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Towards a national set of ecosystem service indicators: Insights from Germany

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ABSTRACT

Target 2, Action 5 of the EU Biodiversity Strategy requests member states "to map and assess ecosystems and their services" (Mapping and Assessment of Ecosystems and their Services – MAES initiative). The objective of this paper is to present and discuss the preliminary outcomes of the approach taken to define indicators for implementing MAES in Germany. The paper introduces the requirements for using indicators from a perspective of nature conservation policy, in particular the need to discern the demand and supply of ecosystem services, including their potentials, actual and future use, as well as the natural contributions and human inputs to the generation of ecosystem services. An adapted, differentiated, ecosystem services terminology is presented and a first set of indicators is introduced and explained. The paper closes with an estimate of potential benefits of information produced by implementation of a national MAES for various fields of policy (e.g. local and regional landscape planning) and proposes some recommendations for further research and practical exploration.

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1. Introduction

Target 2 of the EU Biodiversity Strategy outlines the goal that by 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems. As one effort to fulfil this target, Action 5 requests member states (i) to map and assess the state of ecosystems and their services in their national territory by 2014 (abbreviated as MAES[1]), (ii) to assess the economic value of such services, and (iii) to promote the integration of these values into accounting and reporting systems at EU and national level by 2020 (European Commission, 2011). Implementation of MAES by the member states is guided by a conceptual framework (Maes et al., 2013), the Common International Classification of Ecosystem Services (CICES, see Haines-Young and Potschin, 2013), as well as by a proposed list of indicators and assessment approaches (Maes et al., 2014). Even with this guidance, national implementation of MAES requires the development of adapted sets of indicators that are most applicable to each respective context (Maes et al., 2012). This need has spurred an ongoing debate on national indicators (Mononen et al., 2015; Tratalos et al., 2015) and how they can be incorporated into policy, planning, and management (Albert et al., 2014a, 2015a; Hauck et al., 2013; Wissen Hayek et al., 2015).

The objective of this paper is to present and discuss the preliminary outcomes of the approach taken to define indicators for the implementation of MAES in Germany. The paper first introduces the specific German context and requirements for ecosystem services indicators of use from a nature conservation policy perspective. Following this, a preliminary set of indicators is presented and explained. The selected set of indicators is discussed in light of comparable international efforts to define respective indicators. The paper closes with an estimation of the potential benefits of information delivered by implementation of a national MAES for various fields of policy, planning and management, and finally, recommendations are proposed for further research and practical exploration.

2. The German context for indicator development

In general, Germany has a fairly broad amount of environmental data available. For example, a system for biodiversity indicators has already been established to monitor the implementation of the National Strategy on Biological Diversity (Federal Ministry for Environment Nature Conservation and Nuclear Safety, 2010). However, the available data provides a mixed picture concerning its applicability as a basis for national implementation of MAES (Albert et al., 2014b). For some aspects of ecosystem services, such as water quality of rivers and streams, comprehensive monitoring data is already available. For other topics, such as marine ecosystems, data is rare or lacking (Schiele et al., 2015). Landscape planning, as mandated by the German Federal Nature Conservation Act (BNatSchG, §§ 8–12), specifies the purposes of nature conservation and landscape management, for the respective planning area, and identifies applicable requirements and measures for achieving such purposes. In this regard, landscape planning takes into account the capacity of nature and landscapes to provide several ecosystem services (usually referred to as 'landscape functions', see Albert et al., 2015a; von Haaren and Albert, 2011) at the community or county level. Therefore, the task of assessing, safeguarding, enhancing and restoring ecosystems and their services is already addressed at this sub-national level. However, information concerning ecosystems and their services, which is incorporated in landscape plans, cannot be aggregated at a national level due to diverging classification systems, assessment methods, and survey frequencies in the individual federal states. National implementation of MAES in Germany must therefore be performed largely independently of existing datasets on the state level. This is contrary, for example, to the situation in the UK, where researchers in the UK NEA (2011) were able to draw on a wide range of existing, spatially comprehensive, and uniform data (Haines-Young et al., 2008).

The current implementation of MAES in Germany is administered by the Federal Agency for Nature Conservation (Bundesamt für Naturschutz – BfN). The agency issued a research and development project to develop a preliminary set of indicators (Marzelli et al., 2014a, 2014b), incorporating insights from partners in Austria and Switzerland with relevant earlier experiences (Götzl et al., 2011; Helfenstein and Kienast, 2014; Staub et al., 2011). The set of ecosystem service indicators proposed by the research project was presented and discussed in various policy groups (including the German joint federal and state level working group on nature conservation, landscape protection and recreation), resulting in a first proposal of national indicators for the implementation of MAES in Germany (Albert et al., 2015b).

Within the context of German implementation of the European Biodiversity Strategy, the process of indicator selection and definition has so far been nature-conservation-policy-driven with the objective to select indicators that provide insights into support of efforts to conserve, restore, and enhance the status of nature and landscapes. From this particular perspective, five specific requirements need to be adhered to in order to provide useful information for decision and policy-making. In describing these requirements, the terminology introduced in Box 1 is employed.

(1) Appropriate sets of ecosystem service indicators need to account for the supply of ecosystem services in relation to areas of particular demand. For some ecosystem services, no particular spatially explicit demand can be defined (see Wolff et al., 2015 for a review of ecosystem service demand studies). Examples include the global demand for carbon sequestration for which it is irrelevant where GHG emission reductions take place, or international food production which is mostly produced for a global market despite exceptions such as regional marketing and subsistence agriculture. For other ecosystem services, however, the spatial location of demand strongly influences the value of ecosystem services. Typical examples are higher significances of nature-based recreation and drinking water provision near urban areas, the supply of pollination services if provided in the proximity of fields with crops dependent on insect pollination (Schulp et al., 2014), and flood regulation services where a relatively small increase in water retention upstream can be very important if it prevents costly flood damage in urban areas (Nedkov and Burkhard, 2012). If ecosystem service analyses focus only on ecosystem service supply and disregards respective demand, changes in ecosystem services could be completely misinterpreted (Honey-Rosés and Pendleton, 2013). Additionally, ecosystem service capacities can only be transformed to economic values when the supply and demand between each ecosystem service and its beneficiaries match (Carrasco et al., 2014). It is therefore recommended to develop indicator sets that consider both supply of and demand for ecosystem services, at best along with indicators describing gains and losses in human well-being. In cases where this is impossible, alternative proxies for mapping and overlaying spatial demand and supply can be used (Burkhard et al., 2012).
(2) Appropriate sets of ecosystem service indicators should explain if changes in the actual use of particular ecosystem services are caused by changes in ecosystem service potential and delivery,

[1] http://biodiversity.europa.eu/maes.

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Box 1: Terminology.

- **Ecosystem services**: The direct and indirect contributions of nature to human well-being (cf. TEEB, 2010). Ecosystem services include the terms ecosystem goods and services.
- **Ecosystem condition**: The condition of an ecosystem to provide specific ecosystem services. It is important to differentiate between this specific condition to provide specific ecosystem services, and a general understanding of ecosystem condition that refers to the capacity to provide multiple services. Ecosystem condition results from a mix of natural conditions and socio-economic land-use decisions. Changes in land-use (e.g. converting grasslands to fields) results in changes of ecosystem condition and subsequently ecosystem service potentials.
- **Ecosystem service potential** (often referred to as capacity): The hypothetical maximum yield of (selected) ecosystem services (Burkhard et al., 2012) that can be used or gained from a specific extent and quality of ecosystems (→ Ecosystem condition). This potential does not need to be currently used (Bastian et al., 2013). We do not differentiate between capacity and potential. Both terms are used here with regard to only one service. A synonym for ecosystem service potentials is 'offered ecosystem services' (von Haaren et al., 2014). The ecosystem service potential provides the natural contribution to ecosystem services generation, which together with human inputs, leads to goods and benefits gained directly from or with the help or on the basis of ecosystems.
- **Ecosystem service supply**: The actual provision of ecosystem services by a certain ecosystem, either today, in the past or in the future, as determined by the ecosystem service potential and the ecosystem condition. The amount of ecosystem services that is actually generated depends on the natural contributions and anthropogenic contributions (→ Human inputs). For the supply of some ecosystem services, no human contribution is required. Please note: Economic theory would consider ecosystem services supply as the amounts of units of ecosystem services that are being produced at a given price. Prices here would be interpreted as the marginal costs of generating an additional unit of ecosystem service.
- **Ecosystem service flow**: Ecosystem services that are generated and actually used in a specific area and time under respective → Ecosystem conditions. The ecosystem service flow can be higher than the ecosystem service supply, resulting in an unsustainable use of ecosystem services or reliance on → Human inputs. Synonyms for ecosystem service use are 'utilised ecosystem services' (von Haaren et al., 2014).
- **Ecosystem services demand**: The need for specific ecosystem services by society, particular stakeholder groups or individuals. Ecosystem service demand is specific in time and space, with some demand existing globally (e.g. for greenhouse gas mitigation) and other demand existing locally (e.g. for recreation opportunities). Ecosystem services demand can be higher than ecosystem services flow, for example if a local population cannot fully meet its recreation demand due to limited availability or accessibility of green spaces. Other ecosystem services (such as many provisioning services) need to be imported if demand exceeds flow in a region.
- **Human inputs**: Anthropogenic contributions to ecosystem services generation in human-influenced land-use systems (e.g. fertilizer, energy, pesticide, technique, labour or knowledge; Burkhard et al., 2014). These human inputs often converge with → Ecosystem services potentials into → Ecosystem services supply.

changes in ecosystem condition, changes in human inputs, or changes in demand. Changes in ecosystem service demand can happen due to altered preferences, population sizes or other human activities, including those with impacts on the environment that enhance the demand for ecosystem services. This differentiated analysis is, for instance, necessary in order to avoid any misinterpretation of trends of ecosystem service indicators that indicate ecosystem improvements or deterioration. If, for example, the amount of natural contaminant reduction is used as an indicator for water purification ecosystem services, increasing values would not necessarily indicate an enhanced self-purifying potential, but could also be related to increased contamination levels due to an influx of pollutants. Another example of a potentially misleading ecosystem service indicator is the number of visitors to an area, which often is used as proxy for recreational services. However, increasing visitor numbers may not necessarily be related to ecosystem conditions. Instead, visitor numbers may increase due to nearby settlements, enhanced accessibility, or better marketing and recreational infrastructure. Assessing water provisioning services only in terms of the amount of water abstraction, while disregarding the condition of the aquifer, can lead to wrong management decisions. Our suggested solution is to apply clear-cut definitions of ecosystem services supply and demand categories as outlined in Box 1, to clarify what the selected indicators actually describe, and to investigate and communicate where changes in actual supply or use of ecosystem services originate from.

(3) Appropriate sets of ecosystem service indicators should also provide decision support in cases of insufficient information in order to precisely assess and evaluate ecosystem service supply and/or demand. In such cases, we suggest that demand and supply spreadsheets ('ES matrices') and maps based on expert opinion can be compared and superimposed. The 'ES matrix' (after Burkhard et al., 2012, 2014) can be used to integrate data of various quality and quantity, attributing them to specific geospatial units and use the quantification results to illustrate ES supply and demand in the different spatial units. Resulting ecosystem service supply-demand assessments should be published in combination with a systematic discussion and documentation of inherent uncertainties (Hou et al., 2013) including measures of confidence, consistency and reliability (Jacobs et al., 2015). Expert-based approaches do not enable exact and quantitative juxtapositions of supply and demand per se. However, they provide useful information regarding the spatial areas where particular demand and supply exist. Juxtaposing the areas of demand and supply helps to highlight areas where demand is currently not sufficiently met and where management interventions are thus needed to enhance supply. Further analyses can subsequently integrate quantitative supply and demand data and thereby help reducing uncertainties.

(4) Appropriate sets of ecosystem service indicators need to consider, not only the current generation and delivery ('flow') of supplied ecosystem services, but also the potential of ecosystems to deliver these services in the future ('stock of natural capital', which includes biotic and abiotic resources, or 'stock of ecosystem capital', including only ecosystem resources, that at least partially depend on biotic elements) (Burkhard et al., 2014; Schweppe-Kraft, 2013; von Haaren et al., 2014). Such a differentiated analysis is needed as the definition of ecosystem services implicitly includes three aspects: the current delivery, the possibility of a future delivery (in the sense of 'option values' (de Groot et al., 2010)) and the actual future use. Estimating future uses of ecosystem services requires predictions of future demands and future supply. In contrast to man-made capital, ecosystems and their services are not contrasted with a

Table 1
First set of ecosystem service indicators, juxtaposing supply and demand. Respective indicator values can be used to identify and quantify supply and demand mismatches of individual ecosystem services.

CICES "Section"	CICES "Division"	Ecosystem services	Supply indicators (using: ecosystem services potentials as a proxy)	Demand indicators
Provisioning services 1*)	Nutrition materials energy	Providing food and bio-energy from fields	Natural fertility of arable soils	2*)
		Providing fodder from grasslands	Proportion of grasslands in agricultural areas (contribution to animal production)	2*), 3*)
		Providing timber products	Timber stocks (sustainable yield by logging)	2*)
Regulation & maintenance services	Regulation (decomposition, sequestration, etc.) of toxins and waste	Regulating water quality by waterways	Naturalness of river beds and floodplains	Current water quality below water quality standards
		Regulating groundwater quality	Proportion of forest and grassland Protection of soils and geological layers	Proximity of drinking water wells, water protection areas
	Mediation of flows	Mitigating erosion	Proportion of area with a certain minimum ground coverage by continuous vegetation cover Proportion of natural and semi-natural small structures in the agricultural landscape	Active floodplains, areas of steep slopes, areas with sandy soils (easily blown away when dry)
		Mitigating flood hazards	Water retention capacity in flood plains	4*)
	Maintenance of physical, chemical, biological conditions	Facilitating pollination and biological pest control	Proportion of natural and semi-natural small structures in agricultural landscapes	Proportion of arable crops demanding insect pollination
		Storing greenhouse gases	Surfaces of drained/rewetted peatlands	2*)
		Mitigating greenhouse gas emissions	Contribution of land use change and forestry	2*)
		Regulating local climate and air quality	Proportion of green spaces in settlement areas	Degrees of population density, settlement extent, exposure to air pollutants and adverse urban climate effects
Cultural services	Physical and intellectual interactions with biota, ecosystems, and landscapes	Providing opportunities for recreation	Recreational functions of variable ecosystem characteristics (e.g. naturalness, diversity, privacy, supply of specific uses)	Degree of population density, proximity to settlement centres, and designated recreational regions
		Providing opportunities for recreation in urban areas	Proportion of green spaces in urban areas, accessibility of urban green areas	Degree of population density and settlements of certain size

Background: Preliminary set of ecosystem service indicators as suggested by Marzelli et al. (2014a) and supplemented by additional expert consultations and literature considerations.
Explanations:
1*) The suggested indicators do not address ecosystem services supply as the combination of natural and human contributions to ecosystem services generation as this might be contradictory to nature conservation purposes. Instead, indicators for ecosystem services potentials are used. This is particularly relevant for provisioning ecosystem services. For more detailed explanation, please see the manuscript text.
2*) Global supply and demand patterns, spatial localisation difficult and not required in this context.
3*) The indicator "area of grasslands used for fodder production" would be, of course, more targeted on fodder production, whereas the "proportion of grasslands" can better help to point out additional grassland services e.g. for freshwater supply, erosion mitigation or cultural services more explicitly. A decision between alternatives should be based on a test of the whole set.
4*) Relationship between water retention and reduced damage currently only inaccurately modelled in Germany.

technically and economically fixed depreciation period. Due to natural regeneration processes, their capacities can last for an infinite time horizon. Therefore, the results of such a valuation based on a long term forecast would be rather uncertain (Farber et al., 2002). Sustainability targets, such as the preservation of ecosystem capital, can be more easily considered in the indicator set, by representing both, the current delivery and uses of ecosystem services and the potential of ecosystems to provide services (Bastian et al., 2013; Burkhard et al., 2014).

(5) Appropriate sets of ecosystem service indicators should not confuse the natural contributions to ecosystem service generation with the supply of ecosystem services that often originate from a conjunction of natural and anthropogenic contributions (cf. Burkhard et al., 2014; Fisher and Turner, 2008; von Haaren et al., 2014). Ecosystem service supply indicators, which refer to the combination of natural and anthropogenic contributions, are often employed in assessments because related data is readily available in statistical records (e.g. food yields per hectare). However, using such indicators may contradict nature conservation policy as the resulting trends can increase due to enhanced human inputs, even if the contribution by nature diminishes. A typical example of this is when compensating for the loss of fertile soils, e.g. due to land conversion, or diminishing natural soil fertility, e.g. from erosion, by increasing fertilizer inputs. In this case, an indicator for the provision of agricultural products that detects only the amount of products would insufficiently reflect the loss of natural soils and soil fertility. We therefore recommend using indicators which

distinguish between natural contributions and human inputs to the supply of ecosystem services.

In combination, the mentioned requirements suggest that appropriate sets of ecosystem service indicators should consist of analyses which consider both the supply and demand of ecosystem services. Furthermore, consideration of supply and demand dimensions is essential for usefully aggregating ecosystem services across spatial and temporal scales. It eases the economic valuation of ecosystem services and the integration of these values into accounting and reporting systems as envisaged by the European Commission (2011).

3. A first set of ecosystem service indicators for Germany

The first set of ecosystem service indicators for implementing MAES in Germany (Table 1) addresses the requirements listed above by (i) primarily using indicators for denoting natural contributions to ecosystem services supply, (ii) considering both the actual delivery as well as the potential of ecosystems to provide ecosystem services, (iii) considering also the demand for ecosystem services, and (iv) proposing robust and simplified approaches for mapping and assessment of ecosystem services in cases of insufficient information and data.

The suggested set of indicators addresses many of the ecosystem services specified in the CICES catalogue (Haines-Young and Potschin, 2013). However, the set still needs to be extended to consider ecosystem services of coastal and marine areas as well as a broader spectrum of cultural ecosystem services in all types of ecosystems. For pragmatic reasons and based on the nature-conservation-policy-driven approach mentioned above, the current set of indicators purposefully disregards ecosystem services that are considered of low importance, not at risk or already sufficiently protected by government interventions. Therefore, no indicators are proposed for game species, natural products such as mushrooms and berries, commercial and recreational fishing in fresh water ecosystems, fish production in aquaculture, or for the quantity of water supply of a certain quality due to the high supply and falling demand in Germany. The set also precludes indicators for ecosystem services relating to genetic material or the existence and bequest value of species and habitats as this would overlap with the already established nature conservation and biodiversity monitoring schemes.

3.1. Addressing the demand side of ecosystem services

This paper proposes to use the terms ecosystem service supply and demand in valuing ecosystem services and providing planning and policy with relevant information. Such politically relevant information could include, among others things, the spatial areas where important mismatches in the demand and supply of ecosystem services exist and where greatest welfare gains could be generated by enhancing the extent and/or quality of ecosystem service delivery through appropriate management measures (for an analyses of hotspots in the supply of ecosystem services, see Chan et al., 2006; Egoh et al., 2008). In addition, implementation of MAES, with reference to an economic understanding of supply and demand, will be required to address the long-term objective of integrating ecosystem service assessment and valuation in national accounting systems.

Recent developments in one research project on the economic valuation of urban green spaces illustrates progress in efforts to assess ecosystem service supply and demand as outlined above (Kolbe and Wüstemann, 2014; Krekel et al., 2015; Wüstemann, 2014). In most other areas, combining ecosystem service indicators

Table 2
Demand–supply–mismatch matrix. The degree of demand and supply mismatch can simultaneously be interpreted as the degree of welfare gains by investing in natural capital to increase ecosystem service supply.

		Demand for ecosystem services		
		low	medium	high
Supply of ecosystem services	low			
	medium			
	high			
Legend:	Demand-supply-mismatch:	low	…	High

Note: For a similar cross-tabulation, see Burkhard et al. (2012, 2014) and Liquete et al. (2013).

with an economic valuation of demand and supply is still far from realisation. Nevertheless, we should strive for a close alignment between the selection and definition of indicators for ecosystem services and the economic understanding of supply and demand. Having this conceptualization in mind will ease future efforts to economically value changes of these indicator values (on the basis of additional information on cost-structures and individual preferences). In the meantime, however, a simple juxtaposition of rough graduations of indicators, according to the relative level of supply and strength of demand (e.g. high, medium, low) as shown in Table 2, can give an initial guidance to identify areas with special deficiencies and high needs for investments in natural capital (see Section 3.2). A further discussion about the implications of economic analyses of ecosystem services (building upon and expanding from Farley, 2008 and others) is beyond the scope of this paper. However, even without a detailed economic underpinning, distinguishing between supply and demand aims to avoid methodological problems and misinterpretations that may occur if only the change in use of the ecosystem service is monitored. Misinterpretations can occur when no consideration is given to whether changes in current use originate from changes in the potentials of ecosystems to provide services, from changes in human inputs, or from changes in demand.

3.2. Dealing with insufficient information or data to assess or model demand and supply

A juxtaposition of the usually more easily assessable spatial supply with the specific corresponding spatial demand can be used in situations where the lack of data makes a precise assessment of ecosystem services use difficult, unreliable, or even impossible. A simple juxtaposition is also useful in cases where a more complex indicator connecting supply and demand would be too difficult to understand and communicate in policy making. The proposed set of indicators consequently includes several indicators that reflect specific ecosystem service demands, which can be used in addition to indicators representing the respective supply. Overlaying spreadsheets or maps that represent the areas of ecosystem service supply, with the areas of demand for each respective ecosystem service (cf., for instance, Burkhard et al., 2012; Fisher et al., 2009), provides useful information for policy and decision-making as this illustrates where specific demands and thus higher values for provided ecosystem services exist.

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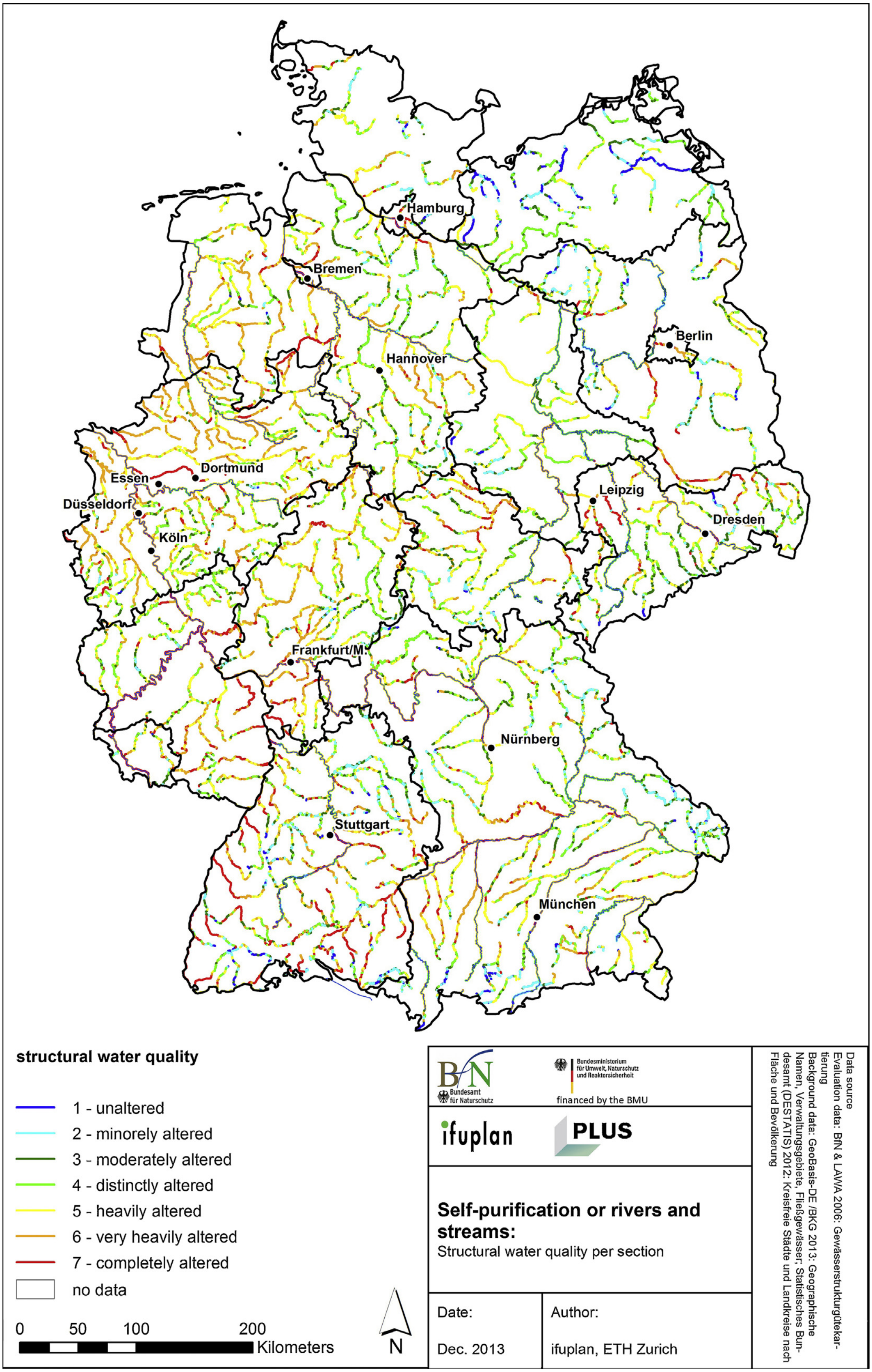

Fig. 1. Structural water quality as an indicator for ecosystem services potential for self-purification of rivers and streams. For better legibility of the figure legend, the reader is referred to the coloured web version of this article.
Source: Marzelli et al. (2014a).

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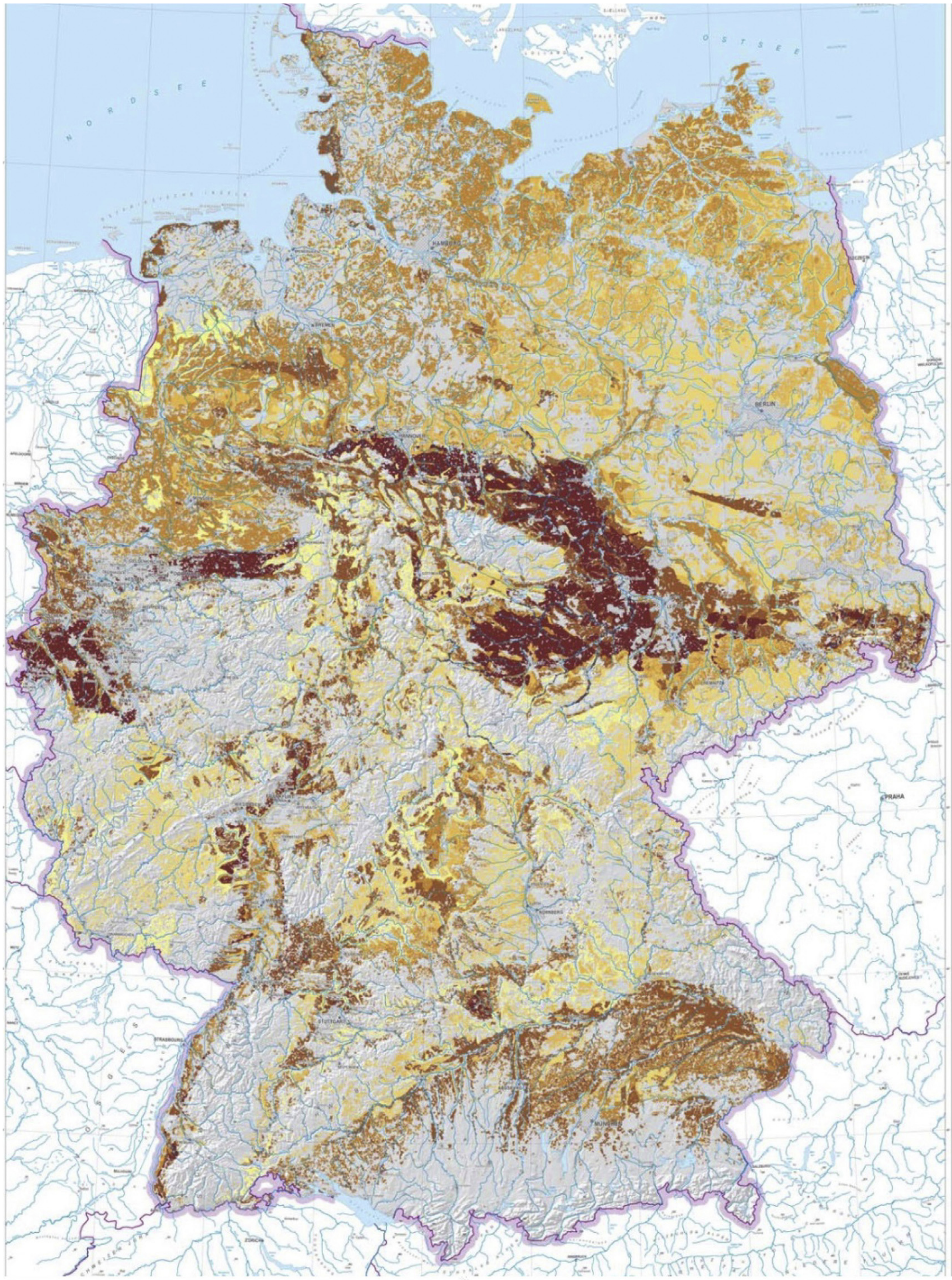

	Class	SQR Rating
	extremely low	< 35
	very low	35 - < 50
	Low	60 - < 60

	Class	SQR Rating
	Middle	60 - < 70
	high	70 - < 85
	very high	= 85
	not assessed	

Fig. 2. Agricultural yield potential according to Muencheberg Soil Quality Rating. For better legibility of the figure legend, the reader is referred to the coloured web version of this article.

Source: Data source: SQR1000 V1.0, (C) BGR, Hannover, 2013 (altered).

A relevant example of this is the water purification service of rivers. This service could be measured as the reduction of contaminants between two sampling points up- and downstream, if no additional contaminant inflows occur in between. However, applying such an indicator could be misleading as an increase of the extent of contaminant reduction, may be caused by either enhanced ecosystem conditions, e.g. a more natural stream bed, or by additional contamination inflows upstream. The information about increased ecosystem service provision can therefore be rather ambiguous, meaning either environmental enhancement or deterioration (see Section 2). Instead, we suggest applying a proxy such as naturalness of the streambed as the supply indicator for the self-cleaning potential (see Fig. 1). This supply can then be overlaid with the demand, for example indicated by the difference between current water quality and water quality targets. Considering changes in supply, in demand, and in the supply–demand relation, provides information about where changes in the self-purification potential have taken place, where the water quality has already reached a relatively good value, or where a great need for cleaning services still exists.

Several indicators of the proposed set illustrate such a spatially explicit demand: The indicator 'areas in need of water quality enhancement' shows areas of specific demand for the ecosystem service 'self-cleaning potential of waterways'. The indicator 'groundwater use' identifies areas where the ecosystem service 'provision of high quality ground water' is of particular significance. The indicator 'proportion of arable crops with insect pollination' helps to identify areas in need of pollination services. An example for the juxtaposition of demand and supply is provided by Burkhard et al. (2012) who compared the suitability for recreation with population density as an indicator of the demand for recreation in each area. This approach enables conclusions to be drawn about whether changes in the supply of ecosystem services have taken place in areas of high or low demand, essential information for a societal evaluation.

An important issue to keep in mind is that there is not necessarily a correlation between areas with a high potential for a particular ecosystem service's supply, and areas of high demand and actual use. For example, the use of cultural services for recreation (measured for example by a rough, simple indicator like the number of visitors) is not necessarily high where the landscape is particularly diverse and attractive. Less attractive landscapes can also be important for recreation, especially when they are located close to densely populated areas with a higher need for recreation. Valuation issues occur if people assign high values to areas they rarely visit (as shown by Boll et al. (2014) for the example of urban dwellers in Hamburg assigning high values to the Lüneburg Heath area).

3.3. Differentiating between ES potentials and delivery

The suggested indicator set follows the pragmatic approach introduced above to consider potential future uses of ecosystem services by developing indicators that address ecosystem service potentials (see Table 1 and Box 1). The approach is in line with the German Nature Conservation Act that, by virtue of their intrinsic value and importance as a basic necessity of human life, calls for permanently safeguarding biological diversity, the performance and functioning of the natural balance (*Leistungs- und Funktionsfähigkeit des Naturhaushalts*), as well as the diversity, characteristic features and beauty of nature and landscape, and their recreational value (BNatSchG, § 1). As such, the Act refers to both ecocentric and anthropocentric values. Furthermore, it meets the requirements for a complete national account. A national account includes, next to the "income account" which contains the current transactions of the last economic period, a so-called "capital account". The capital account reproduces the scope and changes in the various capitals. If a high consumption is achieved through the reduction of capital, this usually means less income generation in future periods. Such relationships also apply to the current and future delivery and use of ecosystem services.

3.4. Differentiating between natural contributions and human contributions

In response to the challenge of not confusing ecosystem service supply with ecosystem service potentials, the proposed set of indicators explicitly refers to nature's contributions to the generation of ecosystem service supply as far as possible, given the availability of data. A typical indicator in this regard is the 'natural fertility of arable soils' (see Table 1, Fig. 2). This indicator is measured according to the Muencheberg Soil Quality Rating, a method that aggregates soil characteristics and other site-specific conditions critical for agricultural production, giving them a score-value between 1 (worst) and 100 (best), which is linearly correlated with yields (Mueller et al., 2007). For instance, scores of 40 and 80 indicate that crops produced on soil with a score of 80 will normally be twice the size as the crop produced on soil with a score of 40. It is possible that the values calculated are not completely independent of changes caused by human use, as it is perhaps economically optimal to vary fertilizer input depending on soil fertility. At a minimum, the use of an indicator based on natural conditions will prevent misinterpretation if yield changes are attributable to changes in human input. Ongoing erosion processes are not part of the national database for the Muencheberg Soil Quality Rating. Therefore, they have to be considered separately with the help of other indicators ("Erosion mitigation by continuous vegetation cover" and "small structures within agricultural landscapes").

Data on the relative suitability of sites for production also exist for meadows and pastures (for fodder production and crops) and also for forests but are not or not comprehensively available on the national scale. As proxies for the related provisioning services, the share of grasslands in agricultural areas and a combination of timber stocks (potential) and logging (use) are proposed (see Table 1, including an explanation for taking the share of grasslands instead of the absolute areas).

4. Discussion and conclusions

The proposed set of indicators fulfils the requirements set out in the introduction and could be very useful for implementation of the EU Biodiversity strategy in Germany. The implications of using this approach for aggregating ecosystem services in national accounts, the added value of the new information in the German context, and the differences with approaches used in other countries are explained below, followed by some conclusions and recommendations for further research.

4.1. Implications for aggregating indicators

Consideration of both, supply and demand indicators for ecosystem services, provides new perspectives and options to address the challenge of aggregating ecosystem service indicators at higher spatial scales (Fisher et al., 2009). The supply or the potential amount of services that could be delivered to a society can usually be thoroughly described on the basis of natural parameters. Local and regional ecosystem service potentials can usually (more or less easily) be aggregated on a national scale. This is also the case for the use of ecosystem services that are not confronted with a specific spatial demand. An indicator for the average yield from a certain area can easily be aggregated on a national scale because – due to currently low transportation costs and available storage techniques – the demand for the crop is (nearly) spatially unspecific.

The situation will be quite different if the supply of services is confronted with a spatially differentiated demand. In this case, the welfare effect of a certain level of supply or the benefits of a certain quantity of service use depends on the intensity of demand met in a specific area. The same service use can have different benefits. Differences in demand can stem from various reasons such as population size, specific preferences, especially for certain cultural services, different soils that need different levels of erosion protection, areas that are especially vulnerable to flooding hazards or particular human activities demanding certain goods and services.

In the case of spatially specific demands for spatially specifically supplied services, the need to take into account the demand may be most relevant for problems with aggregating services. An aggregation at different spatial scales is only possible if supply and demand are calculated precisely enough to predict the amount of service uses and their benefits in each spatial unit. If welfare effects are to be measured, assessments comparable to cost benefit analyses or multi-attribute utility theory will have to be carried out in each spatial unit in order to obtain sufficient data for an aggregation of changes in different areas.

Nevertheless, if coarser information is sufficient for individual ecosystem services, a simple juxtaposition of different "degrees" of spatial supply and spatial demand will be useful to support an aggregated assessment of the overall change of services on the national level. Overlaying techniques to identify combinations of spatial supply and demand patterns are undoubtedly far from being a substitute for differentiated spatially specific cost benefit analyses. However, they can point out whether changes in ecosystem service supply have taken place in areas with low or high demand, in deficient or in well-supplied areas. The relatively rapid generation of information is a considerable advantage compared to inherent uncertainties of the method (Jacobs et al., 2015). In many cases, such information does suffice for political purposes. The political purposes could, besides awareness raising, include weighing of alternatives for decision making.

Furthermore, policy does not have to only look at one aggregated figure on overall welfare. There are also other targets to be considered, for instance distributional equity. The German Federal Spatial Planning Act (Raumordnungsgesetz, § 1) asks for equivalent living conditions throughout Germany. The results of ecosystem service supply–demand overlays may deliver more relevant information for this policy aim than one aggregated number for all areas.

4.2. Benefits of implementing MAES in the German context

As outlined in the introduction, Germany already has substantial environmental data available and considers ecosystem service potentials in assessments and planning at the county and municipal level as part of landscape planning. Implementing a national assessment of ecosystem services in this context has several benefits beyond fulfilling the EU Biodiversity Strategy's Objective 2, Action 5: National monitoring of ecosystem services could serve as a national reference system for planning and decision making on the lower levels and could help investigate whether local decisions meet national requirements (Albert et al., 2014b).

To this end, the accuracy of the national data can be limited to the requirements of giving superordinate guidance. National data does not necessarily need to have the same level of detail as for specific planning decisions on the smaller-scale, for instance in deciding the optimal position for infrastructure or settlement development. In light of this, the proposed indicators, although still relatively coarsely defined, are likely to be useful in the multi-level planning system of Germany as a first approach for a nationwide detection of the development trends of ecosystem services.

An important issue to consider further is what kind of aggregated, national-level information on ecosystem services would be useful, for which type of decisions, and for whom. Nuissl et al. (2009) argue that environmental issues have different properties regarding their spatial implications. A national indicator therefore, cannot simply be applied in assessments of areas at lower spatial scales, but needs to be adapted to the specific context and decision-makers' needs. For example, a farmer requires spatially explicit data on soil fertility that is far more detailed than national maps as represented in Fig. 2. Nuissl et al. (2009) further argue that environmental problems sometimes arise due to the sum of individual small decisions that together cause a problem (as, for instance, for the indicator "Natural fertility of arable soils" in Table 1). Therefore, local and regional assessment and planning, as already institutionalised in Germany, can be complemented with national indicators and monitoring. In other cases, issues of connectivity are relevant, as with example for the indicator "Proportion of natural and semi-natural small structures in agricultural landscapes for pollination and pest control". Finally, the information provided in the context of national MAES implementation could provide new impulses to better assess and take into account synergies and trade-offs between ecosystem services in landscape planning in order to enhance the supply.

4.3. Needs for further research and practical implementation

Requirements for ecosystem service indicators have been defined by different authors (Müller and Burkhard, 2012; van Oudenhoven et al., 2012). They recommend that appropriate indicators must enable the understanding and quantification of interactions between land management, ecological processes and the provision of ecosystem services. Especially the operationalisation of ecosystem service potentials and flows (Schröter et al., 2014), human inputs (Burkhard et al., 2014), and demand for practical applications requires a consistent framework (Wolff et al., 2015). When comparing these requirements with the indicator set suggested in Table 1, issues requiring further research become obvious. The conceptual framework, distinguishing between (natural) ecosystem potentials, human inputs, and ecosystem service supply and demand (see Box 1) seems robust. Moreover, it covers human–environmental interactions with ecosystem service supply. However, the practical application is limited by data availability at appropriate scales. Therefore, compromises and generalisations have to be accepted until better data is available. Potential data sources that may be available in future include improved computer-based modelling or ecosystem services-based monitoring systems.

Nevertheless, practical application and implementation of the proposed set of indicators in Germany has already begun. A first assessment of the recommended supply indicators (Table 1) has been prepared on the basis of available spatial data (Marzelli et al., 2014a). An ongoing project at the Technische Universität Berlin is developing an indicator focusing on the provision of urban green space in major German cities with inhabitants of more than 100,000. This is the first time an indicator has been used to measure access to urban green spaces, on a household level, by merging geocoded panel data on the socio-economic background of households (e.g. income, age, education, migration background) and geocoded data on land use in German major cities. A joint project between Leibniz Universität Hannover and Georg-August-Universität Göttingen is looking at supplementing the two existing sub-indicators for recreational services (supply of bathing water and supply through recreation-related protected areas) with an indicator for a more comprehensive classification and economic valuation of the suitability of landscapes for recreation. All demand indicators still need to be developed. This task is part of an ongoing project at the Leibniz Institute of Ecological Urban and Regional Development (IOER) that started at the end of 2014. This project will (i) identify how the database of the recommended indicator set can be regularly updated and (ii) modified, including possibly adding indicators in co-ordination with the EU-wide process for implementation of Target 2, Action 5 of the EU Biodiversity Strategy, and (iii) it shall deliver two observations for every indicator within a certain period of time to allow for a first assessment of trends of ecosystem service supply and demand. Furthermore, the ecosystem service 'matrix' approach, linking geospatial units with ecosystem service potentials, supply and demand (Burkhard et al., 2012, 2014) is further developed and applied on different scales (including national) at Kiel University.

Overall, with careful optimism, it can be concluded that the suggested ecosystem service indicators will contribute to enhancing landscape planning and decision making, and also identify and monitor pathways for sustainable use of ecosystem services.

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