European Environment Agency
European Topic Centre on
Biological Diversity

Working paper N° B/2013

Review of recent literature on mapping ecosystem services and analysis of methods used

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July 2013

The European Topic Centre on Biological Diversity (ETC/BD) is a consortium of nine organisations under a Framework Partnership Agreement with the European Environment Agency for the period 2009-2013
AOPK-CR ECNC GDNAP TK Turkey ILE-SAS ISPRA JNCC MNHN SLU UBA

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Context:

The Topic Centre has prepared this Working paper in collaboration with the European Environment Agency (EEA) under its 2012/2013 work programmes as a contribution to the EEA's work on Biodiversity-related assessment.

Citation:

Please cite this report as
Götzl, M., Tiefenbach, M., Tramberend, P., and S. Condé, 2013. Review of recent literature on mapping ecosystem services and analysis of methods used. ETC/BD report for the EEA.

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ETC/BD Working paper N° B/2013
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1 Introduction

The European Commission recognises the importance of biodiversity and ecosystem services for attaining a sustainable use of natural capital for human wellbeing and economic prosperity. This is reflected in the EU biodiversity strategy 2020 with its 2020 headline targets and 2050 vision (EC-COM (2011) 244 final). The biodiversity strategy was published in 2011 and aims to achieving by 2050 that biodiversity in Europe and the ecosystem services it provides are protected, valued and appropriately restored. Target 2 of the strategy determines that ‘By 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems’. Therefore, action 5 aims at ‘improve knowledge of ecosystems and their services in the EU’ and appeals the Member States to map and assess the state of ecosystems and their services.

In recent years, a large number of research activities have focused on ecosystem services, resulting in a substantial amount of studies with various methodological approaches and results (e.g. Daily and Matson 2008, Bennett et al. 2009, De Groot et al. 2010, Power 2010, Potschin and Haines-Young 2011, Bastian et al. 2012). Several studies have pointed out the importance of providing maps on ecosystem services as a very valuable tool for decision makers at regional (Gimona and van der Horst 2007, Burkhard et al. 2012), national (Willemen et al. 2008, van Oudenhoven et al. 2012) and EU level (Maes et al. 2001a). Maps have the advantage of providing spatially explicit information and support the understanding of complex systems and interrelationships, a key feature of ecosystems and their services.

This literature review provides an overview of recently published literature on mapping of ecosystem services and ecosystem capacities to deliver ecosystem services in Europe (from regional to continental scale). To facilitate a comparison of the studies´ results we compiled relevant information on the indicators used for quantifying ecosystem capacities and ecosystem services and details on the spatial coverage of the mapping examples. Additionally, we provide information on the data used and their sources as well as a short description of the methodical approaches used.

2 Methodological Approach

2.1 Literature search

The comprehensive literature search used databases provided by the three major publishers for scientific literature: Elsevier, Springer, and Wiley. Additionally, relevant literature was found using the Google search engine. As a third step the literature search was completed by checking the references cited in the relevant papers found in above databases and Google. The literature review concentrated on recently published peer reviewed studies, but also considered comprehensive reports about mapping of ecosystem services (**ESS**) and ecosystem capacities to deliver (specific) services (**ESC**) in Europe and aimed at achieving a reflection of the full variety of ESS according to 'The Economics of Ecosystems and Biodiversity 2010' (TEEB) standard classification.

As far as the choice of the keywords for our literature search is concerned we are in line with other reviews on similar topics (cf. Egoh et al. (2012), 'Indicators for mapping ecosystem services. a review'). For our search we used the terms 'mapping', 'maps', 'biophysical mapping', 'ecosystem services', 'ecosystem functions', 'landscape functions', 'ecosystem capacity', 'landscape capacity', 'evaluation of ecosystem services', 'assessment of ecosystem services', 'spatial indicators' and combined them with the ESS´ names (water, food, raw material, etc.). The choice of these search terms seems to be relevant for a review of 'recently' published papers (not older than year 2000), which was the task of this work.

In total, 65 research papers or reports were included in a further selection process. 34 of them were chosen to be studied thoroughly (see Annex 2) which led to a selection of 13 published research studies being considered in the tables of Annex 1. These tables provide details of 45 ESC/ESS presented in the respective papers. The selection criteria for papers/reports to be presented in Annex 1 were related to the quality and amount of information provided. We chose only those papers which provide sound and sufficient information in an understandable manner on the following issues:

- ✓ the data used and their sources,
- ✓ the indicators used for quantification or qualitative description of ESC and ESS,
- ✓ the quantification of the ESC and ESS,
- ✓ the methodical approach applied, and
- ✓ the maps provided.

Literature on the mapping issue related to areas outside Europe which was found in the course of the literature search is listed in Annex 3. Those papers are not discussed in detail because of the spatial scope of our review.

2.2 Classification of ESS

This literature review uses the classification of ecosystem services compiled for the TEEB assessment (The Economics of Ecosystems and Biodiversity) which evaluates the costs of the loss of biodiversity and the decline in ecosystem services. TEEB proposes a typology of 22 ecosystem services divided into four main categories: provisioning, regulating, habitat and cultural services, mainly following the MEA-classification (Millennium Ecosystem Assessment, MA 2005). In contrast to the MEA-classification, TEEB identified the habitat services as a separate category in order to point out the importance to provide habitat for migratory species and gene-pool protectors and omitted the supporting services such as nutrient cycling and food-chain dynamics which are seen in TEEB as a subset of ecological processes (De Groot et al. 2010).
In table 3.1 we are using the TEEB-Typology of ecosystem services to present the number of published mapping examples per service type.

2.3 Ecosystem functions versus ecosystem services

In some papers considered in this review, authors make a clear differentiation between the terms ‘ecosystem functions’, ‘ecosystem services’ and ecosystem service ‘benefits’ (e.g. Kienast et al. 2009, Haines-Young et al. 2012, van Oudenhoven et al. 2012, Schulp et al. 2012). This differentiation is based on the cascade model (Fig. 2.1), initially suggested by Haines-Young and Potschin (2010). They use the term ecosystem function (ESF) to indicate some capacity or capability of an ecosystem to do something that is potentially useful to people. De Groot and co-authors (2010) published a similar definition for ESF which are defined as the capacity of ecosystems to provide goods and services that satisfy human needs, directly and indirectly (e.g. the amount of fish a lake can provide on a sustainable basis).
With a similar but more specific meaning the term ‘landscape function’ occurs frequently in the literature. It refers to the capacities of landscapes to provide a service (Haines-Young et al., 2012). Here, the landscape function can be considered as a subset of an ecosystem function.

However, whether a function is regarded as an Ecosystem services (ESS) or not depends on the people´s need. Only if specific benefits or beneficiaries can be identified the term ESS should be used according to the cascade model (e.g. the amount of fish harvested for food). This is in line with the definition provided by Boyd and Banzhaf (2007): Ecosystem services are components of nature, directly enjoyed, consumed, or used to yield human well-being. As defined by the authors´ services are things or characteristic, not functions or processes.

This distinction between functions and services is supported by the TEEB study (De Groot et al. 2010) in order to be clear about the meaning of core terms being used. The authors distinguish 'functions' from the even deeper ecological structures and processes in the sense that the functions represent the potential that ecosystems have to deliver a service which in turn depends on ecological structure and processes.

In this context it should be pointed out that the term 'ecosystem function' is used in the literature with different meanings, especially in papers dealing with ecology (Jax, 2005). For example, Cardinale et al. (2012) define ecosystem function as ecological processes that control the fluxes of energy, nutrients, and organic matter through an environment. The authors mention 'primary production', 'nutrient cycling' and 'decomposition' as some examples. But, in our review we are using the following working definition of ecosystem functions: 'Ecosystem functions are the capacity of an ecosystem to deliver a service', which is in the sense of Haines-Young and Potschin (2010, 2012), as mentioned above and used by several of authors (Oudenhoven et al 2012, Schulp et al. 2012, Bollinger and Kienast 2009, Kienast et al. 2009, Willemen et al. 2008).

According to the work of Boyd and Banzhaf (2007) services and benefits are quite distinct. Fisher and Turner (2008) define that a benefit is something that directly impacts on the welfare of people and changes the level of well-being and has to be distinguished from ecosystem services. Van Oudenhoven and co-authors (2012) use the following definition: The benefit is the socio-cultural or economic welfare gain provided through the ecosystem service, such as health, employment and income. This is in contrast to other definitions (e.g. Daily 1997, MA 2005) where services are put on a level with benefits: Ecosystem services are the benefit people derive from ecosystems (Costanza 1997, MA 2005).

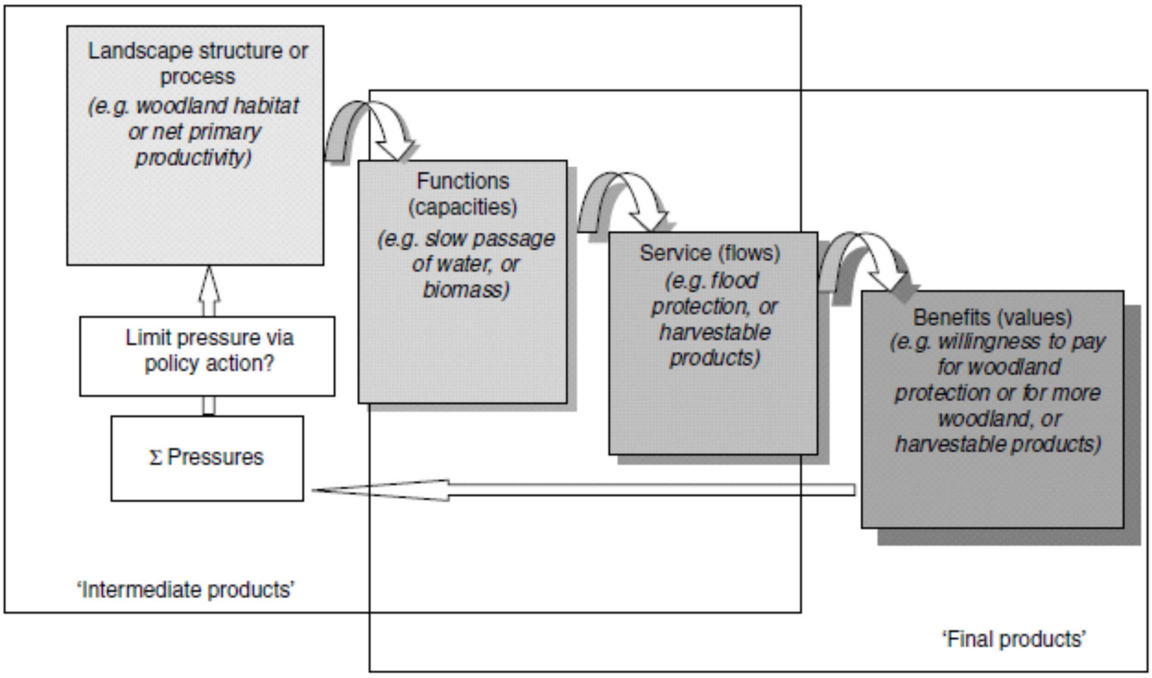


Figure 2.1: The relationship between biodiversity, ecosystem function and human well-being (taken from Haines-Young and Potschin 2010)

It should be noted, that some papers considered in this review do not comply with the definitions of ESF and ESS which are mentioned above. Some authors distinguish between 'supply and demand of ESS' (Burkhard et al., 2012). They relate 'supply of ESS' to the capacity of a particular area to provide a specific bundle of ESS. Therefore, 'supply of ESS' corresponds to the term ESF as used by Haines-Young and Potschin (2010). Whereas, 'demand for ESS' is the sum of all ESS consumed or used in a particular area over a given time period and that corresponds to the term ESS defined at the beginning of this chapter.

Schulp et al. 2012 used the terms 'ESF availability' and "ESS supply". The latter term means the utilization of ecosystem functions (= demand for the function). This may easily be confused with the terminology used by Burkhard et al. (2012), who define the 'supply of ESS' as the ecosystem´s capacity to deliver ESS (see Table 2.1).

Table 2.1 Compilation of different terms corresponding to ESF and ESS used in the literature cited

Ecosystem function (ESF) (= ecosystem capacity to deliver a service)	Ecosystem service (ESS)	e.g. van Oudenhoven et al. 2012 Haines-Young & Potschin 2010 Boyd & Banzhaf 2007
Supply of ESS	Demand for ESS	Burkhard et al. 2012
ESF availability	ESS supply	Schulp et al. 2012
ESS capacity	ESS flow	Maes et al. 2011a

In summary there is no consensus on the terminology and use of the terms ‘ESS’ and EFS’ in the considered papers. Furthermore, the published mapping and quantification examples tend to report jointly on ESF and ESS without a proper distinction. Other studies only focus on ESF (e.g. Willemen et al., 2008; Kienast et al., 2009).

In order to avoid confusion due to the use of a not harmonized terminology, we „translated“ these

various terms in our tables in the following text and in Annex 1 either into ESC (ecosystem capacity to deliver a (specific) ecosystem services, which has the same meaning as ‘ecosystem function’ according to the cascade model presented in Fig. 2.1, but, avoids confusions as the term ‘ecosystem functions’ has different meanings in the ecological literature (see explanation above) or ESS (according to the definitions provided by Haines-Young and Potschin 2012, Boyd and Banzhaf 2007) to make the results of these papers comparable.

3 Results

3.1 Overview of the literature survey

According to the criteria (see chapter 2.1) to select publications for a detailed analysis twelve papers (describing 45 examples for mapping ESC or ESS) were found to provide the essential information necessary for the comparative tables presented in Annex 1. That information contains a clear and comprehensive description of the methodical approach (including the data and the data sources used as well as the indicators and their biophysical units), understandable and sound results and necessary details on the coverage and spatial resolution of the maps presented. Selecting publications according to these criteria should guarantee that each of the 45 mapping examples can be used as a ‘best practice example’ for other mapping projects.

Table 3.1 represents the numbers of the mapping examples per ecosystem service type according to the TEEB-Typology. Additionally, the number of mapping examples for ESC and ESS is provided (see also Fig. 3.1). A further categorization is presented for the parameters ‘use of stock or flow indicators’ and ‘mapping scale’.

Table 3.1: Classification of 45 mapping examples in the analysed literature applying the TEEB 2010 ecosystem services scheme

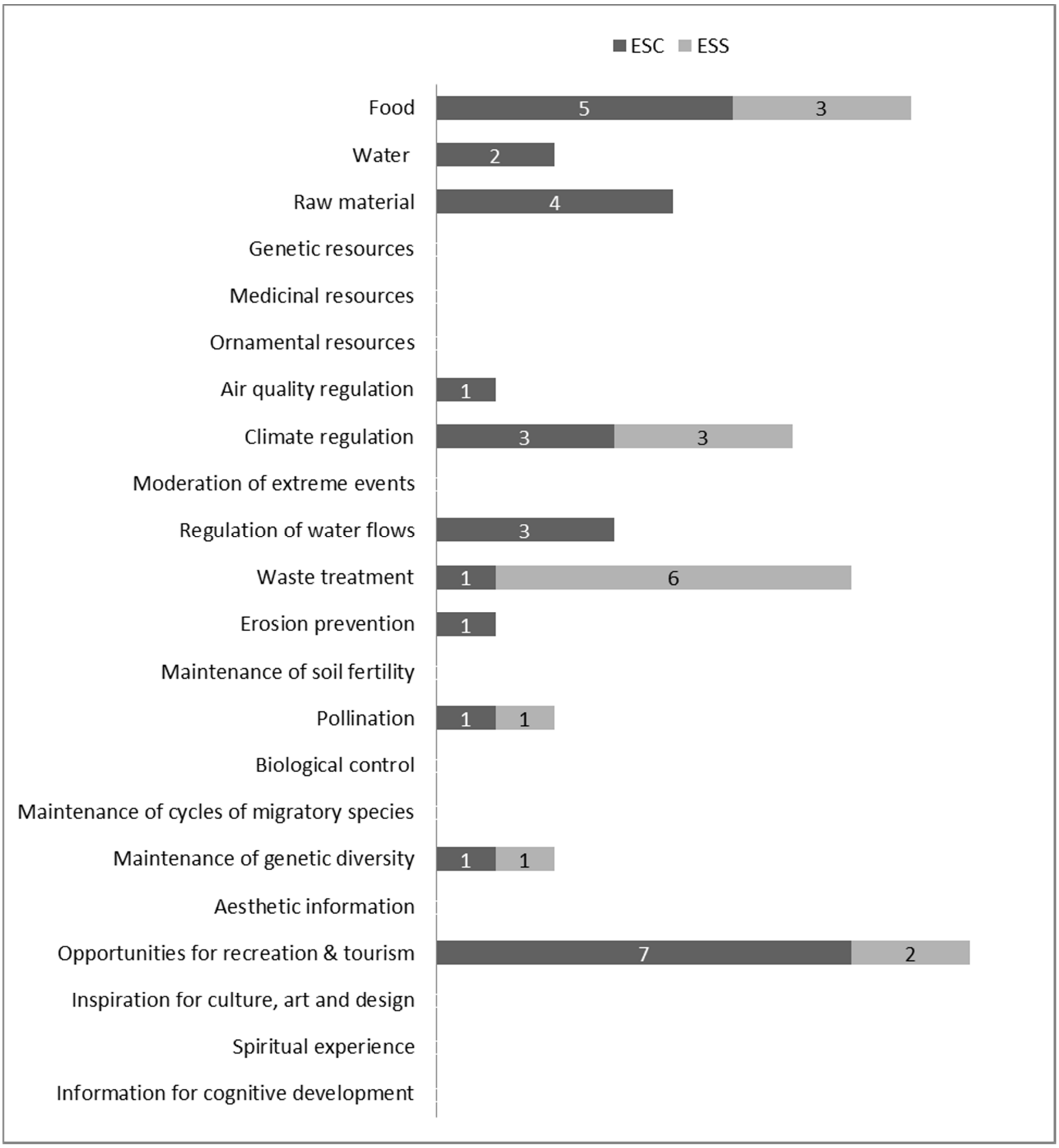
Ecosystem service types (TEEB 2010)	**No. Mapping examples**	Mapping of:		Indicators:		Mapping examples provided at the following scale:				
		ESC	ESS	Stock	Flow	Continental	Sub-continental	National	Regional	Local
PROVISIONING SERVICES	**14**	**11**	**3**	**10**	**4**	**9**	**1**	**1**	**2**	**1**
Food	**8**	5	3	5	3	3	1	1	2	1
Water	**2**	2		1	1	2				
Raw Materials	**4**	4		4		4				
Genetic resources										
Medicinal resources										
Ornamental resources										
REGULATING SERVICES	**20**	**9**	**11**	**9**	**11**	**6**	**5**	**2**	**3**	**4**
Air quality regulation	**1**	1		1			1			
Climate regulation	**6**	3	3	3	3	2	1	2		1
Moderation of extreme events										
Regulation of water flows	**3**	3		3		1	1		1	
Waste treatment	**7**	1	6	1	6	2			2	3
Erosion prevention	**1**	1		1			1			
Maintenance of soil fertility										
Pollination	**2**	1	1	1	1	1	1			
Biological control										
HABITAT SERVICES	**2**	**1**	**1**	**2**		**1**			**1**	
Maintenance of cycles of migratory species										
Maintenance of genetic diversity	**2**	1	1	2		1			1	
CULTURAL & AMENITY SERVICES	**9**	**7**	**2**	**7**	**2**	**2**	**1**	**3**	**2**	**1**
Aesthetic information										
Opportunities for recreation & tourism	**9**	7	2	7	2	2	1	3	2	1
Inspiration for culture, art and design										
Spiritual experience										
Information for cognitive development										
Total	**45**	**29**	**16**	**29**	**16**	**18**	**7**	**6**	**8**	**6**

An example how to read the table (e.g. Climate regulation): There are six examples presented in the literature for mapping approaches relating to Climate regulation. For the mapping of both the ESC and the ESS three examples are provided. Three stock indicators and three flow indicators have been used for the quantification. Two maps are provided at the continental and the national scale each, whereas, one mapping example is provided at the sub-continental and at the local scale each.

The selected mapping approaches (45) relate to eleven ecosystem service categories. Mapping examples are provided for the provisioning services (14), the regulating services (20), the habitat services (2) and the cultural and the amenity services (9).

The frequency of the mapping examples for ESC and ESS are represented in Fig. 3.1 for each of the ecosystem service types. Most of the mapping examples are provided for the service types ‘Food’, ‘Raw materials’, ‘Climate regulation’, ‘Waste treatment’ and ‘Opportunities for recreation & tourism’. For the service types ‘Water’, ‘Raw material’, ‘Air quality regulation’, ‘Regulation of water flows’ and ‘Erosion prevention’ we found only ESC-mapping examples. We found no mapping examples for eleven of the 22 service types.

Figure 3.1: Frequency of mapping examples for ESC and ESS per service type



The authors used different mapping units to display the ESC and the provision of ESS at various spatial scales (see Table 3.2). In particular, NUTS-x regions were used to map ESC or ESS at continental or sub-continental scale (NUTS-x regions are a spatially homogenized combination of NUTS 2 and 3 regions and are preferred over NUTS level 2 and 3, because they have a more uniform size across the European territory (Kienast et al., 2009)).

NUTS-x regions and a 0.5 km x 0.5 km grid were used at continental scale. At the sub-continental scale the authors selected a 0.5° x 0.5° grid. Whereas, at the national scale the ESC and the provision of ESS were displayed using the following spatial units: NUTS 4_5 regions, 10 km x 10 km and 500 m x 500 m. Mapping examples at regional scales were elaborated with grids from 1 km x 1 km to 30 m x 30 m, and CLC polygons. For the local scale the use of grids of 2 km x 2 km and 1 km x 1 km and of various CLC Polygons was reported.

Tab. 3.2: Units for the mapping of ESS and ESC in Europe, at different spatial scales

Mapping units	**Mapping examples provided at the following scales:**				
	Continental	**Sub-Continental**	**National**	**Regional**	**Local**
NUTS-x regions	16				
0.5° x 0.5° grid		7			
NUTS 4_5			2		
10 km x 10 km	1		3		
2 km x 2 km					1
1 km x 1 km				1	2
500 m x 500 m	1		1		
100 m x 100 m				5	
30 m x 30 m				1	
CLC Polygons				1	3
Total	**18**	**7**	**6**	**8**	**6**

3.2 Objectives and uses of the mapping studies

Maes et al. (2012) provide a comprehensive overview of good reasons for mapping ecosystem services. The authors state analyzing the spatial distribution of multiple ecosystem services at various spatial scales as an important field of application for information based on mapping and modelling exercises. There is a strongly varying rationale for mapping ecosystem services among different studies including the evaluation of spatial congruence of ecosystem services with biodiversity, analyzing synergies and trade-offs between different ecosystem services, analyzing trends in ecosystem services, estimating costs and benefits, comparing ecosystem service supply with demand, monetary valuation on biophysical quantities or prioritization of areas in spatial planning and management. In some cases there is a correlation between the objectives of the studies and the spatial scale at witch these modelling and mapping exercises are carried out. Planning studies for example dealing with cost-benefit evaluation, prioritization and trade-off analyses are conducted on sub-national levels, while studies focusing on general trends like spatial distribution and congruence of ecosystem services are carried out on continental or global level.

The studies which were analyzed in the scope of this review cited also some of the objectives mentioned above**. As primary goals for the mapping exercises most the authors specified the establishment of methodologies, the assessment of the spatial arrangement and description of ESC and ESS and their quantification**. Both, the assessment of the spatial arrangement of services and their quantification are basic pre-conditions for all mapping exercises and, therefore, they overlap with all other objectives in these studies.

The following studies mainly focus on the quantification of the ecosystems´ potential to deliver services or on the quantification of ESS itself.

For example, Burkhard et al. (2009) provide a general methodology to evaluate capacities of different landscapes to provide ESS. The authors also describe the use of their methodology in different case studies (in S-Germany, Schwäbische Alp: for establishing the biosphere reserve; in the German North Sea: for the assessment of tourism´s impacts on the Island of Sylt; in the rural-urban region Halle-Leipzig: as part of the PLUREL project; in northern Finland: for forestry and reindeer husbandry).

Willemen et al. (2008) developed a methodological framework to quantify landscape functions and to make their spatial variability explicit. These maps provide policy makers valuable information on regional availability of ESC and ESS.

Another study dealing with the development of methods and the quantification of ecosystem services aims at the quantification of growing stock and above-ground biomass in forests based on remote sensing and field measurements (Gallaun etal. 2010).

In order to produce reliable data to help establish and underpin realistic carbon emission targets and rejection trajectories a quantification of above-ground carbon storage was conducted in a typical British city (Leister) by Davies et al. (2011). The results were compared with a national ecosystem service map to evaluate the national estimates. This work should support acceptable and robust policies for meeting the carbon emission targets.

Lautenbach et al. (2012) developed methods to enable direct mapping of water regulating services compared to classical water quality indicator maps. The multi-scale case study shows how the level of detail of the results varies with the model resolution. The resulting maps are an important information for policy makers and decision makers.

The authors of the following studies mentioned additional objectives for their mapping exercises than quantification.

A study for Eastern Europe presents a methodology to quantify and simulate ESC and ESS (Schulp et al. 2012). The proposed models are targeted for use in the IMAGE framework in scenario studies for assessing **potential impact of global change** on broad spatial patterns of ecosystems´ capacity to deliver services and ESS supply.

Another study dealing with trends of ecosystem services´ provision was published by Haines-Young et al. (2012) who are considering the **effects of land use changes** on the capacity to deliver ESS. This paper also examines how land cover and land use change can be used for the development of a multi-criteria approach to monitoring changes in ecosystem service potential in order to identify where significant changes in natural capital might be taking place.

There was one study estimating the **spatial covariance** between biodiversity and three ESS using Britain as a case study. The authors argue that the location-specific nature of relationships between ecosystem services and biodiversity underscores the importance of multi-scale environmental decision-making in the land use planning.

Kienast et al. (2012) developed a GIS model based on a representative survey to **identify hot spots** for nearby recreation. This methodology can be used by city managers to generate maps of recreation suitability at the local scale for medium sized towns.

A more methodological orientated report (‘A European assessment of the provision of ecosystem services’) was provided by Maes et al. (2011a). In addition to the establishment of various methodologies and the estimation of Europe´s contribution to the provision of ecosystem services, a further objective of this study is to assess **synergies and trade-offs** of ecosystem services. In a further report (Maes et al. 2011b) the authors strive for three objectives: to demonstrate the present **research capacity** for developing maps at different special scales, to identify methods for assessing and reporting on ecosystem **service targets and trade-offs** and to **assess policies** affecting the current and future management of ESS.

One of the studies dealing with the assessment of the capacity of different ecosystems to regulate floods provide maps of supply and demand which were merged to produce a map of regional **supply-demand balances** (Nedkov and Burkhard 2012).

An approach for quantification and **monetary valuation** of ESS is presented by Hönigová et al. (2011). This report also accounts for the full (economic) benefits provided by grasslands in the Czech Republic.

The studies´ analyses did not reveal different objectives of the mapping approaches dealing with ESC or with ESS. In a lot of mapping exercises there are no data available on the amount of ESS´ use by humans. Therefore, quantification of ESC or their qualitative description is the only way to receive relevant data for the mapping.

There was also no correlation between mapping objectives and the three categories of methods used in the literature we analyzed (A: Quantitative modelling analysis and mapping based on own case studies, B: Quantitative modelling analysis using existing data, C: Mapping approaches based on expert knowledge and literature findings). These three categories differ in the quality and the origin of the data. Additionally, the qualitative and quantitative assessment is based either on modelling analysis or on expert judgement. The most precise results will be received by those modelling analysis which are using a very detailed data basis. This will be the case if the data are derived from own case studies which are harmonized with the objectives of the mapping approach. Usually, the case studies are available on the regional level due to the amount of work and the subsequent costs. At continental or national scale other data sources have to be used often with less detailed data and a lower spatial resolution. In any case, for all the mapping objectives mentioned in the studies the most detailed data analyzed by the most appropriate computer models would be the ideal approach.

3.3 Overview of mapping approaches

The flow of ecosystem services depends on the capacity of ecosystems to deliver different services and the demand from society for the benefits they provide (Bolliger and Kienast 2010). Therefore, to quantify an ecosystem service needs data on the extent of this service to be 'used', 'consumed' or 'enjoyed' by the people who are the beneficiaries of this service (c.f. Boyd and Banzhaf 2007). If this information is not available the quantification and mapping has to focus on the supply side of this service (ESC). It is important to differentiate between these two approaches to avoid misinterpretation if the results are compared (Lamarque et al. 2011).

Spatially explicit information like maps have a high potential to support the understanding of complex systems and interrelationships (Dresner 2008). Therefore, both mapping of ESS and ESC are powerful tools to visualize complex phenomena. But, they produce different information which can be used to answer different questions.

The diverse mapping approaches analysed in this review vary considerably in the scope of the analysis as well as in the assessment of the ESS. Some authors published mapping approaches for 'ESS supply' and 'ESS demand' (e.g. Burkhard et al. 2012, Willemen et al. 2008, both at regional scale). Whereas, other authors focus on the potential of an area to deliver an ESS without biophysical quantification (Schulp et al. 2012, at sub-continental scale). In further studies the estimation of the areas´ current potential to deliver a service is based on expert knowledge (Haines-Young et al. 2012, at continental scale).

In the following text we describe selected mapping exercises for ESC, ESS and the value of ecosystem services to give an impression of what can be mapped in the scope of the ecosystem service concept, what indicators can be used and what methodical approaches are presented in the papers.

Mapping the capacity of ecosystems to provide (single) services

Burkhard et al. (2012) provide in their publication basic considerations on the assessment and mapping of ESC. The authors state that individual ecosystem capacities to supply services are strongly linked to natural conditions (natural land cover, soil conditions, hydrology, fauna, etc.) and human impacts (land uses, emissions, pollution, etc.). All this information and related data should be as detailed as possible, in a relevant resolution and at an appropriate scale when defining the capacities of different ecosystems to supply services. Land cover information from remote sensing, land survey, simulation models, and statistical data are appropriate starting points.

A concrete ESC mapping approach is presented by Nedkov and Burkhard (2012) aiming in the assessment of different ecosystems´ capacity to regulate floods and the demand for this service. **Maps of supply** show the ecosystems´ flood regulating service capacities in a case study area (Etropole municipality, Bulgaria). A comparison with **maps of demands** for flood regulating ecosystem services shows that areas of high relevant demands are located in places of low relevant supply capacities. Regional supply-demand maps reveal if there is a close connection between the area of service supply and service demand. This knowledge allows the planning of further flood regulation measurements.

Haines-Young et al. (2012) used mapping indicators of the potential of ecosystems to supply the ecosystem service ‘crop-based production’. The authors produced maps showing the **potential** of an area to deliver crop-based production indicated by dimensionless values. Furthermore, they included in their analysis whether the historical and the projected land use changes for selected time periods are likely to be supportive or degenerative in the capacity of ecosystems to deliver ecosystem services.

Mapping ecosystem services

Schulp et co-authors (2012) are presenting several examples for the mapping of ESS, for example showing the actual use of the pollination service. In a first step they defined the yield reduction fraction which is the percentage yield loss due to the diminished pollination of pollinator-dependent crops. In a second step the ESS for pollination was calculated as the additional yield per area and year for pulses and oil crops. The **maps of pollination supply** are presented for Eastern Europe and show the extra annual yield due to good wild pollination. In this approach the authors mapped ESS as the use of ESC by humans using spatial data on human impact.

ESS mapping of water purification is described by Maes et al. (2011a). The ESS was quantified based on the annual amount of nitrogen removal per ha and the services flow was calculated using a statistical model to estimate nitrogen fluxes to surface water. The removal of nitrogen is the product of retention capacity and nitrogen input.

Mapping the value of ecosystem services

Ecosystem service values have been reported in many different metrics and currencies for different timer periods and price levels. Expressing the value of ecosystem services in monetary units is an important tool to raise awareness and convey the importance of ecosystems and biodiversity to policy makers (de Groot et al. 2012).

The value of ecosystem services in monetary terms was mapped by Costanza et al. (1997) at global scale. Based on the approach of value transfer other papers present how to quantify and map the monetary value of ecosystem services at global (Turner et al. 2007) and regional scale (Troy an Wilson 2006). The value or benefit transfer method uses valuation results of ecosystem services derived from one study site to transferred is to other localities.

Hönigova and co-authors (2011) presented in their study a mapping approach dealing with the monetary value of water regulation provided by grassland in the Czech Republic. Quantification of the water flow regulation was based on the runoff coefficient which describes the ratio between runoff and rainfall and enables to express in biophysical units the capacity of soil to retain water which reduces runoff. The economic value was calculated using a replacement cost method considering the average costs of artificial water retention. The maps display the ESS´ value provided by various grassland ecosystems in each of the 206 administrative units used in the Czech Republic.

Indicators and methods

The quantification of ESS is a prerequisite for their mapping. Some ESS can be directly quantified if the amount of those ‘components of nature that are directly enjoyed, consumed or used’ (cf. Boyd and Banzhaf 2007) is known. For example, this might be the case for the annually harvested firewood in a region or the amount of drinking water consumed by the inhabitants of a city during a year. If ESS cannot be directly quantified their quantification has to be based on proxy indicators, for example, the quantity of air pollutants captured by leaves as a proxy indicator for air purification services (Maes et al. 2012) or the additional yield of crops due to wild pollination (Schulp et al. 2012).

But, data for the quantification of ESS are limited which is the main obstacle to ESS modelling and mapping approaches. As quantification of ESC does not need data on human use of the respective ESS mapping examples are more often presented in the literature.

Information on ESC can be derived from land-use or land-cover maps. Such approaches are appropriate if the ESC directly relates to the land use (e.g. crop or timber production) (Maes et al. 2012). In this case there is a direct linkage between the land cover and the occurrence of a specific ESC which is quantified by the extent of the land cover.

In other cases, ESC may be non-directly observable, so that location and extent of these functions are only partly known. Non-directly observable landscape capacities necessitate the inclusion of field observations prior to extrapolating ESC from spatial indicators. Assuming, that land cover, biophysical and socioeconomic landscape components can be used to describe the location and ESC, these different components are translated into spatial indicators and empirical models are used to quantify the influence of these spatial indicators on function variability. For example, Willemen et al. (2008) quantified the capacity to provide an attractive landscape for overnight tourism by means of tourism suitability. Delineation of this capacity was considered 'partial' as the suitable landscape for tourism goes beyond the location of tourism accommodations.

If there are no data on location and extent of ecosystem capacity are available spatial indicators and literature based decision rules or expert knowledge based decision rules are used to come to a quantitative landscape function or ESS map. This approach was used for example by Burkhard et al. (2009) who linked available land cover data to expert judgements about the different land cover types´ capacity to provide various ecosystem services. The assessments are based on a high number of qualitative data which does not allow for a sound quantification of the ESC. Maps can be based on this more qualitative assessment using dimensionless values for the capacity.

In the literature usually ESC is described by stock indicators, whereas, ESS should be quantified using flow indicators at the best. If this is not possible changes of stocks can be used as an approximation of flows. For example, Willemen et al. (2008) introduced for the ESS 'Habitat for rare, endemic and indicator plant species' a dimensionless stock indicator for the conservation value as a proxy.

Stock indicators are defined as the quantitative amount of ESC available at a certain point in time. Whereas, flow indicators relate to quantities used by humans over certain time periods.

Maes et al. (2011a) for example quantified the ESC of above- and belowground carbon storage in living plants by using the stock indicator tons of carbon per hectare (t C ha^{-1}). In the same study the ecosystem service ‘climate regulation’ were measured by tons of carbon per hectare and year (t C ha^{-1} yr^{-1}) as flow indicator for the net ecosystem’s annual carbon fixation.

Annex 1 provides information on the use of ‘stock indicators’ and ‘flow indicators’ for the quantification of either ESC or ESS (including details on the biophysical units used).

The development of robust indicators for mapping and modelling ESS or ESC is also an important step towards meeting the EU biodiversity targets for 2020. To support such efforts Egoh et al. (2012) prepared a review on indicators for mapping ecosystem services. They identified spatial indicators that have been used to map and quantify ecosystem services and compiled available spatial data on indicators in the Joint Research Centre. This report complements our review as far as a compendium of indicators for different ecosystem services is concerned which was not task of our review to be delivered.

3.4 Overview of methods used in the literature

This study clusters the applied methodologies in the reviewed papers into three main categories: i) quantitative modelling analysis & mapping based on own case studies, ii) quantitative modelling analysis using (often aggregate) existing data; iii) expert knowledge and literature findings.

It should be noted, that the review presented here does not aim for an assessment of the applied methodologies in the diverse studies for the reason that such an evaluation would require an in depth knowledge of the applied models or the model-based calculations.

Quantitative modelling analysis & mapping based on own case studies *(A)*

Several papers are based on case studies in a certain area or landscape with a focus on one specific ecosystem function or service ore a few ones.

Davies et al. 2011 for example examined the capacity and spatial patterns of above-ground carbon storage at a city-wide scale by surveying vegetation in several urban areas of Britain. Biomass and carbon storage in trees were calculated for each tree using equations obtained from the literature. The authors compared their results with the existing national map for carbon storage service and demonstrated that current national estimates of above-ground carbon storage for Britain do not adequately reflect the capacity and spatial patterns in urban areas.

As a case study on national-scale Anderson et al. (2009) presented estimates of spatial covariance for ESS such as carbon storage and recreation services in the UK. They based their study on vegetation carbon data taken from literature and number of rural outdoor visits from published results of a survey of leisure trips of the entire English population. A similar approach is also used by Eigenbrod et al. (2009).

In a report to the European Topic Centre on Biological Diversity Hönigova et al. (2011) mapped grassland ESC based on land cover data using the 'habitat approach' which combines an assessment based on biophysical indicators and on particular habitat categories. The used data was derived from field survey conducted for the entire Czech Republic.

Quantitative modelling analysis using existing data *(B)*

Maes et al. (2011a) published 'A European assessment of the provision of ecosystem services' presenting indicators for 13 ESC and ESS which cover the European continent. This assessment was largely based on existing information available through pan-European databases providing data predominately derived from remote sensing, simulations, and environmental models. Maes et al. (2011a) followed the approach to collect already existing spatial information on ecosystem services and subsequently linked this information to ecosystems.

Schulp et al. (2012) mapped a set of ESC (7) and ESS (7) based on IMAGE simulations and global-scale data for Eastern Europe. IMAGE is an integrated environmental assessment model framework that simulates the environmental consequences of human activities worldwide. The objective of IMAGE is to explore the long-term dynamics of global change as a result of interacting demographic, technological, economic, social, cultural, and political factors. The models developed in this study were based on processes and describe ESC and ESS provision at continental scale.

Expert knowledge and literature findings *(C)*

Burkhard et al. (2009) allocated 44 CORINE land cover types to 29 ESS by expert judgement and literature findings. The capacity of different land cover types to provide various ESS in the Halle-Leipzig region in Germany was classified in 6 levels from 'no relevant capacity' to ‘very high relevant capacity’. This approach is based on a high amount of qualitative data and rather large spatial units. For future assessments, Burkhard et al. (2009) proposed the integration of additional landscape characteristics such as elevation, slope, type of soils, hydrology, vegetation, climatic and weather conditions as well as changes in land use. This proposed refinement would lead to a better consideration of the heterogeneity of landscape features and values which are not suitably represented in the CORINE classes. The applied method, described above, has also been used in a further paper by Burkhard et al. (2012) for ESC mapping.

Kienast et al. (2009) used a set of context variables, such as bio-geographical region, altitude, slope and proximity to urban areas to modify the strength of linkages between land cover and the potential of ecosystems to provide ESS at European scale.

Haines-Young and co-authors published a study in 2012 presenting an approach to mapping indicators of the potential of ecosystems to supply four ESS. Similar to both of the above mentioned studies the authors used link tables which are expressing to what degree land characteristics have a supportive role or a neutral role for ecosystem services. Those tables were generated with the aid of expert knowledge and the scientific literature. This study is one of a few providing mapping examples at the EU scale, but in contrast to Maes et al. (2011a), only for a limited number of ESC.

Other studies (Troy and Wilson, 2006; Naidoo et al., 2008) show, that complex response functions are able to capture the relationship between ESS or ESC and land cover characteristics quite adequately. However, these approaches seem not to be feasible on continental scale as the interrelationship between land cover characteristics and their potential to provide ESS are either unknown or the level of detail of the input parameters does not meet the requirements for a proper up-scaling of non-linear behaviour observed at a lower scale.

3.5 Methodical approaches and geographical coverage

Tables 3.1 and 3.3 show that 56% of the mapping examples are published for Europe (continental scale) or Eastern Europe (sub-continental scale). At these scales twenty of the mapping examples are based on quantitative modelling analysis using existing data from various data bases. In a few cases estimation of the ecosystems´ capacity to provide services is based on expert judgement or expert knowledge published in the literature. There is only one European case study used as a data base for a GIS model to produce ESC maps (A (26), Tab. 3.3).

Table 3.3: Geographical coverage of mapping examples and kind of methodical approaches used

(letters in the cells refer to the different kinds of approaches used for the mapping of ESS and ESC. Numbers in parentheses refer to the mapping examples listed in Annex 1. Mapping examples of ESS are highlighted with grey fields, *regional* mapping examples are in *italic letters* and **local** mapping examples are in **bold letters**)

	Europe	**Eastern Europe**	**Czech Republic**	**Finland**	**Britain**	**Netherlands**	**Bulgaria**	**Germany**	**Switzerland**
	Continental	sub-continental	national	national	national **local**	national *regional*	*regional*	*regional* **local**	**local**
Provisioning Services									
Food	C (1) B (2,3)	B (4)	A (5)			*B (6,7)*		**C (8)**	
Water	B (9,10)								
Raw materials	B(11,12,13) C (14)								
Regulating Services									
Regulation of air quality		B (15)							
Climate regulation	B (16,17)	B (18)	A (19)		A (20) **A (21)**				
Regulation of water flows	B (22)	B (23)					*B (24)*		
Waste treatment	A (26) B (25)				**B (29)**			*A (28)* *B (27)* **A (30)** **B (31)**	
Erosion prevention		B (32)							
Pollination	B (33)	B (34)							
Habitat Services									
Maintenance of genetic diversity	C (35)					*B (36)*			
Cultural Services									
Opportunities for recreation & tourism	B (37) C (38)	B (39)		B(40)	A (42)	B (41) *B (43, 44)*			**A (45)**
	1 x A 13 x B 4 x C	7 x B	2 x A	1 x B	3 x A 1 x B	6 x B	1 x B	2 x A 2 x B 1 x C	1 x A
	1 x A 20 x B 4 x C		8 x A 11 x B 1 x C						

A: Quantitative modelling analysis based on own case studies (used for 9 mapping examples)
B: Quantitative modelling analysis using existing data (used for 31 mapping examples)
C: Methodical approach based on expert knowledge and literature findings (used for 5 mapping examples)

At the national and sub-national scale data from own case studies were used for 40% of the ESS/ESC maps. 55% of the mapping examples were based on quantitative modelling analysis using existing data. Only in one case expert judgement was the basis for a quantitative evaluation of an ESC.

Mapping examples at the national scale considered in this review are published for Britain, Czech Republic, Finland, and the Netherlands. Only two ecosystem service types are provided for each country at most. There may be several reasons why we found only a limited number of mapping approaches published. On the one hand there are ongoing efforts to map ESS by a number of countries. But, on the other hand they are not published yet. In further cases national mapping approaches might be published in not peer reviewed journals or they are not published in English language. During our literature search we also found several 'ecosystem assessment studies' at the national scale (e .g. for Britain) which might be the first step for an ecosystem service mapping in the future. But, they are no mapping studies in the sense of our review. Additionally, we arranged strict selection criteria (see chapter 2.1) to guarantee the reader best practice examples which may serve as a guidance for own mapping efforts. Therefore, we decided to reject some studies which did not provide all detailed information on the data use, the methodology applied or the mapping itself.

As far as the geographical coverage and the mapping of ESS or ESC is concerned 75% of the mapping examples at continental and sub-continental scale refer to ESC. Only 25% are based on the quantification of ESS (Tab. 3.4). At the national, regional and local scale together 55% of the mapping examples refer to ESS, and 45% to ESC. But, for the national scale there are one third ESS maps provided. This is in contrast to the local scale, because 83% of the maps refer to ESS. A sound reason for this may be that data for quantification of ESS due to case studies are more often available at local or regional scales. This fact justifies that proper guidance is needed on how data from detailed case studies can be used for an up-scaling from lower scales.

Table 3.4 Geographical coverage versus ESS or ESC

	Continental	Sub-continental	National	Regional	Local	
ESS	2	3	2	4	5	16
ESC	16	4	4	4	1	29

	18	7	6	8	6	45

The different methods described in the considered papers are suitable for the assessment of ESS as well as ESC. Table 3.5 shows that a quantitative modelling analysis using existing data (= 'method B') has been used twice as much for the quantification of ESC as for ESS. Additionally, this kind of method was used four times more often to quantify ESC than ESS. This is based on the fact that 64% of all mapping examples considered are dealing with ESC and not because this method is more suitable for the quantification of ESC.

Table 3.5 Methodical approach versus ESS or ESC

	Method A	Method B	Method C	
ESS	5	10	1	16
ESC	4	21	4	29
	9	31	5	45

A: Quantitative modelling analysis based on own case studies
B: Quantitative modelling analysis using existing data
C: Methodical approach based on expert knowledge and literature findings

4 Conclusions

The spatial mapping approaches analysed in our review vary considerably in the scale and scope of the analysis as well as in the selection of the assessed ESS. The literature review reveals an uneven distribution of mapping of ESC and ESS among the 22 service types of the TEEB 2010 Typology scheme

Most studies refer to the ESS categories: “provisioning services” and “regulating services”; only a few to “cultural and amenity services” or “habitat services”. Two thirds of analysed mapping examples focus on four ecosystem services such as food, climate regulation, waste treatment and opportunities for recreation and tourism. Only few mapping examples were found for water provision, pollination and maintenance of genetic diversity. There are no methods and or data described for mapping ecosystem services like biological control, maintenance of life cycles of migratory species, aesthetic information, and inspiration for culture, art and design, spiritual experience, information for cognitive development and medicinal resources. Similar findings are reported by other authors (Maes et al. 2012).

Most of the studies provide information on a limited subset of ESC and / or ESS, which is in line with results published by Seppelt and co-authors (2011).

40 % of the European mapping examples are conducted at the continental scale (EU27 and EU25 plus Switzerland and Norway) published in two studies (Maes et al. 2011a, Haines-Young et al. 2012). Mapping examples at the sub-continental (Eastern Europe), the national, the regional and local scale are provided to a similar extent (16, 13, 18 and 13 % respectively). **Mapping examples at the national scale have been reported for the Czech Republic, Britain, Finland and The Netherlands**.

At the continental and the national scale 80 % of the mapping examples are dealing with ESC. Whereas, at the local scale 80 % of the mapping examples relate to ESS. At the other scales there is no or minor difference in the frequency between ESC and ESS.

Most of the mapping examples refer to **terrestrial and freshwater ecosystems**. Only some studies assessed ecosystem services which are relevant to coastal areas. This finding is also reported by Maes et co-authors (2012) who assert that marine ecosystems are largely overlooked. The reasons for this are discussed in their paper.

Three common methodological approaches for assessing ESS have been identified: quantitative modelling analysis & mapping based on own case studies, quantitative modelling analysis and simulations using often aggregate existing data, and expert knowledge and literature findings.

The literature review revealed the lack of a consistent definition of ecosystem services and a lack of homogeneous differentiation between ecosystem functions and ecosystem services. Some papers e.g. distinguish between the “supply of ecosystem services”, the “demand for ecosystem services” others between “ecosystem function availability” and “ecosystem services supply”. A consensus on common definitions is desirable to reach consistency in mapping approaches. Additionally, Maes et al. (2012) raise the need to adopt more rigid methodical framework as well as the need to standardize definitions for each service and methods for mapping them to achieve comparable results.

It should be noted that the availability of data is the most crucial condition for successful mapping of ecosystem services at any scale. Kienast and co-authors (2009) found that the recent literature covering both ESS and landscape functions, has a strong bias towards production and regulation services, which supports our above mentioned findings. In particular there is lack of appropriate methods and data to assess information function (Willemen et al. 2008). But, also for other cultural services there are no data available at the EU scale.

In response to the lack of data a model-based up-scaling of monitoring data derived at small units (e.g. forest districts, farms) were undertaken. But, up-scaling of detailed data from lower scales does not always contribute to an improvement in the data base on a regional scale. Furthermore, knowledge of the interactions between different ecosystems or land cover classes is rather limited and impacts the credibility of up-scaling modelling results from single ecosystems or land cover classes (Koschke et al. 2012). Some papers could prove that the spatial extent of analyses has a great influence on the results (Kremen et al. 2000, Anderson et al. 2009) which has to be considered if up-scaling is envisaged.

To get an overall comparable picture throughout Europe, data availability in the member states is essential. If there is a lack of similar data within the member states expert judgment should be considered as the most appropriate approach.

Mapping of ecosystem services is a very valuable tool for decision makers at regional, national and EU level, because spatially explicit information, like maps, has a high potential to support the understanding of complex systems and interrelationships.

Taking into account the EU Biodiversity strategy 2020, which guides EU member states to identify ESS provided on their territory in order to prevent any degradation of these ESS and to enable restoring them, a clear terminology and consensus about definitions and more harmonized mapping approaches across EU-member states would surely foster actions for achieving the targets of the EU Biodiversity strategy 2020.

5 Annexes

Annex 1: Details on European mapping examples of ESS & ESC published in recent literature
Annex 2: References referring to the Mapping of ESS & ESC at different European scales
Annex 3: References referring to the Mapping of ESS & ESC outside Europe
Annex 4: Additional references
Annex 5: Abbreviations used in the report

5.1 Annex 1: Details on European mapping examples of ESS & ESC published in recent literature

Annex 1 presents a detailed account of 45 ESC or ESS being mapped in the respective papers. It provides details on the use of stock and flow indicators, on the biophysical units and on the spatial resolution of the maps. Furthermore, the coverage of the maps and the data and their sources are presented. A brief methodological summary should enable an insight into the mapping approach of each example.

This example table provides explanations for the different fields used in the following tables:

Service category (TEEB 2010)	**PROVISIONING SERVICES, REGULATING SERVICES; HABITAT SERVICES OR CULTURAL SERVICES**
Service Type (TEEB 2010)	**Ecosystem service type according to Tab. 3.1 (chapter 3.1)**
ESC name	Name of ESC used by the authors (only if an ESC has been mapped, otherwise n.r.)
ESS name	Name of ESS used by the authors (only if an ESS has been mapped, otherwise n.r.)
Objectives of the study	Objectives of the study providing the mapping approaches mentioned by the author(s)
Stock indicator	Definition of stock indicator used for quantification (if provided by the authors, otherwise n.r.)
Flow indicator	Definition of flow indicators used for quantification (if provided by the authors, otherwise n.r.)
Biophysical unit of indicator	Units of the indicator used
Type of ecosystem(s)	Type of ecosystem(s) for which the mapping examples have been conducted. Typology according to MAES Working Group.
Spatial resolution of the map	e.g. NUTS-x regions (NUTS-x regions are a spatially homogenized combination of NUTS 2 and 3 regions and are preferred over NUTS level 2 and 3 since they have a more uniform size across the European territory)
Coverage	Countries covered by the maps
Mapping scale	Continental, sub-continental, national, regional or local scale
Data & source	Date used for the mapping and the respective data sources
Kind of methodical approach	Quantitative modelling analysis based on own case studies or quantitative modelling analysis using existing data or mapping approach based on expert knowledge and literature findings (detailed explanation is provided in chapter "Overview of methods used in the literature")
Methodical approach	Short description of the methodical approach used by the authors
Comments	Only if there are comments provided by the authors in regard to the method used (e.g. shortcomings or limitations of the method). This information is NO reflection on the methodical approach provided by the review´s authors!
Reference	Author(s), year of publication, and journal / report

1

Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Food**
ESC name	Crop-based production
ESS name	n.r.
Objectives of the study	Develop a methodology for assessing ecosystems´ capacity to supply ecosystem services and for monitoring changes in ESS and scenarios including trade-offs.
Stock indicator	Potential of an area to deliver this service (mean importance score)
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless value
Type of ecosystem	Cropland
Spatial resolution of the map	NUTS-x regions
Coverage	EU25 plus Switzerland and Norway
Mapping scale	Continental
Data & source	CORINE land cover maps (1990, 2000, 2006) Land and Ecosystem Accounting database (LEAC) EURURALIS 2.0 land use scenarios 2000-2030 (based on four IPCC SRES land use scenarios)
Kind of methodical approach	Methodical approach based on expert knowledge and literature findings
Methodical approach	Different classes of independent land characteristics (classes of CLC, mountain terrain, nature protection, landscape protection zones, mean actual net primary production, buffered coasts, wetlands, large rivers, classes of land accounts for Europe) were selected to express its supportive or neutral role for crop-based production. This estimation of the areas´ current potential to deliver the ESS was based on expert knowledge and findings in literature. Additionally, the impact of marginal changes in service output was assessed as well as the consequences of projected changes up to 2030.
Comments	This approach was chosen to create a method for assessing changes in the capacity of ecosystems to deliver ESS. It is based on the assumption, that land cover and land use data are reasonable proxies for estimating the potential of land to provide ESS. But temporal dynamics and variability should kept in mind. Absolute flows of ESS may not be measureable by this method. The continent-wide approach should be improved in future, if more independent data will be available. Trade-off analysis between selected ESS was conducted where land use trajectories over 40 years are taken into account.
Reference	Haines-Young et al. 2012 (based on a method described and used by Kienast et al. 2009)

2

Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Food**
ESC name	Crop services
ESS name	n.r.
Objectives of the study	Establishment of methodologies for estimating the contribution of European ecosystems to the provision of ESS and for assessing synergies and trade-offs.
Stock indicator	Share of cropland per NUTS statistical area
Flow indicator	n.r.
Biophysical unit of indicator	(ha x ha^{-1}) x 100%
Type of ecosystem	Cropland
Spatial resolution of the map	NUTS-x regions
Coverage	EU27
Mapping scale	Continental
Data & source	CLC2000 raster data
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Capacity of agro-ecosystems to provide crop services is approximated using the area of agricultural land cover classes
Comments	Limitations mentioned by the authors: Includes a mixture of different crops, serving as food or fodder and other raw materials. No consideration of cropland productivity.
Reference	Maes et al. 2011a

3

Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Food**
ESC name	Livestock services
ESS name	n.r.
Objectives of the study	Establishment of methodologies for estimating the contribution of European ecosystems to the provision of ESS and for assessing synergies and trade-offs.
Stock indicator	Number of cattle, goat and sheep per NUTS statistical area
Flow indicator	n.r.
Biophysical unit of indicator	Number km^{-2}
Type of ecosystem	Grassland
Spatial resolution of the map	NUTS-x regions
Coverage	EU27
Mapping scale	continental
Data & source	FAO - gridded livestock data
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Assuming that density of grazing livestock reflects the capacity of grassland to provide livestock services
Comments	Limitations mentioned by the authors: Real capacity of grassland to provide livestock is not considered. There is no European harmonized map of grassland available. Information on the management of grassland should be taken into consideration when net capacity is to be mapped.
Reference	Maes et al. 2011a

4

Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Food**
ESC name	n.r.
ESS name	Food crop yield
Objectives of the study	To develop spatially explicit ESS models for quantifying and simulating ESS and ecosystems´ capacities.
Stock indicator	n.r.
Flow indicator	Actual annual food crop yield
Biophysical unit of indicator	Mg km^{-2} yr^{-1} (t km^{-2} yr^{-1})
Type of ecosystem	Cropland
Spatial resolution of the map	0.5° x 0.5° grid cells
Coverage	Eastern Europe (Estonia, Latvia, Lithuania, Belarus, Poland, Albania, Macedonia, Bulgaria, Rumania, Moldova, Ukraine)
Mapping scale	Sub-continental
Data & source	Data on land cover (GlobCover global land cover map), elevation (Gtopo 30 global), precipitation, temperature, soil characteristics, population density, crop fraction and management intensity
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Analysis of ESS provision are based on global-scale data, results are presented for Eastern Europe. The mapping of ESS was based on IMAGE simulations (to explore the long-term dynamics of global change). For each ESS a model of the relationship between ecosystem properties and ecosystem capacity of supplying ESS was developed using published data. ESS were derived from ecosystem capacity by including their use by quantifying the human demand. Food crop yield was defined as the potential yield of all crops a location can provide. Potential yields were calculated as a function of climate, soil and relief conditions. The ESS for food crop yield is the actual yield by and was calculated from the potential yield by including the actual crop cover and the crop specific and region specific management factors.
Comments	The authors argue, that the developed models are suitable for global-scale use to describe availability of ecosystem functions (capacity) and supply of ESS, although the case study area does not comprise the complete range of biophysical, socio-economic, land-cover, soil and climate conditions that should be covered in a global-scale model. The model outputs have been compared with other data from several data sources to prove the credibility of the results.
Reference	Schulp et al. 2012

5

Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Food**
ESC name	Livestock provision
ESS name	n.r.
Objectives of the study	Quantification and monetary valuation of ESS to account for the full benefits provided by grassland
Stock indicator	Maximum Livestock Capacity (MLC)
Flow indicator	n.r.
Biophysical unit of indicator	Livestock units (LU) per mapping unit
Type of ecosystem	Grassland
Spatial resolution of the map	Administrative units ORP (206 units in Czech Republic), which is in between NUTS4 and NUTS5
Coverage	Czech Republic
Mapping scale	national
Data & source	Data for grassland dry matter productivity are taken from literature. Habitat mapping layer is a product of field survey conducted all over the Czech Republic. Habitat classification by the Habitat Catalogue of the Czech Republic.
Kind of methodical approach	Quantitative modelling analysis based on own case studies
Methodical approach	MLC is based on area of particular grassland categories, average dry matter productivity of these categories, livestock weights and pasture period (Hakova et al. 2004). Based on different productivity rates of grassland categories, the maximum livestock number and Livestock units (LU) per ha (and per units) could be estimated.
Comments	Advantage of this method mentioned by the authors: Used MLC methodology takes the different productivity of the specific grassland categories into consideration.
Reference	Hönigová et al. 2011

6

Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Food**
ESC name	n.r.
ESS name	Arable production
Objectives of the study	To present a methodological framework for quantifying and mapping landscape functions depending on the availability of spatial information.
Stock indicator	n.r
Flow indicator	Maize production per year
Biophysical unit of indicator	t ha^{-1} yr^{-1}
Type of ecosystem(s)	Cropland
Spatial resolution of the map	100 m x 100 m
Coverage	Gelderse Vallei region (Netherlands)
Mapping scale	regional
Data & source	Farm characteristics were derived from farm census data (Geografische Informatie Agrarische Bedrijven, Wageningen)
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Function delineation for arable production were based on the location of arable production fields. Arable agriculture cannot be fully delineated by land cover, because of rotation practices. The arable production function was quantified based on the crop yield (only maize) reported per postcode area. Each maize field was assigned the value of the average maize production of the postcode area in which it was located. To analyse the relations between the arable production function and landscape data, a multiple linear regression was used. Important landscape characteristics to explain the spatial variation in arable production in the Netherlands are soil type, groundwater level and farm characteristics (size in hectares, number of farms per postcode areas).
Comments	Although the proposed methodology has been specified for the case study area, the general approach should be applicable to other case studies as well. But different areas will have different data availability, different function definitions and thresholds to be applied.
Reference	Willemen et al. 2008

7

Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Food**
ESC name	Intensive livestock
ESS name	n.r.
Objectives of the study	To present a methodological framework for quantifying and mapping landscape functions depending on the availability of spatial information.
Stock indicator	Economic farm size of intensive livestock farms (Dutch standard unit, DSU)
Flow indicator	n.r.
Biophysical unit of indicator	DSU of economic farm size
Type of ecosystem	Grassland
Spatial resolution of the map	100 m x 100 m
Coverage	Gelderse Vallei region (Netherlands)
Mapping scale	regional
Data & source	Topographic data (1 : 100 000 map, Topografische Dienst Kadaster, Emmen), land use data originated from the Soil Statistics survey (Bodenstatistiek 2000, Centraal Bureau voor de Statistiek, Vorburg/Heerlen)
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	For the function intensive livestock a complete delineation is possible, because this landscape function is directly observable from land cover. Livestock husbandry function was delineated by the location of intensive livestock farms and quantified by the economic farm size in Dutch Standard units (DSU). Only farms larger than 20 DSU were taken into account. 'Odour circles' of 400 m around each farm location were mapped to improve visibility of point locations.
Comments	Although the proposed methodology has been specified for the case study area, the general approach should be applicable to other case studies as well. But different areas will have different data availability, different function definitions and thresholds to be applied.
Reference	Willemen et al. 2008

8

Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Food**
ESC name	n.r.
ESS name	Crop provision
Objectives of the study	To develop a general methodology for evaluating capacities of different landscapes to provide ESS.
Stock indicator	n.r.
Flow indicator	Energy value of harvested masses per year
Biophysical unit of indicator	GJ ha^{-1} yr^{-1}
Type of ecosystems	Urban ecosystem, cropland
Spatial resolution of the map	CLC polygons
Coverage	Halle-Leipzig (Germany)
Mapping scale	local
Data & source	CORINE land cover classes (EEA), harvested data on crops (Saxon State Ministry of the Environment and Agriculture)
Kind of methodical approach	Methodical approach based on expert knowledge and literature findings.
Methodical approach	Quantitative data (harvested mass per ha and year) on crop provision for relevant land cover classes were displayed in 6 classes according to the associated energy values.
Comments	(--)
Reference	Burkhard et al. 2009

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Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Water**
ESC name	Capacity of fresh water ecosystems
ESS name	n.r.
Objectives of the study	Establishment of methodologies for estimating the contribution of European ecosystems to the provision of ESS. Assessing synergies and trade-offs between ecosystem services.
Stock indicator	Surface area of freshwater ecosystems
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless percentage value
Type of ecosystems	Rivers and lakes
Spatial resolution of the map	NUTS-x regions statistical areas
Coverage	EU27
Mapping scale	Continental
Data & source	CLC 2000 raster data
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	The total blue water flow represents the sustainable supply of fresh water that emanates from ecosystems and is then transferred through rivers, lakes and other inland aquatic systems. The capacity of freshwater ecosystems to provide a reserve of freshwater is approximated by the surface area of freshwater ecosystems.
Comments	This assessment doesn´t take into consideration the provision of subsurface fresh water reserves in aquifers and deep groundwater.
Reference	Maes et al. 2011a

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Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Water**
ESC name	Flow of fresh water provision
ESS name	n.r.
Objectives of the study	Establishment of methodologies for estimating the contribution of European ecosystems to the provision of ESS. Assessing synergies and trade-offs between ecosystem services.
Stock indicator	n.r.
Flow indicator	Annual water flow per year
Biophysical unit of indicator	Water flow ($m^3\ yr^{-1}$)
Type of ecosystems	Rivers and lakes
Spatial resolution of the map	NUTS-x regions statistical areas
Coverage	EU27
Mapping scale	Continental
Data & source	Assessment of water availability for Europe (Wriedt and Bouraoui, 2009). Data base: HydroEurope
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	The flow of freshwater provision is approximated by the annual water flow that is available from surface water.
Comments	This assessment doesn´t take into consideration the provision of subsurface fresh water reserves in aquifers and deep groundwater.
Reference	Maes et al. 2011a

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Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Raw materials**
ESC name	Timber services
ESS name	n.r.
Objectives of the study	Establishment of methodologies for estimating the contribution of European ecosystems to the provision of ESS and for assessing synergies and trade-offs.
Stock indicator	Timber stock
Flow indicator	n.r.
Biophysical unit of indicator	$m^3\ ha^{-1}$
Type of ecosystem	Woodland and forest
Spatial resolution of the map	NUTS-x regions
Coverage	EU27
Mapping scale	continental
Data & source	JRC forest inventory & EFISCEN database hosted by EFI
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	The capacity of forest to produce timber was approximated using data from stock inventories.
Comments	Limitations mentioned by the authors: Lack of harmonized data, spatial resolution of data only available at regional level. No differentiation between managed and unmanaged forests.
Reference	Maes et al. 2011a

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Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Raw materials**
ESC name	Timber services
ESS name	n.r.
Objectives of the study	Establishment of methodologies for estimating the contribution of European ecosystems to the provision of ESS and for assessing synergies and trade-offs.
Stock indicator	Timber stock increment (= change of stock → ESC)
Flow indicator	n.r.
Biophysical unit of indicator	m^3 yr^{-1} dry matter
Type of ecosystem	Woodland and forest
Spatial resolution of the map	NUTS-x regions
Coverage	EU27
Mapping scale	continental
Data & source	JRC forest inventory & EFISCEN database hosted by EFI
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	The annual timber increment was approximated using data from various stock inventories.
Comments	Limitations mentioned by the authors: Lack of harmonized data, spatial resolution of data only available at regional level. No differentiation between managed and unmanaged forests.
Reference	Maes et al. 2011a

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Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Raw materials**
ESC name	Timber services
ESS name	n.r.
Objectives of the study	Development of a method for the quantification of growing stock and above-ground biomass in forests based on remote sensing and field measurements.
Stock indicator	Growing stock
Flow indicator	n.r.
Biophysical unit of indicator	m^3 ha^{-1} (for the field data from the national forest inventories)
Type of ecosystem	Woodland and forest
Spatial resolution of the map	500 m x 500 m
Coverage	Pan-Europe (EU, EFTA countries, Belarus, Ukraine, Moldova, Armenia, Azerbaijan, Georgia, Turkey)
Mapping scale	continental
Data & source	National forest inventory data (more than 98 000 locations from 16 countries) & remotely sensed vegetation data (MODIS)
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Mapping is based on data derived from remote sensing. An automatic up-scaling approach is making use of remote sensing data and field measurement data. The approach is based on sampling and allows the direct combination of data with different measurement units such as forest inventory plot data and satellite remote sensing data.
Comments	No specific comments provided
Reference	Gallaun et al. 2010

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Service category (TEEB 2010)	**PROVISIONING SERVICES**
Service type (TEEB 2010)	**Raw materials**
ESC name	Wildlife products according to CICES
ESS name	n.r.
Objectives of the study	To develop a methodology for monitoring changes in ecosystems´ potential to deliver services in order to identify where significant changes in natural capital might be taking place (scenarios).
Stock indicator	Potential of an area to deliver this service (mean importance score)
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless value
Type of ecosystems	Woodland and forest, heathland and shrub, sparsely and unvegetated land, inland wetlands, rivers and lakes, coastal areas
Spatial resolution of the map	NUTS-x regions
Coverage	EU25 plus Switzerland and Norway
Mapping scale	continental
Data & source	CORINE land cover maps (1990, 2000, 2006) Land and Ecosystem Accounting database (LEAC) EURURALIS 2.0 land use scenarios 2000-2030 (based on four IPCC SRES land use scenarios)
Kind of methodical approach	Methodical approach based on expert knowledge and literature findings
Methodical approach	This approach is based on the assumption, that land cover and land use data are reasonable proxies for estimating the potential of land to provide ESS. Different classes of independent land characteristics (classes of CLC, mountain terrain, nature protection, landscape protection zones, etc.) were selected to express its supportive or neutral role for delivering wildlife products. This estimation of the areas´ current potential to deliver the ESS was based on expert knowledge and findings in literature. Additionally, the impact of marginal changes in service output was assessed as well as the consequences of projected changes up to 2030.
Comments	The authors argue, that when using this method temporal dynamics and variability should kept in mind. Absolute flows of ESS may not be measureable by this method. The continent-wide approach should be improved in future, if more independent data will be available. Also trade-off analysis between selected ESS was conducted where land use trajectories over 40 years are taken into account.
Reference	Haines-Young et al. 2012 (based on a method described and used by Kienast et al. 2009)

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Regulation of air quality**
ESC name	Air purification
ESS name	n.r.
Objectives of the study	To develop spatially explicit ecosystem service models for quantifying and simulating ESS and ecosystem capacities.
Stock indicator	capacity of the landscape to capture dust particles <10µm (PM_{10})
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless percentage value
Type of ecosystems	Cropland, grassland, woodland and forest, heathland and shrub, inland wetlands
Spatial resolution of the map	0.5° x 0.5° grid cells
Coverage	Eastern Europe (Estonia, Latvia, Lithuania, Belarus, Poland, Albania, Macedonia, Bulgaria, Rumania, Moldova, Ukraine)
Mapping scale	Sub-continental
Data & source	Data on land cover (GlobCover global land cover map), elevation (Gtopo 30 global), precipitation, temperature, soil characteristics, population density, crop fraction and management intensity
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Analysis of ESS provision is based on global-scale data, results are presented for Eastern Europe. The mapping of ESS was based on IMAGE simulations. For each ESS a model of the relationship between ecosystem properties and ecosystem capacity of supplying ESS was developed using published data. ESS were derived from ecosystem capacity by including their use by quantifying the human demand. The ESS for dust capture capacity was considered as the amount of PM_{10} actually captured (g/km^2)
Comments	The authors argue that the developed models are suitable for global-scale use to describe availability of ecosystem capacity and supply of ESS, although the case study area does not comprise the complete range of biophysical, socio-economic, land-cover, soil and climate conditions that should be covered in a global-scale model.
Reference	Schulp et al. 2012

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Climate regulation**
ESC name	Climate regulation services
ESS name	n.r.
Objectives of the study	Establishment of methodologies for assessing synergies and trade-offs and for estimating the contribution of European ecosystems to the provision of ESS:
Stock indicator	Average carbon stock
Flow indicator	n.r.
Biophysical unit of indicator	$t\ C\ ha^{-1}$
Type of ecosystems	Urban ecosystems, grassland, woodland and forest, heathland and shrub, inland wetlands
Spatial resolution of the map	NUTS-x regions
Coverage	EU27
Mapping scale	continental
Data & source	CDIAC, based on Olson et al. (1983, 1985) and GLC2000
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Data on above- and belowground carbon stored in living plant material where combined with spatial distribution of global vegetation
Comments	No specific comments provided
Reference	Maes et al. 2011a

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Climate regulation**
ESC name	n.r.
ESS name	Climate regulation service
Objectives of the study	Establishment of methodologies for assessing synergies and trade-offs and for estimating the contribution of European ecosystems to the provision of ESS:
Stock indicator	n.r.
Flow indicator	Average annual carbon fixation
Biophysical unit of indicator	$t\ C\ ha^{-1}\ yr^{-1}$
Type of ecosystems	Urban ecosystems, grassland, woodland and forest, heathland and shrub, inland wetlands
Spatial resolution of the map	NUTS-x regions
Coverage	EU27
Mapping scale	continental
Data & source	VITO, Geosucces database
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Net ecosystem productivity is taken as a measure for the carbon service flow
Comments	No specific comments provided
Reference	Maes et al. 2011a

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Climate regulation**
ESC name	n.r.
ESS name	Carbon sequestration
Objectives of the study	To develop spatially explicit ESS models to quantify and simulate ESS and the capacity of ecosystems to provide services.
Stock indicator	n.r.
Flow indicator	Percentage of annual country total CO_2 emission captured by ecosystems
Biophysical unit of indicator	Dimensionless percentage value
Type of ecosystems	Urban ecosystems, cropland, grassland, woodland and forest, heathland and shrub, inland wetlands, coastal areas
Spatial resolution of the map	0.5° x 0.5° grid cells
Coverage	Eastern Europe (Estonia, Latvia, Lithuania, Belarus, Poland, Albania, Macedonia, Bulgaria, Rumania, Moldova, Ukraine)
Mapping scale	Sub-continental
Data & source	Data on land cover (GlobCover global land cover map), elevation (Gtopo 30 global), precipitation, temperature, soil characteristics, population density, crop fraction and management intensity
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Analysis of ESS provision is based on global-scale data, results are presented for Eastern Europe. The mapping of ESS was based on IMAGE simulations (to explore the long-term dynamics of global change). For each ESS a model of the relationship between ecosystem properties and ecosystem capacities of supplying ESS was developed using published data. ESS were derived from ecosystem capacities by including their use by quantifying the human demand. The ecosystem capacity for carbon sequestration was defined as the net ecosystem productivity (t C km^{-2} yr^{-1}) simulated with IMAGE minus respiration. The ESS for carbon sequestration was defined as the climate regulation by capturing CO_2 in soil and vegetation and calculated as the percentage of the annual country total CO_2 emission that is captured by the ecosystem.
Comments	The authors argue that the developed models are suitable for global-scale use to describe availability of ecosystem capacities and supply of ESS, although the case study area does not comprise the complete range of biophysical, socio-economic, land-cover, soil and climate conditions that should be covered in a global-scale model. The model outputs have been compared with other data from several data sources to prove the credibility of the results.
Reference	Schulp et al. 2012

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Climate regulation**
ESC name	n.r.
ESS name	Carbon sequestration
Objectives of the study	Quantification and monetary valuation of ESS to account for the full benefits provided by grasslands.
Stock indicator	n.r.
Flow indicator	Annual Net Ecosystem Production
Biophysical unit of indicator	Mg C ha^{-1} yr^{-1}
Type of ecosystem	Grassland
Spatial resolution of the map	administrative units ORP (206 units in Czech Republic), which is in between NUTS4 and NUTS5
Coverage	Czech Republic
Mapping scale	national
Data & source	Carbon sequestration values for different grassland types based on Jones and Donnelly 2004, Ni 2004, Vries et al. 2009. Habitat mapping layer is a product of field survey conducted all over the Czech Republic. Habitat classification by the Habitat Catalogue of the Czech Republic.
Kind of methodical approach	Quantitative modelling analysis based on own case studies.
Methodical approach	The authors used a habitat approach: Quantified amounts of carbon sequestration (carbon storage as net Biome production) were estimated for grassland habitat categories and used to calculate the amount of ecosystem service of each of the CZ grassland habitats. Mapping is based on aggregated habitats into larger space units (OPR).
Comments	As single habitats represent the basis mapping units, the original habitat mapping layer provides resolution on a very fine scale which enhances accuracy at a local level, but constricts understanding of the situation on a larger scale. Therefore, habitats were aggregated into larger space units (ORP).
Reference	Hönigová et al. 2011

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Climate regulation**
ESC name	Carbon storage
ESS name	n.r.
Objectives of the studies	Estimation of spatial covariance between biodiversity and other ESS using Britain as a case study.
Stock indicator	Carbon content (above and below ground to 1 m depth)
Flow indicator	n.r.
Biophysical unit of indicator	kg C m^{-2}
Type of ecosystem	Urban ecosystems, cropland, grassland, woodland and forest, heathland and shrub, inland wetlands
Spatial resolution of the map	10 km x 10 km
Coverage	Britain
Mapping service	national
Data & source	Vegetation carbon data (Center for Ecology and Hydrology), data on soil parameters, land use data, soil series data (National soil Resources Institute) were included in the calculation of the soil carbon density.
Kind of methodical approach	Quantitative modelling analysis based on own case studies.
Methodical approach	Vegetation carbon data and soil organic carbon density data were used to calculate the total carbon content per 1x1 km and aggregated to 10x10 km grid squares.
Comments	Spatial patterns of selected ESS were analysed to show the spatial covariance between biodiversity and these ESF. It could be proved, that enhancing the resolution of data (from 100 km² to 4 km²) did not change the broad spatial covariance structures. But, changing the spatial extent of the study area (from 100 km² to 4 km²) revealed a different relationship between biodiversity and the selected ESF in about 75% of the 41 investigated grid squares.
Reference	Anderson et al. 2009 (method also used in Eigenbrod et al. 2009)

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Climate regulation**
ESC name	Carbon storage
ESS name	n.r.
Objectives of the study	Quantification of above-ground carbon storage
Stock indicator	Above ground carbon stock
Flow indicator	n.r.
Biophysical unit of indicator	kg C m^{-2}
Type of ecosystem	Urban ecosystem
Spatial resolution of the map	1 km x 1 km
Coverage	Leicester (Britain)
Mapping scale	local
Data & source	Landbase digital cartographic data set (Infoterra)
Kind of methodical approach	Quantitative modelling analysis based on own case studies
Methodical approach	Quantities and spatial patterns of above-ground carbon stored in a typical British city are examined by surveying vegetation across the entire urban area. Land cover characteristics of the study were determined using a GIS, comprised of polygons classified by Infoterra. Each above-ground polygon is assigned to one of four categories (herbaceous vegetation, shrub, tall shrub, and tree). Measurements of tree density refined this categorization of vegetation height, which is indicative of biomass. At 520 survey sites proportion of ground covered by vegetation was estimated in a 5 m x 5 m grid. Material of herbaceous vegetation was harvested at selected sites across the city for carbon analysis. Above-ground dry-weight biomass was calculated for each surveyed tree as well as tree density.
Comments	Comparison with current national estimates of above-ground carbon storage for Britain show, that provision of carbon storage within urban areas is under evaluated by an order of magnitude in the case of Leicester. This is because the national scale map averages carbon stocks across a 1 km grid, based on a limited number of field samples.
Reference	Davies et al. 2011

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Regulation of water flows**
ESC name	Capacity to temporarily store surface water
ESS name	n.r.
Objectives of the study	Establishment of methodologies for estimating the contribution of European ecosystems to the provision of ESS. Assessing synergies and trade-offs between ecosystem services.
Stock indicator	Retention capacity in areas that are sensitive to floods
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless percentage value
Type of ecosystems	Cropland, grassland, woodland and forest, heathland and shrub, inland wetlands,
Spatial resolution of the map	NUTS-x regions statistical areas
Coverage	EU27
Mapping scale	Continental
Data & source	Data derived from the MAPPE model (Pistocchi et al. 2008; Pistocchi et al. 2010)
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	The annually aggregated soil infiltration is used as an indicator for the capacity of terrestrial ecosystems to temporarily store surface water.
Comments	No specific comments provided
Reference	Maes et al. 2011a

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Regulation of water flows**
ESC name	Water retention capacity
ESS name	n.r.
Objectives of the study	To develop spatially explicit ecosystem service models for quantifying and simulating ESS and ecosystem capacities to provide services.
Stock indicator	Retention capacity in areas that are sensitive to floods
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless percentage value
Type of ecosystems	Cropland, grassland, woodland and forest, heathland and shrub, inland wetlands,
Spatial resolution of the map	0.5° x 0.5° grid cells
Coverage	Eastern Europe (Estonia, Latvia, Lithuania, Belarus, Poland, Albania, Macedonia, Bulgaria, Romania, Moldova, Ukraine)
Mapping scale	Sub-continental
Data & source	Data on land cover (GlobCover global land cover map), elevation (Gtopo 30 global), precipitation, temperature, soil characteristics, population density, crop fraction and management intensity
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Analysis of ESS provision is based on global-scale data, results are presented for Eastern Europe. The mapping of ESS was based on IMAGE simulations (to explore the long-term dynamics of global change). For each ESS a model of the relationship between ecosystem properties and ecosystem capacities of supplying ESS was developed using published data. ESS were derived from ecosystem capacities by including their use by quantifying the human demand. The ESS for flood risk was calculated as ESC in areas that are sensitive to floods due to utilization of the land for crop production and urban land
Comments	The authors argue that the developed models are suitable for global-scale use to describe availability of ecosystem capacities and supply of ESS, although the case study area does not comprise the complete range of biophysical, socio-economic, land-cover, soil and climate conditions that should be covered in a global-scale model. The model outputs have been compared with other data from several data sources to prove the credibility of the results.
Reference	Schulp et al 2012

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Regulation of water flows**
ESC name	Flood regulation
ESS name	n.r.
Objectives of the study	Assessment of the capacity of different ecosystems to regulate floods. Produce maps of regional supply-demand balances.
Stock indicator	Flood regulation capacity of different land cover classes

Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless value
Type of ecosystems	Cropland, grassland, woodland and forest, heathland and shrub, inland wetlands, rivers and lakes
Spatial resolution of the map	30 m x 30 m
Coverage	Municipality of Etropole (Bulgaria)
Mapping scale	regional
Data & source	digital elevation model from topographic maps (1:25K);Adjusted CORINE land cover 2000 data by Landsat ETM+ satellite images and arial photographs with high resolution; Bulgarian soil datasets (Bulg. Research Institute for Soil Science), transformed into FAO1974 classification system; Precipitation, river discharge data from Bulgarian National Institute of Hydrology and Meteorology; Statistical data from local authorities and National Statistical Institute
Kind of methodical approach	Quantitative modelling analysis using existing data.
Methodical approach	1) Watershed modelling (AGWA/KINEROS); 2) Capacity assessment based on model results; 3) Spatial analyses - model results/land cover/soil data (ArcGIS); Usage of catchment based hydrological models for river swellings: GIS based AGWA (Automated Geospatial Watershed Assessment) tool and its constituent models KINEROS (KINematic Runoff and EROSion model) and SWAT (Soil and Water Assessment Tool)
Comments	No specific comments provided
Reference	Nedkov & Burkhard 2012

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Waste treatment**
ESC name	n.r.
ESS name	Nitrogen retention service
Objectives of the study	To demonstrate present research capacity for developing maps at different scales. To identify methods for assessing and reporting on ecosystem service targets and trade-offs and synergies. To assess policies affecting the management of ecosystem services.
Stock indicator	n.r.
Flow indicator	Total amount of nitrogen retained per year
Biophysical unit of indicator	t nitrogen km^{-1} $year^{-1}$
Type of ecosystem	Rivers and lakes
Spatial resolution of the map	NUTS - x regions statistical area
Coverage	EU27
Mapping scale	continental
Data & source	Data based on the GREEN model for 2000
Kind of methodical approach	Quantitative modelling analysis using existing data.
Methodical approach	GREEN-Model used based on the pan-European assessment. The removal of nitrogen is calculated as the product of retention capacity and nitrogen input.
Comments	Used methods work for different scales in space. Limitation: Water purification is more than nitrogen retention. The GREEN model ignores the role of biodiversity and the feedback of the nitrogen concentration on the nitrogen removal efficiency. The authors also ignored other ecosystems which act as important sinks for nitrogen and other pollutants
Reference	Maes et al. 2011a+b

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Waste treatment**
ESC name	Water purification services (Risk reduction of pesticides)
ESS name	n.r.
Objectives of the study	To develop methods which enable direct mapping of water regulating services compared to classical water quality indicator maps.
Stock indicator	a) Run-off potential pesticides (5 classes); b) related ecological risk (in %); c) reduction of ecological risks (in %)
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless percentage value
Type of ecosystems	Grassland, woodland and forest, heathland and shrub, inland wetlands, rivers and lakes.
Spatial resolution of the map	10 km x 10 km
Coverage	EU27
Mapping scale	continental
Data & source	Various sources on national level: Input data for pesticide use only available on national scale
Kind of methodical approach	Quantitative modelling analysis based on own case studies
Methodical approach	GIS model based on empirically fitted equations
Comments	Model does not describe the situation at specific stream sites, but reports the percentage of adversely affected sites within the 10 km x 10 km grid cells. Input data for pesticide use only available on national scale. Broad conclusion: 33% of all stream sites in cultivated areas, were predicted not to meet the requirements of the EU-Water framework directive.
Reference	Lautenbach et al. 2012

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Waste treatment**
ESC name	n.r.
ESS name	Water purification services
Objectives of the study	To demonstrate present research capacity for developing maps at different scales. To identify methods for assessing and reporting on ecosystem service targets and trade-offs and synergies. To assess policies affecting the management of ecosystem services.
Stock indicator	n.r.
Flow indicator	Amount of nitrogen removal per year
Biophysical unit of indicator	t nitrogen km^{-1} yr^{-1}
Spatial resolution of the map	1 km x 1 km
Type of ecosystems	Inland wetlands, rivers and lakes
Coverage	Elbe river basin (Germany)
Mapping scale	regional
Data & source	From literature findings
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Mapping nitrogen retention in flood plains: Estimated value of denitrification modified by size of flooded area, duration of floods, nutrient loads of river, and nitrogen retention values by predefined classes of environmental characteristics. Mapping nitrogen retention in river networks based on mass balance calculated of changes in nitrogen stock in a river segment, inflow and outflow of nitrogen per time unit.
Comments	Used methods work for different scales in space.
Reference	Maes et al. 2011b

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Waste treatment**
ESC name	n.r.
ESS name	Water purification services
Objectives of the study	To develop methods which enable the direct mapping of water regulating ecosystem services compared to classical water quality indicator maps.
Stock indicator	n.r.
Flow indicator	Amount of nitrogen removal per year
Biophysical unit of indicator	$t\ N\ ha^{-1}\ yr^{-1}$
Type of ecosystems	Inland wetlands, rivers and lakes
Spatial resolution of the map	Polygon based, 132 sub-basins
Coverage	Elbe river basin (Germany)
Mapping scale	regional
Data & source	Various sources
Kind of methodical approach	Quantitative modelling analysis based on own case studies
Methodical approach	Grey-box model (Elbe-DSS, ordinary differential equations as well as nutrient balance model)
Comments	Loss of information when calculation units were spatially aggregated. Input data like economic farm data (crop types, crop rotation) include many uncertainties because they are only available at aggregated levels due to confidentially laws
Reference	Lautenbach et al. 2012

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Waste treatment**
ESC name	n.r.
ESS name	Water purification services
Objectives of the study	To demonstrate present research capacity for developing maps at different scales. To identify methods for assessing and reporting on ecosystem service targets and trade-offs and synergies. To assess policies affecting the management of ecosystem services.
Stock indicator	n.r.
Flow indicator	Amount of nitrogen removal per year
Biophysical unit of indicator	t nitrogen km^{-1} yr^{-1}
Type of ecosystems	Inland wetlands, rivers and lakes
Spatial resolution of the map	25 m resolution & 2 km resolution
Coverage	Ouse catchment (UK)
Mapping scale	local
Data & source	land cover maps 25m resolution, Defra Agricultural Census 2km resolution
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Mapping soil denitrification: Different approaches for non-agricultural land, agricultural grassland & arable land; Mapping nitrogen retention in river networks based on mass balance calculated of changes in nitrogen stock in a river segment, inflow and outflow of nitrogen per time unit
Comments	Used methods work for different scales in space.
Reference	Maes et al. 2011b

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Waste treatment**
ESC name	n.r.
ESS name	Water purification services
Objectives of the study	Development of methods to enable direct mapping of water regulating ESS compared to classical water quality indicator maps.
Stock indicator	n.r.
Flow indicator	Amount of nitrogen removal per year
Biophysical unit of indicator	$t\ N\ ha^{-1}\ yr^{-1}$
Type of ecosystems	Inland wetlands, rivers and lakes
Spatial resolution of the map	Polygon based, 53 hydrological response units
Coverage	Parthe basin (Germany)
Mapping scale	local
Data & source	Various sources
Kind of methodical approach	Quantitative modelling analysis based on own case studies
Methodical approach	Grey-box model (SWAT, ordinary differential equations)
Comments	No specific comments provided
Reference	Lautenbach et al. 2012

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Waste treatment**
ESC name	n.r.
ESS name	Water purification services
Objectives of the study	Development of methods to enable direct mapping of water regulating ESS compared to classical water quality indicator maps.
Stock indicator	n.r.
Flow indicator	Amount of nitrogen removal per year
Biophysical unit of indicator	t N ha^{-1} yr^{-1}
Type of ecosystems	Inland wetlands, rivers and lakes
Spatial resolution of the map	Polygon based, 49 hydro-geomorphologic units
Coverage	Lödderitzer Forst (Germany)
Mapping scale	local
Data & source	Various sources
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	In this case study the nitrogen retention is directly estimated based on an expert model.
Comments	n.r.
Reference	Lautenbach et al. 2012

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Erosion prevention**
ESC name	Erosion risk by vegetation
ESS name	n.r.
Objectives of the study	To develop spatially explicit ESS models for quantifying and simulating ESS and the ecosystem´s capacity to provide services.
Stock indicator	Decrease of erosion risk by vegetation in areas with high erosion risk
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless percentage value
Type of ecosystem	Cropland, grassland, woodland and forest, heathland and shrub, sparsely and unvegetated land, inland wetland, coastal areas
Spatial resolution of the map	0.5° x 0.5° grid cells
Coverage	Eastern Europe (Estonia, Latvia, Lithuania, Belarus, Poland, Albania, Macedonia, Bulgaria, Rumania, Moldova, Ukraine)
Mapping scale	Sub-continental
Data & source	Data on land cover (GlobCover global land cover map), elevation (Gtopo 30 global), precipitation, temperature, soil characteristics, population density, crop fraction and management intensity
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Analysis of ESS provision is based on global-scale data, results are presented for Eastern Europe. The mapping of ESS was based on IMAGE simulations (to explore the long-term dynamics of global change). For each ESS a model of the relationship between ecosystem properties and ecosystem capacities of supplying ESS was developed using published data. ESS were derived from ecosystem capacities by including their use by quantifying the human demand. The ESS for erosion protection was defined as the decrease of erosion risk by vegetation in utilized areas with a high erosion risk
Comments	The authors argue that the developed models are suitable for global-scale use to describe availability of ecosystem capacities and supply of ESS, although the case study area does not comprise the complete range of biophysical, socio-economic, land-cover, soil and climate conditions that should be covered in a global-scale model. The model outputs have been compared with other data from several data sources to prove the credibility of the results.
Reference	Schulp et al 2012

33

Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Pollination**
ESC name	Pollination services
ESS name	n.r.
Objectives of the study	Establishment of methodologies to estimate the contribution of European ecosystems to the provision of ESS. Assessment of synergies and trade-offs.
Stock indicator	Pollination potential (= Capacity of natural ecosystems to provide pollination services)
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless classes
Type of ecosystems	Cropland, grassland, woodland and forest, heathland and shrub, inland wetlands
Spatial resolution of the map	NUTS-x regions statistical areas
Coverage	EU27
Mapping scale	continental
Data & source	Klein et al. (2007): Crop dependence on pollination; Ricketts et al. (2008): Relationship between distance to (semi-) natural areas and pollinator richness; CLC classes contributing to pollination
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Both, visitation rate of pollinating insects and crop dependency on pollination were used to determine the pollination potential of a natural ecosystem.
Comments	Limitations mentioned by the authors: Only the potential of (semi-) natural areas are considered to provide pollination. Also capacity of cropland, pastures, linear elements in the agricultural landscape and sources of managed pollination should be included. New data on pollinator densities including environmental factors could validate the existing mapping.
Reference	Maes et al. 2011a

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Service category (TEEB 2010)	**REGULATING SERVICES**
Service type (TEEB 2010)	**Pollination**
ESC name	n.r.
ESS name	Pollination
Objectives of the study	To develop spatially explicit ESS models for quantifying and simulating ESS and the ecosystem´s capacity to provide services.
Stock indicator	n.r.
Flow indicator	Extra annual yield due to good pollination
Biophysical unit of indicator	Mg km^{-2} yr^{-1} (t km^{-2} yr^{-1})
Type of ecosystems	Cropland, grassland, woodland and forest, heathland and shrub, inland wetlands
Spatial resolution of the map	0.5° x 0.5° grid cells
Coverage	Eastern Europe (Estonia, Latvia, Lithuania, Belarus, Poland, Albania, Macedonia, Bulgaria, Rumania, Moldova, Ukraine)
Mapping scale	Sub-continental
Data & source	Data on land cover (GlobCover global land cover map), elevation (Gtopo 30 global), precipitation, temperature, soil characteristics, population density, crop fraction and management intensity
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Analysis of ESS provision is based on global-scale data, results are presented for Eastern Europe. The mapping of ESS was based on IMAGE simulations. For each ESS a model of the relationship between ecosystem properties and ecosystem capacities of supplying ESS was developed using published data. ESS were derived from ecosystem capacities by including their use by quantifying the human demand. The pollination ecosystem function was defined as the percentage yield loss due to diminished pollination (yield reduction fraction) and calculated for pulses and oil crops. The ESS was calculated as the additional yield due to wild pollination, based on the yield reduction fraction and the food crop yield (potential yield a location can provide).
Comments	The authors argue that the developed models are suitable for global-scale use to describe availability of ESC and supply of ESS, although the case study area does not comprise the complete range of biophysical, socio-economic, land-cover, soil and climate conditions that should be covered in a global-scale model. The model outputs have been compared with other data from several data sources to prove the credibility of the results.
Reference	Schulp et al. 2012

35

Service category (TEEB 2010)	**HABITAT SERVICE**
Service type	**Habitat diversity** (according to CICES)
ESC name	Habitat diversity
ESS name	n.r.
Objective of the study	To develop a methodology for monitoring changes in ESS and scenarios and trade-offs
Stock indicator	Potential of an area to deliver this service (mean importance score)
Flow indicator	n.r.
Biophysical unit of indicator	dimensionless value
Type of ecosystems	Urban ecosystems, cropland, grassland, woodland and forest, heathland and shrub, inland wetlands, rivers and lakes, coastal areas
Spatial resolution of the map	NUTS-x regions
Coverage	EU25 plus Switzerland and Norway
Mapping scale	continental
Data & source	CORINE land cover maps (1990, 2000, 2006) Land and Ecosystem Accounting database (LEAC) EURURALIS 2.0 land use scenarios 2000-2030 (based on four IPCC SRES land use scenarios)
Kind of methodical approach	Methodical approach based on expert knowledge and literature findings.
Methodical approach	Different classes of independent land characteristics (classes of CLC, mountain terrain, nature protection, landscape protection zones, mean actual net primary production, buffered coasts, wetlands, large rivers, classes of land accounts for Europe) were selected to express its supportive or neutral role for habitat diversity. This estimation of the areas´ current potential to deliver the ESS was based on expert knowledge and findings in literature. Additionally, the impact of marginal changes in service output was assessed as well as the consequences of projected changes up to 2030.
Comments	This approach was chosen to create a method for assessing changes in the capacity of ecosystems to deliver ESS. It is based on the assumption, that land cover and land use data are reasonable proxies for estimating the potential of land to provide ESS. The authors raised the point that temporal dynamics and variability should kept in mind. Absolute flows of ESS may not be measureable by this method. The continent-wide approach should be improved in future, if more independent data will be available. Trade-off analysis between selected ESS was conducted where land use trajectories over 40 years are taken into account.
Reference	Haines-Young et al. 2012 (based on a method described and used by Kienast et al. 2009)

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Service category (TEEB 2010)	**HABITAT SERVICE**
Service type (TEEB 2010)	**Maintenance of genetic diversity**
ESF name	n.r.
ESS name	Habitat for rare, endemic and indicator plant species (comment: as the existence of the habitat is the service itself → ESS and not ESC)
Objectives of the study	To establish a methodological framework to map and quantify landscape functions depending on the availability of spatial information.
Stock indicator	Conservation value (capacity to provide a suitable habitat for rare, endemic and indicator plant species)
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless value between 0 and 10 (= highest plant nature value).
Type of ecosystems	Urban ecosystems, cropland, grassland, woodland and forest, heathland and shrub, inland wetland, rivers and lakes, costal areas
Spatial resolution of the map	100 m x 100 m
Coverage	Gelderse Vallei region (The Netherlands)
Mapping scale	regional
Data & source	Nature value inventory, soil parameters, groundwater level, nitrogen availability, land cover data (forest, open nature, arable and grass lands, urban area, and infrastructure).
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	This landscape function was quantified using a nature value index. Data were taken from a nature value inventory, where occurrence of plant species was recorded. Based on these occurrence data the biodiversity conservation value was calculated for each observation point. Species characteristics taken into consideration are: rareness, trend in occurrence, vulnerability and importance of the species for a specific vegetation type. These plant habitat function data consist of continuous sample data. For the empirical analysis a multiple linear regression was used. The final regression model was used to extrapolate the conservation values for the whole study area (excluding all built-up areas).
Comments	To prove the plausibility of the plant habitat model, the predicted high nature value areas were compared with the location of the State Nature Monuments (which are of exceptionally high nature value). The authors concluded that the described discrepancy between predicted and observed values could be a result of the generalization of landscape characteristics related to nature value. The described habitat model is likely to be biased towards the most abundant plant community habitat requirements.
Reference	Willemen et al. 2008

37

Service category (TEEB 2010)	**CULTURAL SERVICES**
Service type (TEEB 2010)	**Opportunities for recreation & tourism**
ESC name	Recreation services
ESS name	n.r.
Objectives of the study	To demonstrate present research capacity for developing maps at different spatial scales. To identify methods for assessing and reporting on ecosystem service targets, trade-offs and synergies. To assess policies affecting the management of ecosystem services.
Stock indicator	Recreation potential index (RPI)
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless value (between 0 and 1)
Type of ecosystems	Urban ecosystems, grassland, woodland and forest, heathland and shrub, sparsely or unvegetated land, inland wetlands, rivers and lakes, coastal areas
Spatial resolution of the map	NUTS-x regions
Coverage	EU27
Mapping scale	continental
Data & source	European hemeroby map, CLC2000dataset, CAPRI dynaspat dataset, tree species database (JRC, AFOLU action), Natura 2000 database, EEA data on bathing water quality
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Service supply driven approach, which is based on the assumption, that the recreational potential is positively correlated to the degree of naturalness (hemeroby) of landscapes. Variables taken into consideration are: Degree of naturalness (hemeroby), presence of protected areas and cost lines, quality of bathing water, the accessibility of ecosystems, and the distance from urban centres.
Comments	Limitations mentioned by the authors: No harmonized data on accommodation facilities and tourist-fluxes are available at regional level.
Reference	Maes et al. 2011a

38

Service category (TEEB 2010)	**CULTURAL SERVICES**
Service type (TEEB 2010)	**Opportunities for recreation & tourism**
ESC name	Recreation (according to CICES, areas favourable for active recreation purposes)
ESS name	n.r.
Objectives of the study	To develop a methodology for monitoring changes in ESS and scenarios.
Stock indicator	Potential of an area to deliver this service (mean importance score)
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless value
Type of ecosystems	Urban ecosystems, grassland, woodland and forest, heathland and shrub, sparsely or unvegetated land, inland wetlands, rivers and lakes, coastal areas
Spatial resolution of the map	NUTS-x regions
Coverage	EU25 plus Switzerland and Norway
Mapping scale	continental
Data & source	CORINE land cover maps (1990, 2000, 2006) Land and Ecosystem Accounting database (LEAC) EURURALIS 2.0 land use scenarios 2000-2030 (based on four IPCC SRES land use scenarios)
Kind of methodical approach	Methodical approach based on expert knowledge and literature findings.
Methodical approach	Different classes of independent land characteristics (classes of CLC, mountain terrain, nature protection, landscape protection zones, mean actual net primary production, buffered coasts, wetlands, large rivers, classes of Land accounts for Europe) were selected to express its supportive or neutral role for recreation. This estimation of the areas´ current potential to deliver the ESS was based on expert knowledge and findings in literature. Additionally, the impact of marginal changes in service output was assessed as well as the consequences of projected changes up to 2030.
Comments	This approach was chosen to create a method for assessing changes in the capacity of ecosystems to deliver ESS. It is based on the assumption, that land cover and land use data are reasonable proxies for estimating the potential of land to provide ESS. The authors raised the point that temporal dynamics and variability should kept in mind. Absolute flows of ESS may not be measureable by this method. The continent-wide approach should be improved in future, if more independent data will be available. Trade-off analysis between selected ESS was conducted where land use trajectories over 40 years are taken into account.
Reference	Haines-Young et al. 2012 (similar method is also used in Kienast et al. 2009)

39

Service category (TEEB 2010)	**CULTURAL SERVICES**
Service type (TEEB 2010)	**Opportunities for recreation & tourism**
ESC name	Tourism and recreation
ESS name	n.r.
Objectives of the study	To develop spatially explicit ESS models to quantify and simulate ESS and the ecosystem´s capacity to provide services.
Stock indicator	Percentage of landscape attractiveness and accessibility for tourism
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless percentage value
Spatial resolution of the map	0.5° x 0.5° grid cells
Type of ecosystem	Urban ecosystems, grassland, woodland and forest, heathland and shrub, sparsely or unvegetated land, inland wetlands, rivers and lakes, coastal areas
Coverage	Eastern Europe (Estonia, Latvia, Lithuania, Belarus, Poland, Albania, Macedonia, Bulgaria, Rumania, Moldova, Ukraine)
Mapping scale	Sub-continental
Data & source	Data on land cover (GlobCover global land cover map), elevation (Gtopo 30 global), data on presence of coasts, relief, land cover and presence of protected natural areas, GDP, travel time from villages to areas attractive for recreation and population density.
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Analysis of ESS provision is based on global-scale data, results are presented for Eastern Europe. The mapping of ESF/ESS was based on IMAGE simulations (to explore the long-term dynamics of global change). For each ESS a model of the relationship between ecosystem properties and ecosystem capacities of supplying ESS was developed using published data. ESS were derived from ecosystem functions by including their use by quantifying the human demand. Indices for the attractiveness of areas for tourism and recreation were based on landscape features attractive for tourists and holiday makers. The indices were quantified and an average index was calculated. The ESS for tourism was defined as the suitability of attractive areas. People´s wealth in a region was considered as well as accessibility of areas.
Comments	The authors argue that the developed models are suitable for global-scale use to describe availability of ecosystem capacities and supply of ESS, although the case study area does not comprise the complete range of biophysical, socio-economic, land-cover, soil and climate conditions that should be covered in a global-scale model. The model outputs have been compared with other data from several data sources to prove the credibility of the results.
Reference	Schulp et al. 2012

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Service category (TEEB 2010)	**CULTURAL SERVICES**
Service type (TEEB 2010)	**Opportunities for recreation & tourism**
ESC name	Recreation services
ESS name	n.r.
Objectives of the study	To demonstrate the present research capacity for developing maps at different special scales that quantify the flow of ESS. To identify methods for assessing and reporting on ecosystem service targets and trade-offs and synergies between them. T assess policies affecting the current and future management of ESS, including policies in the environmental, agricultural, fisheries, transportation, regional development and other domains.
Stock indicator	Recreation potential index (RPI)
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless value (between 0 and 1)
Type of ecosystems	Urban ecosystems, grassland, woodland and forest, heathland and shrub, sparsely or unvegetated land, inland wetlands, rivers and lakes, coastal areas
Spatial resolution of the map	10 km x 10 km
Coverage	Finland
Mapping scale	national
Data & source	Data on summer cottages, Data on recreation facilities, hemeroby layer recalculated on CORINE level 4, data on protected areas: Natura 2000 databases, UNESCO-sites, nationally designated areas (CDDA), Finish National parks and local protected areas. CORINE LC maps (25 m resolution), EEA data on bathing water quality
Kind of methodical approach	Quantitative modelling analysis using existing data.
Methodical approach	Service supply driven approach. RPI was calculated based on the assumption, that the recreational potential is positively correlated to the degree of naturalness (hemeroby) of landscapes. Variables taken into consideration are: Degree of naturalness (hemeroby), presence of protected areas and cost lines, the quality of bathing water, the accessibility of ecosystems, and the distance from urban centres. A recreation opportunity spectrum (ROS) was calculated considering distance from urban areas classes, distance from road classes and the indicator of recreation provision. Additionally, the population active living potential was used (=integrating physical activity into daily routines). Approximate preferences for outdoor recreation were modelled.
Comments	Limitations mentioned by the authors: Data on visitors are not available yet.
Reference	Maes et al. 2011b

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Service category (TEEB 2010)	**CULTURAL SERVICES**
Service type (TEEB 2010)	**Opportunities for recreation & tourism**
ESC name	Recreation services
ESS name	n.r.
Objectives of the study	To demonstrate the present research capacity for developing maps at different special scales that quantify the flow of ESS. To identify methods for assessing and reporting on ecosystem service targets and trade-offs and synergies between them. T assess policies affecting the current and future management of ESS, including policies in the environmental, agricultural, fisheries, transportation, regional development and other domains.
Stock indicator	Recreation opportunity index (ROS)
Flow indicator	n.r.
Biophysical unit of indicator	Dimension- less value (9 classes)
Type of ecosystems	Urban ecosystems, grassland, woodland and forest, heathland and shrub, sparsely or unvegetated land, inland wetlands, rivers and lakes, coastal areas
Spatial resolution of the map	500 m x 500 m
Coverage	The Netherlands
Mapping scale	national
Data & source	Data for recreational preferences for landscapes (www.daarmoetikzijn.nl) spatial distribution of Dutch citizens, cycling use of cycling network (Participation rate and frequency of recreational cycling)
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Service demand driven approach: preferences for recreation and accessibility of ecosystems are considered. Degree of landscape preference for recreation was estimated, which shows the potential demand for recreation in a region (but not the recreational flow). Therefore, data on accessibility and the supply according to the ROS (Recreation Opportunity Spectrum) were also included. The potential use of the cycling network by recreation cyclists is calculated and mapped. The final Recreation opportunity index provides information on both the quality of recreation and its accessibility.
Comments	No specific comments provided
Reference	Maes et al. 2011b

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Service category (TEEB 2010)	**CULTURAL SERVICES**
Service type (TEEB 2010)	**Opportunities for recreation & tourism**
ESC name	n.r.
ESS name	Recreation
Objectives of the study	Estimation of spatial covariance between biodiversity and other ESS.
Stock indicator	n.r.
Flow indicator	Number of rural outdoor visits
Biophysical unit of indicator	Dimensionless value (absolute numbers)
Type of ecosystem	Urban ecosystems, grassland, woodland and forest, heathland and shrub, sparsely or unvegetated land, inland wetlands, rivers and lakes, coastal areas
Spatial resolution of the map	10 km x 10 km
Coverage	Britain
Mapping scale	National
Data & source	Data on leisure trips of the English population (number of day leisure visits to rural locations) (England Leisure Visits Survey 2005)
Kind of methodical approach	Quantitative modelling analysis based on own case studies
Methodical approach	It is considered, that the number of day leisure visits are representative of the recreation value of the landscapes.
Comments	Spatial patterns of selected ESS were analysed to show the spatial covariance between biodiversity and these ESS. It could be proved, that enhancing the resolution of data (from 100 km² to 4 km²) did not change the broad spatial covariance structures. But, changing the spatial extent of the study area (from 100 km² to 4 km²) revealed a different relationship between biodiversity and the selected ESS in about 75% of the 41 investigated grid squares.
Reference	Anderson et al. 2009 (similar method also used in Eigenbrod et al. 2009)

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Service category (TEEB 2010)	**CULTURAL SERVICES**
Service type (TEEB 2010)	**Opportunities for recreation & tourism**
ESC name	Tourism suitability
ESS name	n.r.
Objectives of the study	To establish a methodological framework to map and quantify landscape functions depending on the availability of spatial information.
Stock indicator	Tourism probability
Flow indicator	n.r.
Biophysical unit of indicator	Dimensionless value (between high and low)
Type of ecosystems	Urban ecosystems, grassland, woodland and forest, heathland and shrub, sparsely or unvegetated land, inland wetlands, rivers and lakes, coastal areas
Spatial resolution of the map	100 m x 100 m
Coverage	Gelderse Vallei region (Netherlands)
Mapping scale	regional
Data & source	Data on accommodation sites, land cover classes (percentage of agriculture, built-up area, natural areas), distance from highways, swimming locations, cultural, historical elements, road network for cycling.
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	The capacity to provide an attractive landscape for overnight tourism was quantified by means of tourism suitability (accommodation sites). Land cover, level of disturbance, recreation possibilities and accessibility were the most important landscape characteristics for tourism to be used as indicators for suitable tourism locations. Land cover indicators considered were percentage of agriculture, built-up area, and natural areas surrounding the tourist locations. Also openness of the landscape, disturbance level and distance to intensive livestock farms were included. Recreation possibilities were indicated by the distance to natural areas, density of trails in the natural areas, distance to swimming locations, presence of cultural historical elements in the neighbourhood and local road network for cycling recreation. A stepwise logistic regression was used to make a selection of predictive variables.
Comments	Although the proposed methodology has been specified for the case study area, the general approach should be applicable to other case studies as well. But different areas will have different data availability, different function definitions and thresholds to be applied.
Reference	Willemen et al. 2008

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Service category (TEEB 2010)	**CULTURAL SERVICES**
Service type (TEEB 2010)	**Opportunities for recreation & tourism**
ESC name	Leisure cycling
ESS name	n.r.
Objectives of the study	To establish a methodological framework to map and quantify landscape functions depending on the availability of spatial information.
Stock indicator	Population living in a reachable distance from suitable cycling area
Flow indicator	n.r.
Biophysical unit of indicator	Absolute number of people
Type of ecosystems	Urban ecosystems, grassland, woodland and forest, heathland and shrub, sparsely or unvegetated land, inland wetlands, rivers and lakes, coastal areas
Spatial resolution of the map	100 m x 100 m
Coverage	Gelderse Vallei region (Netherlands)
Mapping scale	regional
Data & source	Data on population, road network, built-up areas
Kind of methodical approach	Quantitative modelling analysis using existing data
Methodical approach	Landscape functions were quantified and mapped using different methods depending on availability of spatial information. To assess the leisure cycling function the following landscape characteristics were included: residential locations, populations, average cycling distance, cycling facilities, and visual and noise disturbance elements like industry, business parks and highways. All areas with small local roads within a distance of 5 km around each residential neighbourhood were included as leisure areas. Whereas, locations with highways, industry, business parks and waste dumps were excluded. The leisure cycling function was quantified based on the population that could reach the suitability cycling area.
Comments	Although the proposed methodology has been specified for the case study area, the general approach should be applicable to other case studies as well. But different areas will have different data availability, different function definitions and thresholds to be applied.
Reference	Willemen et al. 2008

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Service category (TEEB 2010)	**CULTURAL SERVICES**
Service type (TEEB 2010)	**Opportunities for recreation & tourism**
ESC name	n.r.
ESS name	Recreation
Objectives of the study	To develop a GIS model to identify hot spots for nearby recreation based on a representative survey
Stock indicator	n.r.
Flow indicator	Declared presence (DP) at favourite geographical locations with regard to a time period (3 to 12 month), as a proxy of actual recreation
Biophysical unit of indicator	number of DP per km²
Type of ecosystems	Urban ecosystems, grassland, woodland and forest, heathland and shrub, inland wetland, rivers and lakes
Spatial resolution of the map	1 km x 1 km
Coverage	St. Gallen and Langenthal (Switzerland)
Mapping scale	local
Data & source	People´s landscape preferences and favourite geographical locations for nearby recreation were gathered by a survey. Geo referenced 'objective' landscape properties like distance to recreation site, scenic vista, landscape configuration, or water related properties were derived from existing databases of the Swiss Federal Statistical Office, GEOSTAT, the Swiss Federal Office of Topography Swisstopo and others.
Kind of methodical approach	Quantitative modelling analysis based on own case studies
Methodical approach	A statistical model was developed to predict the dependence between people´s declared locations for nearby recreation around their residences (spatially explicit data) and 'objective' landscape properties of the visited locations. People´s 'subjective' landscape preferences (survey) were related to the significantly correlated 'objective' landscape variables derived from the model calculation. The maps were generated using the predictive model based on those 'objective' landscape characteristics (13 predictor variables) with the strongest hypothesized relations to nearby recreation use. Study areas are representing common landscape located around typical small to medium sized towns in Switzerland (10.000 to 100.000 inhabitants).
Comments	The authors prove that their empirical model is able to mimic the different patterns of people´s declared presence accurately and to identify hotspots of high nearby recreation potential. The use of landscape parameters could explain residents presence around mid-sized towns to a high degree. Additionally, 'objective' landscapes properties of the visited sites and the 'subjective' landscape preferences matched quite well, with some exceptions.
Reference	Kienast et al. 2012

5.2 Annex 2: References referring to the Mapping of ESS & ESC at different European scales

Mapping examples published by authors in bold letters are described in detail in the tables of Annex 1 (Selection process for these papers and their mapping examples is explained in chapter 2.1)

Anderson, B. J., Armsworth, P. R., Eigenbrod, F., Thomas, C. D., Gillings, S., Heinemeyer, A., David, B. R. And Gaston, K. J., 2009, 'Spatial covariance between biodiversity and other ecosystem service priorities', Journal of Applied Ecology, 46, 888–896.

Aspinall, R. and Milne, E., 2009, 'Mapping and modelling ecosystem services in land systems', IOP Conference Series: Earth and Environmental Science, 6, 342009, IOP Publishing. DOI:10.1088/1755-1307/6/4/342009.

Bolliger, J. and Kienast, F., 2010, ‚Landscape Functions in a changing environment', Landscape Online, 21, 1–5, DOI:10.3097/LO.2012021.

Burkhard, B., Kroll, F., Müller, F. and Windhorst, W., 2009, 'Landscapes´ Capacities to provide ecosystem services – a concept for land-cover based assessment', Landscape Online, 15, 1–22. DOI:10.3097/LO.200915.

Burkhard, B., Kroll, F., Nedkov, S. and Müller, F., 2012, 'Mapping ecosystem service supply, demand and budgets', Ecological Indicators 21, 17–29.

Busch, M., La Notte, A., Laporte, V. and Erhard, M., 2012, Potentials of quantitative and qualitative approaches to assessing ecosystem services', Ecological Indicators, 21, 89–103.

Countryside Council for Wales, 2010, 'Sustaining Ecosystem Services for human Well-Being: Mapping Ecosystem Services, retrieved on 05.07.2012 from http://www.ccgc.gov.uk/landscape--wildlife/managing-land-and-sea/sustaining-ecosystem-services.aspx

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Eigenbrod, F., Armsworth, P. R., Anderson, B. J., Heinemeyer, A., Gillings, S., Roy, D. B., Thomas, C. D. and Gaston, K. J., 2010, 'The impact of proxy-based methods on mapping the distribution of ecosystem services', Journal of Applied Ecology, (47) 377–385.

Gallaun, H., Zanchi, G., Nabuurs, G. J., Hengeveld, G., Schardt, M. and Verkerk, P. J, 2010, 'EU-wide maps of growing stock and above-ground biomass in forest based on remote sensing and field measurements', Forest Ecology and Management, 260, 252–261.

Gee, K. and Burkhard, B., 2010, 'Cultural ecosystem services in the context of offshore wind farming: A case study from the west coast of Schleswig-Holstein', Ecological Complexity, 7, 349–358.

Gimona, A. and van der Horst, D., 2007, ‘Mapping hotspots of multiple landscape functions: a case study on farmland afforestation in Scotland’, Landscape Ecology, 22, 1255–1264.

Gret-Regamey, A., Brunner, S. H. and Kienast, F., 2012, ‘Mountain ecosystem services: How cares?’, Mountain research and development, 32, 23-34.

Gret-Regamey, A., Brunner, S. H., Altweg, J. and Bebi, P., 2012, ‘Facing uncertainty in ecosystem service-based resource management’, Journal of the environmental Management, xxx, 1-10.

Haines-Young, R., Watkins C., Wale, C. and Murdock A., 2006, ‘Modelling natural capital: The case of landscape restoration on the South Downs, England’, Landscape and Urban Planning, 75, 244–264.

Haines-Young, R., Potschin, M. and Kienast F., 2012, ‘Indicators of ecosystem service potential at European scales: Mapping marginal changes and trade-offs’, Ecological Indicators, 21, 39–53.

Hönigova, I., Vackar, D., Lorencova, E., Melichar, J., Götzl, M., Sonderegger, G., Ouskova, V., Hosek, M. and Chobot, K., 2011, ‘Survey on grassland ecosystem services’, Report to the European Topic Centre on Biological Diversity, Prague.

Jones, M. B. and Donnelly, A., 2004, ‘Carbon sequestration in temperate grassland ecosystems and the influence of management, climate and elevated CO_2, New Phytologist, 164, 423–439.

Kienast, F., Bolliger, J., Potschin, M., de Groot, R. S., Verburg, P. H., Heller, I., Wascher, D. and Haines-Young, R., 2009, ‘Assessing Landscape Functions with Broad-Scale Environmental Data: Insights Gained from a Prototype Development for Europe’, Environmental Management, 44, 1099–1120.

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5.5 Annex 5: Abbreviations used in the report

Abbreviations used in the report and in Annex 1

CDDA	Common Database on Designated Areas
CDIAC	Carbon Dioxide Information Analysis Center
CICES	Common International Classification of Ecosystem Services
CLC	Corine Land Cover
EFI	European Forest Institute
ESCIFEN	European Forest Information Scenario Database
ESF	Ecosystem function(s)
ESS	Ecosystem service(s)
EURURALIS	Eururalis is a scenario study starting from four contrasting world visions for Europe´s rural areas
FAO	Food and Agriculture Organization
GLC	Global Land Cover
Gtopo 30 global	Global digital elevation model
GREEN	Geospatial Regression Equation for European Nutrient losses
IPCC SRES	Intergovernmental penal on climate change special report emission scenarios
MAPPE	Multimedia Assessment of Pollutant Pathways in the Environment of Europe
MLC	Maximum Livestock Capacity
MODIS	Moderate Resolution Imaging Spectroradiometer
NUTS	Nomenclature des unités territoriales statistiques
OPR	Obce s rozsírenou pusobností (Municipalities with extended powers)
RPI	Recreation potential index
TEEB	The Economics of Ecosystems and Biodiversity study with standardized classes for ecosystem services
VITO	Vision on technology, Research Institute, Belgium