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Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification

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Abstract

The high variety of ecosystem service categorisation systems, assessment frameworks, indicators, quantification methods and spatial localisation approaches allows scientists and decision makers to harness experience, data, methods and tools. On the other hand, this variety of concepts and disagreements among scientists hamper an integration of ecosystem services into contemporary environmental management and decision making. In this article, the current state of the art of ecosystem service science regarding spatial localisation, indication and quantification of multiple ecosystem service supply and demand is reviewed and discussed. Concepts and tables for regulating, provisioning and cultural ecosystem service definitions, distinguishing between ecosystem service potential supply (stocks), flows (real supply) and demands as well as related indicators for quantification are provided. Furthermore, spatial concepts of service providing units, benefitting areas, spatial relations, rivalry, spatial and temporal scales are elaborated. Finally, matrices linking CORINE land cover types to ecosystem service potentials, flows, demands and budget estimates are provided. The matrices show that ecosystem service potentials of landscapes differ from flows, especially for provisioning ecosystem services.

Keywords:
ecosystem service matrix, providing units, benefit areas, landscape, mapping

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Highlights

- Ecosystem service definitions, indicators for ecosystem service potentials, flows and demands are suggested.
- Spatial ecosystem service relations referring to service providing units, benefitting areas, rivalry and scales are discussed.
- Ecosystem service potentials of landscapes differ from ecosystem service flows, especially for provisioning ecosystem services.
- Differentiation between potentials and flows is difficult for regulating ecosystem services.
- Exemplary matrices linking land cover types to ecosystem service potentials, flows, potential vs. flow comparisons, demands, flow-demand budgets are provided.

Focal characteristics of the described method

- Focal ecosystem service(s): regulating, provisioning and cultural services
- Focal ecosystem type(s): generally applicable; example Europe
- Focal temporal scale(s): generally applicable
- Focal spatial scale(s): generally applicable
- Focal target group of the method(s): scientists, decision makers, students
- Focal purpose of the method: ecosystem service indication, quantification and localisation

1 Introduction

The more popular the ecosystem service concept has got, the higher the demand for appropriate indication, quantification and spatial localisation methods has become (Alkemade et al. 2014; Crossman et al. 2013; Burkhard et al. 2013). Prospects of the ecosystem service idea to become a major tool in environmental management are promising, but at the same time expectations of and pressure from practitioners and scientists are raised (Honey-Rosés & Pendleton 2013; Daily et al. 2009; Kienast et al. 2009). Major challenges in all ecosystem service assessment efforts are the high complexity of the topic itself and the need for universal and rather easy-to-apply approaches (Crossman et al. 2013, Seppelt et al. 2012). Different classification systems (TEEB 2010; Costanza 2008a; MA 2005) and varying understanding of ecosystem service supply-benefit delivery chains among scientists (Fisher et al. 2009; Boyd & Banzhaf 2009) have inhibited broad-scale practical applications so far. Focussing on the different ecosystem service delivery components, Villamagna et al. (2013) have recently discussed several highly relevant questions on how ecosystems produce services, how to consistently quantify ecosystem service flows, how services relate to each other and how landscape changes affect future service delivery.

Most of the currently available spatial ecosystem service studies focus on ecosystem service supply (see Crossman et al. 2013; Martínez-Harms & Balvanera 2012; Egoh et al. 2012 for reviews), whereas the demand side has not been sufficiently considered. The integration of societal needs for goods and services enhances currently applied function-oriented landscape planning approaches and environmental management strategies. This reveals the full application potential of the ecosystem service framework (Chan et al. 2012; de Groot et al. 2010).

Since the first publication of the ecosystem service ‘matrix’, which links land cover types to ecosystem service supply capacities (Burkhard et al. 2009 in this journal), the method has successfully been applied to quantify and map ecosystem services in several case studies (e.g. Kandziora et al. 2013b; Kaiser et al. 2013; Vihervaara et al. 2010 and 2012; Müller et al. subm.). It has also inspired the development of other ecosystem service mapping studies (e.g. Clerici et al. 2014; Baral et al 2013; Maes et al. 2011). In 2012, an improved version, including demands for ecosystem services and ecosystem service budget estimates using the same method, was published (Burkhard et al. 2012a). This method has also been applied in different case studies (e.g. Kroll et al. 2012; Nedkov and Burkhard 2012) and improved further. In Schröter et al. (2012), valuable comments on “how and where to map supply and demand of ecosystem services for policy-relevant outcomes" related to the matrix method were provided. These ideas were elaborated further in a recently published case study by Schröter el al. (2014). Hou et al. (2013) discussed the uncertainties related to the matrix method applied for landscape analyses and showed further aspects to improve it.

In our opinion, the attractiveness of the matrix approach results from its flexibility concerning detailedness and levels of abstraction from rather simple to highly complex. Its potential to integrate all kinds of data, from expert-scores to statistics, interview data, measurements or high-end model outcomes makes it applicable in data-poor as well as data-rich environments. Last but not least, results based on the flexible 0-5 ranking system and the linkage to geobiophysical spatial units (e.g. land cover, biotope, vegetation or soil types) in ecosystem service maps provide wide application ranges in science and, hopefully, in decision making.

In this article, recently gained insights concerning ecosystem service quantification and localisation in space and time are presented, and the 'matrix' method is developed further. We hope to trigger scientific debate by contributing to the Special Issue on 'Concepts and Methods for Ecosystem Service Assessments' in Landscape Online. We collected experience and data from different case study applications, international workshops and conferences as well as the work in the IALE-D working group on Ecosystem Services[1] and within the three Ecosystem Services Partnership[2] (ESP) Thematic Working Groups on Indicators[3] , Mapping[4] and Modelling[5] Ecosystem Services. Based on this experience we are aware that no final solution for highly complex ecosystem service assessments has been found yet and that related challenges are manifold. Therefore, we find it important to share our most recent findings and to exchange methods. As defined by the ESP working groups mentioned above, the development of tools, guidelines and standards for improving analyses of ecosystem services is one major goal of related studies.

Our aim is to contribute to the further development of the ecosystem service concept with our ideas and approaches, and thereby to increase its application potential for sustainable decision making. In the following chapter, we present and discuss different ecosystem service definitions, categorisations and indicators related to ecosystem service supply, demands, flows and their spatial localisation. Indicators, definitions and spatial characteristics for 11 regulating, 14 provisioning and 6 cultural ecosystem services are presented. Chapter 3 gives more detailed explanations of methods for regulating, provisioning and cultural ecosystem service assessments. Exemplary assessment matrices of ecosystem service potentials, flows and demands as well as budget estimates are provided in chapter 4. The methods and exemplary results are discussed in chapter 5, followed by the conclusions with a special focus on further research needs in chapter 6.

The following key questions have been of special relevance for the development of the concept on spatial localisation, indication and quantification of ecosystem service potentials, flows and demands:

- Is a distinction between ecosystem service potentials, flows and demands practical?
- What are appropriate indicators for ecosystem service potentials, flows and demands?
- Where are demands for ecosystem services localised best and how can they be quantified?
- Are there patterns of ecosystem service supply, demand and budget estimates when displaying them in land cover-based ecosystem service matrices?

[1] http://www.iale.de/home/arbeitsgruppen/oekosystem-dienstleistungen.html
[2] http://www.es-partnership.org/esp
[3] http://www.es-partnership.org/esp/79024/5/0/50
[4] http://www.es-partnership.org/esp/79222/5/0/50
[5] http://www.es-partnership.org/esp/79026/5/0/50

2 Background concepts

2.1 Ecosystem service definitions, categorisations and indicators

Many different ecosystem service definitions, classification and categorisation systems have been developed during the last decades and are under discussion for application in decision making (Villamagna et al. 2013). Perhaps ecosystem services are too case-specific for applying a common classification system (Burkhard et al. 2012b; Costanza 2008a). Promising attempts for defining and categorising ecosystem services have been undertaken for example by TEEB (2010), MA (2005) or CICES[6]. In our work, we use an approach based on the most commonly applied three ecosystem service categories (regulating, provisioning, cultural services) adding ecosystem functions (structures and processes relevant for ecosystem self-organisation; see concept of ecological integrity; Müller 2005). Based on the comprehensive list of ecosystem function and service definitions published in Kandziora et al. (2013a), we now provide an updated list of ecosystem service definitions. Additionally we differentiate between supply and demand indicators as well as their spatial characteristics. Ecosystem functions have not been specifically considered in this article because they often do not provide direct benefits to humankind (van Oudenhoven et al. 2012; Bastian et al. 2012). Thus, the intended differentiation in potentials and flows as well as demands (see following Chapters 2.2-2.3) is not applicable for ecosystem functions. Comparable problems are discussed for several regulating ecosystem services such as pollination, water flow and nutrient regulation (Chapter 2.2).

We use the following definition for ecosystem services: "Ecosystem services are the contributions of ecosystem structure and function – in combination with other inputs – to human well-being" (Burkhard et al. 2012b, p. 2; see Box 1). The rather new recognition of 'other inputs' into ecosystem services provides an improved representation of conditions in reality. In many human-environmental systems, nature-based ecosystem service contributions are hardly separable from anthropogenic inputs anymore. This point will be further elaborated in the following paragraphs.

Due to the nature of the ecosystem service approach, related indicators include descriptive aspects as well as evaluative items (Müller & Burkhard 2012). Therefore it is mandatory to have a flexible and consistent indicator selection process keeping multiple types of end-users in mind (van Oudenhoven et al. 2012). Unfortunately, many ecosystem service studies, especially at larger spatial scales, tend to be data-driven exercises (Dick et al. 2014). In fact, indicator-indicandum (the object of interest) relations have to be significant for the particular ecosystem service, the studied problem and the actual purpose of the study.

2.2 Ecosystem service supply

According to the definition provided in Box 1, ecosystem services contribute to human well-being. A more detailed look into these contributions reveals difficulties distinguishing between ecosystem structures, functions, stocks, actual flows and beneficiaries (the "ecosystem services cascade" components; Haines-Young & Potschin 2010). Villamagna et al. (2013) ask how to separate ecosystem capacity for service production, actual service production or its use, societal demand and various pressures on ecosystem services. Bastian et al. (2012) distinguish between ecosystem properties, potentials and services. This includes the idea that ecosystems provide a certain potential to supply services based on their functioning (van Oudenhoven et al. 2012). The demand for these potential services from society converts them into real ecosystem services. Thus it is important to distinguish between potential supply and actual flow of ecosystem services. Related measures deliver practical, policy-relevant information on the sustainability of service use (Schröter et al. 2012).

We suggest a framework based on ecosystem functions, ecosystem service supply and demand (Figure 1). Ecosystem functions are strongly influenced by land cover and land use. The supply of ecosystem services is based on specific

[6]http://cices.eu/

Box 1: Definitions used within the approach.

Ecosystem services: contributions of ecosystem structure and function – in combination with other inputs – to human well-being (Burkhard et al. 2012b).

Ecosystem service potential: the hypothetical maximum yield of selected ecosystem services (Burkhard et al. 2012a).

Ecosystem service flows: *de facto* used set (bundles) of ecosystem services and other outputs from natural systems in a particular area within a given time period[7].

Demand for ecosystem services: ecosystem goods and services currently consumed or used in a particular area over a given time period, not considering where ecosystem services actually are provided (Burkhard et al. 2012a).

Additional inputs: non-ecosystem-based anthropogenic contributions to ecosystem services, referring for example to fertiliser, energy, pesticide, technique, labour or knowledge use in human-influenced land use systems. These additional inputs (e.g. agro-, forestry or urban system services) converge with (natural) ecosystem service potentials into e.g. agro-, forestry or urban ecosystem services.

Ecosystem service providing units (SPU): spatial units that are the source of an ecosystem service (Syrbe & Walz 2012). Include the total collection of organisms and their traits required to deliver a given ecosystem service (Vandewalle et al. 2009) as well as abiotic ecosystem components (Syrbe & Walz 2012). Commensurate with ecosystem service supply (Crossman et al. 2013). Hotspots are areas that provide large components of particular services in a comparably small area/spot (García-Nieto et al. 2013; Egoh et al. 2008; Gimona & van der Horst 2007).

Ecosystem service benefiting areas (SBA): the complement to ecosystem service providing units. SBAs may be far distant from relevant SPUs (see next point spatial relations). The structural characteristics of a benefiting area must be such that the area can take advantage of an ecosystem service (Syrbe and Walz 2012). Commensurate with ecosystem service demand (Crossman et al. 2013) but several intermediate steps related to complex production and trade schemes may be included (Burkhard et al. 2012a).

SPU - SBA spatial relations: spatial characteristics describing the relationships between the place of service production and where the benefits are realized (Fisher et al. 2009; Syrbe & Walz 2012). Suggested categories include: i) *in situ* (SPU and SBA are realized in the same location), ii) omni-directional (SPU in one location, SBAs in the surrounding landscape without directional bias), iii) directional (SBA in a specific location to flow direction from the SPU), and iv) decoupled (ecosystem service can be traded over long distances, e.g., many provisioning ecosystem services) (after Fisher et al. 2009).

Ecosystem service rivalry: the degree to which the use of one ecosystem service prevents other beneficiaries from using it (Schröter et al. 2014; Kemkes et al. 2010; Costanza 2008a). Non-rival ecosystem services in return provide benefits to one person that do not reduce the amount of benefits available for others (Burkhard et al. 2012b).

Scale (spatial and temporal): the physical dimensions, in either space or time, of phenomena or observations (Reid et al. 2006). Regarding temporal aspects of ecosystem service supply and demand, hot moments are equally important to be identified as spatially relevant hotspots (Burkhard et al. 2013).

[7] In former publications (e.g. Burkhard et al. 2012a), ecosystem service flows (as defined here) were referred to as ecosystem service supply 'capacities'. However, the distinction between service potentials and capacities did not become sufficiently clear. Therefore, the term 'ecosystem service flows' is preferred instead.

ecosystem service potentials and additional system inputs converging in an ecosystem service flow to societies. The ecosystem service potential is thereby comparable to natural capital stocks, yielding a flow of ecosystem services into the future (Costanza 2008b). The additional inputs are related to the economic concept of social, human, financial and manufactured capital assets (Costanza & Daly 1992). Ecosystem service flows in return relate to *de facto* used ecosystem goods and services. This distinction can relatively easy be made for many of the provisioning ecosystem services, such as timber provision (service flow) from a stock of trees (potential) in a forest. For many regulating as well as cultural ecosystem services, this distinction and respective indicator derivation tend to be more difficult, as will be shown in the following chapters.

Our definitions (see Box 1) and indicators for altogether 31 different ecosystem services (Tables 1-3) distinguish between ecosystem service potentials and flows. The indicators need to be tested in empirical case studies. Suggested indicators for ecosystem service potentials and flows fit well with state (how much of the service is present) and performance indicators (how much can be used/ provided in a sustainable way) proposed by de Groot et al. (2010). Benefits based on ecosystem service flows are the basis for human well-being. The valuation of these benefits that forms the end of the 'ecosystem service cascade' (Haines-Young and Potschin 2010) has not been included in the framework here. The conceptual model is constructed as an ecosystem service supply-demand cycle from environment to human society and back. The framework can be linked to the Driver-Pressure-State-Impact-Response (DPSIR) model of human-environmental systems (Müller and Burkhard 2012).

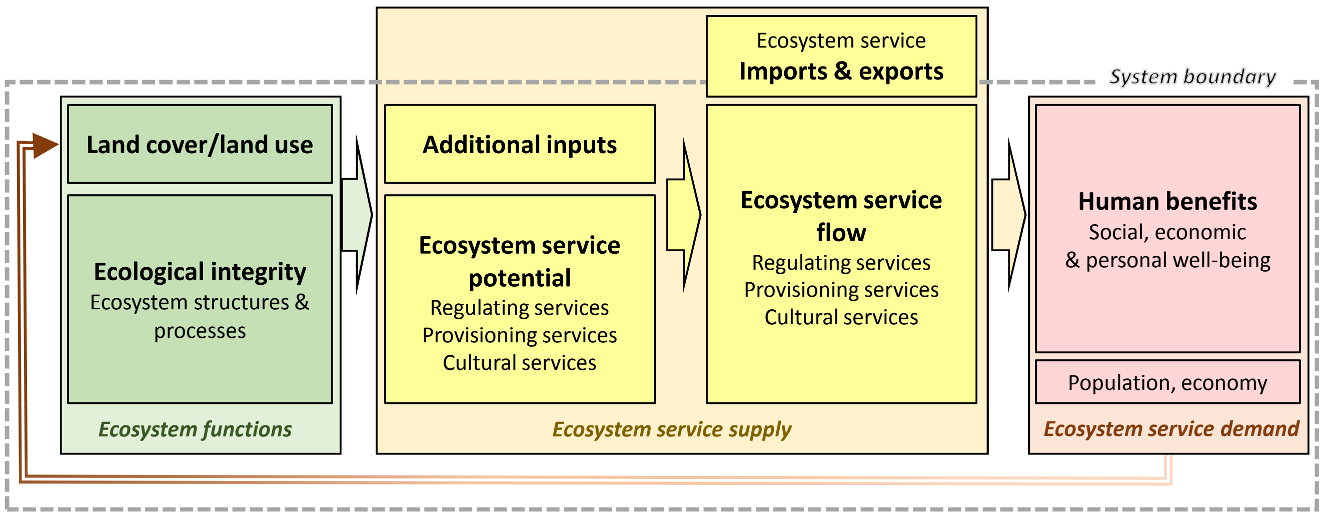

Figure 1: Conceptual model showing relations of ecosystem functions, services and benefits. For definitions, see Box 1.

One important concept regarding ecosystem service supply is the concept of service providing units (SPUs; see Box 1) or areas (SPAs). They include the total collection of organisms, their abundance, phenology, distribution and trait attributes required to deliver certain ecosystem services (Vandewalle et al. 2009) as well as abiotic components (water bodies, soil units) hosting the service supplying ecosystems (Syrbe & Walz 2012). Spatial ecosystem service assessments should preferably refer to these units or to areas affected by related processes (floodplains, catchments) instead of administrative units, which often mark artificial system boundaries. Hotspots (and coldspots as their opposite) of ecosystem service supply are special types of SPUs. They can be either small local point sources or larger sources within larger SPUs. Examples for such hotspots are given in Tables

1-3. Times of particularly high ecosystem service supply, for example due to seasonal variations, can be identified as hot moments. It is highly relevant for landscape management to identify spatial hotspots (García-Nieto et al. 2013; Palomo et al. 2013; Schneiders et al. 2012; Egoh et al. 2008; Gimona & van der Horst 2007) and temporal hot moments of ecosystem service supply and demand.

2.3 Ecosystem service demands and flows

Studies and models on the supply side of ecosystem services on different scales have developed quite far already (see reviews by Crossman et al. 2013; Martínez-Harms & Balvanera 2012; Egoh et al. 2012). But there is still a clear underrepresentation of research on the demand side for ecosystem services (Honey-Rosés & Pendleton 2013; Burkhard et al. 2013). Nevertheless, several studies have included aspects of ecosystem service demands and developed promising assessment methods (Bagstad et al. 2013a; Mubareka et al. 2013; García-Nieto et al. 2013; Kroll et al. 2012; Nedkov & Burkhard 2012; Lautenbach et al. 2011). Ecosystem service flows were assessed for example in Bagstad et al. (2013b), Willemen et al. (2013) and Palomo et al. (2013).

The demand for ecosystem services refers to ecosystem goods and services currently consumed or used in a particular area over a given time period (Burkhard et al. 2012a; Box 1). Demand can change over time and space, independent from actual ecosystem service supply (and *vice versa*; Villamagna et al. 2013). Ecosystem service use will also be driven in the future by demand. For separate demand assessments or regional supply-demand budget calculations (see Kroll et al. 2012; Burkhard et al. 2012), it is not imperative to consider where ecosystem services are actually supplied. However, for integrative large-scale ecosystem service supply-demand assessments, origins and flows of goods and services should be considered. Ecosystem service flows are the spatially explicit routing of an ecosystem service from sources to beneficiaries (Bagstad et al. 2013b). Thus, service benefiting areas (SBAs) are complementary to SPUs, but in contrast, SBAs do not relate primarily to ecosystems or geobiophysical units but to beneficiaries of certain ecosystem services. Therefore, typical locations for SBAs are urban areas or rural settlements and respective assessment units are administrative and/or planning units (Syrbe & Walz 2012).

Flows of ecosystem goods and services from SPUs to SBAs can take place via service connecting areas (SCAs; Syrbe & Walz 2012) or certain ‘carriers’ (Bagstad et al. 2013b). SCAs can be of natural origin (natural waterways, gas circulation paths, viewsheds) or human-made/modified (artificial waterways, transport ways, pipelines). For a differentiated analysis of ecosystem service flows, the spatial relations between areas of ecosystem service supply and demand are of special interest. Fisher et al. (2009) and Syrbe & Walz (2012) identified four different types of SPU-SPA spatial relations:

i. *in situ* - where the services are provided and the benefits are realized in the same location,

ii. omni-directional - where the services are provided in one location, but benefit the surrounding landscape without directional bias,

iii. directional - where the service provision benefits a specific location due to the flow direction, and

iv. decoupled - where the ecosystem service can be traded over long distances.

Costanza (2008a) applied a comparable system, based on the ecosystem service classes ‘global or local non-proximal’, ‘directional flow related’, ‘in situ’ and ‘user movement related’. Many regulating ecosystem services show in situ, omni-directional or directional (but never decoupled) SPU-SBA relationships. Demand for regulating ecosystem services has to be met locally or regionally (except global climate regulation), whereas provisioning and cultural services can show decoupled supply-demand relationships (Villamagna et al. 2013). This was shown for the example of flood regulating ecosystem services (Nedkov & Burkhard 2012), where SPUs and SBAs have to be physically connected because flood regulation cannot be imported from decoupled remote regions (‘‘local proximal service supply” after Costanza 2008a). In the case of cultural ecosystem services, flows are generally more difficult to grasp, because most of them are intangible assets (see Chapter 3.3).

Rivalry and excludability are further important features when assessing demands for ecosystem services. The degree of rivalry indicates how much the use of one service by an individual or a user group impacts the quality or quantity of that service available to other users (Schröter et al. 2014; Kemkes et al. 2010). Excludability occurs if institutions or technologies exist that prevent other individuals or groups from using the good or service. Costanza (2008a) classified market goods and services (most provisioning services) and open access resources (some provisioning services) as rival. Some recreation services and most regulatory and cultural services were classified as non-rival. Most of the rival goods and services can be made excludable by institutions (Kemkes et al. 2010). Therefore, many ecosystem services are best treated as 'public goods' (Burkhard et al. 2012b).

In Tables 1-3 we provide lists of ecosystem service demand indicators, spatial relationships between SPUs and SBAs and their rivalry for each ecosystem service. Unfortunately, most of the suggested demand indicators do not clearly distinguish between ecosystem service demand (consumption rates) and actual human needs (as defined for example in Ruppert & Schaffer 1969; Maslow 1943). Food demand, for example, can be indicated by average crop consumption in kg or kJ/person per year. Respective numbers may however differ from nutritional needs in the assessed region. Similar problems emerge when indicating demands for many other provisioning but also cultural ecosystem services.

2.4 Spatial ecosystem service assessments

In general, ecosystem service supply, demands and flows are spatially explicit items (Schröter et al. 2012; Burkhard et al. 2012a and 2009; Fisher et al. 2009; Costanza 2008a). Respective models are needed in order to synthesize and quantify our understanding of ecosystem services and in order to understand dynamic, spatially explicit trade-offs as part of larger human-environmental systems (Burkhard et al. 2012b; Raudsepp-Hearne et al. 2010). For improved landscape planning, monitoring and sustainable environmental resource management, a better understanding of where, when and what services are provided by certain pieces of land, landscapes, regions, states, continents and globally has to be developed (Crossman et al. 2012; Swetnam et al. 2010). Spatial visualisations in maps are powerful tools with high potentials (but also risks) for the explanation of complex phenomena (Burkhard et al. 2012a; Wood et al. 2010).

The most recent ecosystem service mapping efforts have been reviewed by Crossman et al. (2013); Martínez-Harms & Balvanera (2012) and Egoh et al. (2012) and related Special Issues have been edited for example by Burkhard et al. (2013) and Crossman et al. (2012). Many mapping studies apply complex ecosystem service models and maps dealing with ecosystem service supply. However, they apply related ecosystem service demands and flows to a smaller degree. Most of the more recent work (e.g. Palomo et al. 2013; Bastian et al. 2013) clearly refers to aspects of practical application and stakeholder involvement and provide clear recommendations on how to improve mapping for application in science, policy and practice. Spatial and temporal scales, both key map attributes, and their appropriate selection are a recurring challenge of ecosystem service science and practical application. Ecosystem service assessment units (SPUs and SBAs) and related indicators, models and maps should match scales of their geobiophysical supply origin, flow and demand units on the one hand. On the other hand, they should match scales of administrative units for better application in decision making (Burkhard et al. 2013). Spatial mismatches can result in misinterpretations or inapplicability of assessment results (Kandziora et al. 2013b).

As ecosystem services are relevant over a broad range of scales in space, time and complexity, various and flexible measurement, model, accounting and assessment tools are needed (Burkhard et al. 2012b). We believe that the concept for ecosystem service assessment presented in this article provides sufficient flexibility to fulfil these demands if applied appropriately. In Tables 1-3 we suggest spatial and temporal scales for related ecosystem service assessments. To keep the approach sufficiently flexible, the scale definitions and transitions between them are rather fuzzy (especially between local and regional scales). Spatial scales include:

- local (e.g. communities, farms, ecosystems),
- regional (e.g. administrative districts, watersheds, landscapes),
- continental (e.g. Europe, Asia) and
- global

Spatial units suggested for quantification of the indicators in Tables 1-3 can refer to 'regions', which can be administrative units (such as states, counties, communities), environmental regions (e.g. biomes) or geobiophysical spatial units (soil associations, watersheds). Several of the regulating ecosystem services relate to specific spatial process units such as catchments. Temporal assessment scales include:

- short-term (e.g. events, peak flows),
- seasonal (e.g. harvest rhythms, tourist seasons, growing seasons),
- annual (e.g. sums, yearly average values),
- medium-term (e.g. decades) and
- long-term (e.g. generations, centuries, millennia) periods.

3 Methodology

In the following, we present and discuss comprehensive tables, providing details on the information discussed above, separately for regulating (Table 1), provisioning (Table 2) and cultural (Table 3) ecosystem services.

3.1 Regulating ecosystem services

Regulating ecosystem services are by nature closely related to ecosystem structures, processes and functions. For some regulating ecosystem services, such as nutrient flow, water flow or waste regulation, clear overlaps with ecosystem functions like nutrient or water cycling are obvious in almost all current ecosystem service categorisation systems. This induces a high risk for double-counting when no clear separation between ecosystem functions and services is made and both are jointly valuated (Fisher et al. 2009). Regarding land use impacts, many ecosystem functions and regulating ecosystem services can take place (or would perform even better) without human intervention or demand. Therefore, several ecosystem service definitions, referring to ecosystem services as direct benefits to human societies (e.g. Fisher et al. 2009; MA 2005), are not applicable for all the different regulating services. Many regulating ecosystem services are not perceived as services by the public because they lack clear (direct) benefits to the society, although progress has been made in their evaluation (see Kumar & Wood 2010).

The perhaps most prominent example here is pollination, one of the regulating ecosystem services assessed and mapped frequently (Schulp et al. 2014; Lautenbach et al. 2011). The final good would be the fruit or flower to be consumed or enjoyed, whereas the pollination process itself (the pollen transfer) would be an intermediate service (according to Fisher et al. 2009), or perhaps even better would be treated as ecosystem function (Boyd and Banzhaf 2007). Distinctions between pollination potentials and actual flows are also intricate. Here we used potential habitats for pollinators as well as species numbers and amount of pollinators as indicators for ecosystem service potential (Table 1). The amount of pollinated plants was then used to indicate actual pollination service flow. According to Lautenbach et al. (2011), demand for pollination services is generated by the farmer's decision to plant crops depending on/profit from pollination. Similar to this definition, we use the amount of agricultural, garden or wild plants demanding pollination.

For many regulating ecosystem services it is difficult to distinguish between potential supply and actual flows. For more event-related regulating ecosystem services, such as natural hazard protection, erosion regulation or pest and disease control, we choose service flow indicators to be proportional to amounts of prevented hazards, prevented erosion events or prevented pest and disease outbreaks. Numbers and effects of prevented events are of course difficult to measure in most cases. Furthermore, a clear localisation of demands for regulating ecosystem services is not always possible, in some cases perhaps not even reasonable. Local climate regulation for example continuously takes place over space and time. Thus, there are continuous flows or states, no matter what potential has been indicated for a particular site. Therefore, indicators suggested for local climate regulation potential and flows in Table 1 are relatively similar, except that service flows refer to deviations of local climate components compared to surrounding areas.

Another mostly unsolved problem is the distinction between purely nature-based regulating ecosystem service supply and additional (mostly anthropogenic) inputs, especially in intensive agricultural land use systems (delivering agro[eco]system services; Papendiek et al. 2012). We understand agrosystem services to be additional anthropogenic system inputs such as fertiliser, water, energy, technology, labour or knowledge affecting especially regulating ecosystem service supply (e.g. regulation of nutrients, erosion, natural hazards or water flows). Agrosystem services converge with (nature-based) ecosystem services in agro-ecosystem services (see Box 1 and Figure 1). The concept is related to the idea of Human Appropriation of Net Primary Production (HANPP) (Haberl et al. 2012). However, HANPP compares potential natural vegetation with human-modified systems, whereas agrosystem services refer to human-modified agricultural systems and contrast anthropogenic inputs with natural potentials for actual agro-ecosystem service flows.

For many regulating ecosystem services the spatial localisation, as well as the clear definition of beneficiaries, are problematic, mainly due to the lack of a final good or end-product (Villamagna et al. 2013). For pollination services mentioned above, omni-directional spatial relationships between potential service providing units (suitable habitats for pollinators) and benefitting areas (plants demanding pollination) are likely to occur (Fisher et al. 2009). Similar patterns can be found regarding pest and disease control. Villamagna et al. (2013) suggest using ecological work performed instead of conventionally used environmental quality measures to indicate regulating ecosystem services. For example, elements removed from water should be used to indicate water purification regulating services. This idea, although introducing a lot of uncertainty, was implemented to distinguish potentials from flows for several regulating ecosystem services, for example for water purification and nutrient regulation (see Table 1).

We are aware, that regulating ecosystem service demands and related perceived human benefits may differ considerably. For global climate regulating services for example, human benefits refer to non-desired temperature changes, storm events or coastal hazards. Nevertheless, the indicators suggested in Table 1 relate to regulating processes (e.g. greenhouse gas emissions) relevant for climate regulation. This relation to regulating processes makes more sense in terms of developing, quantifying and localising suitable avoidance strategies (for example the ‘polluter pays’ principle as well as carbon emission trading).

3.2 Provisioning ecosystem services

In general, the distinction between provisioning ecosystem service potentials and flows can be carried out more easily than the distinction between regulating ecosystem service potentials and flows. Natural capital stocks (e.g. forests, agricultural fields or water bodies) for potential use can be measured and related service flows assessed. Problems emerge when goods and services go through long supply chains from providing units to traders, processing, refinement, finishing, selling and transporting entities before the end product reaches the final consumer (Figure 2). The questions are where to locate the demand (Schröter et al. 2012) and who has to be considered as beneficiary from the large group of actors involved? One exception is direct marketing, where the group of actors involved would be much smaller. Otherwise each involved entity in the production chain needs to supply respective return flows (money or other services), thereby getting a share of the value of the good or service traded. This normally leads to an increasing price of the product. But does it really add up to a higher value of the product?

In such complex supply chains, involving natural, social and manufactured capital, a separation into intermediate and final ecosystem services as suggested by Boyd & Banzhaf (2007) provides relevant aspects but would not sufficiently solve the dilemma. In reality, various ecosystem services in different intermediate stages can be contributing to

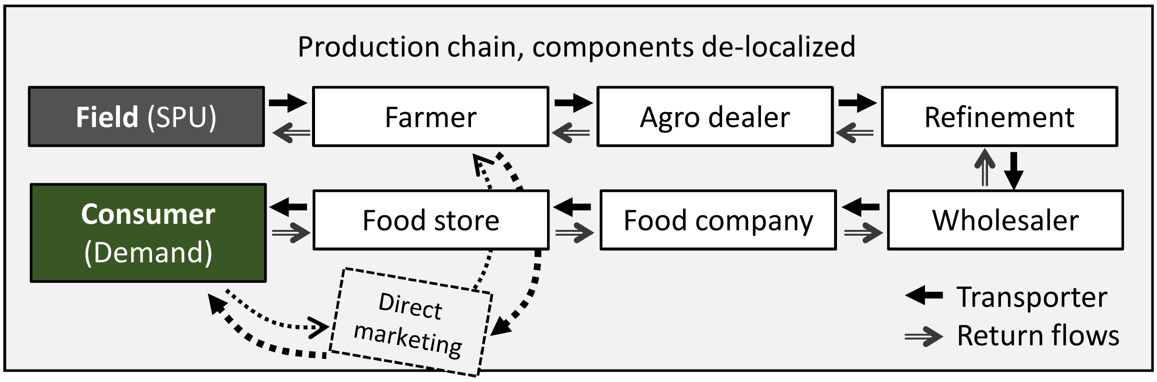

Figure 2: Complex ecosystem service supply chain, example of food provisioning services. Direct marketing could provide a more direct link. Several further 'short-cuts' between supply and demand are possible.

one final product. Schröter et al. (2012) suggested localising the demand for non-spatially confined (thus tradable or actively transportable) ecosystem services at the site of the last contribution of the ecosystem. We prefer to use this definition to locate provisioning ecosystem service flows in combination with the indicators suggested in Table 2. Ecosystem service demand should be located at the site of the final beneficiary, usually the end-consumer. If, however, the demand for an ecosystem service has been quantified at another site, the localisation has to be clearly defined.

Additional inputs modifying ecosystem structures and functionality, as mentioned above, make assessments of provisioning ecosystem services even more complex (Lautenbach et al. 2011). Difficulties emerge especially in highly human-dominated systems such as intensive agricultural areas, greenhouses, aquaculture systems or intensive mass animal farming (Baral et al. 2014; Petz & van Oudenhoven 2012). Other strongly anthropogenic-shaped systems such as cities, other settlements or industrial units have high demands for provisioning goods and services (Burkhard et al. 2012a). Problems with the share of natural ecosystem inputs to the supply of provisioning (agro-)ecosystem services remain, similarly to problems with regulating ecosystem services. Anthropogenic inputs are likely to be higher in assessed provisioning ecosystem service flows than in related potentials for the same service. This effect can be found in many agricultural systems requiring many inputs.

Mineral resources or abiotic energy sources also need a lot of facilities and other human-made inputs and equipment to finally be harvested. In most ecosystem service categorisation systems, mineral resources and abiotic energy sources are not acknowledged as ecosystem services in the strictest sense (see Haines-Young and Potschin 2010). After De Groot et al. (2002), fossil fuels, wind and solar energy are usually non-renewable abiotic resources which can neither be attributed to specific ecosystems nor be called ecosystem services. In the provisional CICES[6] classification, they are (temporally) treated as 'abiotic outputs from natural systems'. However, mineral resources and abiotic energy sources are both highly relevant for policy decisions and land use, as well as resource management strategies. Therefore, their spatial localisation and quantification need to be included in ecosystem service assessments as they can influence the amount and supply of other ecosystem services (Kandziora et al. in review).

The supply of other, more nature-based provisioning ecosystem services, such as freshwater, can be very hard to localise appropriately based on surface data (such as land cover) alone. If the water is not withdrawn from surface reservoirs but from groundwater, the aquifer's location has to be considered as service providing unit. In most cases, the SPU's location will not be related to land cover or land use forms identified on the study area's surface. Wells on the surface are only point sources of freshwater supply, linked to much bigger (underground) SPUs. The same problem emerges when localising SPUs of mineral resource provision based on underground mining. Proxies like groundwater recharge rates were used to calculate freshwater potentials (Kroll et al. 2012). Vigerstol & Aukema (2011), provide a comprehensive review of freshwater ecosystem service modelling tools.

Besides location, temporal aspects are of high relevance when quantifying provisioning ecosystem services. Single events like agricultural harvests, normally taking place only 1-3 times per year (depending on geographical conditions), can definitely be named as hot moments of provisioning ecosystem service supply. During the growing season, the provisioning ecosystem service potential increases constantly, whereas the flows temporarily remain more or less at zero until the final harvest. During harvest, the potential decreases dramatically, whereas service flows (from field to farmer, the first two elements of the supply chain in Figure 2) show a (short-term) peak (Figure 3). Therefore, rural agricultural landscapes are characterized by regular growth and harvest phases, reflected by related changes in their ecosystem service supply (Burkhard et al. 2011). Of course, additional agricultural strategies and crops with various growing and harvesting rhythms exist. Better information on these variations is highly relevant for site-specific landscape management, i.e. to optimise additional inputs. Respective seasonal patterns can be found for regulating (e.g. during storm or rain seasons) and cultural ecosystem service (e.g. tourist season) supply (and demand) as well. Other provisioning ecosystem services, such as timber, show much longer rotation periods taking several decades to grow before being harvested rather suddenly. Therefore, the selection and definition of appropriate temporal assessment scales have to be carried out very carefully.

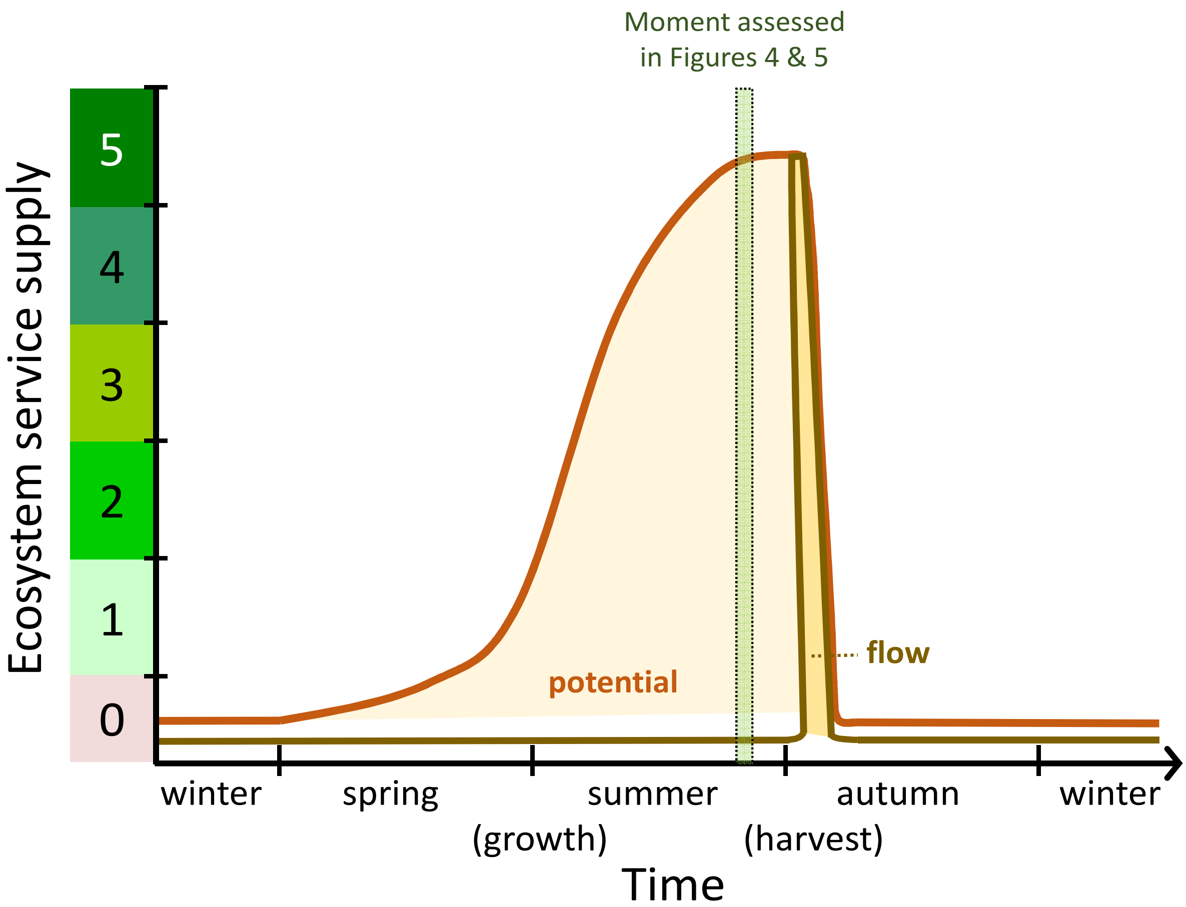

Figure 3: Ecosystem service potential and flow. Example of monoculture summer annual (e.g. wheat) crop-related food provisioning ecosystem service during the growth and harvest period (compare values with Figures 4 and 5).

3.3 Cultural ecosystem services

Cultural ecosystem services are difficult to assess due to their intangible nature and due to several methodological concerns. Therefore, they are rarely fully considered in ecosystem service assessments (Plieninger et al. 2013). Most of related quantifications and indicators reduce cultural ecosystem services to marketable services such as (eco)tourism and recreation (see review of Hernández-Morcillo et al. 2013). More intangible cultural ecosystem services, such as landscape aesthetics, spiritual experience or knowledge systems, have been assessed based on interviews, questionnaires and hedonic price models. More recent studies tend to integrate further assessment tools like landscape metrics to assess landscape aesthetics (Frank et al. 2013), Participatory GIS (PGIS; Palomo et al. 2013; Plieninger et al. 2013; Fagerholm et al. 2012) or Delphi surveys (Scolozzi et al. 2012).

A clear distinction between potentials and flows is not trivial in the case of cultural ecosystem services. Schröter et al. (2014) assessed recreational residential amenity service potentials by delineating suitability of SPUs for providing a location for second homes. Related ecosystem service flows were indicated based on existing cabins. Following our ecosystem services definition (Box 1), we considered existing facilities such as cabins, hotels or recreational areas as well as occurring events as ecosystem service potentials (stocks). The actual utilisation of these facilities or events is used to indicate cultural ecosystem service flows (see Table 3). Nahuelhual et al. (2013) applied a comparable method to calculate and map recreation and ecotourism potentials versus recreation and ecotourism opportunities. Potentials were calculated based on tourism attraction capacity for locations with touristic facilities and natural attractions. Opportunities were indicated by tourism carrying capacities (maximum visitor number in the study area depending on physical and biological settings and management). Visitor or consumer carrying capacities can also be used to estimate ecosystem service flows related to potentials for several other cultural ecosystem services. Here, biophysical carrying capacities need to be considered, as well as the sensibility of visitors towards a maximum number of other visitors. This fact can become relevant in crowded areas or periods (Brandt et al. 2013).

Nevertheless, appropriate SPU and SBA delineations remain delicate for cultural ecosystem services. For most of them, spatial mismatches exist between the ecosystems that supply services and people that enjoy them (Bagstad et al. 2013b). Lautenbach et al. (2011) evaluated demands for recreation services as the possibility for people to access the services. However, access is not always easy to specify for intangible services such as landscape aesthetics. Is the SPU located where the aesthetic landscape is or where the consumer (observer) is at a good location to look at it? One approach to solve this dilemma is creating viewsheds. Viewsheds can be lines of sight to connect view paths between source locations (e.g. aesthetic landscape features) and locations for human use (areas of potential enjoyment; Bagstad et al. 2013b). Calculations are mainly carried out using Digital Elevation Models (DEM) in GIS. The whole viewshed (the area that can be seen from a given location) would be the SPU for landscape aesthetic cultural ecosystem service potential. If other data are not obtainable, methods such as questionnaires, interviews, surveys, travel cost estimations, hedonic price models or willingness to pay are regularly applied for cultural ecosystem service assessments.

The demand for spatially confined ecosystem services was recommended to be mapped at the location where the final beneficiary uses the ecosystem service by Schröter et al. (2012). For the time being, we decided to denote all benefitting entities, such as touristic infrastructure, educational and spiritual facilities, their visitors, communities or households (at home location). as service benefitting areas (or sites). However, we prefer to localise demands for cultural ecosystem services at the consumer's home site, i.e. the place where she/he spends the majority of the year. This strict definition still needs to be proven further. For example, it is not clear for how long recreational or spiritual experiences are "taken home" by the consumer or whether the demand should better be located within the SPUs.

4 The Matrix

The ecosystem service matrices consist of ecosystem services (currently 11 regulating, 14 provisioning and 6 cultural services; according to Tables 1-3) on the x-axis and geobiophysical spatial units (e.g. the 44 CORINE[8] land cover types used here) on the y-axis. At the intersections (here altogether 1364), the different spatial units' ecosystem service potentials (Figure 4), flows (Figure 5) or demands (Figure 6) were assessed on a scale from 0 (no relevant supply or demand) to 5 (maximum relevant supply or demand) for a hypothetical 'normal' European landscape at one time point in summer before harvest. For further description of the method see Burkhard et al. (2009 and 2012a). The normalisation to this relative 0-5 scale aims at making different ecosystem services (measured and assessed by various indicators and units) comparable with each other. For calculations of the single values per land cover type, statistics (Kandziora et al. 2013b; Kroll et al. 2012), model results (Nedkov and Burkhard 2012), expert knowledge (Vihervaara et al. 2010 and 2012), interview results (Kaiser et al. 2013), monitoring or other data sources (Baral et al. 2013) can be used. Respective data then have to be classified to the six categories using appropriate class breaks[9]. Furthermore, it should be noted that the 0-class indicates no 'relevant' ecosystem supply or demand. Depending on the ecosystem service type, on land cover type, as well as on spatial and temporal scale, this can mean that the ecosystem service is not supplied or demanded at all or at a low amount. We know from recent case studies (e.g. Kandziora et al. 2013a and 2013b; Kaiser et al. 2013; Müller et al. subm.) that earlier published versions of the ecosystem service matrix (Burkhard et al. 2012a and 2009) did not consequently differentiate between ecosystem service potentials and flows (as defined in Chapter 2.2; Box 1; Tables 1-3). Moreover, the set of assessed ecosystem services had to be changed. Therefore, we now provide two different matrices: one for ecosystem service potentials (Figure 4) and one for ecosystem service flows (Figure 5).

It is important to note that assessed potentials and flows as well as demand values are exemplary numbers for hypothetical central European 'normal' landscapes, based on our experience from the work in different case studies. Like all expert-based assessments, the values are strongly dependent on the evaluator's experience, knowledge and objectivity (Burkhard et al. 2012a). We defined a day in summer, before the main harvest period, as appropriate time step for the evaluation. This is especially relevant for the assessment of many provisioning and several cultural ecosystem services. The given values are exemplary and illustrate the application potential of the matrix method. In other studies, the evaluations have to be modified according to the specific conditions, points in time and data obtained. Modification may also be needed for the matrix' axes to reflect peculiarities in land cover, to include other geobiophysical characteristics (y-axis) or specific relevant ecosystem services (x-axis).

4.1 Ecosystem service potential matrix

The matrix in Figure 4 shows a clear pattern of high potentials in the land cover types with less human impacts. Forests, wetlands and water bodies received especially high rankings. The more anthropogenically influenced land cover types (most of them in the upper part of the matrix) have considerably lower ecosystem service potentials, except for some cultural ecosystem services available in urban areas. Many agricultural land cover types show high potentials for food-related ecosystem service supply. This is typical for agricultural areas before harvest (see Chapter 3.2). As mentioned before (Chapter 3.2), the linkage of freshwater supply from groundwater sources to above-ground land cover types is not always feasible. Therefore, only above-ground water bodies were considered for freshwater supply here.

[8] http://www.eea.europa.eu/data-and-maps/figures/corine-land-cover-types-2006

[9] Equal intervals classification methods should be used to group the data into the 0-5 classes. Other methods such as natural breaks or quantiles would manipulate results and are less suitable to make the different classes and their values comparable with each other.

	Regulating services	Global climate regulation	Local climate regulation	Air quality regulation	Water flow regulation	Water purification	Nutrient regulation	Erosion regulation	Natural hazard regulation	Pollination	Pest and disease control	Regulation of waste	Provisioning services	Crops	Biomass for energy	Fodder	Livestock (domestic)	Fibre	Timber	Wood Fuel	Fish, seafood & edible algae	Aquaculture	Wild foods & resources	Biochemicals & medicine	Freshwater	Mineral resources*	Abiotic energy sources*	Cultural services	Recreation & tourism	Landscape aesthetics & inspiration	Knowledge systems	Religious & spiritual experience	Cultural heritage & cultural diversity	Natural heritage & natural diversity
Continuous urban fabric		0	0	0	0	0	0	2	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1		3	3	2	2	1	0
Discontinuous urban fabric		0	0	0	0	0	0	1	0	1	1	0		1	0	0	0	0	0	0	0	0	0	0	0	0	1		3	2	2	2	2	0
Industrial or commercial units		0	0	0	0	0	0	2	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0	0	0	2	0
Road and rail networks		0	0	0	0	0	0	1	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	1	0
Port areas		0	0	0	0	0	0	3	3	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	2	0	0	1	0
Airports		0	0	0	0	0	0	1	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Mineral extraction sites		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	5	3		0	0	2	0	1	0
Dump sites		0	0	0	0	0	0	0	0	0	0	2		0	1	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Construction sites		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	2	0
Green urban areas		2	2	2	2	2	2	2	1	2	2	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0		3	3	1	0	2	1
Sport and leisure facilities		1	1	1	1	1	1	1	0	0	1	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0		5	1	0	0	1	0
Non-irrigated arable land		1	2	1	2	0	1	0	1	1	2	2		5	5	5	0	5	0	0	0	0	1	3	0	0	2		1	1	2	0	3	0
Permanently irrigated land		1	3	1	1	0	1	0	1	1	2	2		5	1	2	0	4	0	0	0	0	1	3	0	0	1		1	1	2	0	3	0
Ricefields		0	2	1	1	0	1	0	0	1	1	2		5	1	2	0	0	0	0	0	0	0	0	0	0	0		1	1	2	0	3	0
Vineyards		1	1	1	1	0	1	1	0	1	1	1		4	1	0	0	0	0	1	0	0	0	0	0	0	0		3	2	3	0	5	0
Fruit trees and berries		2	2	2	2	1	2	2	2	5	3	2		4	1	0	0	0	2	2	0	0	0	2	0	0	0		3	2	2	0	4	1
Olive groves		1	1	1	1	1	1	1	0	1	2	2		4	1	0	0	0	2	2	0	0	0	2	0	0	0		2	2	2	0	4	0
Pastures		2	1	0	1	0	1	1	1	0	2	4		0	1	5	5	0	0	0	0	0	2	0	0	0	5		2	2	2	0	3	1
Annual and permanent crops		1	2	1	1	0	1	2	1	1	2	2		4	2	4	1	5	0	0	0	0	1	1	0	0	2		1	1	2	0	3	0
Complex cultivation patterns		1	2	1	1	0	1	1	1	2	3	2		4	2	2	1	4	0	1	0	0	1	2	0	0	1		2	2	2	0	3	0
Agriculture & natural vegetation		2	3	2	2	2	2	2	1	2	3	2		3	3	2	2	4	1	1	0	0	2	1	0	0	1		2	2	3	1	3	3
Agro-forestry areas		2	2	2	2	2	2	3	1	3	3	3		2	3	2	3	2	3	3	0	0	2	1	0	0	0		2	2	2	0	3	2
Broad-leaved forest		5	5	5	3	5	5	5	4	4	4	4		0	1	1	0	1	5	5	0	0	5	3	0	0	0		5	5	5	3	4	5
Coniferous forest		5	5	5	3	5	5	5	4	4	4	4		0	1	1	0	1	5	5	0	0	5	3	0	0	0		5	5	5	3	4	4
Mixed forest		5	5	5	3	5	5	5	4	4	5	5		0	1	1	0	2	5	5	0	0	5	3	0	0	0		5	5	5	3	4	5
Natural grassland		5	2	0	1	3	4	5	1	1	1	2		0	1	2	3	0	0	0	0	0	5	1	0	0	2		3	4	5	1	3	3
Moors and heathland		3	4	0	2	3	3	2	2	2	2	3		0	1	1	1	0	0	2	0	0	2	1	0	0	0		4	4	5	1	2	4
Sclerophyllous vegetation		2	2	1	1	1	2	1	1	2	2	3		0	1	1	1	1	2	2	0	0	1	3	0	0	1		2	3	4	1	2	4
Transitional woodland shrub		2	2	1	1	1	2	1	1	2	2	3		0	2	1	1	1	1	2	0	0	1	1	0	0	1		2	3	4	1	2	2
Beaches, dunes and sand plains		0	0	0	1	1	1	0	5	0	1	1		0	0	0	0	0	0	0	0	0	0	1	0	1	0		5	4	4	1	3	2
Bare rock		0	0	0	0	1	0	2	1	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	1	0		2	3	3	2	2	1
Sparsely vegetated areas		0	1	0	1	1	1	1	1	0	1	1		0	0	0	1	0	0	0	0	0	1	0	0	0	2		1	1	3	0	2	1
Burnt areas		0	1	0	0	0	0	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	2	0	0	0
Glaciers and perpetual snow		3	4	0	5	0	0	0	0	0	1	1		0	0	0	0	0	0	0	0	0	0	0	5	0	0		5	5	4	0	0	1
Inland marshes		2	2	0	3	2	4	1	4	1	2	3		0	0	4	2	0	0	0	0	0	1	0	0	0	0		1	2	3	0	2	2
Peatbogs		5	4	0	4	4	4	2	3	2	3	4		0	2	0	0	0	0	0	0	0	1	2	1	0	0		3	2	3	0	2	4
Salt marshes		1	1	0	1	1	2	1	4	1	2	2		0	0	2	2	0	0	0	0	0	1	0	0	0	0		3	2	3	0	2	2
Salines		0	3	0	0	0	0	0	0	0	1	1		0	0	0	0	0	0	0	0	0	0	2	0	2	0		2	2	3	0	4	0
Intertidal flats		1	1	0	1	1	1	1	5	0	2	3		0	1	0	0	0	0	0	0	0	1	0	0	0	0		4	2	3	0	2	2
Water courses		0	1	0	3	3	3	0	3	0	3	5		0	2	0	0	0	0	0	3	0	4	0	5	0	3		4	4	4	2	3	3
Water bodies		1	2	0	5	2	3	0	3	0	3	5		0	1	0	0	0	0	0	4	5	4	0	5	0	1		5	4	4	2	3	3
Coastal lagoons		1	1	0	4	2	3	0	4	0	3	5		0	1	0	0	0	0	0	4	5	4	1	0	0	0		3	4	4	0	2	3
Estuaries		1	0	0	3	3	3	0	3	0	3	5		0	2	0	0	0	0	0	4	5	4	1	0	0	1		3	4	4	0	2	3
Sea and ocean		3	3	0	1	2	3	0	0	0	3	5		0	4	3	0	0	0	0	5	5	4	3	0	1	3		4	5	5	2	3	3

*abiotic outputs from natural systems (after CICES)

Figure 4: Exemplary ecosystem service potential matrix. The exemplary evaluation refers to a hypothetical European „normal“ landscape in summer (before the harvest period). Scale from 0/rosy = no relevant potential; 1/grey green = low relevant potential; 2/light green = relevant potential; 3/yellow green = medium relevant potential; 4/blue green = high relevant potential; and 5/dark green = very high (maximum) relevant potential (after Burkhard et al. 2009 and 2012).

4.2 *Ecosystem service flow matrix*

	Regulating services	Global climate regulation	Local climate regulation	Air quality regulation	Water flow regulation	Water purification	Nutrient regulation	Erosion regulation	Natural hazard regulation	Pollination	Pest and disease control	Regulation of waste	**Provisioning services**	Crops	Biomass for energy	Fodder	Livestock (domestic)	Fibre	Timber	Wood Fuel	Fish, seafood & edible algae	Aquaculture	Wild foods & resources	Biochemicals & medicine	Freshwater	Mineral resources*	Abiotic energy sources*	**Cultural services**	Recreation & tourism	Landscape aesthetics & inspiration	Knowledge systems	Religious & spiritual experience	Cultural heritage & cultural diversity	Natural heritage & natural diversity
Continuous urban fabric		0	0	0	0	0	0	2	0	1	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		3	2	2	2	1	0
Discontinuous urban fabric		0	0	0	0	0	0	1	0	2	1	0		0	0	1	0	0	0	0	0	0	0	0	0	0	1		2	1	2	2	2	0
Industrial or commercial units		0	0	0	0	0	0	2	0	1	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0	0	0	2	0
Road and rail networks		0	0	0	0	0	0	1	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	1	0
Port areas		0	0	0	0	0	0	3	3	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	2	0	0	1	0
Airports		0	0	0	0	0	0	1	0	0	1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Mineral extraction sites		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	3	1		0	0	1	0	0	0
Dump sites		0	0	0	0	0	0	0	0	0	0	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Construction sites		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	1	0
Green urban areas		2	2	2	2	2	2	2	1	2	2	2		0	0	1	0	0	0	0	0	0	0	0	0	0	0		3	3	1	0	2	1
Sport and leisure facilities		1	1	1	1	1	1	1	0	0	1	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0		4	1	0	0	1	0
Non-irrigated arable land		1	2	1	2	0	3	0	1	3	2	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1	0	1	0
Permanently irrigated land		1	3	1	3	0	3	0	1	3	2	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1	0	1	0
Ricefields		0	2	1	4	0	3	0	0	1	1	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1	0	2	0
Vineyards		1	1	1	1	0	1	1	0	2	1	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0		2	1	2	0	4	0
Fruit trees and berries		2	2	2	2	1	2	2	2	3	3	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0		2	1	1	0	3	1
Olive groves		1	1	1	1	1	1	1	0	2	2	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0		2	2	2	0	3	0
Pastures		1	1	0	1	0	1	1	1	1	2	4		0	0	4	2	0	0	0	0	0	0	0	0	0	0		2	2	2	0	2	1
Annual and permanent crops		1	2	1	2	0	2	2	1	2	2	2		0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1	0	2	0
Complex cultivation patterns		1	2	1	2	0	2	1	1	3	3	2		0	0	1	0	0	0	0	0	0	0	1	0	0	0		2	2	1	0	2	0
Agriculture & natural vegetation		1	3	2	2	1	2	2	1	2	3	2		0	0	1	0	1	0	1	0	0	0	1	0	0	1		2	2	2	1	2	1
Agro-forestry areas		1	2	2	2	1	1	3	1	2	3	3		0	0	0	1	1	1	1	0	0	0	1	0	0	0		2	2	1	0	2	1
Broad-leaved forest		4	5	5	3	4	5	5	3	1	4	4		0	1	1	0	1	1	1	0	0	1	1	0	0	0		4	4	4	2	2	4
Coniferous forest		4	5	5	3	4	5	5	3	1	4	4		0	1	1	0	1	1	1	0	0	1	1	0	0	0		4	4	4	2	2	3
Mixed forest		4	5	5	3	4	5	5	3	1	5	5		0	1	1	0	1	1	1	0	0	1	1	0	0	0		4	4	4	2	2	4
Natural grassland		2	2	0	1	3	4	5	1	2	1	2		0	0	2	1	0	0	0	0	0	1	1	0	0	0		3	4	4	1	2	2
Moors and heathland		2	4	0	2	3	3	2	2	2	2	3		0	1	1	0	0	0	1	0	0	1	1	0	0	0		3	4	4	1	1	3
Sclerophyllous vegetation		1	2	1	1	1	2	1	1	1	2	3		0	0	1	0	0	1	1	0	0	1	0	0	0	0		2	3	4	1	1	3
Transitional woodland shrub		1	2	1	1	1	2	1	1	1	2	3		0	1	1	0	1	1	1	0	0	1	1	0	0	0		2	3	4	1	1	1
Beaches, dunes and sand plains		0	0	0	1	1	1	0	5	0	1	1		0	0	0	0	0	0	0	0	0	0	1	0	0	0		5	4	4	1	1	1
Bare rock		0	0	0	0	1	0	2	1	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		2	3	3	1	1	1
Sparsely vegetated areas		0	1	0	1	1	1	1	1	0	1	1		0	0	0	1	0	0	0	0	0	0	0	0	0	0		1	1	2	0	1	1
Burnt areas		0	1	0	0	0	0	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	2	0	0	0
Glaciers and perpetual snow		3	4	0	3	0	0	0	0	0	1	1		0	0	0	0	0	0	0	0	0	0	0	1	0	0		2	4	3	0	0	1
Inland marshes		2	2	0	2	2	4	1	4	1	2	3		0	0	2	1	0	0	0	0	0	0	0	0	0	0		1	2	3	0	1	1
Peatbogs		4	4	0	3	4	4	2	3	2	3	4		0	2	0	0	0	0	0	0	0	0	1	0	0	0		3	2	3	0	1	3
Salt marshes		0	1	0	1	1	2	1	4	1	2	2		0	0	2	1	0	0	0	0	0	0	0	0	0	0		3	2	3	0	1	1
Salines		0	2	0	0	0	0	0	0	0	1	1		0	0	0	0	0	0	0	0	0	0	2	0	2	0		2	2	3	0	3	0
Intertidal flats		1	1	0	1	1	1	1	5	0	2	3		0	0	0	0	0	0	0	0	0	0	0	0	0	0		4	2	3	0	1	1
Water courses		0	1	0	3	3	3	0	3	0	3	5		0	0	0	0	0	0	0	2	0	2	0	2	0	2		4	4	3	1	2	2
Water bodies		1	2	0	3	2	3	0	3	0	3	5		0	0	0	0	0	0	0	2	2	3	0	2	0	1		5	4	3	1	2	2
Coastal lagoons		1	1	0	2	1	3	0	4	0	3	5		0	0	0	0	0	0	0	2	2	2	0	0	0	0		3	4	3	0	1	2
Estuaries		1	0	0	2	3	3	0	3	0	3	5		0	0	0	0	0	0	0	2	2	2	0	0	0	0		3	4	3	0	1	2
Sea and ocean		2	3	0	1	1	3	0	0	0	3	5		0	1	1	0	0	0	0	3	2	3	2	0	1	1		4	5	3	1	2	2

*abiotic outputs from natural systems (after CICES)

Figure 5: Exemplary ecosystem service flow matrix. The exemplary evaluation refers to a hypothetical European „normal“ landscape in summer (before the harvest period). Scale from 0/rosy = no relevant flow; 1/grey green = low relevant flow; 2/light green = relevant flow; 3/yellow green = medium relevant flow; 4/blue green = high relevant flow; and 5/dark green = very high (maximum) relevant flow (after Burkhard et al. 2009 and 2012).

The ecosystem service flow matrix (Figure 5) clearly shows that most provisioning ecosystem service potentials (as indicated in Figure 4) have not been harvested yet (evaluation time was set to be summer, before the harvest period). In this case, differences between potentials and flows become especially clear. For regulating ecosystem services, values for several service flows in agricultural systems (agro-ecosystems) and urban systems were higher compared to earlier matrix values (in Burkhard et al. 2012a and 2009). This is because, according to the ecosystem service definition in Box 1, additional inputs have been included to better reflect conditions and flows in real agro-ecosystems. This can lead to higher *de facto* used ecosystem service flows (based on additional system inputs) compared to naturally available ecosystem service potentials. However, the differentiation between purely natural and anthropogenic inputs remains complex in many cases.

The most extreme cases of human-dominated 'landscapes' are urban (eco)systems. Many studies on urban ecosystem services have been carried out recently (Larondelle & Haase 2013; Elmqvist et al. 2013; Bastian et al. 2012). The dependence of urban areas on surrounding rural regions for decoupled or directional supply of almost all regulating and provisioning ecosystem services was shown by Kroll et al. (2012) and is clearly reflected in Figure 5. Regarding cultural ecosystem services, most of the potentials were fully used during the summer period.

4.3 Ecosystem service flow/potential comparison matrix

The comparison of ecosystem service potentials versus ecosystem service flows shows clear differences that are subject to seasonal influences mainly related to time-delayed growing/harvest periods. This becomes obvious especially for agricultural provisioning ecosystem services. Other provisioning ecosystem service potentials, such as fish stocks or forest stands, will (by management intention) not be depleted to their full extent. Comparisons between potentials and flows can deliver important information for sustainable resource management (Villamagna et al. 2013) or nature protection. Data on areas where ecosystem service potentials significantly exceed actual flows should not be abused however, for further environmental exploitation or identification of areas for increasing human activities.

For most of the regulating ecosystem services, a coherent distinction between potential and flow is difficult (see Chapter 3.1), resulting in similar potential and flow scores (0-values in Figure 6). For pollination, water flow and nutrient regulation in agricultural systems, actual flows exceed potentials significantly. Here, additional service flows have been added to the system in the form of omni-directional pollination supply, added irrigation water or fertiliser application. Pollination supply flows (and demands) would be higher for several land cover types and plants during the blooming period. However, a summer period was assessed in the matrices, which means lower pollination service flows compared to earlier periods of the year. Cultural ecosystem services show a more or less balanced pattern with some exceptions where potentials have not fully been harnessed in summer. This was the case in urban areas or in cases related to cultural heritage and cultural diversity linked for example to traditional forms of land use.

	Regulating services	Global climate regulation	Local climate regulation	Air quality regulation	Water flow regulation	Water purification	Nutrient regulation	Erosion regulation	Natural hazard regulation	Pollination	Pest and disease control	Regulation of waste	Provisioning services	Crops	Biomass for energy	Fodder	Livestock (domestic)	Fibre	Timber	Wood Fuel	Fish, seafood & edible algae	Aquaculture	Wild foods & resources	Biochemicals & medicine	Freshwater	Mineral resources*	Abiotic energy sources*	Cultural services	Recreation & tourism	Landscape aesthetics & inspiration	Knowledge systems	Religious & spiritual experience	Cultural heritage & cultural diversity	Natural heritage & natural diversity
Continuous urban fabric		0	0	0	0	0	0	0	0	-1	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	1	0	0	0	0
Discontinuous urban fabric		0	0	0	0	0	0	0	0	-1	0	0		1	0	-1	0	0	0	0	0	0	0	0	0	0	0		1	1	0	0	0	0
Industrial or commercial units		0	0	0	0	0	0	0	0	-1	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Road and rail networks		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Port areas		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Airports		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Mineral extraction sites		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	2	2		0	0	1	0	1	0
Dump sites		0	0	0	0	0	0	0	0	0	0	0		0	1	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Construction sites		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	1	0
Green urban areas		0	0	0	0	0	0	0	0	0	0	0		0	0	-1	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Sport and leisure facilities		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	0	0	0	0	0
Non-irrigated arable land		0	0	0	0	0	-2	0	0	-2	0	0		5	5	5	0	5	0	0	0	0	1	3	0	0	2		0	0	1	0	2	0
Permanently irrigated land		0	0	0	-2	0	-2	0	0	-2	0	0		5	1	2	0	4	0	0	0	0	1	3	0	0	1		0	0	1	0	2	0
Ricefields		0	0	0	-3	0	-2	0	0	0	0	0		5	1	2	0	0	0	0	0	0	0	0	0	0	0		0	0	1	0	1	0
Vineyards		0	0	0	0	0	0	0	0	-1	0	0		4	1	0	0	0	0	1	0	0	0	0	0	0	0		1	1	1	0	1	0
Fruit trees and berries		0	0	0	0	0	0	0	0	2	0	0		4	1	0	0	0	2	2	0	0	0	2	0	0	0		1	1	1	0	1	0
Olive groves		0	0	0	0	0	0	0	0	-1	0	0		4	1	0	0	0	2	2	0	0	0	2	0	0	0		0	0	0	0	1	0
Pastures		1	0	0	0	0	0	0	0	-1	0	0		0	1	1	3	0	0	0	0	0	2	0	0	0	5		0	0	0	0	1	0
Annual and permanent crops		0	0	0	-1	0	-1	0	0	-1	0	0		4	2	4	1	5	0	0	0	0	1	1	0	0	2		0	0	1	0	1	0
Complex cultivation patterns		0	0	0	-1	0	-1	0	0	-1	0	0		4	2	1	1	4	0	1	0	0	1	1	0	0	1		0	0	1	0	1	0
Agriculture & natural vegetation		1	0	0	0	1	0	0	0	0	0	0		3	3	1	2	3	1	0	0	0	2	0	0	0	0		0	0	1	0	1	2
Agro-forestry areas		1	0	0	0	1	1	0	0	1	0	0		2	3	2	2	1	2	2	0	0	2	0	0	0	0		0	0	1	0	1	1
Broad-leaved forest		1	0	0	0	1	0	0	1	3	0	0		0	0	0	0	0	4	4	0	0	4	2	0	0	0		1	1	1	1	2	1
Coniferous forest		1	0	0	0	1	0	0	1	3	0	0		0	0	0	0	0	4	4	0	0	4	2	0	0	0		1	1	1	1	2	1
Mixed forest		1	0	0	0	1	0	0	1	3	0	0		0	0	0	0	1	4	4	0	0	4	2	0	0	0		1	1	1	1	2	1
Natural grassland		3	0	0	0	0	0	0	0	-1	0	0		0	1	0	2	0	0	0	0	0	4	0	0	0	2		0	0	1	0	1	1
Moors and heathland		1	0	0	0	0	0	0	0	0	0	0		0	0	0	1	0	0	1	0	0	1	0	0	0	0		1	0	1	0	1	1
Sclerophyllous vegetation		1	0	0	0	0	0	0	0	1	0	0		0	1	0	1	1	1	1	0	0	0	3	0	0	1		0	0	0	0	1	1
Transitional woodland shrub		1	0	0	0	0	0	0	0	1	0	0		0	1	0	1	0	0	1	0	0	0	0	0	0	1		0	0	0	0	1	1
Beaches, dunes and sand plains		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	1	0		0	0	0	0	2	1
Bare rock		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	1	0		0	0	0	1	1	0
Sparsely vegetated areas		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	1	0	0	0	2		0	0	1	0	1	0
Burnt areas		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Glaciers and perpetual snow		0	0	0	2	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	4	0	0		3	1	1	0	0	0
Inland marshes		0	0	0	1	0	0	0	0	0	0	0		0	0	2	1	0	0	0	0	0	1	0	0	0	0		0	0	0	0	1	1
Peatbogs		1	0	0	1	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	1	1	1	0	0		0	0	0	0	1	1
Salt marshes		1	0	0	0	0	0	0	0	0	0	0		0	0	0	1	0	0	0	0	0	1	0	0	0	0		0	0	0	0	1	1
Salines		0	1	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	1	0
Intertidal flats		0	0	0	0	0	0	0	0	0	0	0		0	1	0	0	0	0	0	0	0	1	0	0	0	0		0	0	0	0	1	1
Water courses		0	0	0	0	0	0	0	0	0	0	0		0	2	0	0	0	0	0	1	0	2	0	3	0	1		0	0	1	1	1	1
Water bodies		0	0	0	2	0	0	0	0	0	0	0		0	1	0	0	0	0	0	2	3	1	0	3	0	0		0	0	1	1	1	1
Coastal lagoons		0	0	0	2	1	0	0	0	0	0	0		0	1	0	0	0	0	0	2	3	2	1	0	0	0		0	0	1	0	1	1
Estuaries		0	0	0	1	0	0	0	0	0	0	0		0	2	0	0	0	0	0	2	3	2	1	0	0	1		0	0	1	0	1	1
Sea and ocean		1	0	0	0	1	0	0	0	0	0	0		0	3	2	0	0	0	0	2	3	1	1	0	0	2		0	0	2	1	1	1

*abiotic outputs from natural systems (after CICES)

Figure 6: Exemplary ecosystem service potential - flow comparison matrix. The evaluations' (from Figures 4 and 5) comparison refers to a hypothetical European „normal“ landscape in summer (before the harvest period). Scale from −5/brown red = flow (actual use) exceeds potential (potential supply) significantly; via 0/rosy = flow = potential; to 5/dark green = potential exceeds flow significantly.

4.4 Ecosystem service demand matrix

Demand calculations are mainly based on population numbers and average consumption patterns but also on land use activities and on their demands for certain services (Kroll et al. 2012; Burkhard et al. 2012a). For example, all agricultural activities show high demands for whole bundles of regulating ecosystem services (Figure 7). If they cannot be fulfilled by the ecosystem service potentials, additional inputs (as mentioned before) come into play, increasing ecosystem service flows in order to meet increased demands. This differentiation between natural functions, additional inputs, as well as between service flows and demands in the case of specific land use forms is complicated and no satisfying solution has been found yet.

The ecosystem service demand matrix (Figure 7) clearly illustrates that land cover types with the highest population numbers and high human activities (uppermost parts of the matrix) have the highest demands for multiple ecosystem services. More near-natural land cover types show much lower or no relevant demands for ecosystem services because normally less people are present there.

4.5 Ecosystem service flow and demand budget matrix

Figure 8 shows the comparison between ecosystem service flows (as evaluated in Figure 5) in relation to demands for ecosystem services (Figure 7). The compared entities need to be quantified in the same units or need to be normalised into the relative 0–5 scale (Burkhard et al. 2012a). Figure 8 shows an obvious undersupply of ecosystem services in the human-dominated land cover types (upper part of the matrix), whereas several of the more near-natural land cover types show ecosystem services oversupply. For a more detailed description of the method and exemplary applications see Kroll et al. (2012); Nedkov & Burkhard (2012); Burkhard et al. (2012a).

With regard to environmental management and related land use decisions, regional budgets for individual ecosystem service flows and demands do not necessarily need to be neutral (0-values in Figure 8). Some ecosystem services with decoupled supply patterns may be better and more sustainably provided by other regions. It is one task of future-oriented environmental management to optimise land use decisions toward sustainability based on ecosystem services. However, global supply-demand budgets have to be zero in the long-term if sustainable management is to be achieved and a depletion of natural capital is to be avoided.

A matrix comparing ecosystem service potentials with actual demands could easily be estimated using the same approach. However, exposing ecosystem service potentials directly related to human demands holds the risk of being abused for further exploitation of natural resources. Particularly spatial designation of ecosystem service potentials in maps can foster further or new land conversions towards more intensive forms of land use or even support land-grabbing activities. Therefore, information on ecosystem service supply has to be prepared and documented carefully and has to fulfil certain criteria for end-use.

	Regulating services	Global climate regulation	Local climate regulation	Air quality regulation	Water flow regulation	Water purification	Nutrient regulation	Erosion regulation	Natural hazard regulation	Pollination	Pest and disease control	Regulation of waste	Provisioning services	Crops	Biomass for energy	Fodder	Livestock (domestic)	Fibre	Timber	Wood Fuel	Fish, seafood & edible algae	Aquaculture	Wild foods & resources	Biochemicals & medicine	Freshwater	Mineral resources*	Abiotic energy sources*	Cultural services	Recreation & tourism	Landscape aesthetics & inspiration	Knowledge systems	Religious & spiritual experience	Cultural heritage & cultural diversity	Natural heritage & natural diversity
Continuous urban fabric		4	5	5	4	5	1	1	5	1	5	3		5	5	1	5	3	3	1	5	5	5	5	5	4	2		4	4	3	4	4	4
Discontinuous urban fabric		3	5	5	5	4	2	1	4	2	4	2		4	4	2	4	3	3	1	4	4	4	5	5	3	3		4	4	3	3	2	3
Industrial or commercial units		5	2	5	4	5	3	1	5	1	3	4		3	5	1	3	5	5	4	4	4	4	5	5	5	5		1	1	4	1	3	1
Road and rail networks		4	2	4	4	0	0	3	4	0	2	1		1	4	0	1	0	2	0	0	0	0	0	1	2	0		2	2	1	1	1	0
Port areas		3	2	2	5	3	0	4	5	0	5	2		1	5	0	1	2	5	2	2	2	1	1	3	3	1		2	2	2	1	2	0
Airports		5	2	4	1	2	1	1	5	0	5	1		1	5	0	1	1	1	0	1	1	1	1	3	2	1		1	1	1	1	1	0
Mineral extraction sites		1	0	0	2	4	0	4	3	0	0	3		0	3	0	0	1	2	0	0	0	0	0	2	1	0		0	0	0	0	0	0
Dump sites		2	2	2	0	3	0	0	5	0	4	5		0	1	0	0	0	0	0	0	0	0	0	2	0	0		0	0	0	0	0	0
Construction sites		1	2	1	2	2	2	2	3	0	1	2		0	4	0	0	4	4	0	0	0	0	0	2	4	1		0	0	0	0	0	0
Green urban areas		0	3	2	2	0	0	0	2	2	3	1		0	1	0	1	0	0	0	0	0	0	0	2	0	0		4	4	2	0	2	1
Sport and leisure facilities		0	3	3	1	1	0	0	3	0	3	1		0	1	1	1	1	1	0	2	2	2	3	3	1	1		3	3	1	0	2	0
Non-irrigated arable land		2	2	1	2	0	3	3	2	3	4	3		0	1	0	0	0	0	0	0	0	0	1	0	0	0		0	0	1	0	1	0
Permanently irrigated land		2	2	1	2	5	3	2	2	3	4	3		0	1	0	0	0	0	0	0	0	0	1	5	0	0		0	0	1	0	1	0
Ricefields		3	2	1	5	5	3	2	2	1	4	3		0	1	0	0	0	0	0	0	0	0	1	5	0	0		0	0	2	0	3	0
Vineyards		1	3	1	1	4	3	5	3	2	4	2		0	1	0	0	0	1	0	0	0	0	2	4	0	0		0	0	2	0	3	0
Fruit trees and berries		1	2	1	1	2	3	1	3	3	4	2		0	1	0	0	0	1	0	0	0	0	2	3	0	0		0	0	2	0	2	0
Olive groves		1	2	1	1	2	3	1	3	2	4	2		0	1	0	0	0	0	0	0	0	0	2	1	0	0		0	0	2	0	2	0
Pastures		3	1	1	1	2	3	1	2	1	4	4		0	1	5	0	0	1	0	0	0	0	1	2	0	0		0	0	1	0	1	0
Annual and permanent crops		1	1	1	1	2	5	1	3	2	3	2		0	1	0	0	0	0	0	0	0	0	1	1	0	0		0	0	1	0	1	0
Complex cultivation patterns		1	1	1	1	2	5	1	2	3	3	2		0	1	0	0	0	0	0	0	0	0	1	1	0	0		0	0	1	0	1	0
Agriculture & natural vegetation		1	1	1	1	2	3	1	1	2	3	2		0	1	0	0	0	0	0	0	0	0	1	2	0	0		0	0	1	0	1	0
Agro-forestry areas		1	1	1	1	2	3	1	2	2	3	2		0	1	0	0	0	0	0	0	0	0	1	2	0	0		0	0	1	0	1	0
Broad-leaved forest		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Coniferous forest		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Mixed forest		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Natural grassland		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Moors and heathland		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Sclerophyllous vegetation		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Transitional woodland shrub		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Beaches, dunes and sand plains		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	0	0	0	0	0
Bare rock		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Sparsely vegetated areas		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Burnt areas		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Glaciers and perpetual snow		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Inland marshes		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Peatbogs		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Salt marshes		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Salines		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Intertidal flats		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Water courses		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Water bodies		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Coastal lagoons		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Estuaries		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Sea and ocean		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0

*abiotic outputs from natural systems (after CICES)

Figure 7: Exemplary ecosystem service matrix showing demands for ecosystem services within different land cover classes. The exemplary evaluation refers to a hypothetical European „normal“ landscape in summer (before the harvest period). Scale from: 0/rosy = no relevant demand; 1/dark rosy = low relevant demand; 2/light red = relevant demand; 3/red = medium relevant demand; 4/dark red = high relevant demand; and 5/brown red = very high relevant demand (after Burkhard et al. 2012).

	Regulating services	Global climate regulation	Local climate regulation	Air quality regulation	Water flow regulation	Water purification	Nutrient regulation	Erosion regulation	Natural hazard regulation	Pollination	Pest and disease control	Regulation of waste	**Provisioning services**	Crops	Biomass for energy	Fodder	Livestock (domestic)	Fibre	Timber	Wood Fuel	Fish, seafood & edible algae	Aquaculture	Wild foods & resources	Biochemicals & medicine	Freshwater	Mineral resources*	Abiotic energy sources*	**Cultural services**	Recreation & tourism	Landscape aesthetics & inspiration	Knowledge systems	Religious & spiritual experience	Cultural heritage & cultural diversity	Natural heritage & natural diversity
Continuous urban fabric		-4	-5	-5	-4	-5	-1	1	-5	0	-4	-3		-5	-5	-1	-5	-3	-3	-1	-5	-5	-5	-5	-5	-4	-2		-1	-2	-1	-2	-3	-4
Discontinuous urban fabric		-3	-5	-5	-5	-4	-2	0	-4	0	-3	-2		-4	-4	-1	-4	-3	-3	-1	-4	-4	-4	-5	-5	-3	-2		-2	-3	-1	-1	0	-3
Industrial or commercial units		-5	-2	-5	-4	-5	-3	1	-5	0	-2	-4		-3	-5	-1	-3	-5	-5	-4	-4	-4	-4	-5	-5	-5	-4		-1	-1	-4	-1	-1	-1
Road and rail networks		-4	-2	-4	-4		0	-2	-4		-2	-1		-1	-4		-1		-2						-1	-2			-2	-2	-1	-1	0	
Port areas		-3	-2	-2	-5	-3		-1	-2		-4	-2		-1	-5		-1	-2	-5	-2	-2	-2	-1	-1	-3	-3	-1		-1	0	-2	-1	-1	0
Airports		-5	-2	-4	-1	-2	-1	0	-5		-4	-1		-1	-5		-1	-1	-1		-1	-1	-1	-1	-3	-2	-1		-1	-1	-1	-1	-1	0
Mineral extraction sites		-1			-2	-4		-4	-3			-3			-3			-1	-2						-2	2	1				1			
Dump sites		-2	-2	-2		-3			-5		-4	-3			-1										-2									
Construction sites		-1	-2	-1	-2	-2	-2	-2	-3		-1	-2			-4			-4	-4						-2	-4	-1						1	
Green urban areas		2	-1	0	0	2	2	2	-1	0	-1	1			-1	1	-1								-2				-1	-1	-1		0	0
Sport and leisure facilities		1	-2	-2	0	0	1	1	-3		-2	0			-1	-1	-1	-1	-1		-2	-2	-2	-3	-3	-1	-1		1	-2	-1		-1	
Non-irrigated arable land		-1	0	0	0		0	-3	-1	0	-2	-1			-1									-1					1	1	0		0	
Permanently irrigated land		-1	1	0	1	-5	0	-2	-1	0	-2	-1			-1									-1	-5				1	1	0		0	
Ricefields		-3	0	0	-1	-5	0	-2	-2	0	-3	-1			-1									-1	-5				1	1	-1		-1	
Vineyards		0	-2	0	0	-4	-2	-4	-3	0	-3	-1			-1				-1					-2	-4				2	1	0		1	
Fruit trees and berries		1	0	1	1	-1	-1	1	-1	0	-1	0			-1				-1					-2	-3				2	1	-1		1	1
Olive groves		0	-1	0	0	-1	-2	0	-3	0	-2	0			-1									-2	-1				2	2	0		1	
Pastures		-2		-1	0	-2	-2	0	-1	0	-2	0			-1	-1	2		-1					-1	-2				2	2	1		1	1
Annual and permanent crops		0	1	0	1	-2	-3	1	-2	0	-1	0			-1									-1	-1				1	1	0		1	
Complex cultivation patterns		0	1	0	1	-2	-3	0	-1	0	0	0			-1	1								0	-1				2	2	0		1	
Agriculture & natural vegetation		0	2	1	1	-1	-1	1	0	0	0	0			-1	1		1		1				0	-2		1		2	2	1	1	1	1
Agro-forestry areas		0	1	1	1	-1	-2	2	-1	0	0	1			-1		1	1	1	1				0	-2				2	2	0		1	1
Broad-leaved forest		4	5	5	3	4	5	5	3	1	4	4			1	1		1	1	1			1	1					4	4	4	2	2	4
Coniferous forest		4	5	5	3	4	5	5	3	1	4	4			1	1		1	1	1			1	1					4	4	4	2	2	3
Mixed forest		4	5	5	3	4	5	5	3	1	5	5			1	1		1	1	1			1	1					4	4	4	2	2	4
Natural grassland		2	2		1	3	4	5	1	2	1	2				2	1						1	1					3	4	4	1	2	2
Moors and heathland		2	4		2	4	3	2	2	2	2	3			1	1				1			1	1					3	4	4	1	1	3
Sclerophyllous vegetation		1	2	1	1	1	2	1	1	1	2	3				1			1	1			1						2	3	4	1	1	3
Transitional woodland shrub		1	2	1	1	1	2	1	1	1	2	3			1	1		1	1	1			1	1					2	3	4	1	1	1
Beaches, dunes and sand plains					1	1	1		5		1	1												1					4	4	4	1	1	1
Bare rock						1		2	1																				2	3	3	1	1	1
Sparsely vegetated areas			1		1	1	1	1	1		1	1					1												1	1	2		1	1
Burnt areas			1				1					1																			2			
Glaciers and perpetual snow		3	4		3						1	1													1				2	4	3			1
Inland marshes		2	2		2	2	4	1	4	1	2	3				2	1												1	2	3		1	1
Peatbogs		4	4		3	4	4	2	3	2	3	4			2									1					3	2	3		1	3
Salt marshes			1		1	1	2	1	4	1	2	2				2	1												3	2	3		1	1
Salines			2								1	1												2		2			2	2	3		3	
Intertidal flats		1	3		1	1	1	1	5		2	3																	4	2	3		1	1
Water courses		1	1		3	3	3		3		3	5									2		2		2		2		4	4	3	1	2	2
Water bodies		1	2		3	2	3		3		3	5									2	2	3		2		1		5	4	3	1	2	2
Coastal lagoons		1	1		2	1	3		4		3	5									2	2	2						3	4	3		1	2
Estuaries		1			2	3	3		3		3	5									2	2	2						3	4	3		1	2
Sea and ocean		2	3		1	1	3				3	5			1	1					3	2	3	2		1	1		4	5	3	1	2	2

*abiotic outputs from natural systems (after CICES)

Figure 8: Exemplary ecosystem service flow - demand budget matrix. The exemplary evaluation refers to a hypothetical European „normal“ landscape in summer (before the harvest period). Scale from −5/brown red = demand exceeds flow significantly = strong undersupply; via 0/rosy = demand = flow = neutral balance; to 5/dark green = flow exceeds the demand significantly = strong oversupply. Empty fields = neither a relevant flow of nor a relevant demand for the particular ecosystem service (after Burkhard et al. 2012).

5 Discussion

5.1 Potentials, flows, demands and their localization, indication and quantification

Ecosystem service flow evaluations (as defined here) are more closely linked to actual flows of goods and services. Therefore, the information they provide can be better connected to demands for ecosystem goods and services and related trade-off assessments. This is where added values for current environmental management and landscape planning can be found. Until now, most landscape planning approaches mainly consider landscape functions without sufficiently and spatially explicitly integrating demands for goods and services (de Groot et al. 2010). The opportunity and technology to provide spatially explicit ecosystem service evaluations and supply-demand budgets on different scales has the potential to make ecosystem services a focal tool for environmental management.

More elaborated analyses of demand localisations and demand flows as well as quantification examples are essential next steps in spatially connecting ecosystem service potentials, flows and demands. Improvement of ecosystem service demand indicators is needed to distinguish between consuming motivations, consumption rates and actual needs. A distinction between demand potentials versus demand flows is conceivable here. A better consideration of ecosystem service flows from remote regions, for example by integrating ecosystem service or ecological footprint calculations, life cycle analyses or supply chain analysis, are important further steps for the integration of the concept into decision-making and environmental management in broader contexts and on larger scales. The distinction of ecosystem service potentials, flows and demands is especially difficult for regulating ecosystem services. This dilemma became apparent when deriving the exemplary indicators (shown in Table 1) and assigning the ecosystem service matrix scores. A stronger integration of regulating ecosystem services by more detailed analyses of actual ecosystem service 'production', interrelations and societal needs (demand) is required. This includes interpretations of legal and administrative constraints. Until now, no direct demands from human societies could be indicated for most of the regulating ecosystem services.

5.2 The ecosystem service matrix concept

Applications of the approach in case studies and related ecosystem service map compilations delivered expressive results (e.g. Kandziora et al. 2013b; Nedkov and Burkhard 2012; Vihervaara et al. 2010). The matrices presented in this article show clear patterns when applying a land cover-based evaluation of ecosystem service potentials, flows and demands. The quality and depth of such analyses are of course strongly dependent on the quality and suitability of the data and information used. An accounting concept on a relative normalised scale (like the 0-5 scale applied here) can be used as representative for any appropriate quantification unit such as GJ, tons, currency units, species numbers, NPP, °C, turnover rates, availabilities or abundances.

Concerning the score estimation patterns, the ecosystem service potential and flow matrices of regulating services show considerable similarities with high scores from more nature-near land cover types and low scores from more human-influenced or inhabited land cover types. This phenomenon also applies to most cultural ecosystem services, except to those generated by urban areas. Urban areas can provide high recreation and tourism services as well as knowledge and religious experiences. Nevertheless, the two matrices in Figures 4 and 5 show notably different score patterns for provisioning ecosystem services provided by agricultural and more natural lands, as the estimation time was set to summer before the harvest period. This setting led to a high potential surplus for most agricultural products in the ecosystem service potential - flow comparison matrix (Figure 6). The differences between the potential and flow matrices reveal the importance of defining an appropriate point in time to assess ecosystem service flows. With respect to the ecosystem service demand matrix (Figure 7), a generally opposing pattern to the potential matrix can be observed. In other words, greater demands come from more human-inhabited land cover types (mainly in the upper part of the matrix) with more natural land covers showing negligible demands.

The ecosystem service flow - demand budget matrix (Figure 8) shows significant spatial mismatches between ecosystem service flows and demands, especially between urbanised areas and non-urban regions (as shown in Radford & James 2013; Kroll et al. 2012).

However, the notion of relevant supply or demand introduces uncertainty into the method because 'relevant' can be interpreted differently. Moreover, appropriate reference values to calibrate the assessed values in space and time need to be defined. What if, for example, today's assessed maximum relevant ecosystem service supply (assessed with 5) is not the maximum anymore in a future state and theoretically a higher class (6) needs to be introduced? We recommend using an adaptive approach, where the maximum values are always in class 5. This means that the classification may need to be adapted if values show an increase or decrease or if different regions are to be compared with each other. For comparison and budget estimations of ecosystem service potentials, flows and demands, all 0-5 normalisations should preferably be based on the same quantification units and dimensions to make the values better comparable.

The integration of temporal supply and demand dynamics (seasonal aspects, medium- and long-term dynamics, "hot moments") is important in the assessment of certain ecosystem services as their potentials, flows and demands can vary significantly through time, especially in regions with distinct seasonal fluctuations. For other ecosystem services, average annual values may provide sufficient information. In case of the matrix method, the third dimension Z (time) (see Figure 9) should be included and a clearly defined temporal assessment scale (cp. summer period before harvest as in Figures 3-8) is inevitable for a successful application of the approach.

Furthermore, the cross-comparisons of ecosystem service assessment values need to be improved: a) vertically within ecosystem service categories and across different spatial units (e.g. land cover types; comparisons are relatively reliable), and b) horizontally within individual spatial units across different ecosystem services (comparisons still need to be improved; see horizontal and vertical arrows in Figure 9). The values shown in the different matrices here are meant to explain the method and to demonstrate its application potential. The proper quantification and testing of the values should be done within distinct case studies. The results will feed back into the refinement of the method.

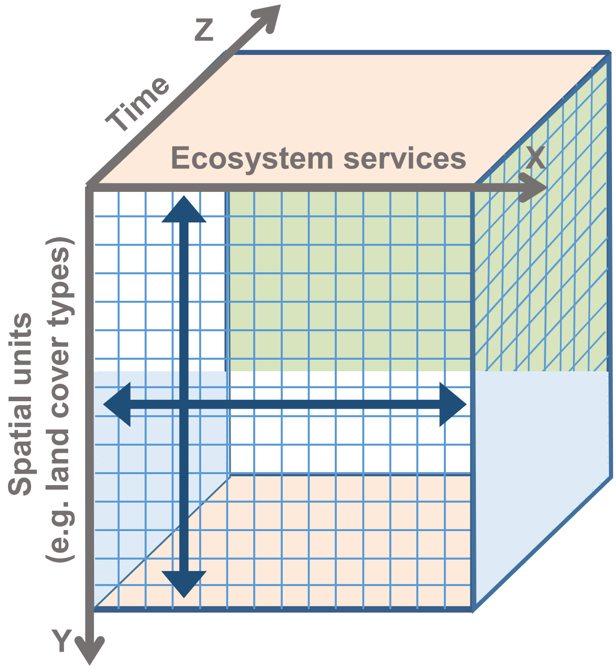

Figure 9: Integration of temporal aspects into the matrix by including a third dimension (3D-Matrix) and horizontal (within spatial units) as well as vertical (within ecosystem service types) cross-comparisons of assessment values.

Most of the evaluation values in the matrices presented here are based on expert opinions. The integration and combination of more comprehensive quantification methods (models, measurements, statistics, surveys) will improve the reliability of evaluation values for the different classes. Moreover, land cover is only one aspect of ecosystems, and therefore only a proxy indicator. Further integration of geobiophysical (biotic, abiotic), land use (intensity) and socio-economic data for quantification and localization will foster a more comprehensive assessment. Uncertainty analyses of evaluation methods and results are required as further important steps in the matrix assessment method.

6 Conclusions

Summing up the questions raised in the introduction, we can conclude that a distinction between ecosystem service potentials, flows and demands is needed and practical for the integration of this concept into research, decision making and environmental management. Appropriate indicators for service potentials, flows and demands were proposed, which need to be applied and further developed in case studies. The indicators presented here are examples and further ones should be added to the tables. Ecosystem service indicators have to reflect case study peculiarities and are depending on specific research/management questions. The demand for ecosystem services is considered to be best localized in the areas where people live and spend most of their time. However, additional development is needed in the conceptualisation of ecosystem service demand but also for supply assessments, especially with regard to regulating ecosystem services.

Information on ecosystem service potentials should be used to assess future options for long-term landscape planning and environmental management in terms of sustainable flows of ecosystem services. Ecosystem service maps are useful for sustainable decision making, for example by identifying supply-demand mismatches across landscapes and their changes over time. They should not be used to enhance human exploitation of natural resources. Therefore, appropriate institutions to sustainably manage ecosystem services on spatial and temporal scales that match the scales of the service supply and demand should be established.

The concepts, indicators and exemplary evaluated numbers provided here are open for discussion. We hope to stimulate scientific debate in these highly relevant and dynamic research topics. We are looking forward to future discussions in order to jointly improve concepts and methods for ecosystem service assessments to be used for sustainable environmental management. Better linkages between knowledge and method providers and end-users in science, decision and policy making must be established.

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Table 1: Regulating ecosystem services: definitions, service potential (stock) indicators, service flow indicators, demand indicators, exemplary service providing units (hotspots) and service benefitting areas, suggested spatial and temporal assessment scales (based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010).

Regulating ecosystem service	**Definition**	Exemplary **Service potential indicators**	Exemplary **Service flow indicators**	Exemplary **Demand indicators***	Exemplary **Service providing units (SPU)** (hotspots)	Exemplary **Service benefitting areas (SBA)**	**SPU - SBA spatial relations**	**Rival**	**Spatial assessment scale**	**Temporal scale** (hot moments)
Global climate regulation	Long-term storage of potential greenhouse gases in ecosystems.	Amount of methane, carbon dioxide and water vapour stored in vegetation, soils and marine systems (t C/ha)	Amount of methane, carbon dioxide and water vapour taken up by vegetation, soils and marine systems (t CO_2/ha per year)	Greenhouse gas emissions by industry, traffic, households (t CO_2/ha per year)	Soils, forests (standing biomass), peatlands, oceans	The world, climate change-affected regions, agriculture	In situ, omni-directional	Yes	Global, continental	Long-term
Local climate regulation	Changes in local climate components like wind, precipitation, temperature, radiation due to ecosystem properties.	Temperature (°C); albedo (%); precipitation (mm); wind (Bft); evapotranspiration (mm); shaded areas (ha; %)	Temperature amplitudes (K); precipitation, wind or evapotranspiration deviation from surrounding areas (%)	Excess heat, rain or storm performance (°C, mm. Bft) or periods (d/a); Air conditioning use (kWh/a)	Forests, wetlands, lakes, oceans, (urban) green areas, air-circulation corridors	Residential and recreation areas	In situ, omni-directional, directional	No	Local, regional	Medium-term, annual, seasonal
Air quality regulation	Capturing/filtering of dust, chemicals and gases from air.	Leaf area index, difference between open land and throughfall deposition (kg/ha); immission concentrations (ppm)	Aerosols or pollutants removed (kg/ha per year); air quality standards amplitudes (ppb)	Level of pollutants in the air (ppb); air quality standards deviation (ppb); critical loads exceedance (kg/ha per year)	Woods, hedges, green areas	Residential and recreation areas	In situ, omni-directional, directional	No	Local, regional	Medium-term, annual, seasonal
Water flow regulation	Water cycle feature maintenance (e.g. water storage and buffer, natural drainage, irrigation and drought prevention).	Water storage capacity (m^3/ha); groundwater recharge rate (mm/ha per year)	Water released for hydrological process use, e.g. plant or animal uptake, soil processes (m^3/ha per year); available water con-tent (v%);amount of excess water (m^3/ha per year)	Periods at permanent wilting point (d/a); soil field capacity (v%); periods of excess water or floods (d/a)	Water bodies, wetlands, forests, glaciers	Agricultural areas, residential areas, industrial areas	In situ, omni-directional, directional	Yes (agri-culture) No (floods)	Regional	Medium-term, annual, seasonal
Water purification	Ecosystem ability to purify water, e.g. from sediments, pollutants, nutrients, pesticides, disease-causing microbes and pathogens.	Water quality indicators: sediment load (g/l); total dissolved solids (mg/l)	Elements removed from water (kg/m^3 per year); water quality standards amplitudes (ppb; mg/l)	Level of pollutants in the water (ppb); water quality standard deviation (ppb; mg/l)	Water bodies, aquatic flora, riparian strips, filtrating soils, forests, wetlands, grasslands	Residential or recreation areas, agriculture, industry	In situ, omni-directional, directional	Yes	Local, regional, catchment	Medium-term, annual, seasonal
Nutrient regulation	Ecosystem ability to recycle nutrients, e.g. N, P.	Nutrient turnover rates of, e.g. N, P (y^{-1}); water quality indicators, e.g. N (mg/l), P (mg/l); electrical conductivity (µS/cm); total dissolved solids (mg/l); soil potentials (CEC; SOC; texture)	Nutrients available for plant uptake (kg/ha per year); amount of excess nutrients (kg/ha per year); nutrients filtered or adsorbed (kg/ha per year)	Periods of nutrient deficit or excess (d/a); fertilizer needs (kg/ha per year); periods of eutrophication (d/a)	Forests, grasslands, wetlands, marshes, water bodies, oceans	Agricultural areas, communities	In situ, omni-directional, directional	Yes	Local, regional, catchment	Medium-term, annual, seasonal
Erosion regulation	Soil retention and the ability to prevent and mitigate soil erosion and landslides.	Vegetation cover (%); loss of soil particles by water and wind (kg/ha per year); USLE factors for assessment of potential soil loss and landslide frequency (n/ha per year)	Amount of soil retained or sediment captured (kg/ha per year); amount of prevented erosion events (n/a)	Number of erosion events (n/ha per year); soil loss by erosion (kg/ha per year)	Forests, hedges, groves around and between acre fields, pastures, grasslands	Agricultural fields, infra-structure, residential areas	In situ, omni-directional, directional	No	Local, regional	Short-term (events), long-term (regulation)
Natural hazard protection	Protection and mitigation of floods, storms, fires and avalanches.	Water-storage potential (m^3/ha); natural barriers (dunes, mangroves, wetlands, coral reefs, forests) (%; m/ha; ha)	Number of prevented hazards (n/a); Prevented fatalities, damage to property or infrastructure (n/a; €/a)	Number of hazards and fatalities (n/a); damage costs (€/a)	Forests, mangroves, beaches, coral reefs, wetlands, water bodies	Built areas, land uses, infra-srtucture and industry within hazard-prone zones	In situ, omni-directional, directional	No	Local, regional	Short-term (events), long-term (regulation)
Pollination **	Bees, birds, bats, moths, flies, wind, non-flying animals contributing to pollen transfer and reproduction of plants.	Species numbers and amount of pollinators (n/ha); potential habitats for pollinators (ha/ha; %; n/ha)	Amount of pollinated plants (n/ha per year; %/a; kg/ha per year)	Amount of agricultural, garden or wild plants demanding pollination (n/ha per year; %/a; kg/ha per year)	Gardens, fruit and berry plantations, forests, wetlands, agricultural areas	Agricultural, garden and wild plant areas, fruit tree plantations, farmers	Omni-directional	No	Regional	Annual
Pest and disease control**	Ecosystem ability to control pests and diseases due to genetic variations of plants and animals making them less prone to diseases and actions of predators and parasites.	Populations of biological disease and pest control agents (n/ha); Potential habitats for control agents (ha/ha; %; n/ha)	Number of prevented pest and disease outbreaks or predator and parasite actions (n/ha per year; %/a)	Number of pest and disease outbreaks (n/ha per year); Plants and animals damaged (%/a; n/a); Yield losses (%/a; €/a)	Forests, wetlands, water bodies, gardens, agricultural areas	Com-munities, transport facilities, agricultural fields, farms, stables, crops, animals, farmers	In situ, omni-directional, directional	No	Local, regional	Annual, long-term
Regulation of waste**	Ecosystem ability to filter and decompose organic material in water and soils.	Amount and number of decomposers (n/ha); immobilization potential in plants and soils	Decomposition rate (kg/ha per year); Pollutants recycled or Immobilized (kg/ha per year)	Level of organic material in water and soils (ppb); environmental standards deviation(ppb)	Soils, forests, pastures, wetlands, water bodies, oceans	Com-munities, industry, dump sites, agriculture	In situ, omni-directional, directional	Yes	Local, regional	Annual, long-term

* Demand for regulating ecosystem services is problematic to indicate because direct ecosystem service-human benefit relations are often very complex. Indicators suggested here relate to relevant ecosystem states or regulating processes instead. The demand is mostly oriented toward a reduction of the indicator values or the indicating concentrations.

** For these ecosystem services a strong overlap with ecosystem functions and a high potential of double-counting must be noted.

Table 2: Provisioning ecosystem services: definitions, servicepotential (stock) indicators, service flow indicators, demand indicators, exemplary service providing units (hotspots) and service benefitting areas, suggested spatial and temporal assessment scales (based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010).

Provisioning ecosystem service	**Definition**	Exemplary **Service potential indicators**	Exemplary **Service flow indicators**	Exemplary **Demand indicators**	Exemplary **Service providing units (SPU)** (hotspots)	Exemplary **Service benefitting areas (SBA)**	**SPU - SBA spatial relations**	**Rival**	**Spatial assessment scale**	**Temporal scale** (hot moments)
Crops	Plants usable for human nutrition.	Standing stock +/or net primary production (t C/ha + t C/ha per year; kJ/ha + kJ/ha per year)	Harvested crops (t/ha per year, kJ/ha per year); Yield (€/ha per year)	Crop product consumption (kg/person per year; kJ/person per year)	Agricultural fields, gardens, fruit and berry plantations	Farms, food industry, communities, households	Decoupled	Yes	Regional, local	Annual, seasonal, short-term (harvest rhythm)
Biomass for energy	Plants usable for energy conversion (e.g. sugar cane, maize).	Standing stock +/or net primary production (t C/ha + t C/ha per year; kJ/ha + kJ/ha per year)	Harvested plants (t/ha per year, kJ/ha per year); Yield (€/ha per year)	Energy use based on biomass (kWh/person per year)	Agricultural fields, short rotation coppice, oceans	Farms, industry, communities, households	Decoupled	Yes	Regional, local	Annual
Fodder	Nutritional substances for domestic animals.	Standing stock +/or net primary production (t C/ha + t C/ha per year; kJ/ha + kJ/ha per year)	Fodder plant harvest (t/ha, kJ/ha per year); Yield (€/ha per year); Area used for harvesting fodder (ha)	Fodder use for domestic animals (kg/livestock per year)	Graslands, pastures, agroforestry, marshlands	Farms, stables, pastures	Decoupled	Yes	Regional, local	Annual
Livestock (domestic)	Domestic animals useable for nutrition and related products (dairy, wool).	Number of animals (n/ha; kJ/ha); Animal production (t C/ha per year; kJ/ha per year)	Respective animal products (t/ha per year); Yield (€/ha per year)	Meat consumption (kg/person per year); Related products consum-ption (kg/person per year)	Pastures, farms, stables, grassland, agroforestry	Farms, communities, households	Decoupled	Yes	Regional	Annual
Fibre	Natural fibre (e.g. cotton, jute sisal, silk, cellulose) usable for e.g. cloths, fabric, paper.	Biomass +/or growth of fibre (t/ha + t/ha per year)	Harvested fibre (t/ha per year; kJ/ha per year); Yield (€/ha per year)	Fibre use (t/region per year)	Agricultural fields, farms, natural vegetation	Farms, industry, construction, communities, households	Decoupled	Yes	Regional	Annual
Timber	Wood useable for human purposes (e.g. construction).	Standing stock +/or net primary production (t C/ha + t C/ha per year; kJ/ha + kJ/ha per year)	Harvested wood (solid m³/a; volume/a); Yield (€/ha per year)	Timber use (t/region per year)	Forests, silvicultural areas, fruit and berry plantations, agroforestry	Forester, sawmills, wood industry, construction, communities, households	Decoupled	Yes	Regional, local	Long-term
Wood fuel	Wood suitable for energy conversion and/or heat production.	Standing stock +/or net primary production (t C/ha + t C/ha per year; kJ/ha + kJ/ha per year)	Harvested wood fuel (m³/ha per year); Yield (€/ha per year)	Wood used as fuel (m³/person per year)	Forests, short rotation coppice, hedgerows, agroforestry	Forester, industry, communities, households	Decoupled	Yes	Regional, local	Medium-term
Fish, seafood and edible algae	Seafood, algae useable for food, fish meal and fish oil.	Fish stock +/or growth (t C/ha + t C/ha per year; kJ/ha + kJ/ha per year)	Caught fish/seafood/algae (t/ha per year, kJ/ha per year); Yield (€/ha per year)	Seafood/algae consumption (kg/person per year)	Water bodies and courses, coastal lagoons, oceans	Fishermen, food industry, communities, households	Decoupled	Yes	Regional, local	Medium-term
Aquaculture	Seafood/algae in marine and terrestrial aquaculture farms.	Animal stock +/or growth (t C/ha + t C/ha per year; kJ/ha + kJ/ha per year)	Harvest of seafood/algae (t/ha per year, kJ/ha per year); Yield (€/ha per year)	Aquaculture product consumption (kg/person per year)	Aquaculture farms, fish ponds, water bodies, rice fields, coastal lagoons, estuaries, oceans	Fish farmer, food industry, communities, households	Decoupled	Yes	Local	Medium-term, annual
Wild food, semi-domestic livestock and ornamental resources	Berries, mushrooms, (edible) plants, wild animals, fish and natural ornaments available for recreational fishing, hunting or collection; semi-domestic animal husbandry.	Amount of respective items available; stock +/or growth of respective wild species (n/ha; kg/ha; kg/ha + kg/ha per year; kJ/ha + kJ/ha per year)	Catch of fish; game taken (kg/ha per year); Harvested plant biomass (t C/ha per year); Yield (€/ha per year)	Wild food consumption (kg/person per year); Ornamental item sale (n/region per year); Business volumes (€/a)	Forests, grasslands, agricultural fields, water bodies and courses, mountains	Forester, hunter-gatherers, angler, herder, industry, communities	Decoupled	Yes	Local, regional	Annual
Biochemicals and medicine	Natural products useable as biochemicals, medicine and/or cosmetics.	Amount or number of substances useable for medicine, biochemical, cosmetics (kg/ha; n/ha); Stock +/or net primary production (t C/ha + t C/ha per year; kJ/ha + kJ/ha per year)	Yield of respective products (€/ha per year)	Substances used (kg/ha per year); Products sale (€/region per year)	Forests, gardens	Gatherer, gardener, pharmacy, beauty industry, consumer	Decoupled	Yes	Local, regional	Annual
Freshwater	Fresh and process water available for e.g. drinking, domestic use, industrial use, irrigation.	Fresh- and/or process water availability (l/ha per year; m³/ha per year); Total amount of water (m³/ha); Groundwater recharge rate (m³/ha)	Water withdrawal (l/region per year; m³/region per year)	Water use (l or m³ /person per year; l or m³/industrial sector per year)	Water reservoirs, water bodies and courses, glaciers, groundwater	Water supply companies, agriculture, industry, communities, households	In situ; directional; (decoupled)	Yes	Local, regional	Annual, medium-term
Mineral resources* **	Minerals extractable close from surface or above surface (e.g. sand for construction, lignite, gold, salts).	Minerals available for extraction (t/ha)	Excavated minerals (t/ha per year); Earnings (€/a)	Minerals used (t/person per year; t/industrial sector per year)	Coal beds, ore veins, moraines, eskers, sea bed, salines	Mining companies, industry, construction, communities, households	Decoupled	Yes	Local	Annual, long-term
Abiotic energy sources* **	Abiotic energy sources useable for conversion (e.g. solar, wind, water and geothermic power).	Areas and natural settings potentially suitable for energy conversion (ha/ha; n/ha; GW/ha)	Converted energy (kWh/ha per year); Produced electricity (kWh/ha per year); Yields (€/ha per year)	Energy use (kWh/person per year; kWh/industrial sector per year)	Open spaces on- and offshore, water bodies, geothermal fields	Wind or solar farmer, energy companies, communities, households	Decoupled (electricity); in-situ (water mill; geothermic)	No	Local, regional	Annual

*** Abiotic outputs from natural systems (after CICES); often not acknowledged as ecosystem services, but of high relevance for policy decisions and land use/resource management.

Table 3: Cultural ecosystem services: definitions, service potential (stock) indicators, service flow indicators, demand indicators, exemplary service providing units (hotspots) and service benefitting areas, suggested spatial and temporal assessment scales (based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010).

Cultural ecosystem service	**Definition**	Exemplary **Service potential indicators**	Exemplary **Service flow indicators**	Exemplary **Demand indicators**	Exemplary **Service providing units (SPU)** (hotspots)	Exemplary **Service benefitting areas (SBA)**	**SPU - SBA spatial relations**	**Rival**	**Spatial assessment scale**	**Temporal scale** (hot moments)
Recreation and tourism	Outdoor activities and tourism relating to the local environment or landscape, including forms of sports, leisure and outdoor pursuit.	Number of facilities (e.g. hotels, restaurants, hiking paths, parking lots; n/ha); Results from questionnaires on nature and leisure preferences (wildlife-viewing, hiking, fishing, sports)	Number of facility visitors (n/facility per year); Turnover from tourism (€/ha per year)	Results from question-naires on holiday plans and expectations	Forests, water bodies, beaches, mountains, urban green, gardens, leisure facilities	Touristic infrastructure, visitors, communities, households (at home location)	In situ, omni-directional, directional, decoupled	De-pen-ding on visitor car-rying capa-city	Local, regional	Seasonal, annual
Landscape aesthetic, amenity and inspiration	Visual quality of the landscape/ecosystems or parts of them influencing human well-being and the need to create something as well as the sense of beauty people obtain from looking at landscapes/ecosystems.	Evaluations from questionnaires; Scenic beauty estimation via landscape metrics	Number of paintings/illustrations, songs, products portraying the resp. landscape/ecosystem (n/landscape type); results of travel cost or willingness to pay estimations	Results from question-naires on landscape preferences and expectations	Viewsheds, seascapes, water bodies and courses, forests	Touristic infrastructure, trader, industry, visitors, communities, households (at home location)	In situ, omni-directional, directional, decoupled	No	Regional	Seasonal, annual
Knowledge systems	Environmental education based on ecosystems/landscapes and knowledge in terms of traditional knowledge and specialist expertise arising from living in this particular environment.	Number of environmental educational-related facilities (n/ha)	Number of environmental educational-related events and number of their users (n/a)	Requests for environment al education (n requests/a)	Geotopes, traditional land use systems, forests	Education facilities, research, industry, visitors, households (at home location)	In situ, decoupled	No	Regional - global	Medium-term, long-term
Religious and spiritual experience	Spiritual or emotional values that people or religions attach to local ecosystems or landscapes due to religious and/or spiritual experience.	Number of spiritual facilities or items (n/ha)	Number of visitors of spiritual facilities or items for performance of rituals and maintain the relationship with ancestors (n/facility per year)	Requests for religious and spiritual experience (n requests per year)	Forests, trees, water bodies, rocks, graveyards	Spiritual facilities, visitors, households (at home location)	In situ, decoupled	No	Regional	Seasonal, annual
Cultural heritage and cultural diversity	Values that humans place on the maintenance of historically important (cultural) landscapes and forms of land use (cultural heritage).	Areas and natural settings potentially suitable for traditional land use (ha/ha; n/ha); Results from question-naires on local people's personal preferences	Number of traditional land use forms (n/ha); Number of employees in traditional land use forms (n/ha)	Number of job appli-cations and trainees in traditional land use forms (n/a)	Agricultural fields, gardens, vineyards, terraced fields, hedgerows, silviculture, villages	Traditional land use regions, visitors, households (at home location)	In situ, decoupled	No	Local - Global	Long-term
Natural heritage and natural diversity	The existence value of nature and species themselves, beyond economic or direct human benefits.	Potential habitats for endangered, protected and/or rare species (n/ha)	Abundance of endangered, protected and/or rare species (n/ha)	Relevant guidelines for nature protection (n/ha)	Natural forests, peatlands, water bodies and courses, mountains	Nature itself, households (at home location)	In situ, decoupled	No	Regional - global	Long-term