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Landscapes‘ Capacities to Provide Ecosystem Services – a Concept for Land-Cover Based Assessments

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Abstract

Landscapes differ in their capacities to provide ecosystem goods and services, which are the benefits humans obtain from nature. Structures and functions of ecosystems needed to sustain the provision of ecosystem services are altered by various human activities. In this paper, a concept for the assessment of multiple ecosystem services is proposed as a basis for discussion and further development of a respective evaluation instrument. Using quantitative and qualitative assessment data in combination with land cover and land use information originated from remote sensing and GIS, impacts of human activities can be evaluated. The results reveal typical patterns of different ecosystems‘ capacities to provide ecosystem services. The proposed approach thus delivers useful integrative information for environmental management and landscape planning, aiming at a sustainable use of services provided by nature. The research concept and methodological framework presented here for discussion have initially been applied in different case studies and shall be developed further to provide a useful tool for the quantification and spatial modelling of multiple ecosystem services in different landscapes. An exemplary application of the approach dealing with food provision in the Halle-Leipzig region in Germany is presented. It shows typical patterns of ecosystem service distribution around urban areas. As the approach is new and still rather general, there is great potential for improvement, especially with regard to a data-based quantification of the numerous hypotheses, which were formulated as base for the assessment. Moreover, the integration of more detailed landscape information on different scales will be needed in future in order to take the heterogeneous distribution of landscape properties and values into account. Therefore, the purpose of this paper is to foster critical discussions on the methodological development presented here.

Keywords:

ecosystem integrity, ecosystem services, land use, Corine land cover, indicators

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1 Introduction

The ecosystem services concept is strongly based on the approach of de Groot's "Functions of Nature" (1992), which has predecessors in landscape ecology and planning. For example in the Eastern German landscape literature, landscape functions and landscape potentials have been an important item of research (see Haase & Mannsfeld 2002, Bastian & Steinhardt 2003, Bastian & Schreiber 1999). In the Western German area Marks et al. published their instructions for the evaluation of landscape system performances in 1992. In the global context, the contributions of Costanza et al. (1997) and Daily (1997) have been milestones in ecosystem services research. Nowadays, ecosystem services have become a very popular research theme and a conceptual framework for numerous research projects (e.g. the Millennium Ecosystem Assessment; MA 2003). The attractiveness of the approach most likely originates in its integrative character, which supports inter- and transdisciplinary research, linking environmental and socio-economic concepts (Müller & Burkhard 2007). Moreover, today's environmental and economic crises and upcoming problems related to environmental degradation and resource depletion make the necessity of new management tools obvious (Vandewalle et al. 2009, Rees 1998, Dailey et al. 2009). From a systems analytical point of view, the concept provides a systematic listing of the most important ecosystem components and processes and the dependence of human societies on them (de Groot 2006). Most studies carried out so far provide very appealing conceptual frameworks and interdisciplinary scientific methods.

However, one main obstacle seems to be the application of the ecosystem goods and services concept at the landscape level due to the lack of appropriate data for their quantification. Many studies are focussing on global assessments (Naidoo 2008, Costanza et al. 1997), which provide valuable information but are not directly applicable for regional or local decision making. A review of concepts of dynamic ecosystems and their services in the RUBICODE project showed, that most quantifications of ecosystem services are carried out with economic measures. Assessments in non-monetary terms are very few although standardised approaches to quantify ecosystem services are required (Vandewalle et al. 2009). As a suitable spatial reference RUBICODE explored the concept of Service Providing Units (SPUs) which are „the total collection of organisms and their trait attributes required to deliver a given ecosystem service at the level needed by service beneficiaries. The SPU must be quantified in terms of metrics such as abundance, phenology and distribution" (Vandewalle et al. 2009). This is an interesting approach as it divides (but also reduces) landscapes into service providers which might result in the derivation of new landscape classification units. A comparison of these service providing units with natural units or land cover units thus seems to be interesting.

The mapping of ecosystem services has been listed as one key element that is required in order to improve the recognition and implementation of ecosystem services into institutions and decision-making by Daily & Matson (2008). In recent years, many new mapping approaches of ecosystem services have been developed by various scientists (e.g. Tallis & Polasky 2009, Nelson et al. 2009, Egoh et al. 2008, Naidoo et al. 2008, Troy & Wilson 2006, Willemen et al. 2008). These approaches vary considerably in the scale and scope of the analysis as well as in the assessment method of ecosystem goods and services production. Reviewing these studies reveals the striking difficulty of combining spatial accuracy with comparability of different case studies. Following the first attempt of Costanza et al. (1997) to estimate and map the value of ecosystem services in monetary terms at global scale, Turner et al. (2007), Kreuter et al. (2001) and Troy & Wilson (2006) are using the same approach of value transfer in order to quantify and map the monetary value of ecosystem services at global or regional scales. The value or benefit transfer method, in which the valuation results of ecosystem services at one study site are transferred to others, has been criticised for neglecting spatial differences of habitat types (Tallis & Polasky 2009, Nelson et al. 2009). Other mapping attempts quantify a dif-

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ferent number of ecosystem services in biophysical units, without including monetary valuation. Naidoo et al. (2008) present a method for the global mapping and quantification of four ecosystem services in biophysical units and compare the service production with priority sites for biodiversity conservation. They restrict their analysis of ecosystem services quantification to four services because of the lack of available data at the global scale. Also Egoh et al. (2008) who conducted their study of mapping ecosystem services at the national scale for South Africa, concentrate on the biophysical quantification and assessment of spatial congruence and relationships of only five soil and water related ecosystem services. They identify areas of meaningful (ranges) and hotspot supply of each analysed ecosystem service and count the number of ranges and hotspots per catchment for the visualisation of the total service supply in their maps. Willemen et al. (2008) map and quantify the capacities of eight landscape functions to provide ecosystem services for the Gelderse Vallei in the Netherlands. The authors emphasise the biophysical variation of landscapes which leads to an uneven distribution of goods and services. Only parts of the landscape functions are directly observable from land cover data. Non-directly observable landscape functions necessitate the inclusion of field observations prior to extrapolating landscape functions from spatial indicators. For those landscape functions, Willemen et al. (2008) apply rules based on literature reviews as has been previously done by Haines-Young et al. (2006) and Gimona & van der Horst (2007). Recently, two ambitious projects emerged to further develop spatial explicit modeling and mapping of ecosystem services. The first is the MIMES approach (Multiscale Integrated Model of the Earth Systems' Ecological Services, www.uvm.edu/giee/mimes) which builds on the GUMBO model (Boumans et al. 2002) and aims at evaluating the effects of land use changes on ecosystem services on various scales by integrating participatory model building, data collection and valuation. This integrated model system is still under development. The second modeling tool, the Integrated Valuation of Ecosystem Services and Tradeoffs tool (InVEST) that has been developed by the Natural Capital Project (www.naturalcapitalproject.org) has already been described in published studies (Tallis & Polasky 2009, Nelson et al. 2009). So far, this tool, which aims at linking models of ecological production functions with economic valuation methods, includes a limited number of ecosystem services as well as terrestrial biodiversity.

Unlike InVEST, our approach aims at developing a more general methodology to evaluate capacities of different landscapes to provide ecosystem services. It does not focus on the economic evaluation of ecosystem services or environmental accounting (like e.g. Mäler et al. 2008, Boyd & Banzhaf 2006), whose pertinence is debated due to its economic terminology, its anthropocentric orientation and the underestimation of biological principles (Ludwig 2000, Chee 2004, Rapport & Singh 2006). Nevertheless, economic evaluations are an essential part of human-environmental systems research. They support awareness raising for the dependence of human societies on nature and help design institutions for the conservation of important natural systems in a sustainable manner (Heal 2000). In this sense, there is no either-or among ecological and economic evaluation methods (Farber et al. 2002). Turner et al. (2003) have shown in their survey of the nature valuation literature that there is a need of studies to encompass a range of interdependent ecological functions, uses and values at different sites. This type of study is of great relevance to environmental managers who have to deal with complex trade-offs between conservation and land use development. Although we do not integrate an economic valuation in our proposed method, a classification of the service production capacities allows a comparison between different biophysical units.

In contrast to the studies presented above, our approach includes the concept of ecological integrity as a prerequisite for providing ecosystem goods and services to humans and therefore widens the purely anthropocentric view of other studies (Müller & Burkhard 2007). As defined by Barkmann et al. (2001), ecological integrity denotes the „support and preservation of those processes and structures which are essential prerequisites of the ecological ability for self-organisation" of ecosystems. It is mainly based on variables of energy and matter budgets and structural features

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of whole ecosystems. These components are similar to those referred to as „supporting services" in other ecosystem services studies (MA 2003). In the assessment framework presented here, ecological integrity and related indicators (Müller 2005) represent the base for the provision of regulating, provisioning and cultural ecosystem services. The different ecosystem services of these three groups were mainly selected from lists provided by de Groot (2006), MA (2005) and Costanza et al. (1997).

As spatial units, the land cover classes of the European CORINE project (EEA 1994) were used as starting points. Originating from remote sensing data, these land cover units provide a logical combination of land cover and land use - as it can be found in the real landscapes. As CORINE land cover units are quite coarse data with regard to their spatial and thematic resolution, a lot of information is aggregated with a high degree of generalization. Hence, several landscape features, qualities, rarities and configurations cannot be represented. Therefore, CORINE data are used as a starting point and the integration of additional data is planned step by step. This will improve the value and explanatory power of spatial assessments of ecosystem services. The information needed for an appropriate evaluation of ecosystem services and the estimation of their value are difficult or - in many aspects - even impossible to obtain. But, „even imperfect measures of their [ecosystem services] value, if understood as such, are better than simply ignoring ecosystem services altogether, as is generally done in decision making today" (Daily 1997: 8).

In this paper, we are therefore proposing the first step of a comprehensive assessment strategy for ecosystem services provision at the landscape level. It is a new approach as it offers great potential to combine various data sources and different topics. Outcomes are descriptive tables and maps which illustrate the potentials of particular areas to provide ecosystem services. We are aware that a broad range of central issues like for example questions of scale-dependencies and scale–interactions, habitat heterogeneities and temporal aspects are not considered yet. But this was not the aim of this paper. Our approach aims at developing and discussing a research framework to answer the following questions:

- What potential do the different land cover units have to provide which ecosystem services?
- How can we combine expert judgements with quantitative data to assess landscapes' capacities to provide ecosystem services?
- Is it possible to derive a general assessment methodology, applicable and transferable to various areas and scales?

2 Assessment framework

The basic idea of the assessment strategy is the analysis of existing landscape data to evaluate capacities to provide ecosystem services in a spatial manner. In a first step, which is presented here, easily available land cover data (like CORINE) were linked to expert judgements about the different land cover types' capacities to provide various ecosystem services. For future assessments, the successive integration of quantitative data as well as further landscape attributes and configurations are planned. With this paper, we want to introduce and demonstrate the potentials of spatial assessments of ecosystem services. At the current state of application, the assessments are based on a high amount of qualitative data and rather large spatial units. Hence, generalizations of particular habitat features are unavoidable. Nevertheless, we do not assume that every part of a given habitat type is of equal value with regard to its capacity to provide ecosystem services, social values or management practices. This kind of information is planned to be generated during future applications. After that, results are expected to provide statistical and spatial information and illustrations (maps) which are useful for landscape planning and environmental management. Conceptual models and, in particular, spatially explicit information, like maps, have a high potential to support the understanding of complex systems and interrelationships (Dresner 2008).

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2.1 CORINE land cover classes as reference areas

The aim of the CORINE program of the European Union is to compile information on the state of the environment with regard to certain topics which have priority for all member states of the community (EEA 1994). Therefore, a geographical information system has been created to provide information on the environment which is essential when preparing and implementing community policies. CORINE includes 44 land cover classes altogether grouped in a three-level nomenclature into 1) artificial surfaces, 2) agricultural areas, 3) forests and seminatural areas, 4) wetlands and 5) water bodies (for descriptions of the land cover classes, see Appendix 2 of this paper). These classes (are supposed to) represent all land cover types in Europe. The classes are clearly defined in the nomenclature provided by the project (EEA 1994). One task during the development and application of our assessment framework in theory and in case studies was to find out, whether these predefined land cover classes are suitable and sufficient to represent the ecosystems and land cover types occurring in our case study areas.

The geographical data in the European CORINE data base have been converted to a European geographical reference system and contain a minimum mapping unit of 25 ha. The national CORINE data bases are collected by national teams and disseminated on demand by National Reference Centres. The European CORINE data base is the result of the integration of these national databases. Datasets on a 100 metre grid, a 250 metre grid and a 1 km grid are available at marginal cost respectively downloadable for free from the EEA website (http://dataservice.eea.europa.eu/). For our studies, CORINE data in ESRI ArcView polygon shape format were used. The vector data have the advantage of being more spatially explicit and it is easy to join the spatial data with ecosystem services evaluation matrices in the related attribute tables.

2.2 Definition of ecosystem services

Based on the ecosystem services lists provided by de Groot (2006), MA (2005) and Costanza et al. (1997) and the list of ecological integrity components described by Müller & Burkhard (2007) and Müller (2005), a general set of ecosystem services was derived. The individual services are grouped in the four categories 1) ecological integrity (supporting services), 2) provisioning services, 3) regulating services and 4) cultural services. As cultural services are very difficult to grasp and to value (MA 2005), they are reduced to „recreation and aesthetic value" and „intrinsic value of biodiversity". The first term was generated because appropriate indicators like visitor numbers are easily available; the second one because, in our point of view, the lack of appreciation of nature and species diversity as such (besides their contribution to human welfare) is a considerable drawback in many of the available concepts of ecosystem services. For definitions of the selected services and potential indicators for their quantification, see Appendix 1 of this paper. The selection and quantification of appropriate indicators and data for the individual ecosystem services are as crucial as the selection of the services themselves. We have to be aware that the whole analysis is a model of reality trying to reduce the complexity of human-environmental systems in an appropriate, logical and reproducible manner. Hence, generalizations and simplifications have to be tolerated in order to receive a holistic picture of complex systems.

2.3 Assessment matrix: land cover vs. ecosystem services

To assess different land cover types' capacities to provide ecosystem services, a matrix was created. On the y-axis of this matrix, the 44 CORINE land cover types are placed. On the x-axis, the 29 ecosystem services as defined in Appendix 1 are placed. At the intersections (altogether 1276), different land cover types' capacities to provide the individual service were assessed on a scale consisting of:

0 = no relevant capacity, 1 = low relevant capacity, 2 = relevant capacity, 3 = medium relevant capacity, 4 = high relevant capacity and 5 = very high relevant capacity.

The assignments in Table 1 are based on first expert evaluations (conceptual and from different case studies) and can be seen as research hypotheses which are to be tested in further case study applications with data from measurements, modeling or additional expert assessments. Table 1 shows concentrations of high capacities to provide a broad range of ecosystem services for the different forest land cover types, peatlands, moors and heathlands. Moreover, it reveals rather high capacities of many nature-

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Table 1: Matrix for the assessment of the different land cover types' capacities to provide selected ecosystem goods and services (for definition of land cover types and ecosystem services see Appendices 1 and 2). The assessment scale reaches from 0 = rosy colour = no relevant capacity of the land cover type to provide this particular ecosystem service, 1 = grey green = low relevant capacity, 2 = light green = relevant capacity, 3 = yellow green = medium relevant capacity, 4 = blue green = high relevant capacity and 5 = dark green = very high relevant capacity. In the rows between the assessments (yellow colour), sums for the individual ecosystem services groups were calculated.

	Ecological Integrity Σ	Abiotic heterogeneity	Biodiversity	Biotic waterflows	Metabolic efficiency	Exergy Capture (Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	Provisioning services Σ	Crops	Livestock	Fodder	Capture Fisheries	Acquaculture	Wild Foods	Timber	Wood Fuel	Energy (Biomass)	Biochemicals / Medicine	Freshwater	Regulating services Σ	Local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	Cultural services Σ	Recreation& Aesthetic Values	Intrinsic Value of Biodiversity
Continuous urban fabric	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	0	0
Discontinuous urban fabric	7	1	1	1	1	1	1	1	3	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial or commercial units	2	1	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	0	0	0
Road and rail networks	4	2	2	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	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	1	1	0
Airports	7	1	1	1	1	1	2	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	4	2	2	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
Dump sites	8	2	1	0	0	0	0	5	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
Construction sites	3	2	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	0	0	0
Green urban areas	18	3	3	2	1	4	3	2	2	0	0	0	0	0	1	0	1	0	0	0	11	2	1	0	2	1	2	1	1	1	3	3	0
Sport and leasure facilities	16	2	2	2	1	4	3	2	0	0	0	0	0	0	0	0	0	0	0	0	9	1	1	0	2	1	1	1	1	1	5	5	0
Non-irrigated arable land	22	3	2	3	4	5	1	4	21	5	5	5	0	0	0	0	0	5	1	0	5	2	1	1	1	0	0	0	0	0	1	1	0
Permanently irrigated land	21	3	2	5	2	5	1	3	18	5	5	2	0	0	0	0	0	5	1	0	5	3	1	1	0	0	0	0	0	0	1	1	0
Ricefields	20	3	2	5	1	5	1	3	7	5	0	2	0	0	0	0	0	0	0	0	4	2	0	0	2	0	0	0	0	0	1	1	0
Vineyards	14	3	2	3	1	3	0	2	5	4	0	0	0	0	0	0	1	0	0	0	3	1	1	0	1	0	0	0	0	0	5	5	0
Fruit trees and berries	21	4	3	4	2	3	2	3	13	5	0	0	0	0	0	4	4	0	0	0	19	2	2	2	2	2	2	1	1	5	5	5	0
Olive groves	17	3	2	3	2	3	1	3	12	4	0	0	0	0	0	4	4	0	0	0	7	1	1	0	1	1	1	1	1	0	5	5	0
Pastures	24	2	2	4	5	5	2	4	10	0	5	5	0	0	0	0	0	0	0	0	8	1	1	1	1	0	4	0	0	0	3	3	0
Annual and permanent crops	18	2	2	3	2	4	2	3	20	5	5	5	0	0	0	0	0	5	1	0	7	2	1	1	1	1	1	0	0	0	1	1	0
Complex cultivation patterns	20	4	3	3	2	4	1	3	9	4	0	3	0	0	0	0	0	0	2	0	5	2	1	1	1	0	0	0	0	0	2	2	0
Agriculture& natural vegetation	19	3	3	3	2	3	2	3	21	3	3	2	0	0	3	3	3	3	1	0	13	3	2	1	2	1	3	0	1	0	5	2	3
Agro-forestry areas	27	4	4	4	3	4	4	4	14	3	3	2	0	0	0	3	3	0	0	0	13	2	1	1	1	1	2	1	1	3	3	3	0
Broad-leaved forest	31	3	4	5	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0	39	5	4	3	2	5	5	5	5	5	10	5	5
Coniferous forest	30	3	4	4	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0	39	5	4	3	2	5	5	5	5	5	10	5	5
Mixed forest	32	3	5	5	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0	39	5	4	3	2	5	5	5	5	5	10	5	5
Natural grassland	30	3	5	4	4	4	5	5	5	0	3	0	0	0	2	0	0	0	0	0	22	2	3	1	1	0	5	5	5	0	6	3	3
Moors and heathland	30	3	4	4	5	4	5	5	10	0	2	0	0	0	1	0	2	5	0	0	20	4	3	2	2	0	0	3	4	2	10	5	5
Sclerophyllous vegetation	21	3	4	2	3	3	4	2	8	0	2	0	0	0	1	0	2	0	3	0	7	2	1	1	1	0	0	0	0	2	6	2	4
Transitional woodland shrub	21	3	4	2	3	3	4	2	5	0	2	0	0	0	1	0	2	0	0	0	3	1	0	0	0	0	0	0	0	2	4	2	2
Beaches, dunes and sand plains	10	3	3	1	1	1	0	1	2	0	0	0	0	0	0	0	0	2	0	0	6	0	0	5	1	0	0	0	0	0	7	5	2
Bare rock	6	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	1	0	0	0	1	0	4	4	0
Sparsely vegetated areas	9	2	3	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	1	1	0	0	0	0	0	0	0	0
Burnt areas	6	2	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Glaciers and perpetual snow	3	2	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	5	10	3	3	0	4	0	0	0	0	0	5	5	0
Inland marshes	25	3	2	4	4	4	3	5	7	0	2	5	0	0	0	0	0	0	0	0	14	2	2	4	2	0	0	4	0	0	0	0	0
Peatbogs	29	3	4	4	4	4	5	5	5	0	0	0	0	0	0	0	0	5	0	0	24	4	5	3	3	0	0	3	4	2	8	4	4
Salt marshes	23	2	3	4	3	3	3	5	2	0	2	0	0	0	0	0	0	0	0	0	8	1	0	5	0	0	0	2	0	0	3	3	0
Salines	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	2	2	0
Intertidal flats	13	2	3	0	2	1	4	1	0	0	0	0	0	0	0	0	0	0	0	0	7	1	0	5	0	0	0	1	0	0	4	4	0
Water courses	18	4	4	0	3	3	3	1	12	0	0	0	3	0	4	0	0	0	0	5	10	1	0	2	1	0	0	3	3	0	10	5	5
Water bodies	23	4	4	0	4	4	3	4	12	0	0	0	3	0	4	0	0	0	0	5	7	2	1	1	2	0	0	1	0	0	9	5	4
Coastal lagoons	25	4	4	0	5	5	3	4	16	0	0	0	4	5	4	0	0	3	0	0	5	1	0	4	0	0	0	0	0	0	9	5	4
Estuaries	21	3	3	0	5	5	3	2	17	0	0	0	5	5	4	0	0	3	0	0	9	0	0	3	0	0	0	3	3	0	7	4	3
Sea and ocean	15	2	2	0	3	3	4	1	11	0	0	1	5	5	0	0	0	0	0	0	13	3	5	0	0	0	0	5	0	0	6	4	2

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near land cover types to support ecological integrity. The highly human-modified land cover types, like urban fabric, industrial or commercial areas, mineral extraction and dump sites, have very low or no relevant capacities to provide ecosystem services. Hence, a pattern emerges which matches well with the results one would assume. The application in case studies will reveal, whether this matrix is applicable in real cases, if the hypotheses can be tested with existing data and if these proxies will lead to modifications. During this „maturing“ process of the matrix, which has already started with first case studies and will continue in future, the whole approach receives a better foundation. The matrix might on the one hand be seen as the most innovative point of our concept, on the other hand it seems to be the most vulnerable also.

2.4 Applications in case studies

Up to now, a similar assessment framework has been applied in different case studies: i) related to the establishment of the biosphere reserve „Schwäbische Alb“ in southern Germany, ii) in boreal areas in northern Finland with forestry and reindeer husbandry (Burkhard et al. 2009a , http://joyx.joensuu.fi/~tkumpula/clmirf), iii) in the German North Sea related to the installation of offshore wind parks (www.coastal-futures.org), iv) to assess the impacts of tourism on the German island of Sylt (Schmidt 2008) and v) about the rural-urban region Halle-Leipzig/Germany as part of the PLUREL project (www.plurel.net). In the individual case studies, relevant CORINE land cover classes were selected from the whole set of 44 classes in a first step. This means, only land cover types occurring in the particular study areas were considered (e.g. there are no olive groves in Finland). In a second step, the list of 29 ecosystem services was checked for relevance in the particular study. It becomes obvious that in some cases, the list presented here had to be supplemented by additional, case study-specific services. For example, the provisioning service “food by reindeer meat” is of such a high relevance for the case study in northern Finland, that it was included as an individual class in addition to the other groups. For the study in the North Sea, ecological integrity parameters had to be adapted to marine conditions (Burkhard et al. 2009b). The data behind the assessments in the case studies origin in modeling, statistical data or are based on expert evaluations.

2.5 Further development and future applications of the concept

In order to attain better access to suitable data in future, a cooperation with the German chapter of the Long Term Ecological Research (LTER-D) network is planned. Different LTER-D sites were selected to be representative for forest ecosystems, coastal regions, agricultural areas, city regions and mountainous areas. Thus, the main biomes in Germany can be covered and exemplary assessments and calibrations of the assessment tools can be carried out in the near future.

Besides a better data appliance, the integration of further landscape components is the main target in future. There are a) static features like elevation, slope, soils, hydrology, vegetation data (more detailed than in CORINE) and b) dynamic features like climatic and weather conditions, land use technology improvements or changes in land use intensity to be considered. This will lead to a better consideration of spatial and temporal heterogeneities of landscape features and values, which are probably not suitably represented in the CORINE classes.

3 Exemplary first results

To illustrate the procedure, we present selected results from the PLUREL project‘s case study area Halle-Leipzig in central eastern Germany (Fig. 1). In this region, the main land use changes during the last decades were related to urban sprawl, including housing and commercial areas and a change in agricultural production patterns following the German reunification. Additionally, the region is characterized by open pit brown coal mining areas often having been converted to lakes after abandonment. Figure 2 shows the CORINE maps of the region illustrating the land cover distribution in the years 1990 and 2000. An expansion of discontinuous

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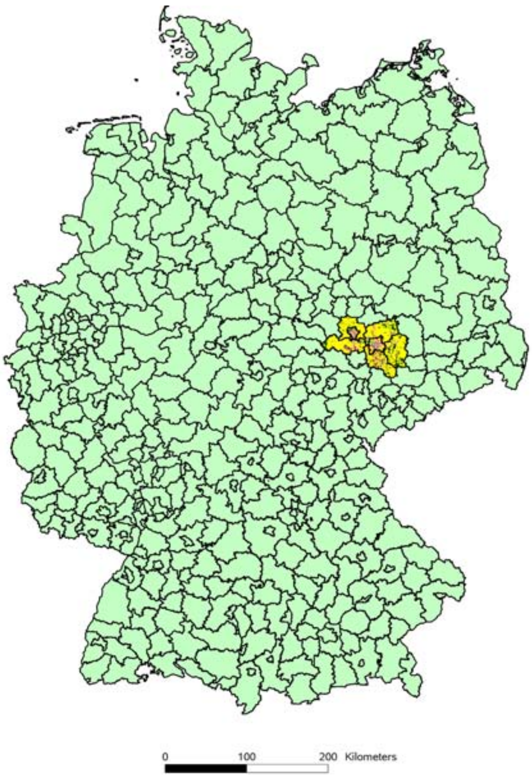

Figure 1: Location of the case study region Halle-Leipzig within Germany.

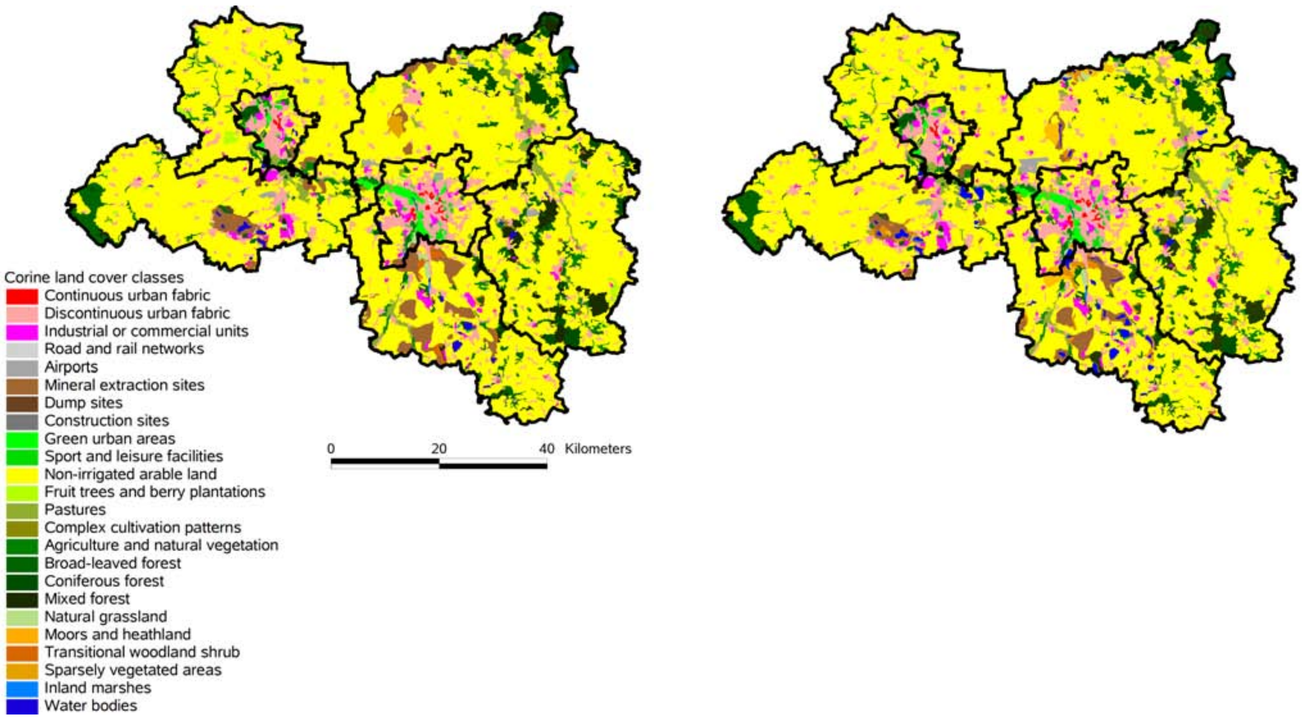

Figure 2: CORINE land cover maps of the research area, showing the land cover distribution of 1990 (left) and 2000 (right) and the administrative borders of Leipzig, Halle, and surrounding districts.

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urban fabric and industrial or commercial units around the urban areas of Leipzig and Halle is visible during the ten years period illustrated here.

3.1 Quantification of ecosystem services

To give an example of a possible quantification of selected ecosystem services, data on the provisioning ecosystem service „food provision" were collected for the study area Halle-Leipzig, covering the years 1990 and 2000. Table 2 shows respective data for the provision of crops, fodder, livestock, capture fisheries & aquaculture, wild food and total food (weighted and aggregated) in GJ/ha land cover type per year. For the calculation of a single value per land cover type, statistical data about the crop composition in % have been combined with harvest masses in dt/ha per crop type (fruit, meat, milk, fish) and finally with the associated energy values in GJ/dt. The results show an increase in agricultural production in all classes except water bodies (Table 2). The production data were classified according to the same scale as in the ecosystem service provision matrix (Table 1). Hereby, the maximum values were taken as reference values to represent the class „5 = very high relevant capacity". First, the classification was carried out for each land cover type individually, resulting in a high valuation of fish and wild foods in the land cover types water bodies, respectively forests, in spite of the very low food provision per hectare in comparison to the other land cover types. In order to provide a general view of food provision and to put the food providing land cover types in relation to each other, the results of all food types were subsequently aggregated. Before doing so, a weighting between the food types "crops" and "fodder" was necessary, as they are both provided by the land cover class "non-irrigated arable land". For the weighting, each of the two food types was included according to its share of cultivated arable land in the respective year. Additionally, the energy in GJ/ha that is provided by fodder was divided by ten because of the lower energy value of meat in comparison to fodder crops necessary to produce that

Table 2: Provisioning ecosystem service „food provision" in the Halle-Leipzig region divided by types of food and land cover classes and as weighted aggregation of all food providing services (Data sources: Saxon State Ministry of the Environment and Agriculture 2001, 2003; KTBL 2005).

Land cover class [GJ/ha]	Year	Crops	Fodder	Livestock	Capture Fisheries & Aquaculture	Wild Foods	Food provision (weighted aggregation)
		Classification					
Non-irrigated arable land	1990	43,7	183	0	0	0	38
	2000	59,9	200,6	0	0	0	49,2
Fruit trees and berry plantations	1990	25,5	0	0	0	0	25,5
	2000	70	0	0	0	0	70
Pastures	1990	0	0	9,4	0	0	9,4
	2000	0	0	14	0	0	14
Complex cultivation pattern	1990	22	45,7	0	0	0	21,1
	2000	37,7	50,1	0	0	0	30
Arable land and natural vegetation	1990	32,8	137	0	0	0	28,8
	2000	44,9	150	0	0	0	36,8
Water bodies	1990	0	0	0	1,3	0	1,3
	2000	0	0	0	0,5	0	0,5
Forests	1990	0	0	0	0	0,01	0,01
	2000	0	0	0	0	0,02	0,02

very high relevant capacity · high relevant capacity · medium relevant capacity · relevant capacity · low relevant capacity · no relevant capacity

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meat. The classification of the aggregated food provision service shows another picture than the individual land cover type classifications.

3.2 Spatial distribution of ecosystem services

If we combine the data presented in Table 2 with the spatial GIS data by joining the crop production data to the attribute table of the GIS polygon shape file, the spatial distribution of ecosystem services can be displayed in maps (Fig. 3). The increase in crop production is visible in the darker areas.

To get an impression of the overall capacity for food provision, the individual food types in Table 2 were aggregated to one class „food" and the same classification scale was applied to the land cover types occurring in the study area. Figure 4 shows the maps of food provision in the Halle-Leipzig region in the year 1990 and 2000. The low food provision capacities of urban and suburban areas, mineral extraction and dump sites as well as forest areas become obvious in both years.

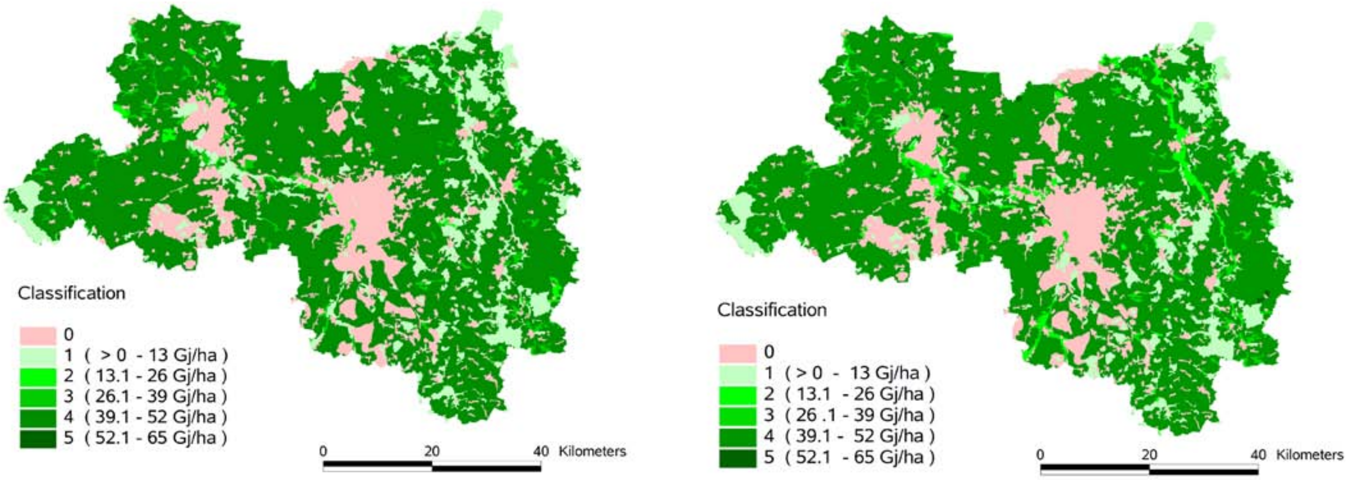

Figure 3: Spatial distribution of the ecosystem service "crop provision" in the year 1990 (left) and 2000 (right) for the region of Leipzig, Halle, and surrounding districts.

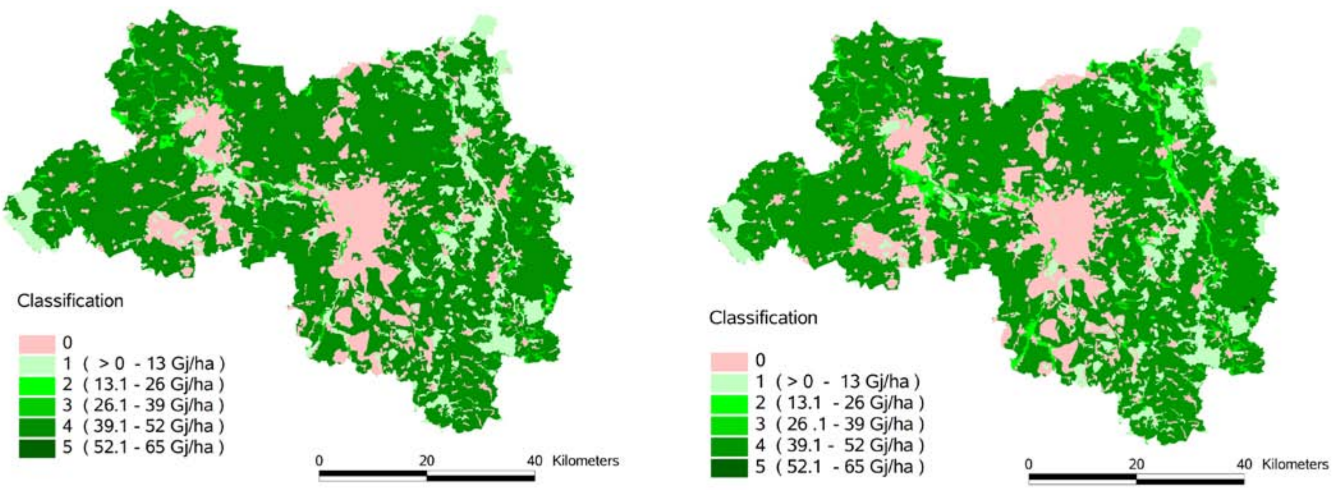

Figure 4: Spatial distribution of the aggregated ecosystem service "food provision" in the year 1990 (left) and 2000 (right) for the region of Leipzig, Halle, and surrounding districts.

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4 Discussion

The example of food provision in the Halle-Leipzig region demonstrates that a combination of the hypotheses from the expert judgements (Table 1) with statistical data (Table 2) is possible. The methodology offers results showing clear patterns of ecosystem service distribution. Comparable results were achieved in the other case studies applying a similar methodology. The application of CORINE land cover data from the years 1990 and 2000 has demonstrated changes in the case study region. Typical effects of urban sprawl with increasing urban and commercial areas around the cities of Leipzig and Halle became visible. The conversion of open pit mining areas into lakes is another common phenomenon in this region. Both developments have impacts on the provision of ecosystem services. But, the reduction of arable land did not cause a decrease in food production services. On the contrary, improvements in agricultural productivity have caused an increase in food provisioning services despite the shrinkage of agricultural area. Therefore it was important, not to look at spatial extensions of land use alone but also on their intensities respectively productivities. By modifying the spatial land cover and the production data, future scenarios have been simulated in the PLUREL project. The simulations show that the trends presented here are probable to continue in this region for the next decades.

The question of suitable accounting units is still debated. In the Halle-Leipzig study we decided to use energy (GJ food produced per hectare land per year), a rather neutral unit that nevertheless includes additional qualitative information on the food supply in comparison to the mass unit dt/ha. Monetary accountings are more value-laden and therefore trickier to apply. Additionally, market prices (e.g. for food) are strongly fluctuating between years and countries hindering spatial and temporal comparisons of monetary accountings.

The evaluations of the ecosystem services provision capacities/land cover matrix (Table 1) are probably the most crucial point in this methodology. So far, the assessments are based on expert evaluations and experience from the case studies. As the material presented here is a first attempt to develop, discuss and establish a new methodology, estimations and input data were intentionally kept as simple as possible. With a better data base and in a longer perspective, it is not convenient just to count and to add different ecosystem services, respectively the processes behind them. There must be a weighting procedure which enables an appropriate accounting of different components and their relevance. Nevertheless, the assessment matrix (Tab. 1) reveales interesting patterns of relations between land cover types and their capacities to provide ecosystem services.

The CORINE land cover types appear to provide a suitable spatial and thematic reference, at least to start the assessment with. As they originate from satellite imagery, they represent the real situation at the earth's surface. The land cover which can be found there is a combination of natural conditions and human action (land use). Therefore, satellite data are a suitable base for ecosystem services assessments. The idea of ecosystem services has been built on a comparable linkage of natural conditions and human use/benefits of them. Whether an additional spatial subdivision in service providing units (Vandewalle et al. 2009) is advisable, has to be proven in further case study applications. Certainly, the rough spatial resolution and thematic generalizations of the CORINE data are strongly limiting the outcomes presented here. Especially if working on the local or regional level, further data have to be integrated in order to obtain a better representation of landscape and land use features.

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5 Conclusions

With this paper, we present a new methodology to evaluate ecosystem service provisions of different land cover and land use types in relation to human activities. One must bear in mind, that the assessments and the table/map compilations have been mainly based on expert judgements up to now. The successive substitution of these expert assessments by „real“ or model data, constituting the major task and work plan in future, will reveal whether this method and the hypotheses made will stand or if they have to be modified. However, the assessment of the capacities of different (eco)systems or land cover/land use types to provide ecosystem services seems to be very promising. The coupling with GIS and spatial displaying of ecosystem services‘ distributions in maps have a very high potential for landscape analysis and management. Maps of landscapes‘ capacities to provide ecosystem services give an idea about potentials, possible conflicts and limits in environmental management. The integration and analysis of further landscape data, like land use information (types and intensities), biotic information (additional vegetation data, fauna, habitats) and abiotic information (soil types, elevation models, climate data, hydrological information), in the assessment process open further opportunities. Figure 5 shows the conceptual framework, including the current steps of analysis (CORINE data, expert judgements and exemplary quantitative assessments), future integration of additional data sources and further quantifications.

During the conceptual work on the assessment framework and within our case studies it became obvious, that the conditions, structures, problems, spatial and temporal scales we want to address are more diverse than expected. Impacts of land-use intensity on ecological functioning often depend on spatial scales much larger than a single field or land use (Zurlini & Girardin 2007). The land cover classes, ecosystem services and

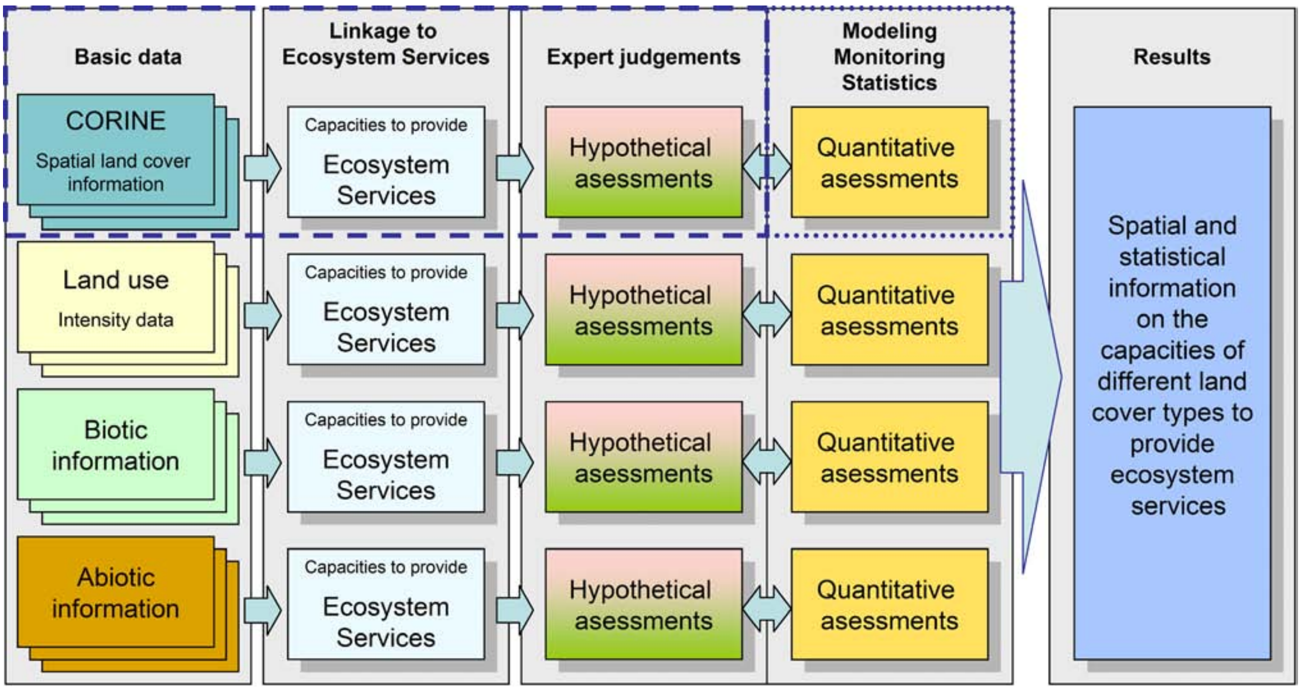

Figure 5: Conceptual framework to assess and quantify landscapes’ capacities to provide ecosystem services. The dashed and dotted lines indicate the components presented with examples in this paper.

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respective indicators suggested here may not have the capacity to cover all topics and scales in general. Therefore, we suggest them as a core set of ecosystem services and land cover/use types with respective potential indicators. It is apparent, that CORINE data with their coarse resolution of at least several hundreds of metres do not have the potential to represent natural conditions on a local scale. Therefore in the individual studies, supplementary case study-specific ecosystems and land cover/use types needed to represent the particular circumstances at the individual study site have to be integrated. Moreover, temporal dynamics and processes taking place on different scales should be taken into account. The same should be done for the ecosystem services. Where there are further significant components not being covered by the list presented here, it is simple to include additional topics by integrating further ecosystem services.

As main points open for discussion with regard to the research idea presented here the following questions emerge:

- Does the methodological framework add value to the current research on ecosystem services and their modeling?
- Are there appropriate data available to assess ecosystem services in the way presented here?
- How can these data and information be integrated and aggregated into indicators using which units?
- Is the list of ecosystem services sufficient and which services can be quantified?
- Is there an appropriate way to weight the individual ecosystem services with regard to their relevance?
- How can we cope with complexities of landscapes with regard to spatial and temporal scales, heterogeneities and dynamics?

We are looking forward to respective discussions, comments and questions about these issues in the future.

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Appendix 1

List of ecosystem services with definitions and potential indicators (based on Müller & Burkhard 2007, de Groot 2006, MA 2005 and Costanza et al. 1997).

Ecosystem service	Definition	Potential indicators
Ecosystem integrity		
Abiotic heterogeneity	The provision of suitable habitats for different species, for functional groups of species and for processes is essential for the functioning of ecosystems.	habitat divers ity indices heterogeneity indices, e.g. humus contents in the soil number/area of habitats
Biodiversity	The presence or absence of selected species, (functional) groups of species or species composition.	Indicator species representative for a certain phe nomenon or sensitive to distinct changes.
Biotic water flows	Referring to the water cycling affected by plant processes in the system.	transpiration / total evapotrans piration
Metabolic efficiency	Referring to the amount of energy necessary to maintain a specific biomass, also serving as a stress indicator for the system.	respiration / biomass (metabolic quotient)
Exergy capture	The capability of ecosystems to enhance the input of usable energy. Exergy is derived from thermodynamics and measures the energy fraction that can be transformed into mechanical work. In ecosystems, the captured exergy is used to build up biomass (e.g. by primary production) and structures.	Net primary production Leaf area index LAI
Reduction of nutrient loss	Referring to t he irreversible output of elements from the system, the nutrient budget and matter flows.	Leaching of nutrients e.g. N, P
Storage capacity	Is referring to the nutrient, energy and water budgets of the system and the capacity of the system to store them when available and to release them when needed.	Solved organic matter N, C_{org} in the soil N, C in biomass
Provisioning services		
Crops	Cultivation of edible plants.	Plants / ha kJ / ha
Livestock	Keeping of edible animals.	Animals / ha kJ / ha
Fodder	Cultivation and harvest of animal	Fodder plants / ha

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Ecosystem service	Definition	Potential indicators
Capture fisheries	Catch of commercially interesting fish species, which are accessible for fishermen.	Fishes available for catch / ha kJ / ha
Aquaculture	Animals kept in terrestrial or marine aquaculture.	Number of animals / ha kJ / ha
Wild foods	Harvest of e.g. berries, mushrooms, wild animal hunting or fishing.	Plant biomass / ha Animals available / ha kJ / ha
Timber	Presence of trees or plants with potential use for timber.	Wood / ha kJ / ha
Wood fuel	Presence of trees or plants with potential use as fuel.	Wood or plant biomass / ha kJ / ha
Energy (biomass)	Presence of trees or plants with potential use as energy source.	Wood or plant biomass / ha kJ / ha
Biochemicals / medicine	Production of biochemicals, medicines.	Amount or number of products kg / ha
Freshwater	Presence of freshwater.	l or m^3 / ha
Regulating services		
Local climate regulation	Changes in land cover can locally affect temperature, wind, radiation and precipitation.	Temperature, albedo, precipitation, wind Temperature amplitudes Evapotranspiration
Global climate regulation	Ecosystems play an important role in climate by either sequestering or emitting greenhouse gases.	Source-sink of water vapour, methane, CO_2
Flood protection	Natural elements dampening extreme flood events	Number of floods causing damages
Groundwater recharge	The timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes in land cover, including, in particular, alterations that change the water storage potential of the system, such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.	Groundwater recharge rates

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Ecosystem service	Definition	Potential indicators
Air quality regulation	The capacity of ecosystems to remove toxic and other elements from the atmosphere.	Leaf area index Air quality amplitudes
Erosion regulation	Vegetative cover plays an important role in soil retention and the prevention of landslides.	loss of soil particles by wind or water vegetation cover
Nutrient regulation	The capacity of ecosystems to carry out (re)cycling of e.g. N, P or others.	N, P or other nutrient turnover rates
Water purification	Ecosystems have the capacity to purify water but can also be a source of impurities in fresh water.	Water quality and quantity
Pollination	Ecosystem changes affect the distribution, abundance, and effectiveness of pollinators. Wind and bees are in charge of the reproduction of a lot of culture plants.	amount of plant products distribution of plants availability of pollinators
Cultural services		
Recreation & aesthetic values	Refers specifically to landscape and visual qualities of the resp. case study area (scenery, scenic beauty). The benefit is the sense of beauty people get from looking at the landscape and related recreational benefits.	Number of visitors or facilities Questionnaires on personal preferences
Intrinsic value of biodiversity	The value of nature and species themselves, beyond economic or human benefits.	number of endangered, protected or rare species or habitats

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Appendix 2

CORINE land cover – description of categories (from EEA 1994).

Code	Name	Description
111	Continuous urban fabric	Buildings, roads and artificially surfaced areas cover more than 80% of the total surface.
112	Discontinuous urban fabric	Buildings, roads and artificially surfaced areas cover between 50 and 80% of the total surface area; they are associated with vegetated areas and bare soil.
121	Industrial or commercial units	Entire industrial or commercial complexes, including access roads, landscaped areas, car parks, wasteland etc. (e.g. sanatoriums, spa facilities, hospitals, rest homes, military bases, educational establishments, university sites, commercial centres, waste water treatment plants)
122	Road and rail networks and associated land	Motorways and railways, including associated installations (stations, platforms, embankments). Minimum width: 100 m.
123	Port areas	Infrastructure of port areas, including quays, dockyards and marinas. Inland and marine basins are not included.
124	Airports	Airport installations: runways, buildings and associated land. Buildings (offices, terminal buildings, hangars, workshops, warehouses, storage tanks, car parks), grassed areas and associated spaces are included in the airport surface area.
131	Mineral extraction sites	Areas with open pit extraction of construction material (sandpits, quarries) or other minerals (open-cast mines). Includes flooded gravel pits, except for river -bed extraction. This heading includes buildings and associated industrial infrastructure (e.g. cement factories) and small water bodies of less than 25 ha created by mining.
132	Dump sites	Public, industrial or mine dump sites.
133	Construction sites	Spaces under construction development, soil or bedrock excavations, earthworks.
141	Green urban areas	Areas with vegetation within the urban fabric, including public parks, private green areas, cemeteries with vegetation, and mansions and their grounds.
142	Sport and leisure facilities	Camping grounds, sports grounds, leisure parks, golf courses, racecourses, etc. Includes formal parks not surrounded by urban areas.
211	Non-irrigated arable land	Cereals, legumes, fodder crops, root crops and fallow land. Includes flowers and tree nurseries, vegetables in green houses, aromatic, medicinal and culinary plants.

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Code	Name	Description
212	Permanently irrigated land	Crops irrigated permanently or periodically, using a permanent infrastucture (irrigation channels, drainage network). Most of these crops coul d not be cultivated without an artificial water supply. Does not include sporadically irrigated land. Sprinkler irrigation is not to be considered here. Only flood or flush irrigation techniques are to be taken into account.
213	Rice fields	Land prepared for rice cultivation. Flat surfaces with irrigation channels. Surfaces periodically flooded.
221	Vineyards	Areas planted with vines
222	Fruit trees and berry plantations	Parcels planted with fruit trees or shrubs: single or mixed fruit species, fruit tre es associated with permanently grasses surfaces. Includes chestnut and walnut groves.
223	Olive groves	Areas planted with olive trees, including mixed occurrence of olive trees and vines on the same parcel.
231	Pastures	Dense grass cover, of floral composition, dominated by graminaceae, not under a rotation system. Mainly for grazing, but the fodder may be harvested mechanically. Includes areas with hedges (bocage).
241	Annual crops associated with permanent crops	Non-permanent crops (arable land or past ure) associated with permanent crops on the same parcel. Parcels consisting of orchards mixed with non -associated annual crops represent less than 25% of the total surface area.
242	Complex cultivation patterns	Juxtaposition of small parcels of diverse an nual crops, pasture and/or permanent crops, provided that none of these three categories covers an identifiable surface unit of more than 25 ha within a single land unit. Arable land, pasture and orchards each occupy less than 75% of the total surface area of the unit. City gardens are included in this category.
243	Agriculture and significant natural vegetation mosaics	Areas principally occupied by agriculture, interspersed with significant natural areas. Agricultural land occupies between 25 and 75% of the total surface of the unit. Hedged (bocage) areas are excluded from this category.
244	Agroforestry areas	Annual crops or grazing land under the wooded cover of forestry species. This category appears frequently in Southern Europe. It is usually linked to very extensive areas with a very variable spectral signature (different species, tree density, soil types).
311	Broad-leaved forest	Vegetation formation composed principally of trees, including shrub and bush understoreys, where broad-leaved species predominate. Broad -leaved trees must represent more than three-quarters of the surface unit in this category. Young coppices and young plantations belong to this category.

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Code	Name	Description
312	Coniferous forest	Vegetation formation composed principally of trees, including shrub and bush understoreys, where coniferous species predominate. Surface planted with conifers must represent at least 75% of the total surface of the unit; otherwise, the unit is one of mixed forest.
313	Mixed forest	Vegegation formation composed princi pally of trees, including shrub and bush understoreys, where neither broad-leaved nor coniferous species predominate. This category includes not only mixed forest in the strict silvicultural sense (single tree or clump mixtures), but also complex forest parcels comprising an intricate mosaic of broadleaved and softwood species where no homogeneous stand of more than 25 ha can be distinguished.
321	Natural grassland	Low productivity grassland. Often situated in areas of rough, uneven ground. Frequently includes rocky areas, briars and heathland. Length of time during which animals can graze must be less than 120 days: from June to September.
322	Moors and heathland	Vegetation with low and closed cover, dominated by bushes, shrubs and herbaceous plants (heather, briars, broom, gorse, laburnum, etc.).
323	Sclerophyllous vegetation	Bushy sclerophyllous vegetation, including maquis and garrigue
324	Transitional woodland shrub	Bushy or herbaceous vegetation with scattered trees. Can represent either woodland de gradation or forest regeneration/ colonisation. This category includes areas subject to erosion or where plant health is giving cause for concern, and areas which are being afforested.
331	Beaches, dunes and sands	Beaches, dunes and expanses of sand or pebbles in coastal or continental locations, including beds of stream channels with torrential regime. Beaches must be at least 100 m wide to be included. Sandy riverbanks can be included only if they occupy 25 ha or more. 'Grey' dunes fixed by specific vege tation (marram grass, sedge, couch grass, mosses and lichens, etc.) belong in this category.
332	Bare rock	Scree, cliffs, rocks outcrops, including active erosion, rocks and reef flats situated above the high-water mark.
333	Sparsely vegetated areas	Includes steppes, tundra and badlands. Includes scattered high - altitude vegetation which are sparsely vegetated owing to erosion or late melting of snow or ice cover (mountain steppes).
334	Burnt areas	Areas affected by recent fires, still mainly black.
335	Glaciers and perpetual snow	Land covered by glaciers or permanent snowfields.

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Code	Name	Description
411	Inland marshes	Low-lying land usually flooded in winter and more or less saturated by water all year round. Marshes may be made up of river ox-bows, areas in which waterways shift from their course, depressions where the round water table reaches the surface permanently or seasonally, or basins where run off or drainage water accumulates. Includes marshes adjacent to lagoons or near rivers flowing into lagoons.
412	Peatbogs	Peatland consisting mainly of decomposed moss and vegetable matter. May or may not be exploited.
421	Salt marshes	Vegetated low -lying areas, above the high tide line, susceptible to flooding by sea water. Often in the process of filling in, gradually being colonised by halophilic plants. Includes estuary marshes receiving fresh or brackish water.
422	Salines	Salt-pans, active or in process of abandonment. Sections of salt marsh exploited for the production of salt by evaporation.
423	Intertidal flats	Generally unvegetated expanses of mud, sand or rock lying between high and low water marks.
511	Water courses	Natural or artificial water courses serving as water drainage channels. Includes canals. Minimum width for inclusion: 100 m.
512	Water bodies	Natural or artificial stretches of water. Includes the water surfaces of dams.
521	Coastal lagoons	Stretches of salt or brackish water in coastal areas which are separated from the sea by a tongue of land or other similar topography. These water bodies can be connected to the sea at limited points, either permanently or for parts of the year only. Estuarine lagoons belong to this category.
522	Estuaries	The mouth of a river, within which the tide ebbs and flows.
523	Sea and ocean	Zones seaward of the lowest tide limit.

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