, the Leibniz Institute of Ecological Urban and Regional Development (IOER) monitor map (www.ioer-monitor.de) on the right-hand side of Figure 3 shows the

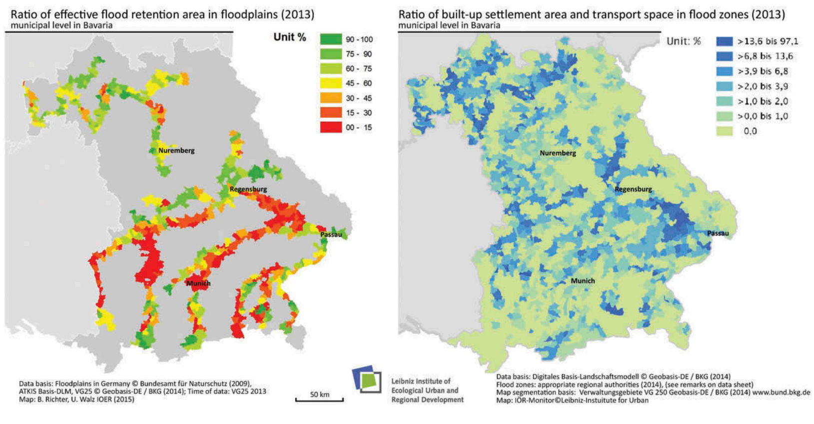

Figure 3. Flood protection in river valleys (supply, left) and built-up area in flood risk areas (demand, right).

proportion of vulnerable built-up and traffic area in (officially fixed) flood zones using colour resp. dark shade of grey. The highest demand for flood protection is where floodplains are full of cities and infrastructure, for instance south of the Bavarian centre, around the River Danube in the middle-right part and in the northern section of the right map. While the northern demand areas benefit from a good supply (large retention areas – green resp. bright in the left map), there is not enough retention possible in the south and eastern part along the Danube. In such areas, for instance between Regensburg and Passau, we have to expect the highest flood risks and damage in Bavaria.

Though there are areas outside the large river valleys, one can recognize the high vulnerability even in the areas that no longer provide protection. The potential victims are complicit in the flood risk in general, and each measure to protect settlements by higher dikes and walls will enhance the problem further. The development of these indicators has not yet been completed, but soon, the IOER monitor will prepare indicators and maps (partly in 100-m raster resolution) to show all decision makers in Germany where there are generated risks and whether we will achieve success in the future.

This example fits with the third case 'ES process' of the scheme in Figure 1. Flood protection can be provided by upstream ecosystems if they are able to withhold, trickle, transpire, or retard the water of a rainstorm. The benefits arise along the entire valley below. However, a floodplain can also retain high water if there is space enough to spread out. Since the floodplain's characteristics shape a flood wave from upstream, it actually acts as an 'SCA'. The largest effect comes from humans who build settlements into a floodplain because the houses likewise narrow the water meadow (increasing every flood) and are themselves endangered by floods.

Cultural indicators for recreation in urban green spaces

Since people drive, walk, or are transported to the recreational areas, this example fits with case 4 'ES access'. The most frequently assessed cultural ESs are aesthetics of scenery and the possibility of recreation (Maes et al. 2013; Ifuplan, ETH-Zürich, Universität Bayreuth 2014). While the scenic quality is critical – particularly in rural landscapes – recreation in cities as an ES depends on the possibility to access green spaces before and after work, at weekends and in other leisure time. The provision of valuable green areas in dense populated cities can be a serious challenge for planners and administrators. Cities need to search for innovative solutions to increase public space with vital vegetation which we call urban green space. The most frequent types of public green spaces are parks, cemeteries, sports fields, playgrounds, nature experience areas, open-air pools, urban forests, allotment gardens, community gardens, and other gardens such as zoos or botanic gardens (Schmidt et al. 2014).

Table 1. Ranking of the greenest cities in Germany by *Berliner Morgenpost* (2016).

Rank	City >500,000 inhab.	Share of green spaces (%)
1	Hamburg	**71.4**
2	Dortmund	**70.7**
3	Stuttgart	**69.9**
4	Dresden	**69.4**
5	Bremen	**68.2**
6	Essen	**68.0**
7	Hannover	**65.2**
8	Berlin	**59.0**
9	Köln	**58.4**
10	Frankfurt am Main	**58.2**
11	Düsseldorf	**56.7**
12	München	**49.9**
13	Nürnberg	**47.9**
14	Leipzig	**42.4**

The proportion of urban green spaces has often been mapped as an indicator for supply, for instance by the newspaper *Berliner Morgenpost* (2016) using satellite data analyses (Table 1). Critical constraints are how to deal with green space at the urban edge that sometimes belongs to the municipal area. Another issue is that urban green space can be unequally distributed within the city area, so that parts of the population live in the green and other parts lacking the possibility to go there. Therefore, a supply–demand comparison must not only regard the numerical quantity but should also take the location into consideration.

The demand for green spaces depends on the activities people aim to carry out there. A survey on the example of Dresden, Germany (Schmidt et al. 2014), found that the favoured activities are (in this order) walking, hiking, cycling, swimming, skiing, jogging, skating, aquatics (rowing, water-skiing, diving etc.), climbing, sailing, and riding. Moreover, there are specific needs of children, sports enthusiasts, disabled, and elderly people, which have to be considered in designing green spaces. Demand can also be determined by a travel cost analysis among tourists. But the value of green spaces in a city for its own inhabitants is contingent upon the quality (size, diversity) and accessibility.

It is recommendable to design an indicator that considers both the supply of green spaces and the positional relation to dwelling areas. Grunewald, Richter et al. (2017) calculated the access of the population to public green spaces as a sociocultural ES using the indicator 'accessibility of urban green for city dwellers' that summarizes supply and demand. The latter has been calculated using the new German census raster data on population density, which are only occasionally available. A linear distance of 300 m is used to approximate an actual walking distance of 500 m. On a large scale, a more realistic modelling of actual path distance can be achieved using a network analysis if suitable data are available; such a study is in progress and will give insights as to where small connections can give high accretion of green spaces. Distance indicators take the green spaces into account that are available to the population in the residential environment.

Nearby public green spaces are reachable for approximately 80.9% of the population in the German cities with more than 50,000 inhabitants. In absolute numbers, 25.6 million inhabitants in these cities have access to public green spaces in their immediate residential environment and 6.1 million lack close recreational opportunities (Figure 4).

People enjoy local recreation as a way to a happy and healthy life and find new social relationships there. The existence of green spaces that are valuable for local recreation often represents a soft local factor for the economic development of a town. Urban green spaces provide opportunities for recreation if people are able to access them (Kabisch and Haase 2013; Elmqvist et al. 2015). Therefore, the best benefit is available for people living in close proximity to green areas. However, this is a case where the plain comparison of SPA and SBA is too simple as a basis for planning decisions. Therefore, instead of mapping both indicators independently, the example shows a balance of distances between urban dwelling and green areas. Access is the key variable, measured by linear distance in this nationwide study. But planners can not only bring in more green spaces into existing housing areas or reserve green elements for new ones but also improve the connections to these areas for people, e.g. by offering short (green) paths or removing barriers.

Provisioning indicators for reared animals

The production of meat and animal products in agriculture is predominantly shaped by farmers, so that the example seems to fit with case 5 ‘ES commodity’. Though farm animals live for the most part in stables, farmers let them graze in pastures or provide feed from grasslands and fields. Very large quantities of livestock can also impose a load on the environment through the need for agricultural intensification (fertilization, more mowings per year), by compressing the soil and, above all, by nutrient loads in the waterbodies since the slurry must be disposed on the available land. Therefore, it is worth comparing the grassland and the number of livestock, where the former can be regarded not only as a supply of feed but also as a supply of waste-disposal area for ruminant animal production, and the latter indicates the

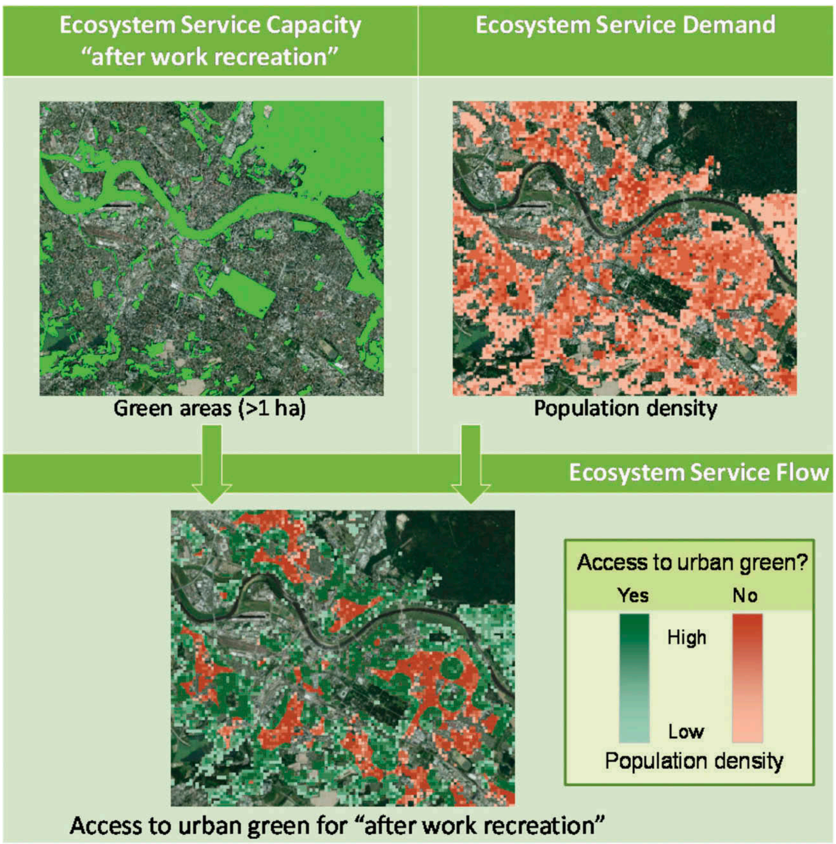

Figure 4. Urban green space access as combined supply–demand indicator exemplified for a section of Dresden (Artmann et al. 2017).

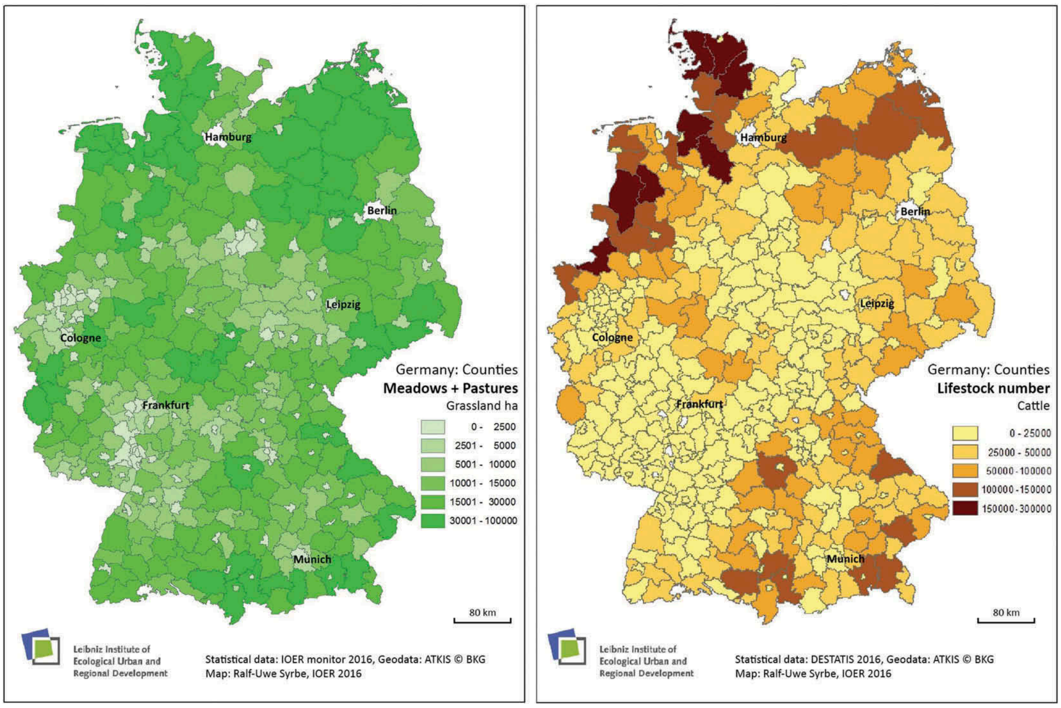

Figure 5. Grassland proportion (supply, left) and livestock number (demand, right) for the ES animal feed in Germany.

demand of society, expressed by the farmers' decisions about their size of the herd. Livestock numbers can be obtained from statistical data from the Federal Statistical Office (Statistisches Bundesamt) which offers them in its online database DESTATIS (2014). Only the cattle livestock data structured at the district level are regularly available, while the other livestock species are only available in this resolution every 10 years. The grassland share is calculated based on topographical data (ATKIS) every year by the IOER and provided on the Internet in the so-called IOER Monitor (http://www.ioer-monitor.de/home/?L=1).

The maps in Figure 5 show both values for Germany in 2013. It is not very meaningful to compare supply and demand numerically because animals can also be fed with field products, even from imports, and other animals can graze on grassland as well. But the juxtaposition of grassland share and livestock numbers yields insights into critical accumulations and potential overuse of the environmental goods. Strictly speaking, it is not the critical supply of feed for the livestock but the impact of nitrogen-loaded slurry to the meadows and water bodies, which are depicted here. The demand map in Figure 5 (right) shows the drastic accumulation of livestock in a few counties in Northwest Germany that cannot be covered by more grassland (left). Potential enhancement of these indicators would try to include more animal species beyond cattle, which was the only one used here, but this is unfortunately constrained due to limited available statistical data.

Reared animals are used to provide meat, milk, eggs and some other materials for a worldwide market. But the first benefits arise locally for the livestock owners who have to earn their livelihood thereby. Only these farmers are capable of and responsible for preserving the fertility of grasslands, the quality of soils and even environmental goods such as groundwater quality in rural landscapes, whereas the final consumers cannot control this directly. We compared the grassland area with the livestock number because overstocking will damage pasture and groundwater due to a possible overload of slurry output (recently a serious problem in Germany). However, the slurry cannot be transported worldwide, actually it makes only good economic sense if they stay within a certain distance. On the other hand, slurry transports even cross regional and national borders and are conducted by commercial enterprises as well as the decision to rear more or less cattle so that each approach to govern these relationships must start with common agricultural policy.

Discussion

The examples show some key challenges to balancing spatial mismatches of ES supply and demand. The first challenge is that the supply–demand relation seldom explains the pluralism of ES using an overlay of two maps as it is done for instance by Burkhard et al. (2014) for a multitude of ES and by Nedkov and Burkhard (2012), in particular, for flood regulation (see below) using a 5-tier classification, which can be qualitatively compared but not subtracted. Schulp et al. (2014) presented a model of pollination which even used quantitative values (of visiting bees) for a comparison that covered the entire EU in a relatively coarse scale. A comparable model was also considered for the indicator development in Germany, especially as it has been specified by Priess et al. (2016), but the effort to use and calibrate it for nationwide mapping was unfeasible.

Depending on the service, there are several factors involved between ecosystem and social system and even more spatial relations, depending on the type of ES transfer (Figure 1). We hope to clarify the relations through the aid of our proposed scheme. Let's regard the above-mentioned question as to whether there are suitable factors dependent on the types of transfer. Since we had at most one example for each case, it can be difficult to generalize.

Case 1, 'ES local', does not require any kind of transfer function exceeding the site of generation. If an ES was provided in the same area as used (SPA and SBA are identical), transfers would mainly remain local even though not negligible in each case. However, a management staff must concentrate on fair access to the service and on the prevention of on-site overuse. In this case, supply and demand studies can provide arguments for maintenance of resources in land use (Marta-Pedroso et al. 2007). By a monetary calculation of erosion based on the valuation system by Pimentel et al. (1995) and using the same model as in Example 1, Bastian et al. (2013) were able to show that the service of erosion is higher than the potential yield on the 5% most vulnerable arable areas in the German Görlitz district, so that a land freeze would be recommendable there for farmers – even from an economic perspective. Though the national study does not heretofore include monetary calculations, this could be a future path for development based on the presented physical indicators. National data are useful for general political decisions; therefore, BGR (2014) offers for instance similar erosion data and the basic soil map (BGR 2016) used for this study.

Case 2, 'ES proximity', requires an analysis not only of ES potential but also of demand in close vicinity. Besides the habitat characteristics, buffering tools and structure metrics can be the most suitable instruments for assessment. Partly, one may consider density indicators as a proxy for the entire ES assessment. Since the BGR erosion data are only valid for arable fields and do not consider small landscape elements, the model applied here is a further step for policy recommendations. Now there is more specific information available for soil erosion (cf. Möckel 2015).

Case 3, 'ES process', requires some kind of process-based analysis, which can be done using models or indicators measuring process variables such as a flood retention area in our example. This case seems to be explainable regarding the SCA. But this is only one aspect of a variety of factors shaping the ecosystem-society interaction. Regulating services can be understood through the aid of risk theory and experience with disaster precaution, which would extend beyond the scope of this paper. These services are often side effects of the primary economic use. Their actors and the users of the SCA are similarly responsible for caring for the ES, but must be informed or get clear rules and sometimes be compensated for this. Nedkov and Burkhard (2012) overlaid demand and supply estimations using 5-tier classifications for each indicator. Such a direct overlay is very instructive even though the semi-quantitative tiers cannot be subtracted; they proposed to consider also quantitative SWAT modelling but this is hardly an alternative for nationwide mapping.

Quite clear is case 4, 'ES access', regarding the access of visitors to recreational destinations or landscape elements. Other cultural services can delight people perhaps without personal contact, e.g. by means of artworks.

But this is already the next case 5, 'ES commodity', in Figure 1, since artists who make the cinema films, paintings, literature, etc. are quasi-mental actors, even if the products are not always commodities in the narrow sense. This case should concentrate analysis on the actors, and it is the most interesting case regarding the question of sustainable resources' use. The actors must be regarded as firstly responsible for sustainable use of their entrusted ecosystems, which have values for mankind beyond the pure ownership of single persons. Final users can only decide through the aid of knowledge which the actors are willing to hand over. Many actors accept this responsibility, but society (mostly government) has to guarantee that, effectively, all actors act transparently and sustainably in order to avoid the preference for primarily profit-oriented and even irresponsible players.

The last case 6, 'ES global', provided no example because we cannot limit particular areas of beneficiary groups. However, the case shows characteristically that every limitation of a certain group or area of benefit must not keep sight of trade-offs, which can occur very far away. Our economy is intertwined to such an extent worldwide that each decision about resource use in Europe also has to be double-checked for its long-distance effects. Just like the concept of virtual water that is carried in products using it for production abroad (Hoekstra and Chapagain 2007), concepts for virtual land imports are necessary in order to balance the effects on land use in foreign countries (Meier et al. 2014).

The second challenge is to find indicators that are not only (quantitatively) comparable but also provide meaningful insights into the charged relationship between limited resources and inevitable needs of people. Kroll et al. (2012) found that not only land use changes but also a higher land use intensity had the strongest impact on ESs supply; thus indicators must also entail intensity issues. Why do land users need a service, and what aspect of this service is crucial? For instance, the availability of fodder is not the limiting factor for animal husbandry here; rather, it is the area for slurry application regarding the endangered water quality and all the other functions that grasslands serve additionally (cf. Sala and Paruelo 1992). What is demand in regard to erosion? It is pointless to discuss thresholds here, but policy and land users must find the most vulnerable areas and change their respective usage there, or at least restructure landscapes through new protective measures and/or denser crop rotation.

Third, a quantitative comparison as a precondition for each balance depends very critically on data quality since one would otherwise be unable to distinguish analytical artefacts from real differences. Only data that cover an entire planning or politically relevant area can be used here; ideally, data would be publicly available also in other European countries to ensure EU-wide comparability (Kroll et al. 2012). We see the blank spots in the cities on many maps, which are only just tolerable. Nowadays, frequently incomplete data trigger bitter compromises and may even raise the issue of potential monitoring. Recent statistical data lack specific crucial years (Example 3: the population data used are only occasionally available after a census), livestock species (Example 4: other animals, such as sheep, are only available every 10 years), several municipalities (Example 2: no data outside the big river valleys). Since the German soil map 1: 200,000 lacks five map sheets, we could not currently use this official data source for erosion modelling (Example 1).

Our hypothesis was that a confrontation of supply and demand indicators can uncover imbalances and thus unsustainable use of ES. The first example of soil erosion did not show such an added value. One can find, however, the most critical areas of recent erosion and those of prevented soil loss. But to conduct measures, the view must be much finer in the proximity of endangered fields and the agricultural practices regarding soil conservation. On the coarse national level, perhaps quantitative comparisons could be more meaningful to monitor balances of prevented resp. actual soil losses in order to assess the success of policy. The second example could be more instructive and its red areas are comparable to real flood damage. The 'ES process' case seems to be relevant for comparisons also on the coarse (regional/national) scale due to distant geo-ecological effects. The recreation example is presented, with reason, as a previously balanced supply–demand comparison. Using the completed balance, one can find cities with more or less need for action. But if city planners and politicians want to improve the situation in their city, they need to look deeper into the respectively existing interim results. The last example, reared animals, shows quite clear indications for regional problems and possible solutions. Our small set of examples offers different answers to the hypothesis depending on the distance and kind of benefit transfer.

But what are the solutions for making the choice on land use actionable in the real world in order to answer to landscape planning needs? Information about supply–demand ratios can help decision makers to alter the landscape in order to achieve a sustainable use of resources (Kroll et al. 2012). Therefore, decision makers need to be informed and encouraged to know about the potential mismatches and spatial problems. This can be done with catchy information using many pictures and clearly understandable language that deals with locally relevant data such as in Bastian et al. (2014a). But in the end, precise measures must be suggested such as by Brandhuber (2012), LfULG (2013), or Hiller (2007) regarding erosion prevention, and the costs should be calculated for entire administrative units (Grunewald and Syrbe 2014).

We stated the question of whether a clear distinction between the arising cases can improve the possible conclusions (and not only enhance the workload and complexity of analysis). Based on the presented scheme, recently calculated indicators can offer partly interesting insights – although not all comparisons are instructive (such as the erosion map on the national level). In some cases, the view should be focused on a finer scale or on local quantitative relations between supply and demand. But in order to zoom in, the scope must be known. Therefore, the coarse maps can help as well. The differentiation of six cases proved to be useful for a selection of fitting scale. As the examples suggest, possible planning and governance solutions depend on the agents and distances of benefit transfer and, thus, on the differentiated cases.

Conclusions

The actual benefits of ES are generated by natural processes. But the prerequisite is a suitable use of land considering the target function and the non-target ES, which are connected with each individual land plot in the sense of multifunctionality. The users or managers of the land are not the actual service providers (e.g. in flood control and aesthetics), but are required in the sense of social obligation of property and even more so as the recipients of subsidies to allow these services on their land and – if possible – to increase them.

Well-selected indicators of supply and demand and their comparable mapping can uncover mismatches between the potential of ecosystems if the distances and processes, i.e. agents of transfer, are considered. A differentiation of natural processes versus economic activities for the transfer of benefit helps to make comparisons between supply and demand more appropriate. Long distances between service supply and demand make it meaningful to compare maps of both also at a national level. If only short distances between supply and demand arise, quantitative balances can be more useful to map. In particular, maps of density seem to be more instructive than individual measurements if short distances or small elements are essential for ES supply–demand connections.

The presented scheme differentiating six cases of ES transfer from provider to beneficiary proved to be meaningful in the four examples under study. Further research should try to employ the scheme and perhaps to enhance this small sample. The results showed starting points to sustainably supply goods and services. With the highly focused view of individual cases, areas can be identified where the socially triggered demand exceeds supply and thus the suspicion of irresponsible use should be pursued. This is an essential step towards governing land use processes in order to ensure environmental justice in regard to a fair sharing of ES and preventing an increase in irresponsible players. Particularly, political decision makers, entrepreneurs, and land owners should be enabled to consider environmental issues in their daily work by making use of subsidies and programmes of nature protection, but also by informing them of success and failure.

The examples show that some ESs can be well differentiated between supply and demand sides, which allow recognition of whether or not the potential of nature is used sustainably – the latter would cause an exploitation of natural goods, of vulnerable areas or weaker groups of society. Sometimes, rather special aspects (such as the question of small landscape elements against soil erosion) are relevant to indicate since possible erosion-avoiding management can begin at this point. But it is not meaningful to stubbornly work out all mentioned topics for each service. Instead of a calculation of supply and demand indicators, it can even make sense to incorporate the manner or access between the ecosystem (process) and the beneficiary, depending on the type of relation. In our recreation example, the calculation of an access indicator between dwelling area and green space may easier guide urban planning decisions.

Most ESs have supply and demand aspects that can be calculated and mapped by indicators (cf. Burkhard et al. 2012). These indicators allow the development of land use to be monitored at least in regard to target values and direction of development. Additionally, there are other relevant topics such as ecosystem structure, potential, human inputs and the flow between supply and demand. The elaborated scheme promises to put a step forward to more precise monitoring and assessment of ESs. This shall enable science, policy, and planning to apply the upcoming huge environmental data base for better conservation of ecosystems and, in particular, their services.

Acknowledgements

The authors would like to thank the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), which funded the research of this paper via the so-called environmental research plan of its Federal Agency for Nature Conservation (BfN). Special thanks are due to Burkhard Schweppe-Kraft (BfN) for the functional supervision, support and encouragement he spent for our project. We are grateful for the fine language polishing by Felix Pahl and Paul Ronning.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The authors would like to thank the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), which funded the research of this paper via the so-called environmental research plan of its Federal Agency for Nature Conservation (Bundesamt für Naturschutz, BfN) [3514830100].

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