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A European assessment of the provision of ecosystem services

Towards an atlas of ecosystem services

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1 INTRODUCTION

Biodiversity provides vital goods and services, such as food provision, carbon sequestration and water regulation that underpin economic prosperity, social well-being and quality of life. Together with climate change, the loss of biodiversity is the most critical global environmental threat we face, and entails substantial economic and welfare losses (European Commission, 2010).

In 2001, the EU set itself the target to halt biodiversity loss in the EU by 2010. In spite of substantial efforts in order to better protect nature, there is compelling evidence that the globally agreed 2010 target of stopping the loss of biodiversity has not been met. In contrast, biodiversity, ecosystems and the services they provide continue to deteriorate. Many of the pressures that affect habitats and species, including the conversion of ecosystems for other purposes of land use, climate change, invasive species, fragmentation of the land, pollution and overexploitation of biological resources, continue to impact biodiversity.

In 2010 the EC proposed a renewed vision and targets for biodiversity for the ensuing period, building on and contributing to the international deliberations on a global vision for biodiversity beyond 2010, which will be part of a revised and updated strategic plan for the United Nations Convention on Biological Diversity (CBD) (European Commission, 2010). A crucial step in setting the new targets is the provision of a first set of biophysical maps of ecosystem services of key importance at the EU level.

Mapping the biophysical provision of ecosystem services at continental, sub global or global scale is in general constrained by data availability. Beyond local case studies, there is little evidence of the spatially explicit estimation of ecosystem services and of the flow of benefits to near and distant human populations, neither in Europe, nor elsewhere. An attempt to produce a global map of ecosystem services was presented by Naidoo et al. (2008). They succeeded in mapping four proxies: carbon storage and sequestration, grassland production for livestock and fresh water provision. An important conclusion of the preliminary analysis was that regions selected to maximize biodiversity provided no more ecosystem services that randomly selected regions. Therefore, the European Commission called for a more coherent approach to development and spatial planning needs to be set up for the territory falling outside protected areas, recognizing that important services may be delivered by semi-natural and agricultural ecosystems as well.

Such an assessment necessitates the development of ecosystem services maps and models in order to estimate where ecosystem services are produced, to quantify the changes in service provision over time, to describe the production of ecosystem services as a function of patterns of land use, climate and environmental variation. Importantly, a spatially explicit assessment of ecosystem services can couple biophysical estimates of service provision to an economic and monetary valuation.

The spatial assessment of Europe's ecosystem services is a major objective of the BIOMES action of the JRC. This report is a first deliverable in reaching this objective. The main objectives of this report are

- To establish a methodology for ecosystem service mapping
- To summarize the key resources needed for this mapping exercise.
- To map the provision of ecosystem services at EU scale
- To assess synergies and trade-offs of ecosystem services at EU scale
- To estimate the contribution of European ecosystems to the provision of ecosystem services

The approach used in this study is a pragmatic one. Contrary to studies which have used ecosystems as a basis for the assessment and attributed different services to these ecosystems, we collected spatial information on ecosystem services and subsequently coupled this information to ecosystems. This is possible since the concept of ecosystem services presents a common framework for integrating different environmental and economic disciplines. Atmospheric, climatic, soil or hydrological models often have an ecosystem component addressing interactions between vegetation and the environment. Or they make use of land cover and land use data sets for assigning spatially different values to parameters.

As a result, this assessment of ecosystem services is largely based on existing information that is either available through pan-European databases, often based on remote sensing of vegetation, or on data and results captured in, or simulated by, environmental models that assess air pollution, water quantity and quality or soil related problems.

Not all ecosystem services, however, are the focus of large scale modeling studies or can be observed using remote sensors. This is particularly true for those services that are strongly connected to biodiversity, such as the provision of medicinal, ornamental and genetic resources, regulating services as pollination and biological control (of pests) and all cultural ecosystem services. Indicators for these services are under development and in this report we present some first results on this work.

2 SPATIALLY EXPLICIT MAPPING OF ECOSYSTEM SERVICES

In a Communication (European Commission, 2010) published at the onset of the year of biodiversity, the European Commission commits itself to develop a first set of biophysical maps of ecosystem services of key importance at the EU level by the end of 2010. These maps must identify the spatial differences in ecosystem services supplied by all ecosystems situated in the European Union, including also semi natural and agricultural systems which fall outside the Natura2000 network and which contribute to the green infrastructure.

2.1 A LIST OF ECOSYSTEM SERVICES

This report will use the list of ecosystem services compiled for the TEEB assessment (The Economics of Ecosystems and Biodiversity) as a starting point. TEEB proposes a typology of 22 ecosystem services divided into 4 main categories: provisioning, regulating, habitat and cultural services, mainly following the MEA-classification (Millennium Ecosystem Assessment; Table 1). An important difference, as compared to the MEA, is the omission of supporting services such as nutrient cycling. Instead, the habitat service has been identified as a separate category to highlight the importance of ecosystems to provide habitat for migratory species (e.g. as nurseries) and gene-pool protectors (e.g. natural habitats allowing natural selection processes to maintain the vitality of the gene pool). The availability of these services is directly dependent on the state of the habitat providing the service.

2.2 A DATA DRIVEN APPROACH FOR MAPPING ECOSYSTEM SERVICES

Given the broad spectrum of scientific disciplines that cover the concept of ecosystem services, a full assessment of the impact of drivers and pressures on the provision of ecosystem services requires an interdisciplinary modeling approach. It requires coupling large scale environmental models that simulate processes taking place in the atmosphere, watersheds, soils and ecosystems with models that simulate socio-economic and agricultural systems in close relation with the consequences of resource use on land and ocean dynamics. Such integrated assessment needs to be translated into suitable indicators for ecosystem functions and services and subsequently to the benefits obtained from these services. Clearly, such development requires international, scientific cooperation and considerable IT efforts (for instance see Schröter et al. 2005; Metzger et al. 2008).

In order to create a series of maps, a more data driven methodology is suggested in this report focusing on the use of the present knowledge base of environmental models in order to produce a set of indicators for ecosystem services that cover the European continent. An assumed link between these spatial indicators and land cover data will be used to explore the changes of ecosystem service provision over time and to calculate policy scenarios.

Table 1. Typology of ecosystem services used in TEEB.

PROVISIONING SERVICES: THE GOODS OR PRODUCTS OBTAINED FROM ECOSYSTEMS Food (e.g. fish, game, fruit) Water (e.g. for drinking, irrigation, cooling) Raw materials (e.g. fiber, timber, fuel wood, fodder, fertilizer) Genetic resources (e.g. for crop improvement and medicinal purposes) Medicinal resources (e.g. biochemical products, models & test organisms) Ornamental resources (e.g. artisan work, decorative plants, pet animals, fashion)
REGULATING SERVICES: THE BENEFITS OBTAINED FROM AN ECOSYSTEM'S CONTROL OF NATURAL PROCESSES Air quality regulation (e.g. capturing (fine)dust, chemicals, etc.) Climate regulation (incl. C-sequestration, influence of vegetation on rainfall, etc.) Moderation of extreme events (e.g. storm protection and flood prevention) Regulation of water flows (e.g. natural drainage, irrigation and drought prevention) Waste treatment (especially water purification) Erosion prevention Maintenance of soil fertility (incl. soil formation) Pollination Biological control (e.g. seed dispersal, pest and disease control)
HABITAT SERVICES: SERVICES SUPPORTING THE PROVISION OF OTHERS BY PROVIDING HABITAT Nursery habitat Gene pool protection
CULTURAL SERVICES: THE NONMATERIAL BENEFITS OBTAINED FROM ECOSYSTEMS Aesthetic information Opportunities for recreation & tourism Inspiration for culture, art and design Spiritual experience Information for cognitive development

2.3 CAPACITY, FLOW AND BENEFITS OF ECOSYSTEM SERVICES: A FRAMEWORK FOR MAPPING AND VALUATION

The monetary valuation framework adopted by the TEEB proposes to value ecosystem services using two main components that constitute together the total economic value of the ecosystem: insurance value and output value (TEEB chapter 5, de Groot et al. 2010). The insurance value relates to the ecosystem's resilience or the **capacity** to maintain a sustained flow of benefits. The output value is the value attached to direct ecosystem's **flow** of services and benefits.

Ecosystem service capacity and service output are closely related to the notion of (standing) stocks and flows. Layke (2009) defines stocks of ecosystem services as the capacity of an ecosystem to deliver a service while the flow corresponds to the benefits people receive. Stocks may be expressed in total size area or the total biomass whereas the associated ecosystem service flow or output must have units per time period.

The capacity of an ecosystem to provide a flow is not necessarily measured in hectares or tons since the capacity does not only contain a quantity aspect but also a quality aspect. For a given quantity, an ecosystem may provide more output if it is in a healthy state, or at least be able to provide a sustained flow of services. As a result, the capacity of such a system to produce services will be higher. Ecosystems in a healthy state are considered resilient systems which are able to recover after disturbance and they are characterized by high species diversity and a balanced trophic community.

Benefits derived from ecosystem services are food, drinking water, clear air, fuel, fibre, construction materials, protection against disasters and stable climate. Demand for these benefits will also vary spatially but these differences are not mapped in this study.

2.4 MAPPING METHODOLOGY

The approach to map ecosystem services will follow a common procedure for all services. The aim of this study is to provide a first assessment of European ecosystem services based on present knowledge of models and datasets that cover the European continent. As such, we have developed a set of indicators that can be used to map the capacity and provision of ecosystem services at EU scale.

2.4.1 SPATIAL INDICATORS FOR ECOSYSTEM SERVICES

Ecosystem service indicators communicate spatial variability in ecosystem services. Indicators of ecosystem services ideally convey information about the flow of service - the benefits people receive (Layke 2009). Many of the ecosystem services are, however, difficult to model or to measure (for instance soil quality or cultural services) and we rely on proxy indicators for assessing changes in the provision of these services (for instance the number of tourists that enjoy nature in an area).

For each service listed in Table 1 we have attempted to find a set of suitable indicators or proxies which reflect the capacity of ecosystems to generate services and the associated ecosystem service flow. These indicators are based on existing spatial data at the European scale, or they are drawn from models that were adapted in order to produce the spatial indicator of interest. Each indicator is identified by a definition, units, spatial resolution, model or data from which is has been extracted and the spatial scale.

The focus of this report is on ecosystem services that are currently provided by terrestrial and freshwater ecosystems. The following services are excluded from this report: services provided by European coastal zones and regional seas, services delivered by subsoil systems or by the atmosphere, services performed in the past (for instance fossil fuel reserves). We do not consider mining and extraction of (non living) minerals or the provision of water for human consumption by extraction from groundwater reserves.

2.4.2 MAPPING UNITS, PROJECTION AND RESOLUTION

All spatial indicators for ecosystem services differ in spatial resolution and scale. The spatial scale at which pan-European ES indicators can be mapped depends essentially on the mapping resolution of the biophysical models that have been used to derive the indicators. Land related ES such as soil services are commonly available at resolutions of < 1 km, while services related to the atmosphere are usually available at scales >1km. Water related services are often calculated on the basin or sub basin level. Spatial information for cultural services is generally only available at a provincial level.

So whereas individual ecosystem service maps will be presented in their original resolution, the spatial unit of a tradeoff assessment will be a compromise between the different spatial units in which the indicators can be mapped and more importantly, the spatial resolution at which an economic valuation is still meaningful.

For a first assessment cycle, we have opted to use the NUTSx statistical area as the spatial mapping unit. This corresponds to NUTS 3 units for most EU countries and NUTS 2 units for Belgium, The Netherlands and Germany.

This choice is mainly determined by the economic valuation that follows the biophysical mapping. Evidently, indicator maps will be made available at finer spatial resolution but the assessment of tradeoffs in ecosystem services will be performed at the NUTSx level.

However, a more appropriate classification based on a regionalization of the area of interest using ecosystem properties and geo-biophysical features such as land cover, primary production, soil properties and topography can be considered in later phase.

All data are projected using the GCS-ETRS-1989 coordinate system.

2.5 DELIVERABLES

The methodology will result in a series of maps that will be made for each ecosystem service:

- A map showing the spatial variation of the ecosystem service at original resolution and scale.
- A map with the indicator aggregated over NUTSx for the EU27

3 SPATIAL INDICATORS FOR ECOSYSTEM SERVICES

We collected spatially explicit indicators for 13 ecosystem services. For each service, we identified indicators for service capacity and service flow, the benefits derived from each service, the biodiversity components that are essential to sustain the generation of these services and the contributing land cover classes using the CORINE land cover data (Tables 3-5). These tables serve as a basis for the further assessment. Not all components are already mapped or assessed in this study. The report contains predominantly information on service capacity, less on service flow and none on the spatial distribution of the benefits associated to each service.

Provisioning services supplying food, fuel, fibre and water are summarized in Table 2. They include food production by crops and livestock, timber production by forests and water supply by freshwater ecosystems. No pan-European spatial information was found to approximate the contribution of ecosystems to the provision of medicinal, genetic and ornamental resources. Also, no information is provided on wild foods from plants such as berries or from inland fish and game.

Regulating services for which information was found at the EU scale include the regulation of air quality, water quantity and quality and climate, the regulation of soil and the control of erosion and pollination. Most of the indicators included in Table 3 capture only a partial aspect of the service. The role of ecosystems in climate regulation is, for instance, much larger that only the sequestration of carbon from the atmosphere and includes at various spatial scales the global, regional and local effect of vegetation on climate via regulation of water vapor and temperature and the provision of shade.

For **cultural services** information at the scale of Europe is lacking. A first indicator on the recreation potential of natural systems is presented in this report (Table 4).

In the remainder of this section, the different indicators for ecosystem service capacity and flow are presented including detailed information on the data sources, a presentation of EU ecosystem service maps and a discussion on possible limitations and recommendations for further research and development of each of these services.

Table 2. Provisioning services.

Capacity	Flow	Benefits	Biodiversity
Timber			
Forest capacity to produce timber • Timber stock (ha, m^3)	Timber increment • Average dry matter productivity in forests (m^3 $year^{-1}$)	Products for fuel, construction and paper • Round wood production (m^3 $year^{-1}$)	• Forest connectivity • Conservation status of forests • Tree species diversity
Crops			
Potential production of agro-ecosystems • Total area of cropland (ha) • Agricultural limits for soil (ha)	• Realized crop production (ton ha^{-1} $year^{-1}$)	• Realized crop production (ton ha^{-1} $year^{-1}$)	• Genetic diversity in crops • Wild crop diversity
Livestock			
Potential livestock production • The total area of grasslands suitable for grazers • The density of grazing livestock	• Total livestock production derived from grazing on (unimproved) grassland (ton ha^{-1} $year^{-1}$)	• Livestock production of grazers (ton per NUTS2 $year^{-1}$)	• Genetic diversity in livestock species
Water provision			
The reserves of renewable fresh water • Total area of inland water bodies and inland wetlands (ha)	• Total annual renewable freshwater supply (m^3 $year^{-1}$) by surface waters	• Total annual freshwater consumption per sector	

Definition and indicators expressing the capacity, flow and benefits of timber, crop production and livestock production and water provision. Identification of the biodiversity needed to sustain service production. Data sources are provided in the text.

Table 3. Regulating services.

Capacity	Flow	Benefits	Biodiversity
Water quantity regulation			
Potential of ecosystems to store water • Soil infiltration capacity (mm)	• Total amount of water stored, m^3 $year^{-1}$ • Total number of floods mitigated	Prevented flooding Total population protected	
Capacity of ecosystems to retain and process pollutants and excess nutrients • Nitrogen retention (%)	• Total amount of pollutants removed annually (ton ha^{-1} $year^{-1}$) • Total amount of water purified	Clean water for drinking, recreation and other uses	• Aquatic micro-organisms and planktonic species • Waterplants
Climate regulation			
Capacity of ecosystems to store greenhouse gasses • Carbon storage (ton)	Annual carbon fixation • Carbon fixation (gC m^{-2} $year^{-1}$)	• Carbon offsets (m^3 CO2 eq $year^{-1}$)	• Vegetation (forest diversity and grassland diversity)
Storm protection			
Capacity of ecosystems to moderate the impact of storms and to prevent flooding • Total area of coastal wetlands (ha)	• Total number of storms mitigated	• Total damage prevented • Total population protected	
Air quality regulation			
Capacity of ecosystems to capture and remove air pollutants • Deposition velocity of air pollutants on leaves (m $year^{-1}$) • Leaf area index • Critical loads	• Total amount of pollutants removed via dry deposition on leaves (ton ha^{-1} $year^{-1}$)	• Effect on air quality • Contribution to clean air	• Vegetation nearby pollution sources
Erosion control			
Potential of ecosystems to retain soil and to avoid erosion • Area of forest in vulnerable zones	• Total amount of soil retained (ton ha^{-1} $year^{-1}$)		• Vegetation

Definition and indicators expressing the capacity, flow and benefits of regulating services. Identification of the biodiversity needed to sustain service production. Data sources are provided in the text.

Table 4. Continued.

Capacity	Flow	Benefits	Biodiversity
Pollination			
Pollination capacity of ecosystems • Distance to crops (km) • Crop dependency (%) • Pollinator abundance (nests per km^2)	Increased yield of crops attributable to pollination • Crop dependency × Annual production (ton $year^{-1}$)	• Contribution to realized crop production (ton ha^{-1} $year^{-1}$)	• Pollinator species diversity • Habitat diversity • Linear elements
Soil quality regulation			
Capacity to maintain the soil's biological activity • Soil quality indicator • Soil organic carbon (%)	Increased yield of crops attributable to soil quality (ton $year^{-1}$)	• Contribution to realized crop production (ton ha^{-1} $year^{-1}$)	• Soil diversity • Soil PH

Definition and indicators expressing the capacity, flow and benefits of regulating services. Identification of the biodiversity needed to sustain service production. Data sources are provided in the text.

Table 4. Cultural services.

Capacity	Flow	Benefits	Biodiversity
Recreation			
Capacity of natural ecosystems to provide recreation • Recreation potential × Accessibility	• Number of visitors		• Attractive biodiversity

Definition and indicators expressing the capacity, flow and benefits of recreation as cultural service. Identification of the biodiversity needed to sustain service production. Data sources are provided in the text.

3.1 PROVISIONING SERVICES

3.1.1 TIMBER SERVICES

Timber provision refers to the products made from trees harvested from natural forest ecosystems and plantations.

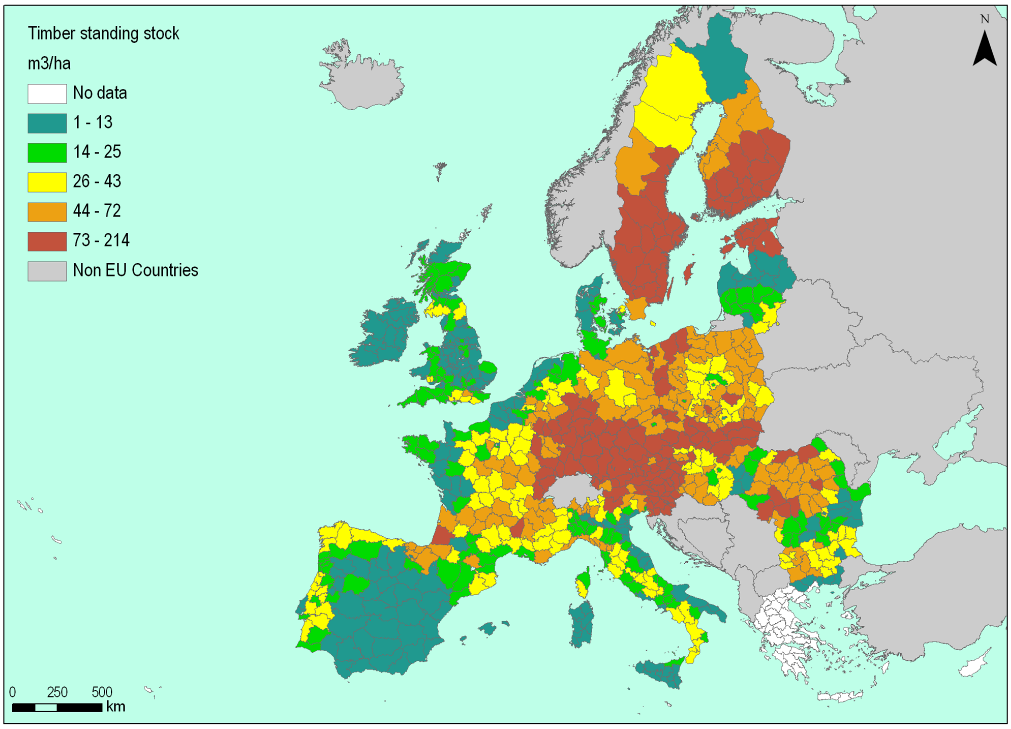
3.1.1.1 Data for mapping timber services at EU scale

The **capacity of forests to produce timber** as well as the associated annual **timber increment** was approximated using two standing stock inventories. We firstly used the JRC forest inventory created by the AFOLU action to acquire regional statistics of the total area (ha), the standing stock volume (m^3 per statistical area per year) and the stock increment (m^3 ha^{-1} $year^{-1}$). Next, data for missing countries were gapfilled using the ESCIFEN database. These data were subsequently disaggregated to the $NUTS_X$ level using the CLC2000 data displaying the distribution of forests and agro-forestry areas as spatial surrogate.

The European Forest Institute (EFI) hosts the European Forest Information Scenario Database (EFISCEN) a forest inventory database of European countries, based on input from national inventory experts. The bases of the EFISCEN Inventory database are the individual national forest inventories of 32 European countries. For each forest type and age class, the forest area, the total and mean volume, the total annual increment and the current annual increment may be retrieved from the EFISCEN Inventory database. Such data are available for all countries which have an even-aged forest structure. Input data on area, growing stock volumes and increment are usually derived from national forest inventories. (http://www.efi.int/portal/virtual_library/databases/). Based on the EFISCEN inventory, the AFOLU action of the JRC produced provides aggregated statistics on the timber stock, expressed in ha and m^3 and increment (m^3 $year^{-1}$). (http://fi.jrc.ec.europa.eu/Frameset.cfm).

3.1.1.2 Maps

Fig. 1 shows the disaggregated forest inventory data (timber standing stock and timber increment).



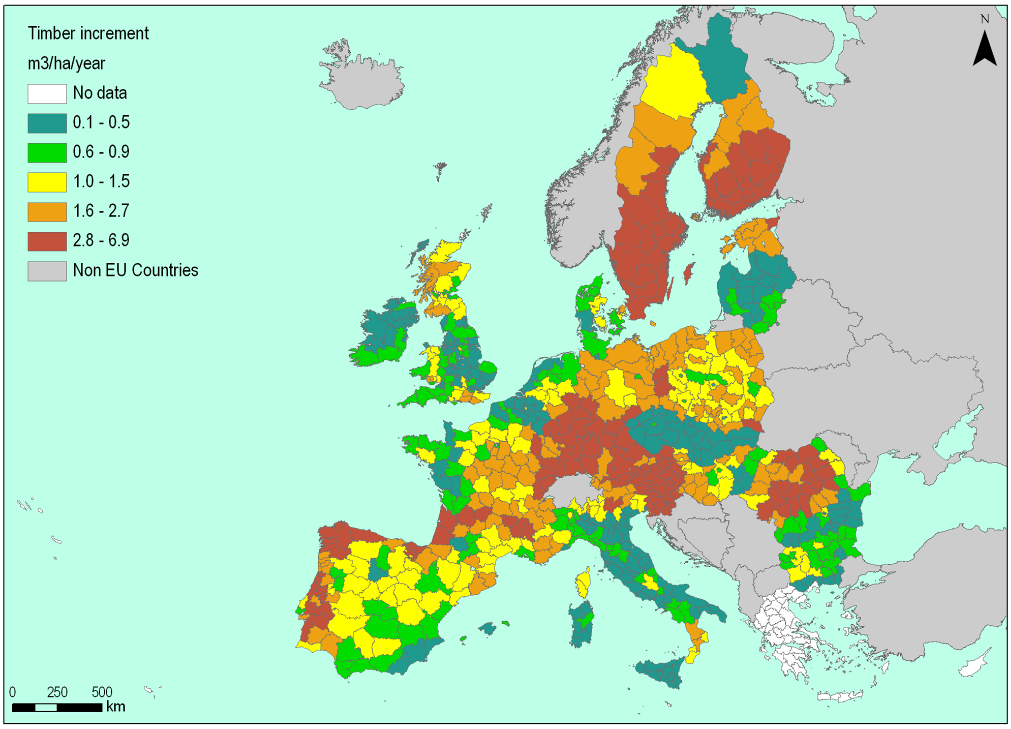


Fig. 1. Timber standing stock and increment per NUTSx statistical area. Source: European Forest Institute, EFISCEN forest inventory database

3.1.1.3 Limitations and further work

There remain several shortcomings with the approach followed to map timber stocks and increment. The EFISCEN forest inventory data are not harmonized over the different countries and the spatial resolution of the data is only at regional level.

There are no data available that make distinction between managed and unmanaged forests. While both types of forest posses capacity to produce timber, only managed forest contribute to timber production and this production trades off with other services that are delivered by forests. Arguably, timber producing forests should be excluded as contributors to some of the other services. This has not been done in the present assessment.

An alternative to using the forest inventory data is using dry matter productivity as proxy for timber increment. The Geosucces database, hosted by VITO (Belgium), provides, among others, data based on remote sensing using images from SPOT-VEGETATION. Dry Matter Productivity or DMP products are 10-daily images representing estimates of dry matter, oriented towards agricultural crop monitoring and yield estimation. These DMP-images are very similar to the NPP products, they are also based on the classical Monteith-model which combines the remote sensing imagery (NDVI converted to fAPAR) with meteorological data in order to obtain estimates of the productivity of the terrestrial vegetation. (http://geofront.vgt.vito.be/geosuccess). A detailed study of the DMP data (which are available since 1998) is needed to assess annual changes in accumulated DMP. Such an assessment, combined with ground observations on logging or clear cutting, may identify pixels were logging activities and deforestation (for timber production) occurs. In addition, the data can be used to compare DMP increments with measured timber volume increments.

A approach combining both national forest inventory data and remotely sensed vegetation data (MODIS) is recently presented in Gallaun et al. (2010) who produced pan-European maps on growing stock and above-ground woody biomass for the coniferous and broad leaved forests at a resolution of 500 m (Fig. 2, Galllaun et al. 2010). CLC2000 forest land cover classes were used assigning stock and biomass data to forest pixels.

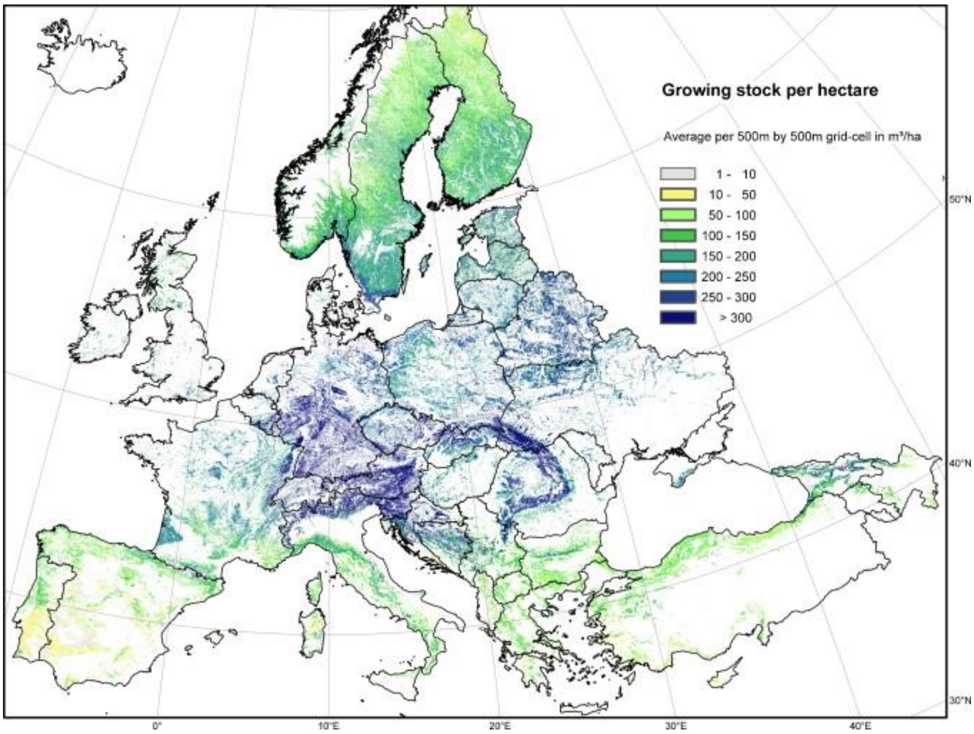


Fig. 2. Estimated European timber growing stock at 500 m resolution (Gallaun et al. 2010)

3.1.2 Crop services

Crops services include the production of crops such as grains, vegetables and fruits, cotton or rapeseed which are the cultivated plants or agricultural produce harvested by people for human or animal consumption as food, for production of fiber or for use as source of energy.

Agricultural services may under some schemes not be considered as ecosystem services but are referred to as environmental services. In this assessment, they are considered as ecosystem services. The main argument is that including provisioning services derived from agriculture or agro-ecosystems is essential in a tradeoff analysis. Furthermore, agricultural systems comply in a strict sense with the definition of an ecosystem.

3.1.2.1 Data and indicators for mapping crop services at EU scale

Indicators for crop services are still under development. For the present, preliminary assessment, the **capacity of agro-ecosystems to provide crop services** was approximated using simply the area of CLC agricultural land cover classes (Table 2).

3.1.2.2 Maps

Crop production capacity of agro-ecosystems is given in Fig. 3 which presents the share of cropland per NUTS statistical area as estimated from the CLC2000 land cover map. An indicator for annual service flow is under development.

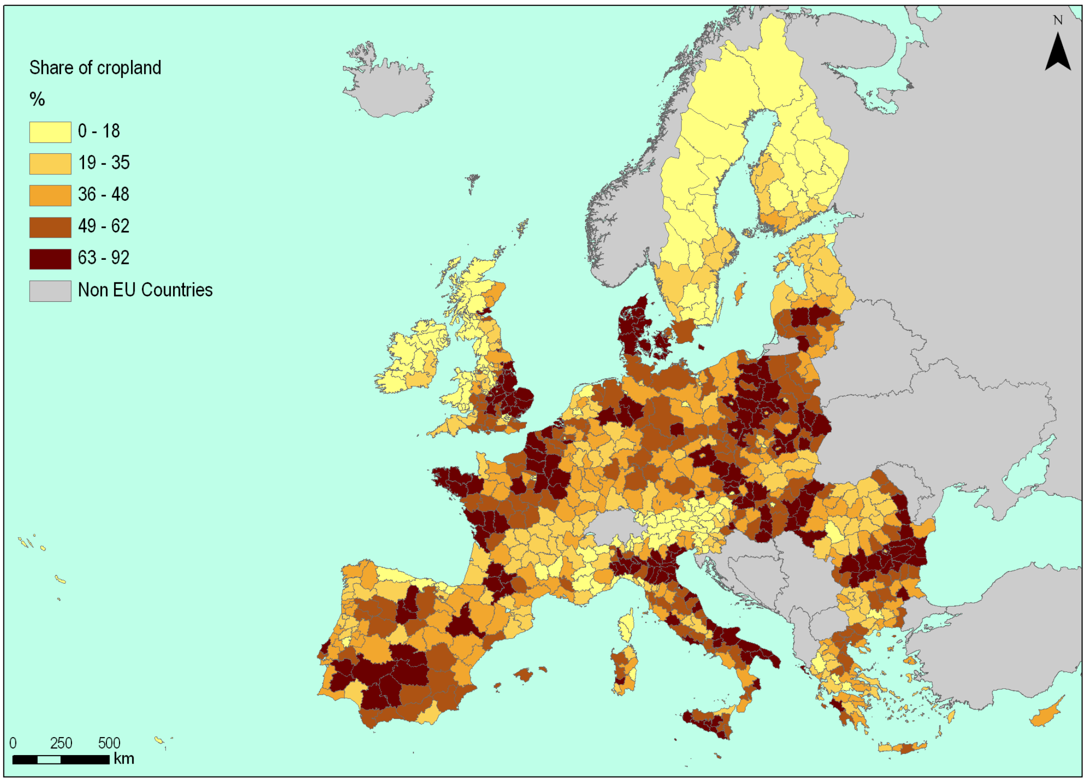


Fig. 3. Share of cropland in the land cover per NUTSx statistical area.
Source: Corine Land Cover 2000 raster data - version 13.

3.1.2.3 Limitations and further work

A more appropriate indicator using output from the CAPRI model is under development. CAPRI (Common Agricultural Policy Regional Impact, Britz and Witzke 2008), is a partial equilibrium model for the agricultural sector developed for policy impact assessment of the Common Agricultural Policy and trade policies from global to regional scale with a focus on the EU. The model is iteratively linking a supply module (separate, regional, non-linear programming models allowing to directly implement most policy measures with highly differentiated set of activities) with a market module (spatial, global multi-commodity model for agricultural products, 47 product, 60 countries in 28 trade blocks). The model comprises the spatial downscaling for EU27 of crop shares, yields, stocking densities, fertilizer application rates to 150.000 Homogenous Soil Mapping Units (HSMU) for environmental impact assessment and link to bio-physical models.

EUROSTAT holds crop production statistics at the regional level (NUTS 2) which are used as inputs in the CAPRI model.

An appropriate indicator of crop services assesses the potential production of agro-systems based on natural capacity, removing water, energy and fertilizer subsidies. In order to estimate the contribution of the ecosystem relative to the contribution of subsidies and in order to compare between regions, the crop production may be normalized for the amount of fertilizer that is applied reducing the crop production delivered in intensively fertilized systems or for the total amount of energy or water that is used as input to produce consumables. Note that there is a risk of double counting when considering soil services (which are categorized under regulating services).

An indicator for service flow starts from the realized crop production and assesses the share of natural capacity to this production.

3.1.3 LIVESTOCK SERVICES

Livestock services refer to animals raised for domestic or commercial consumption or use such as cattle, pigs and poultry.

3.1.3.1 Data and indicators for mapping of livestock services at EU scale

Naidoo et al. (2008) provide a methodology for global mapping of grassland production of livestock, from grazing on unimproved grasslands. To map livestock production on natural pastures, 3′-resolution global maps of livestock distributions were used and intersected with the spatial distribution of (unimproved) grasslands. Maps of gridded livestock data are produced by and are available at the FAO statistics database (FAO, 2007) http://www.fao.org/geonetwork (keyword gridded livestock).

EUROSTAT holds European livestock data at the spatial resolution of NUTS2 providing numbers of animal populations subdivided in 20 categories as well as the production of milk in ton. Meat production data is only available at national level. This data can be used to extract national conversion factors to convert from livestock numbers to units of mass.

EUROSTAT compiles information on livestock density statistics under the agri-environmental indicators with the number of different livestock per utilized agricultural area or per fodder area (consisting of fodder crops and permanent grassland) on the NUTS3 level. Also milk production data are available at the regional level.

We used the FAO maps of grazing livestock (the sum of cattle, goat and sheep densities) assuming that their total density reflects the **capacity of grasslands to provide livestock services.** Grasslands refer to the CLC classes pasture (label 3) as well as scrub and herbaceous vegetation associations (label 2).

3.1.3.2 Maps

The capacity of grasslands to support livestock is mapped for aggregated NUTSx units in Fig. 4. The map shows the average number of grazing animals (sum of cattle, sheep and goat) per km². A map with the original livestock density data is given in Annex 1. An indicator for service flow (production of meat and milk) is under development.

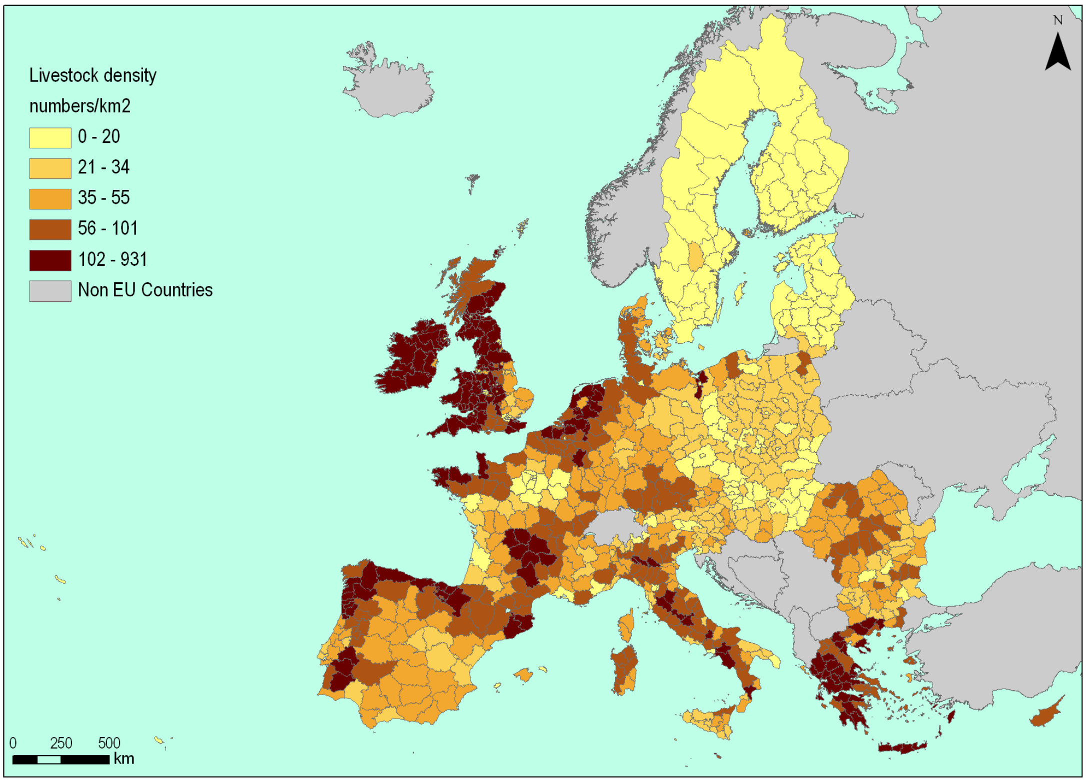


Fig. 4. Livestock density.
Data based on aggregated numbers of cattle, goat and sheep per NUTSx statistical area.
Data source: FAO.

3.1.3.3 Limitations and further work

A European harmonized map of grasslands is not available. The CORINE dataset which maps pasture and natural grasslands tends to underestimate the total area of available grasslands.

We did not use spatial information on the management of grasslands. Mainly pastures are improved with fertilizer or manure which increases the productivity. To account for fertilization, the capacity indicator can be normalized using data on fertilizer and manure application, reducing the capacity of improved grass lands.

We assumed that the livestock considered in this analysis is grazing outside. For this reason, we excluded several classes of livestock that are cultivated inside on feed only.

EUROSTAT statistics on livestock production can be used for approximating the service flow by disaggregating the NUTS2 production data of milk and meat provided by grazing animals over the gridded livestock density for European grasslands. This indicator reflects the **flow of livestock services provided by grasslands**.

3.1.4 FRESHWATER PROVISION

Freshwater provision accounts for the availability of fresh water coming from inland bodies of surface waters for household, industrial and agricultural uses. In this assessment, we did not include groundwater resources.

3.1.4.1 Data and indicators for mapping freshwater provision at EU scale

The MEA defines total blue water flow as the renewable water supply computed as surface and sub-surface runoff. It is a subcomponent of total precipitation, representing the net fresh water remaining after evapo-transpiration losses to the atmosphere. Blue water represents the sustainable supply of fresh water that emanates from ecosystems and is then transferred through rivers, lakes, and other inland aquatic systems (MEA, 2005).

Naidoo et al. (2008) used a global hydrological model to map water provision for human consumptive use. They summed consumptive water use across sectors to produce a spatially explicit map of total water use in biophysical units (cubic kilometers per year). Then the volume of water consumption was attributed back to its points of origin by using a basin-level perspective of water production. They calculated the proportional contribution of each 0.5° resolution cell to the total water production of the basin in which it resides, calculated the amount of total water consumption for that basin, and then redistributed the total consumption according to the proportion of basin-wide water production at each grid cell. By redistributing the volume of water consumption in this manner, total water use was attributed to point of origin.

Wriedt and Bouraoui (2009) presented an assessment of water availability for Europe. This assessment presents a simplified methodology to break down the net precipitation water (or hydrological excess water) over surface and subsurface runoff. This analysis was done at the spatial resolution of sub catchments. A European catchment database HydroEurope was developed at IES-RWER Unit, providing catchment and river basin information complying with the ArcHydro database scheme. The database was developed to support water balance and nutrient transport modelling at European scale.

We used this information in combination with the spatial location of freshwater ecosystems, as derived from the CLC dataset, to assess the capacity and flow of freshwater ecosystems to contribute to the provision of fresh water. The **capacity of freshwater ecosystems to provide a reserve of freshwater** is approximated by the surface area of freshwater ecosystems. The **flow of freshwater provision** can be approximated by the annual water flow (mm or m^3 $year^{-1}$) that is available from surface waters.

As mentioned earlier, this assessment does not take into consideration the provision of subsurface fresh water reserves in aquifers and deep ground water.

3.1.4.2 Maps

The capacity of ecosystems to provide fresh water resources, as well as the associated annual surface water flow of fresh water provided by these ecosystems, is presented on an aggregated NUTSx level in Fig. 5.

The hydrological data on surface water flow are presented in Annex 1.

3.1.4.3 Limitations and further work

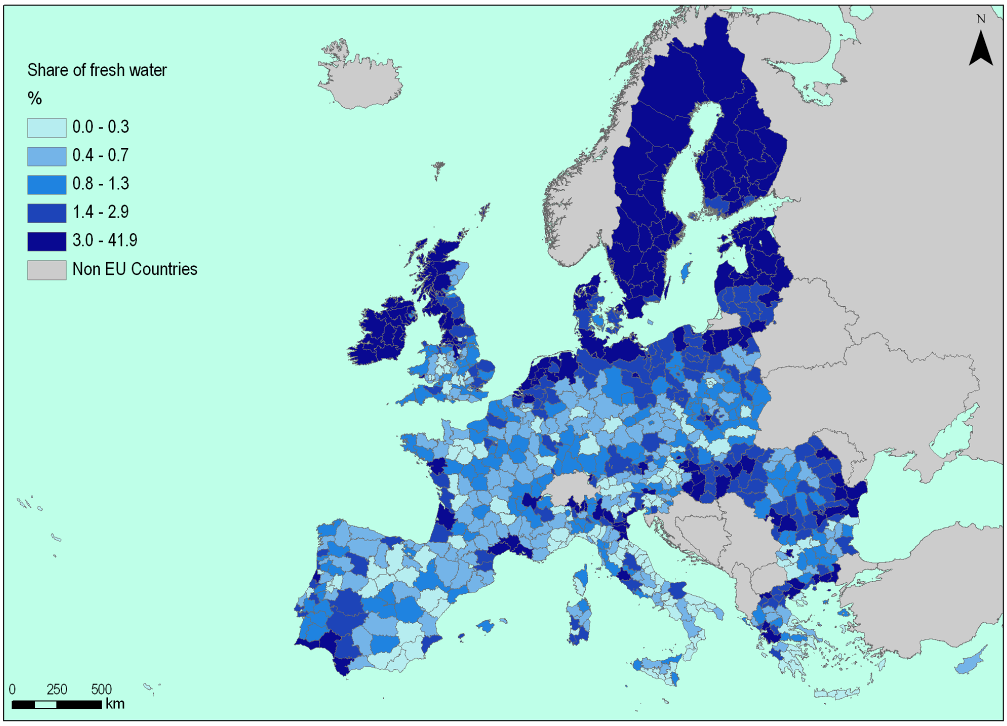
Clearly, the CORINE dataset does not represent water courses well given its low resolution and 25 ha mapping unit. The CLC data are merely used for attributing service values representing capacity and flow to the appropriate land cover classes. The spatial data that represent the flow of surface water are available at sub catchment scale, which provides a better spatial representation of the capacity and flow of water related ecosystem services.

3.1.5 OTHER PROVISIONING SERVICES

Other provisioning services that are listed in Table 3 are genetic, medicinal and ornamental resources. For each of these services, spatial indicators have yet to be defined.

The Community Plant Variety Office may have data or resources that could be used for mapping genetic plant varieties.

The occurrence of medicinal and ornamental resources is to a large extent dependent on the distribution of plant species. Maps representing European flora are not readily available and need to be purchased. Once such information is available, maps of plant species distribution can be coupled to their different uses, such as plants for medicines, edible plants as nitrogen fixers.



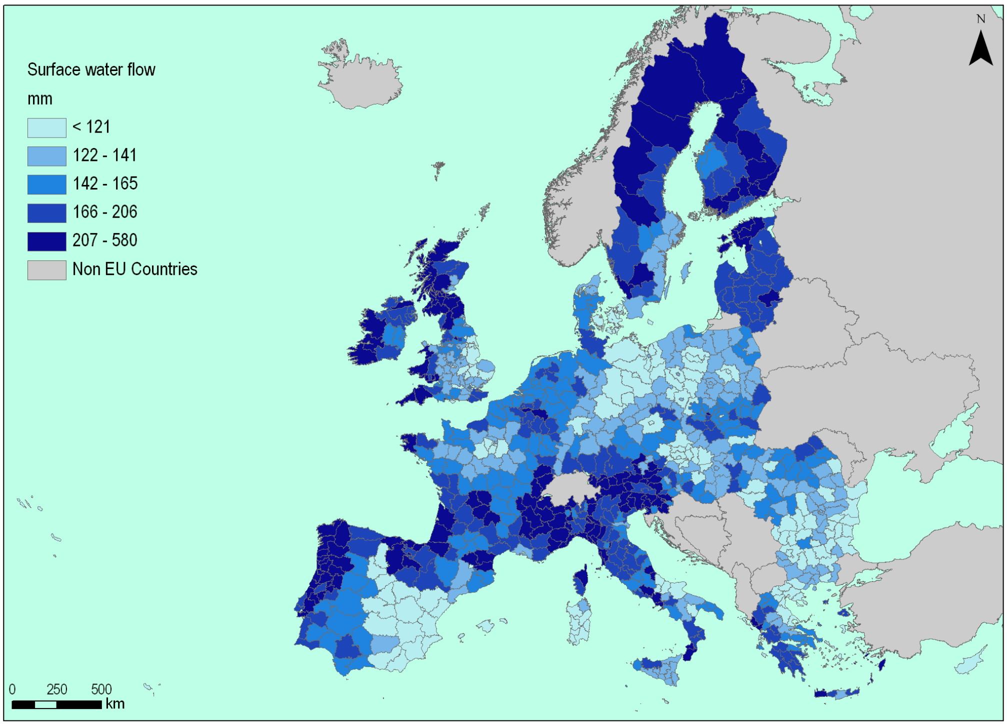


Fig. 5. Water provisioning services.
Top: The share of fresh water providing land cover classes in the land cover per NUTSX statistical area. Source: Corine Land Cover 2000 raster data - version 13. Bottom: The annual average water provision based on surface water flow.
Source: Wriedt and Bouraoui et al. (2009)

3.2 Regulating services

3.2.1 Water regulating services

Water regulation refers to the influence ecosystems have on the timing and magnitude of water runoff, flooding and aquifer recharge, particularly in terms of water storage potential of the ecosystem.

This service is closely related to water provision. For now, we made the distinction based on surface and subsurface water flows classifying ecosystems that capture the surface flow (rivers, lakes, wetlands) as providers of water and terrestrial systems that store or hold as regulators of water.

3.2.1.1 Data and indicators for mapping of water regulating services at EU scale

We used the annually aggregated soil infiltration (mm) as an indicator for the **capacity of terrestrial ecosystems to temporarily store surface water**. The data used are derived from the MAPPE model (Pistocchi et al. 2008; Pistocchi et al. 2010). MAPPE stands for Multimedia Assessment of Pollutant Pathways in the Environment of Europe and consists of models that simulate the pollutant pathways in air, soil sediments and surface and sea water at the European continental scale. Monthly infiltration of precipitated water in soils is calculated by distributing the net precipitation over run off and infiltration.

The **service flow of water regulation** by terrestrial ecosystems was approximated by using the annual sub surface water flow (mm or m^3 $year^{-1}$).

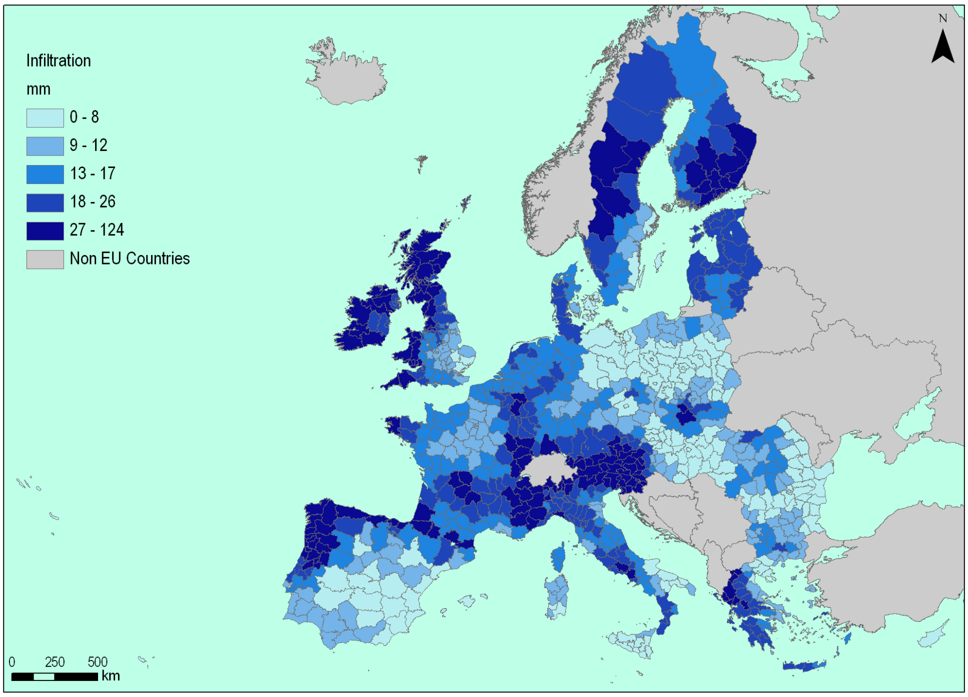
3.2.1.2 Maps

Fig. 6 represents the infiltration capacity of soils, averaged over NUTSx statistical areas.

3.2.1.3 Limitations and further work

Terrestrial ecosystems regulate water by storing it in their soils, buffering the runoff to downstream areas. They also contribute in water provision by recharging aquifers. Aquatic ecosystems, notably wetlands and lakes or reservoirs, provide and regulate water. This involves a tradeoff. Empty reservoirs cannot provide water but they have a high potential to store and hence, regulate water.

Clearly, the water provision service is strongly interweaved with the regulating service and making the distinction between both based on surface and subsurface flow is rather artificial and needs further consideration.



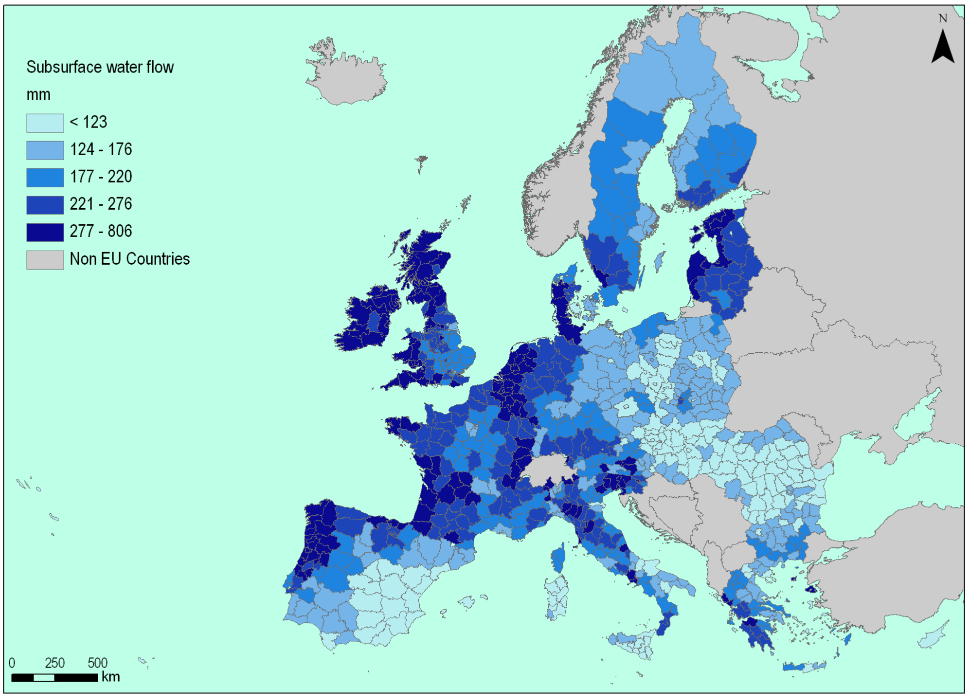


Fig. 6. Water regulation services.
Annually summed soil infiltration averaged over the statistical NUTSx areas (top) and averaged sub surface water flow (bottom). Source: Wriedt and Bouraoui et al. (2009)

The JRC's natural hazard and land management unit has an operational water regulation model called LISFLOOD. LISFLOOD is a GIS-based hydrological rainfall-runoff-routing model that is capable of simulating the hydrological processes that occur in a catchment. The specific development objective was to produce a tool that can be used in large and transnational catchments for a variety of applications, including flood forecasting, and assessing the effects of river regulation measures, land-use change and climate change. The model has been applied to map areas of flooding risk and flood damage potential. Ideally, this model should be used for assessment of water quantity regulation services.

3.2.2 WATER PURIFICATION SERVICES

This service relates to the role ecosystems play in the filtration and decomposition of organic wastes and pollutants in water; assimilation and detoxification of compounds through sediment, soil and subsoil processes.

In this assessment, we focused on the role of rivers and streams in removing nitrogen. The removal of other compounds via retention in other ecosystems will be the focus of subsequent work.

3.2.2.1 Data and indicators for mapping of nitrogen services at EU scale

We used the model GREEN (Geospatial Regression Equation for European Nutrient losses) to derive two indicators that describe the capacity and flow of nitrogen services in Europe. GREEN is a statistical model developed to estimate nitrogen and phosphorus fluxes to surface water in large river basins (Grizzetti, 2006). The model was developed and used in European basins with different climatic and nutrient pressure conditions (Grizzetti et al., 2005) and was successfully applied to the whole of Europe (Grizzetti et al., 2008; Bouraoui et al., 2009).

GREEN contains a spatial description of nutrient sources and physical characteristics influencing the nutrient retention. Europe is divided into a number of sub-catchments that are connected according to a river network structure. The sub-catchments constitute the spatial unit of analysis. In the application at the European scale, a catchment database covering all Europe was developed, based on the Arc Hydro model, with an average sub-catchment size of 180 km^2 (Bouraoui et al., 2009). For each sub-catchment, the model considers the input of diffuse and point nutrient sources and estimates the nutrient fraction retained during the transport from land to surface water (Basin Retention) and the nutrient fraction retained in the river segment (River Retention). In the case of nitrogen, diffuse sources include mineral fertilizers, manure applications, atmospheric deposition, crop fixation, and scattered dwellings, while point sources consist of industrial and waste water treatment discharges. In the model, the nitrogen retention is computed on an annual basis and includes both permanent and temporal removal. Diffuse sources are reduced by processes occurring on land (crop uptake, denitrification, and soil storage), and those occurring in the aquatic system (aquatic plant and microorganism uptake, sedimentation and denitrification), while point sources are assumed to directly enter surface waters and are, therefore, affected only by river retention. For each sub-catchment i the annual nitrogen load estimated at the sub-catchment outlet (Li, ton N/yr) is expressed as following:

$L_i = (1\text{-}RR_i) \times [(1\text{-}BR_i) \times DS_i + PS_i + U_i]$ Equation 1

where DS_i (ton N year^{-1}) is the sum of nitrogen diffuse sources, PS_i (ton N year^{-1}) is the sum of nitrogen point sources, U_i (ton N year^{-1}) is the nitrogen load received from upstream sub-catchments, and BR_i and RR_i (fraction, dimensionless) are the estimated nitrogen Basin Retention and River Retention, respectively. In the model, BR_i is estimated as a function of rainfall while RR_i depends on the river length and the size of lakes. For more details on model parameterisation and calibration see Grizzetti et al. (2008) and Bouraoui et al. (2009).

The **capacity of freshwater ecosystems to remove nitrogen** can be expressed using the in-stream retention efficiency (%), which explains what portion of the nitrogen entering rivers is retained. Fractional nutrient removal is determined by the strength of biological processes relative to hydrological conditions (residence time, discharge, width, volume). The product of the in-stream retention efficiency and the total nitrogen river loading yields the total amount of nitrogen that is retained per unit time. The latter indicator, normalized over the length in km was used as proxy for the nitrogen service flow.

3.2.2.2 Maps

The maps in Fig. 7 present the average nitrogen retention and the associated annual nitrogen removal of the European river and stream network. The map is based on a nitrogen assessment at the sub catchment level based on the model GREEN (Annex 1).

3.2.2.3 Limitations and further work

There remain several gaps in this assessment. Evidently, water purification is more than nitrogen retention. Further work will need to focus on how well this indicator reflects other purification processes as well.

The GREEN model ignores the role of biodiversity and the feedback of nitrogen concentrations on the nitrogen removal efficiency. For a given length a concrete channel retains as much nitrogen as a vegetated river. So the length of the river network is the essential parameter for retention. While residence time (through river length) is indeed a crucial parameter, Mulholland et al. (2008) presented evidence that total biotic uptake and denitrification of nitrate increase with stream nitrate concentration, but that the efficiency of biotic uptake and denitrification declines as concentration increases, reducing the proportion of in-stream nitrate that is removed from transport.

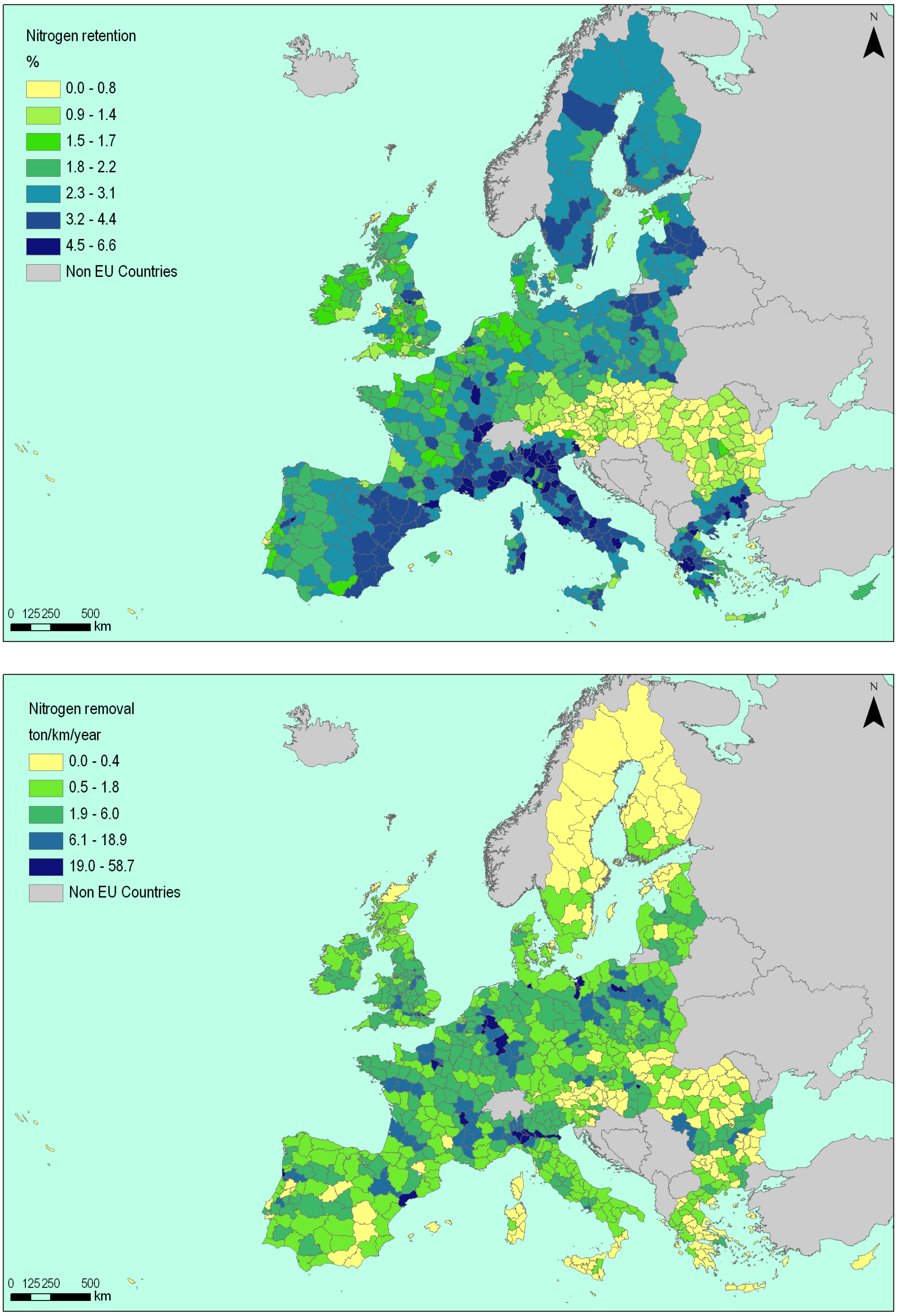


Fig. 7. Average nitrogen retention and removal by rivers and streams in the EU27.

We have also ignored the role of other ecosystems which act as important sinks for nitrogen and other pollutants. Most notable examples are floodplain, wetlands or any type of ecosystem with wet soils and a high amount of carbon. Denitrification that takes place in these ecosystems is by the GREEN model lumped into a single basin retention parameter together with crop uptake and removal processes that take place in the aquifers.

So further modifications to GREEN or an alternative approach are needed to include the above mentioned shortcomings.

3.2.3 CLIMATE REGULATION SERVICES

Climate services are defined as the influence that ecosystems have on the global climate by emitting greenhouse gasses to the atmosphere or by extracting carbon from the atmosphere as well as the influence that ecosystems have on local and regional temperature, precipitation and other climatic factors.

In this study, only the first aspect has been taken into consideration.

3.2.3.1 Data for mapping of climate services at EU scale

Two classically used indicators to approximate climate regulating services are presented in this study. Carbon storage was assumed as a proxy to estimate the **capacity of ecosystems to contribute to climate change mitigation** while the annually accumulated net ecosystem productivity was suggested as measure for the **carbon service flow**.

Carbon storage data were taken from de CDIAC website. This spatially-explicit global data set provides estimates and spatial distribution of the above- and below-ground carbon stored in living plant material, and provides an important input to climate, carbon cycle and conservation studies. The data set was created by updating the classic study by Olson et al. (1983,1985) with a contemporary map of global vegetation distribution (Global Land Cover database; GLC2000).

http://cdiac.ornl.gov/epubs/ndp/ndp017/ndp017b

Data on net ecosystem productivity are available in the Geosucces database, hosted by VITO (Belgium). The net ecosystem productivity (NEP) takes into account the soil respiratory flux originating from heterotrophic decomposition of soil organic matter. These carbon fluxes are quantified using the C-Fix model which is a remote sensed-based carbon balance product efficiency model wherein the evolution of the radiation absorption efficiency in the PAR (Photosynthetically Active Radiation) band (or fAPAR) of vegetation is directly inferred from space observations, SPOT-VEGETATION S10 (SPOT VGT S10) images, using the

Normalized Difference Vegetation Index (NDVI) (Veroustraete et al. 2002). The data are available at:

http://geofront.vgt.vito.be/geosuccess/relay.do?dispatch=NEP_info

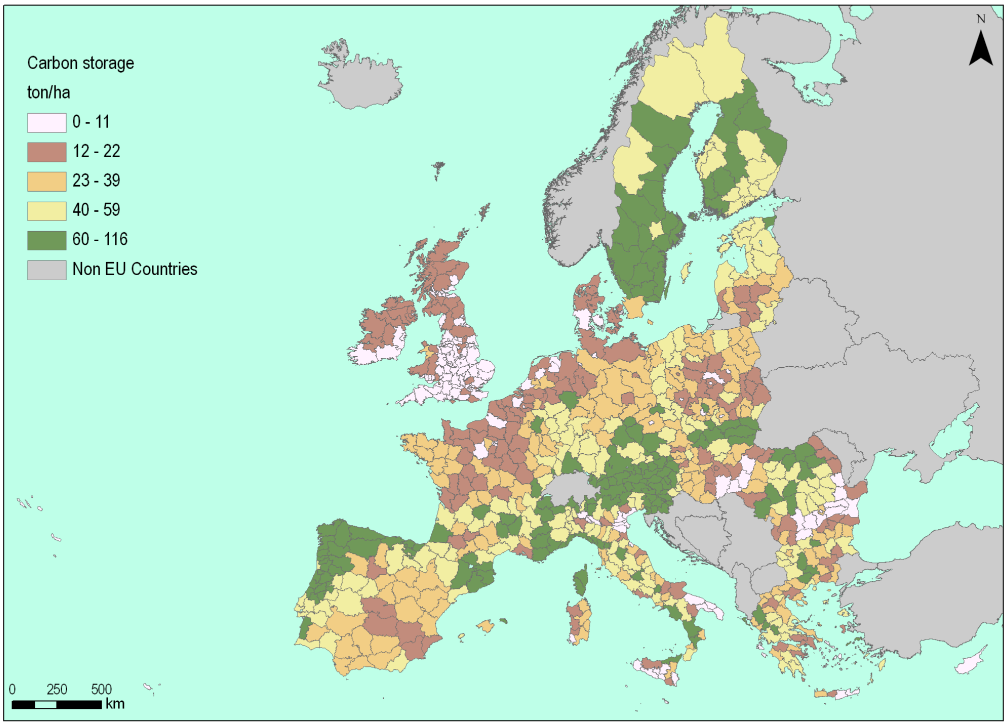
Data of NEP were accumulated for the year 2000 to result in the annual carbon fixation (gram C m^{-2} $year^{-1}$).

3.2.3.2 Maps

Fig. 8 depicts the climate regulation services aggregated at NUTSx scale.

3.2.3.3 Limitations and further work

The major limitation is that the data for carbon storage are based on old data. Better estimates should come from more recent estimates.



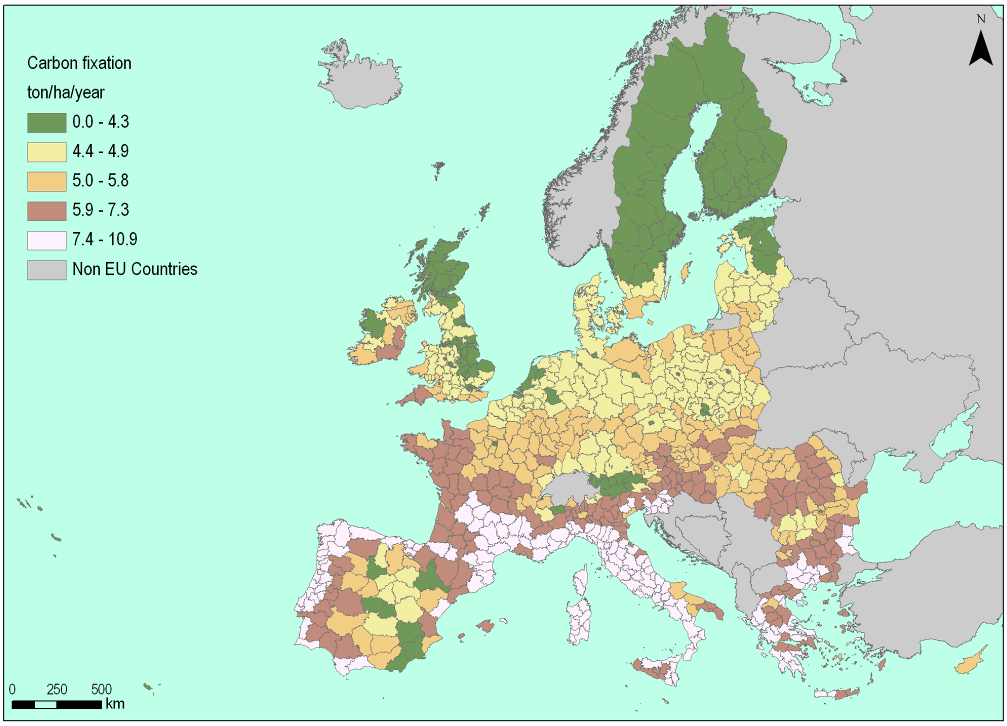


Fig. 8. Climate regulating services
Average carbon stock (top) and average annual carbon fixation (bottom) of ecosystems aggregated per NUTSx unit. Sources: CDIAC and VITO.

3.2.4 Natural hazard protection services

Natural hazard protection refers to the capacity of ecosystems to reduce the damage caused by natural disasters. These include storms, floods, fires and landslides.

To avoid double counting, we refer to water quantity regulating services for the role of ecosystems to regulate water flows and to protect against floods. Similarly, protection against landslides may be covered by erosion control services.

Therefore, this assessment only considers the absorption capacity of coastal ecosystems reducing the effect of storms.

3.2.4.1 Spatial indicators for mapping storm protection services at EU scale

As a first indicator for storm protection services, we mapped the area of coastal wetlands and dunes as a proxy for the capacity of ecosystems to protect against the consequences of sea-borne storms that hit the coast. The CLC2000 data served as source for this mapping.

An indicator assessing the associated service flow has still to be defined.

3.2.4.2 Contribution of CLC classes

Evidently only coastal land classes contribute to this service. We included Salt marshes, Salines, Intertidal flats, Coastal lagoon and Estuaries.

3.2.4.3 Maps

Fig. 9 shows the distribution of NUTSx areas with their relative share of coastal land cover types.

3.2.4.4 Limitations and further development

The present indicator should be complemented with data on quantities differences between types of coastal wetland in reducing the impact of storms as well as data describing the occurrence of storm events.

Barbier et al. (2007) used wave attenuation of different coastal ecosystems to determine how much ecosystems contribute to reducing wave height caused by wind and storms. Eventually, such weights can be assigned to each CLC class to weigh the protective value reflecting better the capacity of coastal systems to protect against storms.

Capacity results in service flow and benefits if there are storms. So an estimate of service flow needs to take into account the (annual) probability of a storm. Useful resources are the international disaster database http://www.emdat.be which collects for each country the occurrence of disasters including data on the economic damage and the European severe weather database http://www.essl.org/ESWD/.

These resources, together with the CLC data can be used to apply the methodology of Costanza (2008) over Europe. These authors developed a methodology to assess the value of coastal wetlands for hurricane protection and applied it to the US. They related using linear regression the total damage cost of hurricanes relative to the GDP to the maximum wind speed and the area of wetlands situated in the storm swath.

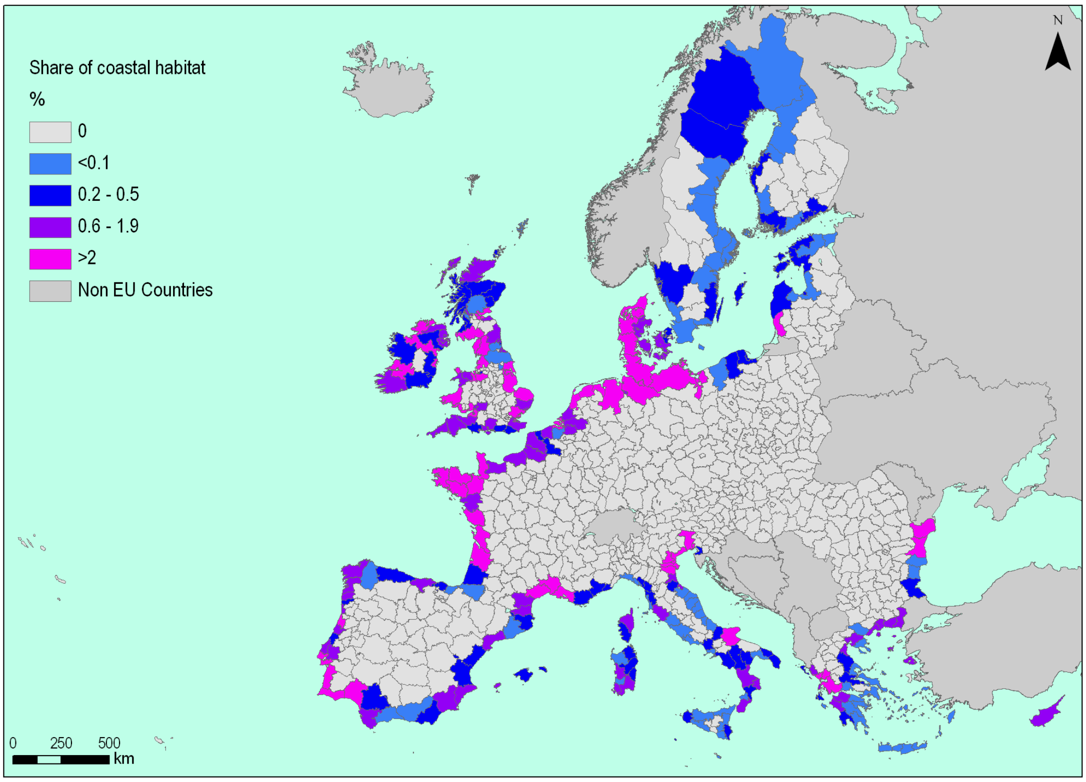


Fig. 9. Share of coastal habitats in the land cover per NUTSx statistical area.
Source: Corine Land Cover 2000 raster data - version 13.

3.2.5 AIR QUALITY REGULATION

Ecosystems influence air quality by emitting chemicals to the atmosphere or by extracting chemicals from the atmosphere. Ecosystems affect air quality on several scales. Locally, at the scale of meters to hectometers, vegetation traps pollutants and particulate matter caused by traffic emissions nearby roads acting as a screen. At the scale of the size of cities, green infrastructure inside cities or surrounding cities has a cooling effect during summer and hence, reduces temperature dependent ozone formation. Regionally, ecosystems capture deposited constituents such as sulfur and nitrogen oxides. Ecosystems also act as sources, emitting biogenic gasses to the atmosphere, such as methane, carbon dioxide and nitrous oxide from wetlands, isoprenes from coniferous forests or smoke from vegetation fires.

3.2.5.1 Spatial indicators for mapping air quality services at EU scale

For this assessment, we used the downward pollutant flux, or pollutant removal as basis for the spatial indicator. This quantity is calculated as the product of dry deposition velocity and pollutant concentration (Wesely and Hicks 2000). Deposition velocity is the inverse sum of three resistances. The main ecosystem based parameters affecting deposition velocity are the height of the vegetation (related to the roughness length of the land) and the leaf area index. Both parameters are high for forests explaining their substantial contribution to the provision of clean air. The deposition flux has been used to estimate the contribution of ecosystems, in particular urban forests, to the reduction of air pollution both in biophysical quantities and as monetary values (Nowak et al. 2006; Escobedo and Nowak 2009; Karl et al. 2010).

We used the deposition velocity as an indicator expressing the **capacity of vegetation to capture and remove air pollutants**. Subsequently, the associated service flow was calculating by multiplying modeled pollutant concentration for NO_2, SO_2 and NH_3 derived from the EMEP air quality model for the year 2000 with maps representing the dry deposition velocity of these compounds based on a parameterization as used in the MAPPE model (Pistocchi 2008). The results of the EMEP model can be downloaded at http://webdab.emep.int/Unified_Model_Results/AN/.

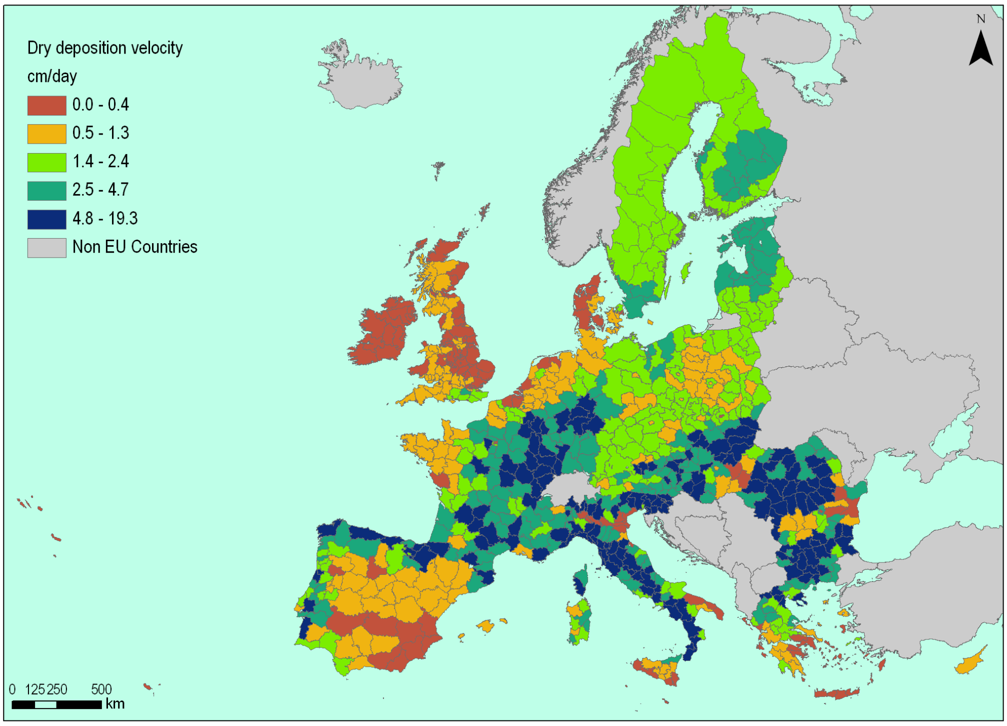
We only considered the contribution of ecosystems that are close to sources of pollution. Here, we buffered the CLC artificial areas with a 3 km buffer assuming that pollutants that are captured by vegetation inside this buffer are also emitted within this perimeter. This avoids tracing back the contribution of trees on air pollutant removal to the sources of emissions.

3.2.5.2 Contribution of CLC classes

Air quality regulation is mainly performed by trees. The following classes are assumed to contribute to this service: Green urban areas, Land principally occupied by agriculture, with significant areas of natural vegetation, Agro-forestry areas, Broad-leaved forest, Coniferous forest, Mixed forest, Natural grasslands, Moors and heathland, Sclerophyllous vegetation, Transitional woodland-shrub, Beaches, dunes, sands.

3.2.5.3 Maps

Fig. 10 presents the spatial indicators used for mapping air quality regulating services. Source maps at finer spatial resolution are given in Annex 1.



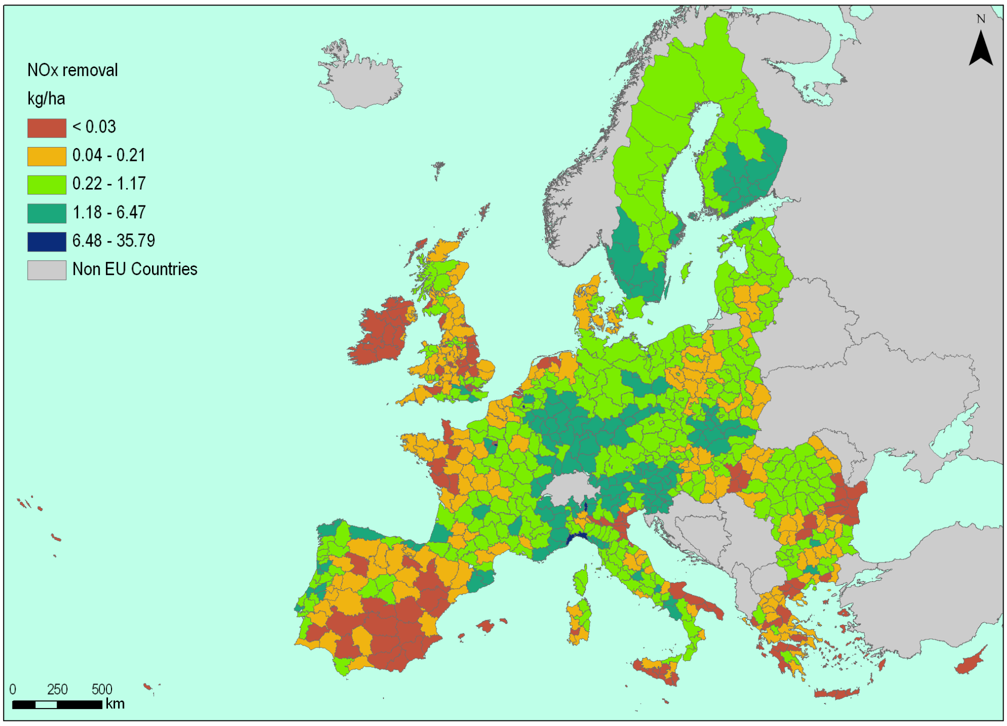


Fig. 10. Air quality regulating services.
Average deposition velocity per NUTSX statistical area (top) and the removal of NO_x by trees in urban and peri-urban areas (bottom).
Sources: MAPPE and EMEP.

3.2.5.4 Limitations and further work

The concept of critical loads may be used to set a second indicator expressing the capacity of ecosystems to process air pollutants derived from deposition. Critical loads are the maximum amount of pollutants that ecosystems can tolerate without being damaged.

Biogenic emissions resulting from ecosystems are not considered may be estimated using the GLOBEIS model. The JRC has a European biogenic VOC emission inventory which estimates the emissions of volatile organic compounds by trees.

3.2.6 EROSION CONTROL

Land use, relief, soil properties and climate (wind and precipitation) are the predominant variables determining the magnitude of erosion. Vegetation, in particular forests, help conserving soils and prevent the siltation of waterways and landslides.

Accelerated soil erosion by water as a result of changed patterns in land use is a widespread problem in Europe. By removing the most fertile topsoil, erosion reduces soil productivity and, where soils are shallow, may lead to an irreversible loss of natural farmland. The capacity of natural ecosystems to control soil erosion is based on the ability of vegetation (i.e. the root systems) to bind soil particles thus preventing the fertile topsoil from being blown or washed away by water or wind.

3.2.6.1 Spatial indicators for mapping erosion control services at EU scale

The JRC's European Soil Data Centre (ESDAC) is the reference point for data provision of all soil related ecosystem services, including erosion control. The MESALES model uses data on land use, slope, soil properties and climate to predict the seasonal and annual averaged soil erosion (5 classes going from very low to very high). We intersected the map of the annual soil erosion risk with a map that retains the CLC classes with natural vegetation. The resulting map was used to spatially identify ecosystems that are situated in areas of different erosion risk giving more weight to ecosystems in areas with high erosion risk. This indicator is assumed to represent the **capacity of ecosystems to provide erosion control services**.

An indicator measuring the associated flow of this service needs to be developed yet.

3.2.6.2 Contribution of CLC classes

The following land cover classes are assumed to contribute to erosion prevention: Broad-leaved forest, Coniferous forest, Mixed forest, Natural grasslands, Moors and heathland, Sclerophyllous vegetation, Transitional woodland-shrub, Beaches, dunes, sands.

3.2.6.3 Maps

Fig. 11 compares at the scale of NUTSx statistical units the area of forests and natural ecosystems in areas subject to erosion. Averages are based on a map with higher spatial resolution (Annex 1).

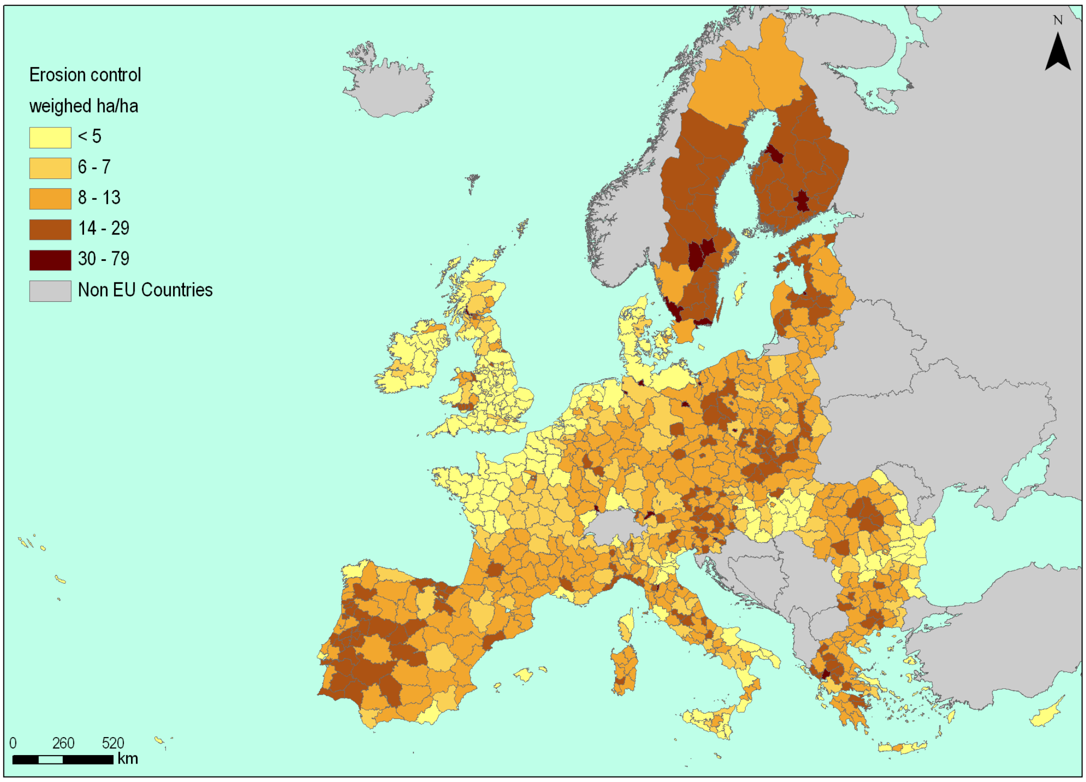


Fig 11. Indicator representing the capacity of forests and natural ecosystems to help preventing soil erosion.
Source: ESDAC; Corine land cover 2000 raster data - version 13.

3.2.6.4 Limitations and further work

The PESERA model is a soil erosion model which operates at the European scale. The model estimates erosion rates as a function of land use, elevation, soil type and climate (precipitation). The model calculates soil erosion rates and soil sensitivity. Output data and maps are available in the European Soil database: http://eusoils.jrc.ec.europa.eu/. The model can be used as a tool to assess at EU scale how changes in land use result in altered erosion patterns.

An indicator or variable representing the flow of soil erosion prevention still needs to be developed. An option is to use the PESERA model to infer potential and actual erosion rates and use the difference as a measure for prevented erosion.

Only forest and semi-natural systems were assumed to contribute to soil erosion and the role of agricultural land itself was not considered. Clearly, pastures contribute to prevention of erosion and adoption of good management and practices has demonstrated significant reductions in erosion rates. Better information on European grasslands (both natural and agricultural) would be an asset for ecosystem services mapping and valuation.

3.2.7 POLLINATION SERVICES

Pollination services refer to the role ecosystems play in transferring pollen between flower parts.

3.2.7.1 Spatial indicators for mapping pollination at EU scale

Klein et al. (2007) reviewed the importance of pollinators for world crops. They labeled 137 single crops and 115 commodity crops according to their dependence on pollination. For each crop, a dependency ratio was fixed. In addition, Gallai. et al (2009) presented an economic valuation of the vulnerability of world agriculture confronted with pollinator decline.

A second key publication (Ricketts et al. 2008) inferred relationships between distance to natural and seminatural areas and pollinator richness, native visitation rate of crops and fruit/seed set.

A first mapping approach for an indicator which shows the capacity of natural ecosystems to provide pollination services has used these three key papers in order to map pollinator visitation rate as a function of distance to natural areas.

We used a European map of land use which includes the spatial distribution of crops, consistent with the official crops reported under the farm structure survey (Grizzetti et al. 2007). Next, crop dependency ratios (Klein et al., 2007; Gallai et al. 2009), indicating the dependency of crops on pollination (0-100%) were assigned to each crop.

For each crop land use pixel, the distance (m) to the nearest ecosystem was calculated using the CLC2000 map. The visitation probability (the probability that a crop gets visitated by a pollinator) was modeled using Ricketts et al. (2008) who presented a regression between distance and visitation rate based on a meta-analysis:

$$P(\text{visitation}) = \exp(-0.53 \times \text{distance})$$

where P stands for probability and distance is expressed in km. A maximum distance of 5 km is used as cutoff value.

For each crop land use pixel, the crop dependency and visitation probability were multiplied and this value was subsequently assigned to the nearest ecosystems which were assumed to sustain pollination (Fig. 12). The sum of these contributions was finally considered as the pollination potential or the **capacity of natural ecosystem to provide pollination services**.

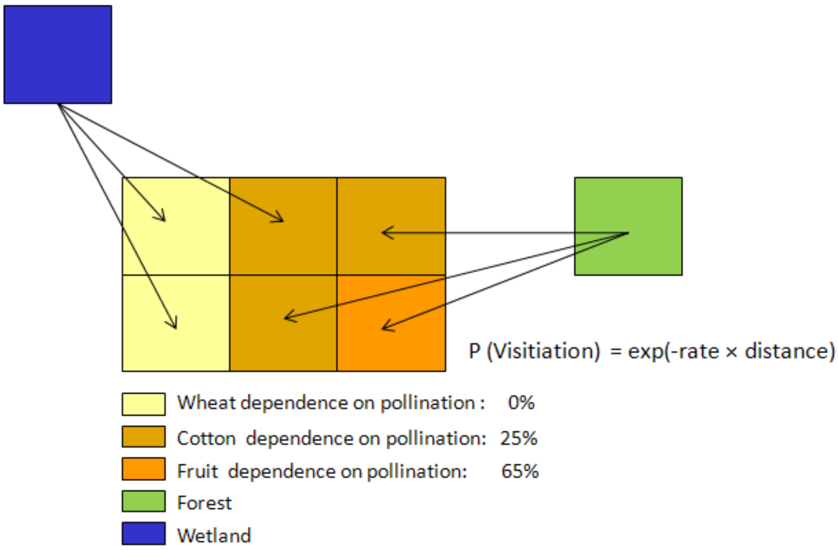


Fig. 12. Conceptual model of assigning pollination potential to natural land cover pixels. Pollination of cropland is assumed to occur from a parcel of wetland and a parcel of forest. Each pixel of cropland received two probabilities: the probability of visitation by a pollinator coming from the nearest pixel containing a natural ecosystem and the dependence of the crop on pollination. Both values are multiplied to results in the total pollination probability, a value between 0 and 1. These values are finally summed and assigned to the nearest pixel containing a natural ecosystem.

3.2.7.2 Contribution of CLC classes

The following land cover classes were assumed to contribute to pollination of adjacent fields: Broad-leaved forest, Coniferous forest, Mixed forest, Natural grasslands, Moors and heathland, Sclerophyllous vegetation, Transitional woodland-shrub, Beaches, dunes, sands, Sparsely vegetated areas, Inland marshes, Peat bogs, Salt marshes, Salines, Intertidal flats, Water courses, Water bodies, Coastal lagoons, Estuaries. The riparian areas of water bodies adjacent to cropland are considered to host populations of pollinators justifying the inclusion of these land cover classes in the assessment.

3.2.7.3 Maps

Fig. 13 shows the EU map containing an indicator for pollination potential, aggregated at the NUTSx level. Detailed maps at km resolution of the source data are provided in Annex 1 including land use, crop dependency and distance to the nearest ecosystem. Also the resulting pollination potential map at km resolution is provided in Annex 1.

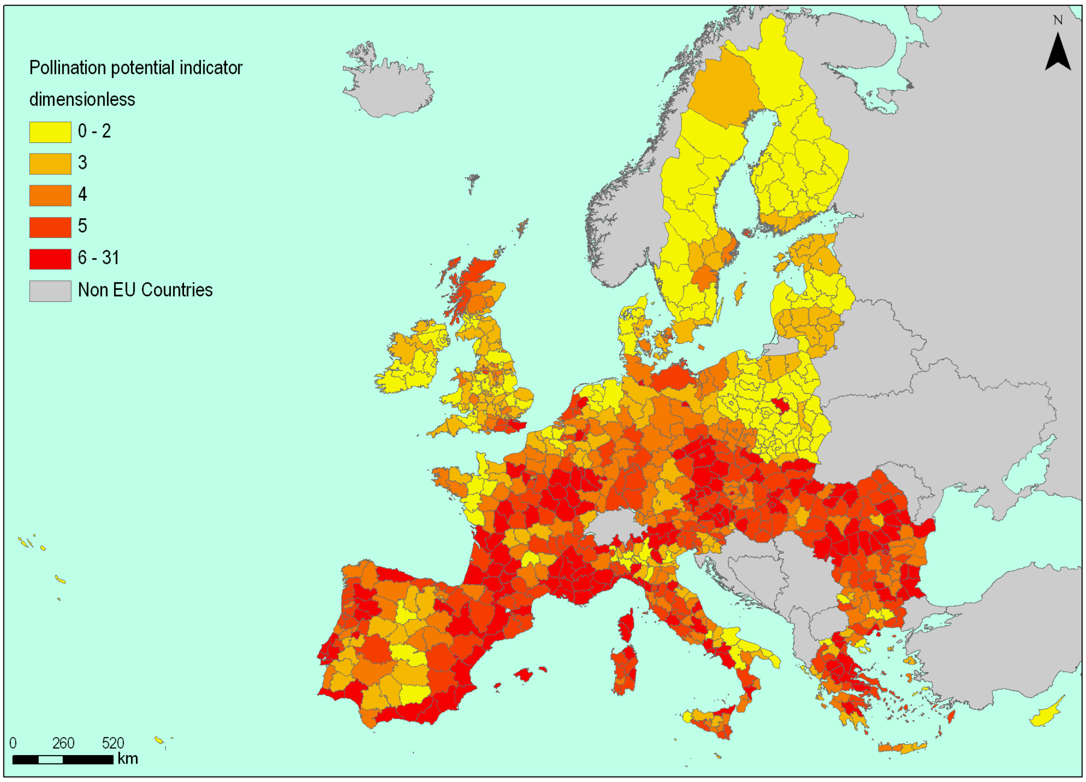


Fig. 13. Average pollination potential of natural ecosystems for NUTSx statistical areas.

3.2.7.4 Limitations and further work

The map in Fig.13 is a first and hence, preliminary, assessment of the pollination potential of natural ecosystems with several shortcomings which need to be addressed in a next version.

The indicator only takes into account the potential of pollination from natural ecosystems. Pollination potential supported by cropland are pasture is not considered, nor the sources of managed pollination, for instance by placing bee hives. Statistics at country level on number of beekeepers, number of beehives and average production of honey are available at http://www.apiservices.com/countries/index.htm

The land use map that was used approximates the spatial location of crops by redistributing yield data at the NUTS2 level over cropland using a probability distribution.

The pollination potential map assumes that pollinator populations are abundantly present and equally distributed over all types of natural ecosystems. However, several references reported a declining trend in pollinator abundances, in particular of wild bees. So there is a need for pan-European data on pollinator densities in order to validate a pollination service map. Also the environmental factors that control for population abundances of pollinator species need to be taken into consideration.

The resolution of the CLC data is insufficient for accurate maps of pollination potential. The assumption made in this study is that pollination takes place from habitats adjacent to cropland. However, linear elements in the agricultural landscape, such as hedges, small patches of forest or edge habitats (small roads and rivers with banks or stretches of flowering vegetation) are believed to be important habitats supporting pollination services. Such data is not available at EU scale. However, the forest/non-forest map at 25 m resolution may be a valuable resource to map patches of forest in cropland from which pollinators may contribute to pollination of crops. Also the inclusion of high nature value statistics must be considered when producing a second version of a pollination map.

It must be repeated that this map is based on a preliminary assessment. A more detailed map is under development at the JRC.

3.2.8 Soil quality regulation control

The role ecosystems play in sustaining the soil's biological activity, diversity and productivity; in regulating and portioning water and solute flow and in storing and recycling nutrients.

3.2.8.1 Spatial indicators for mapping soil quality services at EU scale

The primary source for all European soil related data is the JRC's European soil data centre. Data on soil depth, moisture capacity and organic carbon content are available via the website (http://eusoils.jrc.ec.europa.eu/).

Soil data at the global scale are provided by the FAO. Data are available for top soils and subsoils for organic carbon content, moisture storage capacity, nitrogen content, soil depth and soil productivity. The resolution of these data is in general insufficient to make maps at EU scale.

As a first approximation to address the capacity of ecosystems to maintain the quality of soils, we have used the soil carbon content map.

3.2.8.2 Contribution of CLC classes

The following CLC classes are assumed to contribute in soil quality regulation: Non-irrigated arable land: Permanently irrigated land, Rice fields, Vineyards, Fruit trees and berry plantations, Olive groves, Pastures, Annual crops associated with permanent crops, Complex cultivation patterns, Land principally occupied by agriculture, with significant areas of natural vegetation, Agro-forestry areas, Broad-leaved forest, Coniferous forest, Mixed forest, Natural grasslands, Moors and heathland, Sclerophyllous vegetation, Transitional woodland-shrub, Beaches, dunes, sands, , Sparsely vegetated areas.

3.2.8.3 Maps

Fig. 14 shows the spatial differences in soil carbon contents averaged over NUTSX statistical areas.

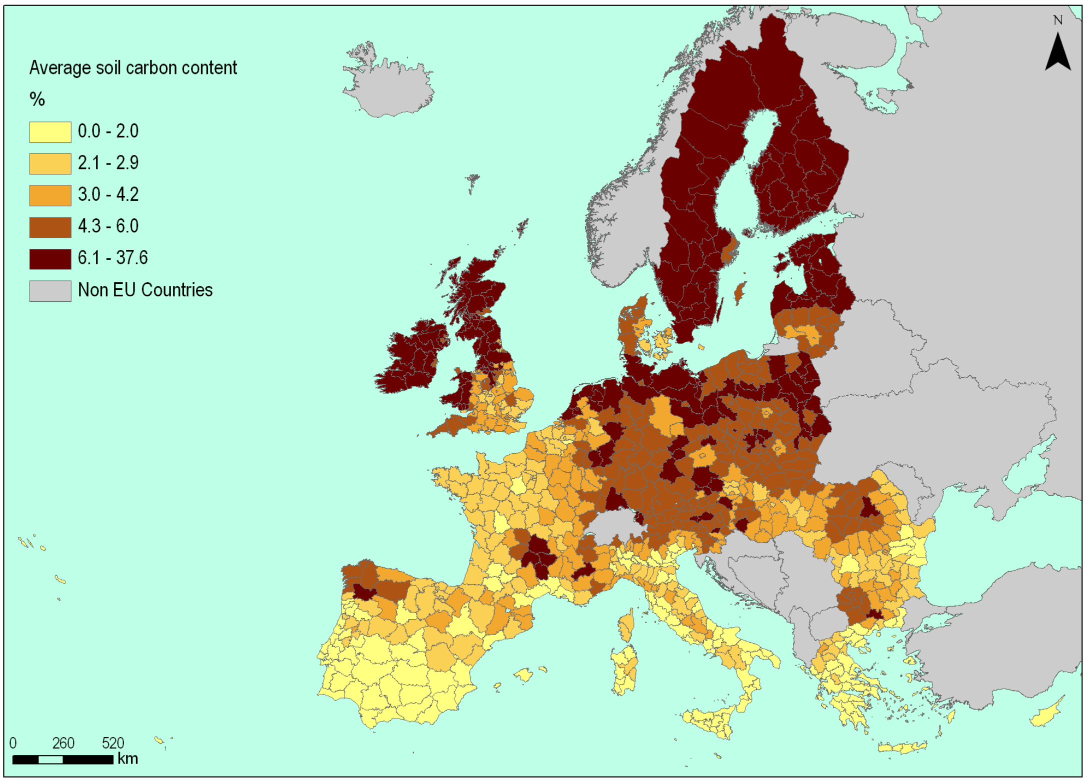


Fig. 14. Soil carbon content averaged per NUTSx statistical area.
Source: ESDAC.

3.2.8.4 Limitations and further work

Soil quality as such cannot be expressed in biophysical units, which hampers an economic valuation as well. An alternative is to use a set of minimum variables that are used in indicators for soil quality and assess these variables separately or integrated into a composite indicator. Currently, the soil action is setting up a methodology to provide statistics that measure soil quality.

3.3 Cultural services

Cultural ecosystem services are defined as the nonmaterial benefits obtained from ecosystems. Among these recreational pleasure that people derive from natural or managed ecosystems is defined as recreation service.

3.3.1 Recreation services

Natural and semi natural ecosystems, as well as cultural landscapes, provide a source of recreation for mankind. People enjoy forests, lakes or mountains for hiking, camping, hunting, fishing or bird watching, or just for being there. Recreation is also supplied by managed ecosystems, such as agricultural lands. Relative to provisioning and regulating services the capacity and the flow of benefits associated with cultural services may be much more intangible and difficult to measure.

The capacity of ecosystems to provide recreation depends on multiple factors: their beauty, their uniqueness, the culture that generated them, the possibility for outdoor activities etc. We call the associated flow of benefits "fruition" which may be measured by performance indicators such as the number of visitors that annually visit a site or the appreciation of sites based on questionnaires. The relation between capacity and fruition is likely to be positive and is influenced by the accessibility of ecosystems to humans and the infrastructure that is in place to host or to guide visitors:

Fruition ~ Capacity × Accessibility

Ecosystems may be of extreme beauty but if they are not accessible, they will not provide a flow of cultural services. Also, ecosystems may be highly accessible but their quality is low, the benefit flow they provide is low as well.

Following this conceptual model we need to find spatial indicators that approximate the capacity of ecosystems to provide recreation services, the fruition or flow of such a service and the infrastructure in place to support the capacity of ecosystems in order to generate a service flow.

3.3.1.1 Data for mapping recreation services at EU scale

It must be underlined that data availability strongly drives the calculation of this service. At the EU scale, in fact, there are no supporting data for calculating the actual fruition of recreational services. There are indeed no harmonised data on accommodation facilities and tourist fluxes in non-urban areas at regional level. Therefore, the exercise is carried out on recreational potential available to EU citizens.

The final results of the exercise will be a zonation of the EU into categories according to the Recreation Opportunity Spectrum (ROS) model (Joyce and Sutton, 2009), and an analysis of what is the provision of the ES recreation service to the average European citizen.

The Recreation Opportunity Spectrum (ROS) was developed in the US to provide a framework for:

- Establishing outdoor recreation management goals and objectives for specific management areas.
- Trade-off analyses of available recreation opportunities as characteristic settings would be changes by other proposed resource management actions.
- Monitoring outputs in terms of established standards for experience and opportunities settings.
- Providing specific management objectives and standards for project plans.

Bullet 2 and partially bullet 3 are the scope of the present study. Furthermore, in this exercise, landscape components of scenic beauty and culture are not addressed, and the provision of the service by the ecosystems in the strict sense is analysed.

Recreation potential is mapped with the assumption that it is positively correlated to the degree of naturalness, to the presence of protected areas (following the assumption that they have been identified as holding a higher degree of naturalness, and as providers of recreation services and facilities), to the presence of coastlines (lakes and sea) and to the quality of bathing water. These variables are aggregated according to the scheme in Fig. 15

- Hemeroby or degree of naturalness is an index that measures the human influence on landscapes and flora. The European hemeroby map is based on CLC land cover data, disaggregated data on nitrogen input and livestock density (provided by the CAPRI model) and the tree species database of the JRC (AFOLU action). CAPRI is an agro-economical model allowing regionalised impact analyses of the CAP. In Capri-Dynaspat dataset, production data of 30 crops in the European administrative regions for EU27 (from FSS statistics) have been broken down to, so-called, Homogeneous Spatial Mapping Units (HSMUs), identified by soil conditions, land cover, slope and administrative boundaries (Nuts 2 or 3), and their minimum size being 1 km^2. On the basis of disaggregated crop share, the model allows calculating indicators of driving forces (as N input and livestock density) at HSMU scale. Input data for the base year are provided by the Farm Structure Survey (FSS). The AFOLU tree species datataset includes the distribution of more than 100 species in 1 km^2-cell grid layers. We used the distribution data of the 26 most abundant species in Europe and of 9 introduced species.

- The presence of protected areas was mapped using the Natura 2000 database and the CDDA database. The Natura 2000 database contains sites designated under the Birds Directive (Special Protection Areas, SPAs) and the Habitats Directive (Sites of Community Importance, SCIs, and Special Areas of Conservation, SACs). The CDDA or European inventory of nationally designated areas holds information about protected sites and about the national legislative instruments, which directly or indirectly create protected areas.

- The CLC2000 dataset was used to extract the coastline of lakes and seas.

- Data on bathing water quality, as measured under the EU Bathing Waters Directive, were used to add weight to the coastline indicator. These data are annually collected by the EEA.

Finally, accessibility was mapped using data of the European road network as provided by TeleAtlas, distance from urban centres was calculated on the basis of CORINE urban classes.

The RPI (recreation potential index) was used as an indicator to express the **capacity of ecosystems to provide recreational services**.

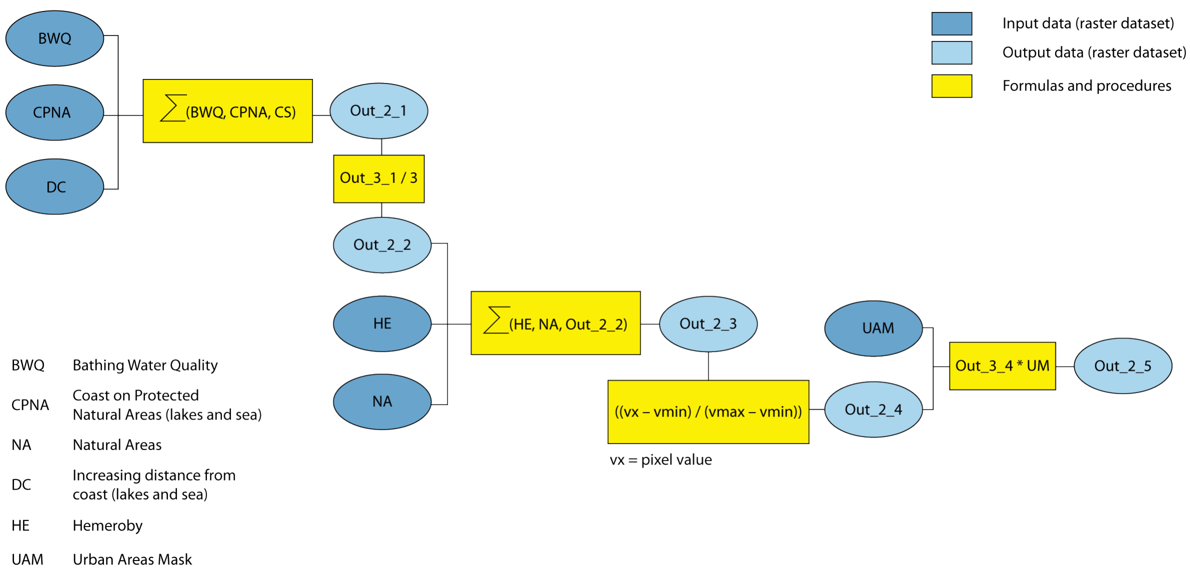


Fig. 15. Recreation services: data aggregation scheme.

3.3.1.2 Contribution of CLC classes

We assumed that all CLC classes but artificial land use contribute to the potential of nature for recreation.

3.3.1.3 Maps

The resulting map is an index of recreation potential (RPI) for the EU (Fig. 16). A map of this index at high resolution is provided in Annex 1.

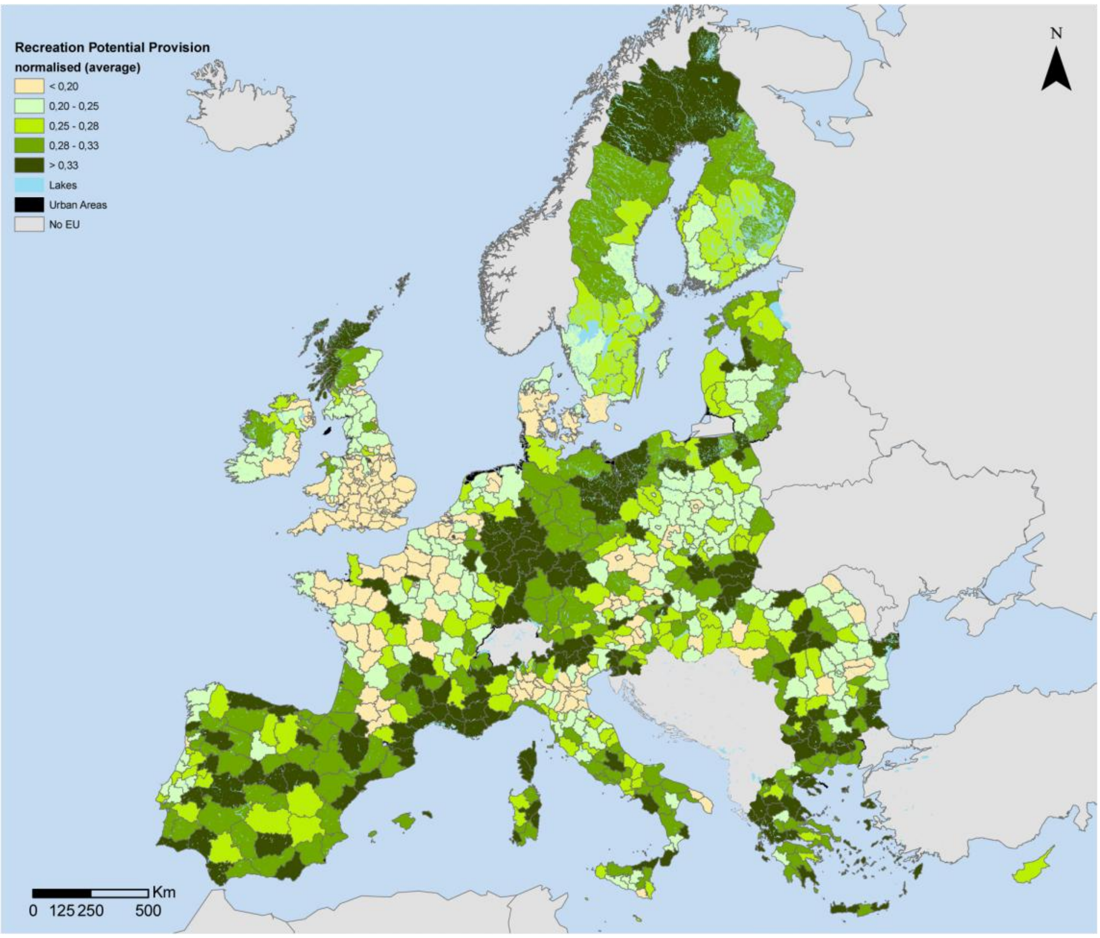


Fig. 16. Recreation potential index.
Average over NUTSx statistical areas.

3.3.1.4 Limitations and further work

Following the conceptual model of recreation services, the service flow provided by ecosystems was referred to as fruition. We assumed that this is a function of recreation potential and accessibility and that it can be measured using vitiation rates or visitor statistics. Collecting visitor statistics at European scale remains however a bottleneck for further development.

The categories of the ROS are built on the basis of RPI and accessibility, calculated on the basis of TeleAtlas road network (levels 1 to 5) and distance from urban, and classifying Europe in ROS zones, more or less natural, more or less accessible.

The resulting zones will be analysed in reference to population density distribution across the EU, and will provide statistics on the type of environment the EU citizens have at their disposal for daily recreation.

4 TRADEOFF ANALYSIS

Thirteen spatial indicators that map the capacity of ecosystems to provide services were subjected to an ordination analysis in order to visualize the spatial tradeoffs that arise between services at the European NUTS level. A statistical procedure called principal component analysis (PCA) was used to reveal the correlation structure that is present in the dataset. The analysis projects the spatial data for each service on a 2-dimentional plane, consisting of 2 axes called principal components, in such a way that the two components capture a great deal of the variance that is present in the data (Fig. 17).

Variables (spatially explicit ecosystem service indicators) are represented as arrows on the biplot pointing towards NUTS regions where they reached their maximum value. The angle between the arrows is a statistical measure for the correlation between the arrows. Arrows pointing in the same direction are correlated; arrows pointing in opposite directions are negatively related; arrows in perpendicular positions are uncorrelated. Samples, in this case the NUTS areas, are presented as points on the graph and receive each two coordinates (one for the first component and one for the second component). The final result permits to visualize synergies (positively correlated services) and tradeoffs (negatively correlated services) as well as the NUTS provinces where these tradeoffs and synergies are realized. To improve interpretation, the NUTS provinces were left out of the graph. Instead, maps reveal their position relative to the two axes of the analysis. In addition to these maps, rose plots show the relative composition of ecosystem services in an average NUTS area of each quadrant.

The PCA explained 42% of the variance present in the data and shows a clear spatial pattern of synergies and tradeoffs among the different indicators for ecosystem service capacity. In particular, the isolated position of crop production capacity is evident, which is the only variable pointing towards the 4th quadrant of the biplot. Crop production capacity is either uncorrelated or more importantly negatively correlated to other ecosystem services, particularly water regulation, erosion control and soil quality regulation. NUTS areas where crop production is dominant are presented on the European map in the lower right corner.

Two services, livestock provision and coastal storm protection capacity are negatively correlated with pollination and water quality regulation. Evidently, these services are mainly situated in the coastal areas of the Atlantic sea board.

Services which are predominantly provided by forest ecosystems are positively correlated with each other. Most notable are timber production capacity, carbon storage, recreation and air quality regulation. To a lesser extent, also pollination and erosion control are positively correlated with services provided by forests.

The second PCA axis distinguishes services that are related to soil functioning and water regulation: soil quality (as indicated by soil carbon content), water regulation (infiltration capacity of soil) and provision, and erosion control. NUTS provinces which provide these services more than the average are situated in areas with high lake and wetland density such as the Northern Europe and the northern parts of the British Isles.

Water quality regulation (indicator: nitrogen retention) is not related strongly to any other service. This is because nitrogen retention was only assessed for rivers and streams and, therefore, does not relate to the other land based services.

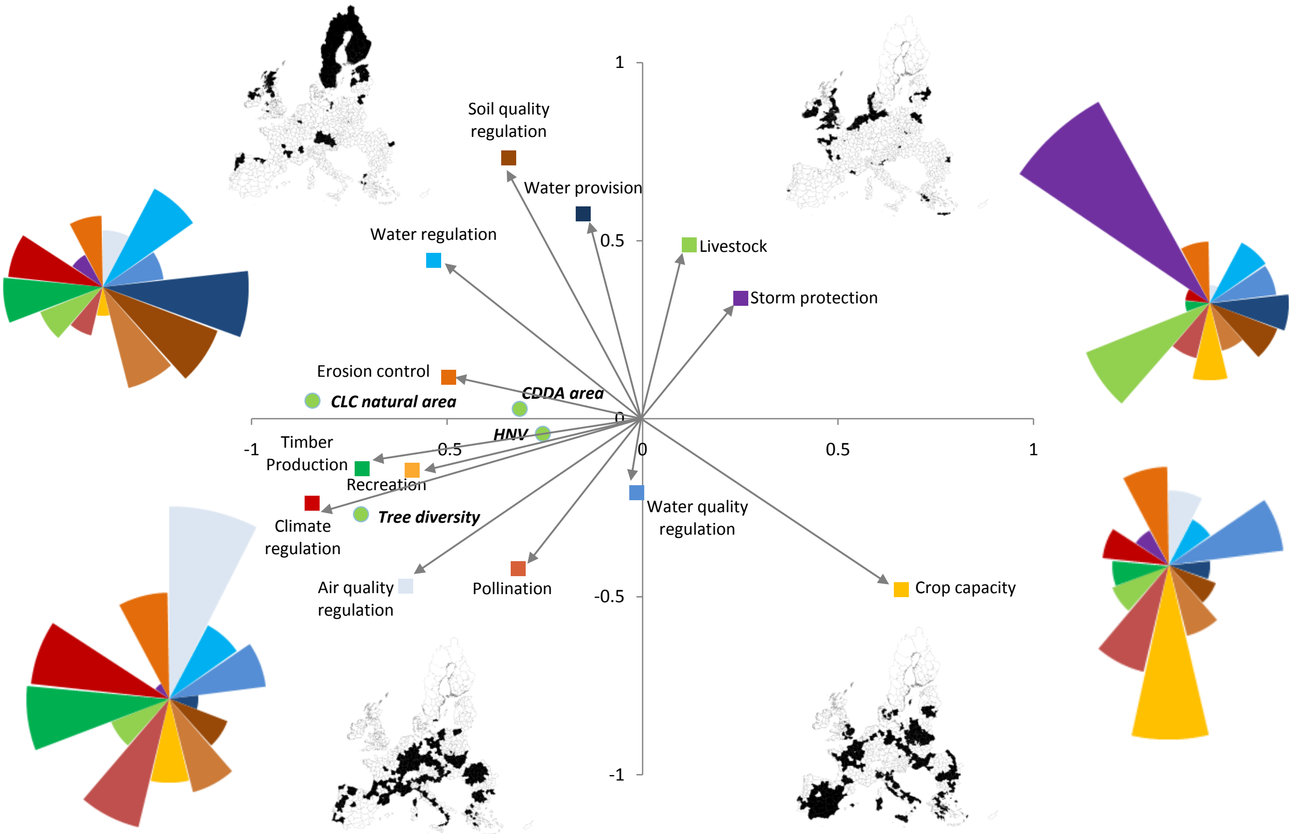


Fig. 17. Trade off analysis based on Principal Component Analysis (PCA) on 13 ecosystem services. Ecosystem service indicators measure the capacity of ecosystems to provide services as explained in the previous sections (EU scale, NUTSx resolution). The PCA explains 25% of the variance along the first axis and 17% along the second axis. Vectors or arrows closely to each other represent correlated services. These services are simultaneously provided. Vectors or arrows that point in opposite directions are services that are negatively related in space. Vectors pointing in perpendicular directions represent services that are not spatially related. Wind rose diagrams show the relative contribution of each ecosystem service to one of the four quadrants of the PCA analysis.

Wind rose maps that are calculated for each quadrant represent the variety of services that are supplied by the average NUTS area. They present the proportional contribution of each service to each quadrant (assuming that the sum of each service is 100%). Consider crop capacity. On average, crop capacity is provided for 40% by NUTS provinces situated in the 4th quadrant. NUTS areas from the 1st and 3rd quadrant contribute each about 25% while the remaining 10% is assigned to NUTS areas in the 4th quadrant. Some services are equally distributed for instance water quality regulation, pollination and recreation but most services dominate in single quadrants. That is especially evident for coastal protection services, livestock, air quality control, water provision and crop capacity. The total surface area of all slices combined per quadrant is an indicator for total ecosystem service value assuming that ecosystem services which are standardized to a percentage can be summed. Under this assumption, most services are provided by NUTS areas situated in the 2nd quadrant, followed by provinces assigned to the 3rd quadrant. The assumption of total ecosystem service value is made spatially explicit in Fig. 18. The 13 ecosystem service maps were standardized between 0 and 1 and subsequently summed and rescaled between 0 and 10. This indicator is made for presentation purposes only and may be interpreted as showing those regions where multiple services are provided. Such regions largely coincide with the distribution of forests and wetlands.

Based on this tradeoff assessment, the following conclusions can be made.

- At the EU scale and at the resolution of NUTS provinces, the capacity to provide crops trades off with all other services that are considered in this analysis. NUTS provinces rich in agro-ecosystems are essentially producing crops and are relatively poor in delivering other ecosystem services. They cover large portions of Spain, France, Italy, Lithuania, Bulgaria and Poland (Fig. 17)

- NUTS provinces rich in forests and wetlands provide a wide array of services. They have high potential to store carbon, aid in erosion and air quality control, provide recreation and timber, and support the regulation of soil and water. This array of services is further divided over 3 different groups of correlated services, depending on spatial synergies: (1) NUTS provinces situated in Atlantic plane provide mainly livestock and have often coastal wetlands providing shelter, (2) NUTS provinces in the north and north-west of Europe combining soil and water services, (3) NUTS provinces along an west-east gradient in providing forest services.

- Water quality regulation does not spatially match with this array of services. Their spatial distribution is related to the river and stream network.

It must be noted that tradeoffs which are apparent at the scale of NUTS areas may differ if a different spatial scale is considered. In particular, good or poor management of ecosystems is likely to result in increased synergies or tradeoffs, respectively. Good agricultural practices for instance may increase the capacity of cropland for infiltration and decreased water runoff rates, increased biodiversity and habitat for pollinators or improved erosion control. Forests have capacity to provide timber and to store carbon provided they are well managed to this end.

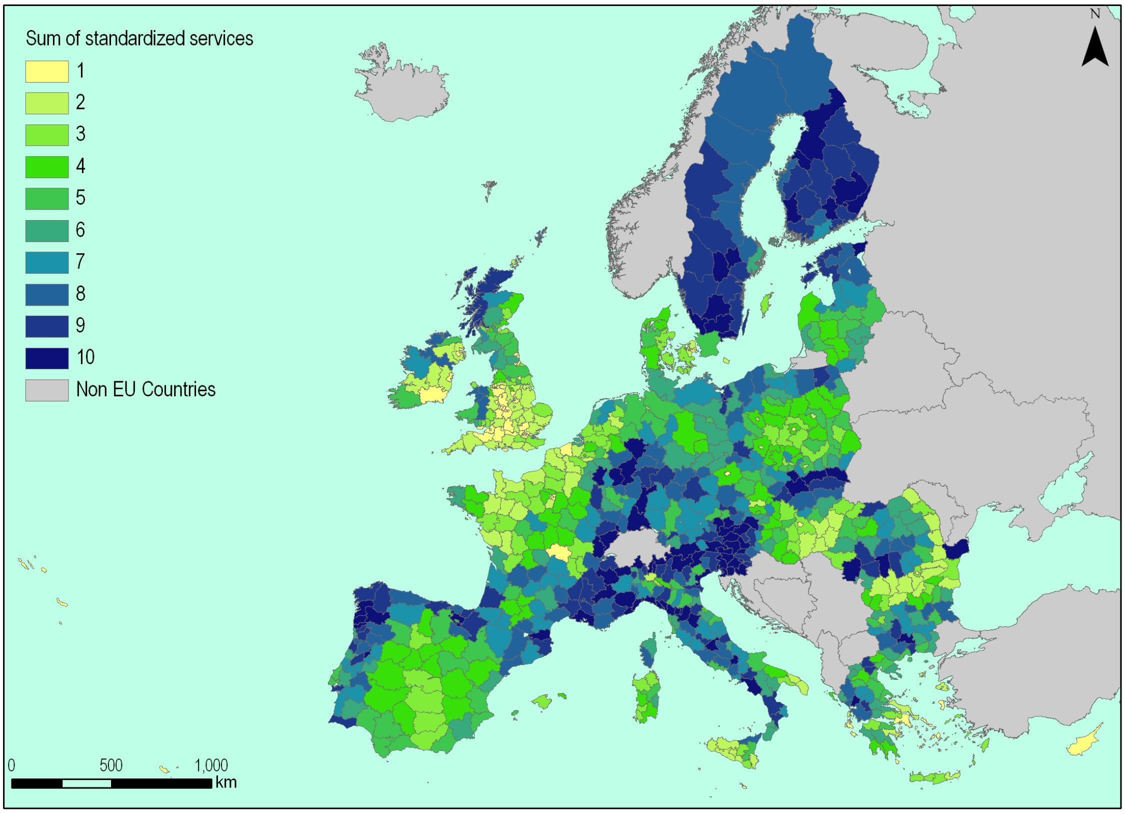


Fig. 18. Total ecosystem service value.

Sum of 13 ecosystem services maps standardized according to $(x-x_{min})/(x_{max}-x_{min})$ where x is the value for each service per nuts area and x_{min} and x_{max} are the minimum and maximum value for that service. For islands, including Cyprus, Malta and the Spanish and Portuguese NUTS areas situated offshore, not all services could be assessed.

5 CONTRIBUTION OF ECOSYSTEMS TO THE FLOW OF ECOSYSTEM SERVICES

5.1 THE USE OF LAND COVER DATA AS A PROXY FOR ECOSYSTEM DISTRIBUTION

The conversion from natural ecosystems to semi-natural, agricultural or artificial systems is a major cause of loss of biodiversity and associated ecosystem services. Therefore, a particular requirement for mapping is that the spatially explicit framework can be coupled to land cover or land use data in order to quantify how historical and future changes in land cover have affected changes in ecosystem service supply. At the European scale, only the CORINE land cover classification data qualify for such an assessment since it is the only dataset of land cover data for which a time-series is available with a first dataset for 1990 and updates for 2000 and 2006. The CORINE data will mainly serve as a surrogate for the classification of ecosystems at the EU scale.

An ecosystem is usually defined as an area, place or environment where organisms interact with the physical and chemical environment. Under this definition, virtually all environments on earth are ecosystems be it with different human impacts. As a result, also cities and farmland are referred to as urban ecosystems or agro ecosystems, respectively. We use therefore this broad definition of an ecosystem to make a qualitative link between the CLC data and the ecosystem services that are included in this study, including in particular green urban areas and agricultural land to this study. Similar approaches are available in the literature for instance Kienast et al. (2009) and Burkhard et al. (2009). Both studies provide keys to link CLC land cover classes to ecosystem services and landscape functions.

The results of this assessment are summarized in Table 1 where each CLC is related to an ecosystem service giving a value of 1 for CLC classes assumed to support a service and a value of 0 for CLC classes that are assumed to have no supportive role. An asterix is given to those services that do contribute to the supply of services (following Burkhard et al. 2009) but which are not covered by this study.

This assessment strongly depends on the kind of indicator we have used for approximating a certain service.

We excluded all urban fabric, industry and mining classes as supportive land cover classes. We did not consider sports and leisure facilities either. Burkhard et al. (2009) included the latter class as well as discontinuous urban fabric as suppliers of some provisioning or regulating services. Virtually all the nature inside these land cover classes is fragmented and to some extent managed, which likely constrains the regulating services at level well below those delivered by agricultural or natural systems. Quantifying the difference in services delivered by nature in artificial areas relative to non-artificial areas will prove to be difficult at the European scale and needs fin resolution data. Green urban areas were included in some services, in particular for their contribution to urban air quality regulation.

Agricultural areas evidently support provisioning services and are in Europe also appreciated for their recreational value explaining their inclusion under recreation services. In this assessment, we excluded agricultural areas from several regulating services. Agricultural areas were not assumed to take part in climate and air quality regulation due to the temporal nature of crops. We also excluded agricultural lands from contribution to pollination and erosion control but this will be revised in further studies.

Natural areas were assumed to support services be it with differences among the different land cover classes. We excluded burnt areas from the assessment and assigned to bare rocks only recreational value. As argued before, fresh water provision is delivered by inland wetlands and inland waters and by glaciers and perpetual snow while water regulation is also performed by terrestrial land cover classes. Water purification services are delivered by several classes but in this report, only the role of surface waters was studied.

As already mentioned, sea and ocean services are not considered but the coastline is used as an indicator for recreational services. Marine land cover classes are considered from the perspective of terrestrial services.

As the research on ecosystem services proceeds, more indicators capturing different aspects of services covered in this study will be included resulting in an update of Table 5.

5.2 ECOSYSTEM SERVICE FLOWS

Table 5 is used to assign service flows to ecosystems. For 7 services, we were able to map the service flow as a quantity that is supplied **per year**. Maps of these service flows are presented in the previous sections of this report. Spatially explicit data on service flows were available for timber (annual increment of the volume of timber, m^3 $year^{-1}$), water purification (total nitrogen removed from surface waters, ton $year^{-1}$), climate regulation (total amount of carbon sequestered by above ground vegetation of forests, grasslands and wetlands, ton $year^{-1}$), atmospheric cleansing by vegetation (total amount of air pollutants removed from the atmosphere by leaves of urban and peri urban forests and vegetation, ton $year^{-1}$), water provision and regulation (the combined total flow of surface and sub surface water, m^3 $year^{-1}$). Maps of these ecosystem service flows covering the EU-27 were cross-tabulated with the CORINE CLC land cover and land use map resulting in the contribution of each land cover class to the service flow. Only CLC classes which contribute to the supply of ecosystem services according to Table 5 were retained in the cross tabulation analysis. These accounts, aggregated at EU-27 scale and based on data for the year 2000, are presented in Table 6.

Table 5. Link between the CLC land cover classes and ecosystem services.

LABEL1	LABEL2	LABEL3	Timber	Crops	Livestock	Water provision	Water regulation	Water quality regulation	Climate regulation	Storm protection	Air quality regulation	Erosion	Pollination	Soil quality	Recreation
Artificial surfaces	Urban fabric	Continuous urban fabric	0	0	0	0	0	0	0	0	0	0	0	0	0
		Discontinuous urban fabric	0	x	0	0	0	0	0	0	0	0	0	0	0
	Industrial, commercial and transport units	Industrial or commercial units	0	0	0	0	0	0	0	0	0	0	0	0	0
		Road and rail networks and associated land	0	0	0	0	0	0	0	0	0	0	0	0	0
		Port areas	0	0	0	0	0	0	0	x	0	0	0	0	0
		Airports	0	0	0	0	0	0	0	0	0	0	0	0	0
	Mine, dump and construction sites	Mineral extraction sites	0	0	0	0	0	0	0	0	0	0	0	0	0
		Dump sites	0	0	0	0	0	0	0	0	0	0	0	0	0
		Construction sites	0	0	0	0	0	0	0	0	0	0	0	0	0
	Artificial, non-agricultural vegetated areas	Green urban areas	0	0	0	0	x	x	x	0	1	x	x	0	0
		Sport and leisure facilities	0	0	0	0	x	x	x	0	x	x	x	0	0
Agricultural areas	Arable land	Non-irrigated arable land	0	1	x	0	1	0	x	0	0	0	0	1	1
		Permanently irrigated land	0	1	x	0	1	0	x	0	0	0	0	1	1
		Rice fields	0	1	0	0	1	0	0	0	0	0	0	1	1
	Permanent crops	Vineyards	0	1	0	0	1	0	x	0	0	0	0	1	1
		Fruit trees and berry plantations	0	1	0	0	1	x	x	0	x	x	x	1	1
		Olive groves	0	1	0	0	1	x	x	0	x	x	0	1	1
	Pastures	Pastures	0	0	1	0	1	0	x	0	0	x	0	1	1
	Heterogeneous agricultural areas	Annual crops associated with permanent crops	0	1	x	0	1	0	x	0	x	x	0	1	1
		Complex cultivation patterns	0	1	x	0	1	0	x	0	0	0	0	1	1
		Land principally occupied by agriculture, with significant areas of natural vegetation	0	0	x	0	1	x	x	0	x	x	0	1	1
		Agro-forestry areas	1	0	0	0	1	x	x	0	x	x	x	1	1
Forest and semi natural areas	Forests	Broad-leaved forest	1	0	0	0	1	x	1	0	1	1	1	1	1
		Coniferous forest	1	0	0	0	1	x	1	0	1	1	1	1	1
		Mixed forest	1	0	0	0	1	x	1	0	1	1	1	1	1
	Scrub and/or herbaceous vegetation associations	Natural grasslands	0	0	1	0	1	x	1	0	1	1	1	1	1
		Moors and heathland	0	0	1	0	1	x	1	0	1	1	1	1	1
		Sclerophyllous vegetation	0	0	1	0	1	0	1	0	1	1	1	1	1
		Transitional woodland-shrub	0	0	1	0	1	0	1	0	1	1	1	1	1
	Open spaces with little or no vegetation	Beaches, dunes, sands	0	0	0	0	1	0	1	1	1	1	1	1	1
		Bare rocks	0	0	0	0	0	x	0	0	0	0	0	0	1
		Sparsely vegetated areas	0	0	0	0	1	0	0	0	0	0	1	1	1
		Burnt areas	0	0	0	0	0	0	0	0	0	0	0	0	0
		Glaciers and perpetual snow	0	0	0	1	x	0	x	0	0	0	0	0	1
Wetlands	Inland wetlands	Inland marshes	0	0	x	1	x	x	1	0	0	0	1	0	1
		Peat bogs	0	0	0	1	x	x	1	0	0	0	1	0	1
	Maritime wetlands	Salt marshes	0	0	x	0	0	0	1	1	0	0	1	0	1
		Salines	0	0	0	0	0	0	1	1	0	0	1	0	1
		Intertidal flats	0	0	0	0	0	0	1	1	0	0	1	0	1
Water bodies	Inland waters	Water courses	0	0	0	1	x	1	0	0	0	0	1	0	1
		Water bodies	0	0	0	1	x	1	x	0	0	0	1	0	1
	Marine waters	Coastal lagoons	0	0	0	0	0	0	0	1	0	0	1	0	1
		Estuaries	0	0	0	0	0	x	0	1	0	0	1	0	1
		Sea and ocean	0	0	0	0	0	0	x	0	0	0	0	0	1

1: land cover class supports service; 0: land cover class does not support service; * land cover class supports the service (based on Burkhard et al. 2009) but this function was ignored in this assessment due to data limitations.

Annual timber increment in the EU-27, based on the forest inventory data, was estimated at 714 million cubic meters. This compares to a value of 413 million cube of round wood that was produced in the EU-27 reported by EUROSTAT for 2000. Since forest inventory data are only available at low resolution (NUTS2), we used the relative contributions of forest land cover classes to distribute timber increment over broadleaf, mixed and coniferous forests.

A similar approach was used to distribute the nitrogen removed by surface waters over water courses and water bodies. The EU-27 river network removed in 2000 1.4 million ton of nitrogen through retention in rivers, streams and lakes. However, the surface area of water courses is considerably underestimated in the CLC data since only water courses with a minimum width of 100 m are included.

Forests, semi-natural areas and wetlands were estimated to fix all together 1.28 pentagram carbon (1Pg = 10^{15} g). This estimate was based on calculation of net ecosystem productivity based on the Normalized Difference Vegetation Index (SPOT VEGETATION). The methodology was developed by Veroustraete et al. (2002). The total carbon fixation over Europe amounted to 2.8 Pg but this includes carbon sequestered in urban and agricultural areas as well. Forests contributed 0.9 Pg with a disproportionally larger contribution of broad leaf forests relative to their percentage land cover. Using a similar approach, i.e. cross-tabulation of the 1997 NEP data with a forest probability map, yielded an estimate of 0.74 Pg carbon sequestered by forests (Veroustraete et al. 2002).

Atmospheric cleansing refers to the removal of air pollutants via dry deposition. In this assessment, we calculated the annual deposition of NH_3, NO_x (mainly NO and NO_2) and SO_x (mainly SO_2) on urban and peri-urban forests and semi-natural areas (<3 km from urban areas). Relative to the emissions of air pollutants in the EU-27 (NH_3: 4.1×10^6 ton; NO_x: 12.7×10^6 ton; SO_x: 10.5×10^6 ton), contributions of urban and peri-urban ecosystems in capturing air pollutants are 3 orders of magnitude smaller. Hence, the effect on local air quality is equally small.

Finally, an account of water provision and water regulation services was made but subdividing the total net precipitation over surface water flow (feeding rivers, wetlands and lakes) and sub surface water flows (charging ground waters). The assessment for 2000 resulted in a total net precipitation of 8 million cubic meter of water equally divided over surface and sub surface flows. Surface water flows are assigned to water bodies and wetlands where as sub surface water flows were assigned to agricultural and terrestrial ecosystems.

The biophysical estimates of service flows can be used in an economic assessment that assigns values to each of these quantities. Clearly, once the methodology is validated and peer reviewed, these economic estimates can be calculated on a country or NUTS basis.

Table 6. Annual flow of ecosystem services for the EU-27.

CLC classes	Land use	Timber production	Total nitrogen removed from surface water	Total carbon sequestered	Atmospheric cleansing by vegetation			Total water flow
	%	10^6 m^3 year^{-1}	10^6 ton year^{-1}	10^9 ton year^{-1}	10^3 NH_3 ton year^{-1}	10^3 NO_x ton year^{-1}	10^3 SO_x ton year^{-1}	10^6 m^3 year^{-1}
Total		**714**	**1.39**	**1.282**	**23**	**25**	**15**	**8.4**
Green urban areas	0.07			0.001	0.13	0.20	0.09	0.004
Non-irrigated arable land	24.60							1.032
Permanently irrigated land	0.72							0.036
Rice fields	0.13							0.009
Vineyards	0.90							0.038
Fruit trees and berry plantations	0.57							0.020
Olive groves	0.91							0.027
Pastures	8.41							0.492
Annual crops associated with permanent crops	0.23							0.009
Complex cultivation patterns	5.45							0.298
Land principally occupied by agriculture, with significant areas of natural vegetation	4.41				4.30	4.27	3.18	0.211
Agro-forestry areas	0.74	16.71			0.01	0.01	0.01	0.024
Broad-leaved forest	9.39	212.52		0.373	7.17	6.57	4.54	0.452
Coniferous forest	14.86	336.47		0.347	5.55	7.02	3.13	0.624
Mixed forest	6.53	147.88		0.177	3.87	4.65	2.38	0.294
Natural grasslands	2.54			0.081	0.40	0.38	0.27	0.115
Moors and heathland	2.04			0.039	0.11	0.13	0.07	0.092
Sclerophyllous vegetation	2.20			0.082	0.18	0.21	0.13	0.065
Transitional woodland-shrub	5.12			0.145	1.10	1.13	0.90	0.223
Beaches, dunes, sands	0.07			0.002	0.08	0.07	0.04	0.004
Bare rocks	0.46							
Sparsely vegetated areas	0.85							0.035
Glaciers and perpetual snow	0.04							0.036
Inland marshes	0.26			0.008				0.245
Peat bogs	1.65			0.022				1.534
Salt marshes	0.06			0.002				
Salines	0.02			0.0003				
Intertidal flats	0.01			0.002				
Water courses	0.22		0.13					0.209
Water bodies	2.18		1.27					2.018

Flows are calculated per land cover class based on data for the year 2000.

6 ECOSYSTEM SERVICE BUNDLES

As a summary, the NUTS based maps reported in the previous sections of this report are presented in four **bundles of services** that contribute to one of the following benefits:

- Timber production
- Food security
- Water security
- Health and wellbeing

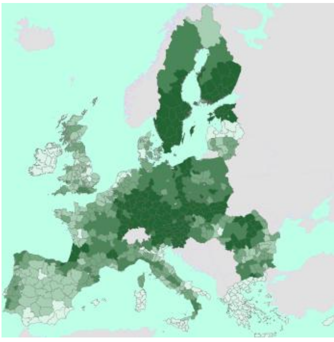
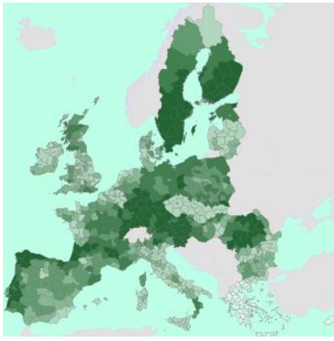
Such bundles of ecosystems are considered useful for reporting and modelling (International workshop on ecosystem services indicators, Cambrigde, 2010). Each bundle is built around a particular topic of concern. For instance, a water security bundle consists of those services that provide clean water including the availability of fresh water as well as regulating services protecting against floods or supplying purified water.

Bundling services in such as way could clarify the messages different services provide and hence enhance communication (UNEP-WCMC 2011). Furthermore, service bundles may prove to be useful for economic assessment and monetary valuation. Consider for instance a food security bundle including those services that contribute to agricultural production: grassland production securing cattle derived products, pollination and pest control securing crop production, erosion control and soil fertility securing good soil conditions for agriculture. The biophysical flow of benefits derived from these services may be measured as the contribution of each service to total crop production facilitating economic assessments and the calculation of scenarios affecting biodiversity.

The NUTSx based maps of ecosystem services are therefore repeated here and presented as bundles of services. When available, both information on capacity (stock) and flow of services is provided. Maps use the NUTSx areas as spatial unit and always classify the range of values into quintiles. Full explanatory legends are given in the previous sections for each service map.

6.1 TIMBER PRODUCTION BUNDLE

Maps include one capacity indicator (timber stock) and one service flow indicator (annual increment of the stock).

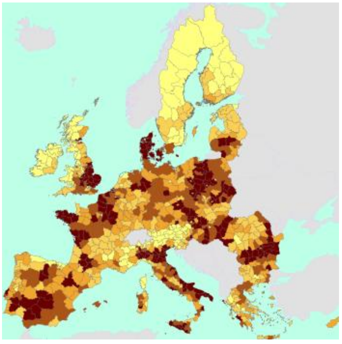
Timber provision and production bundle		
CAPACITY INDICATOR Timber stock (m^3) 	FLOW INDICATOR Timber increment (m^3 $year^{-1}$) 	quin- tiles 1 2 3 4 5

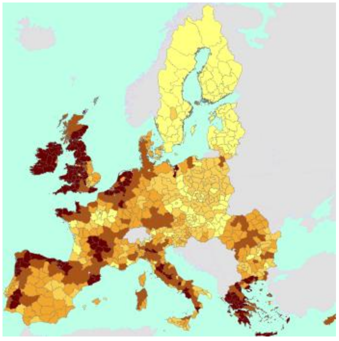
6.2 FOOD SECURITY BUNDLE

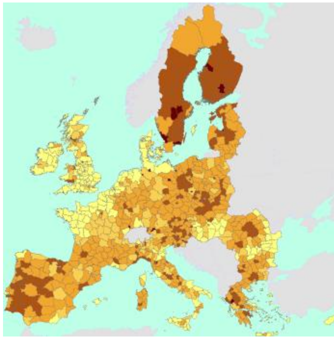
Maps include capacity indicators for cropland, livestock, erosion control and pollination. Three more capacity indicators need to be provided (soil quality and fertility, pest control and genetic diversity) Flow indicators are under development and should measure the contribution of a certain service to the maximum sustainable yield of produce.

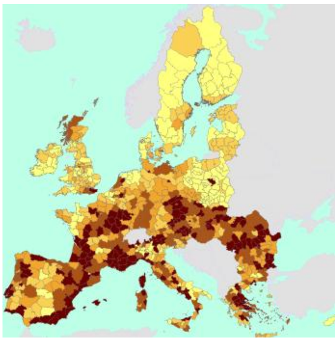
<table>
<tr><td colspan="3">Food security services bundle</td><td rowspan="4">quin-
tiles</td></tr>
<tr><td colspan="3">CAPACITY INDICATORS</td></tr>
<tr><td>Crop capacity
Share of cropland (%)</td><td>Livestock capacity
Livestock density (numbers km^{-2})</td><td>Erosion control capacity
Weighed area of protective ecosystems
(ha ha^{-1})</td></tr>
<tr><td>Pollination potential
Index</td><td colspan="2">Soil quality and fertility
Pest control
Genetic diversity

FLOW INDICATORS
Crop and livestock production statistics
Share in the yield of crop production resulting
from soil quality, erosion, pollination and pest control</td></tr>
</table>









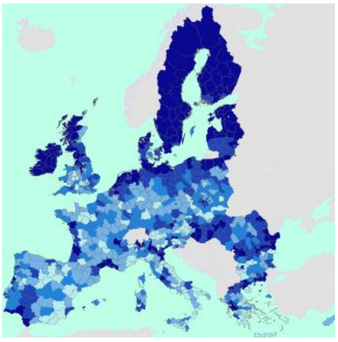
6.3 WATER SECURITY BUNDLE

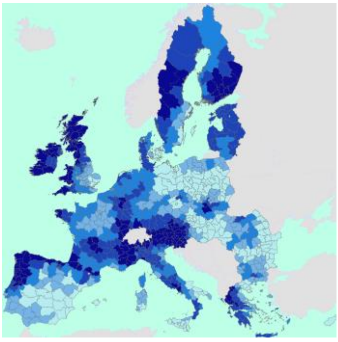
Maps include indicators for capacity and flow of water quantity and water quality regulation by aquatic and terrestrial systems.

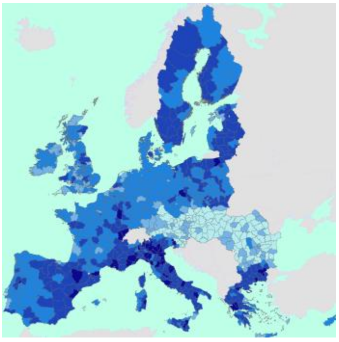
Water security services bundle

CAPACITY INDICATORS

Water provision capacity Share of wetlands and water bodies (%)	Water regulation capacity Infiltration (mm)	Water purification capacity Nitrogen retention (%)	quin- tiles



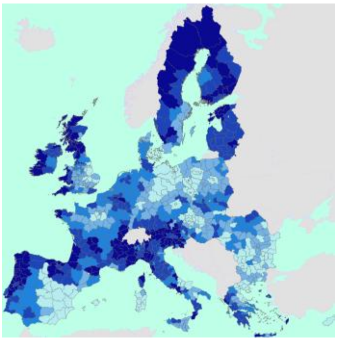


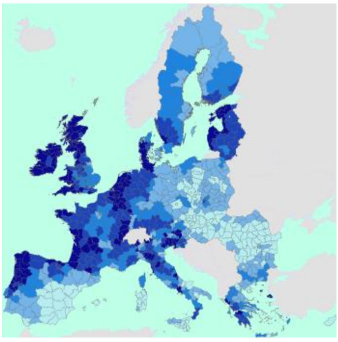


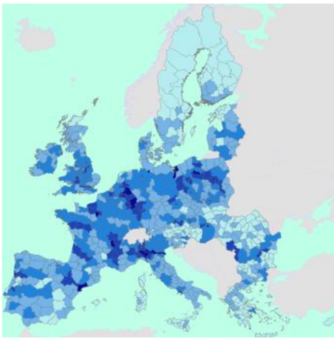
quin-tiles: 1, 2, 3, 4, 5

FLOW INDICATORS

Water flow available from aquatic ecosystems Surface water flow (m^3 year^{-1})	Water flow regulated by terrestrial ecosystems Sub surface water flow (m^3 year^{-1})	Removal of pollutants In-stream nitrogen removal (ton year^{-1})	quin- tiles







quin-tiles: 1, 2, 3, 4, 5

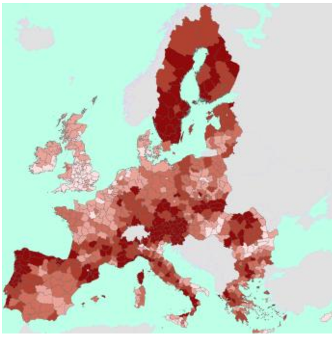
6.4 HUMAN HEALTH AND WELLBEING BUNDLE

This bundle includes services that contribute to human health by offering suitable conditions including a stable climate, clean air, protection against natural disasters and opportunities for recreation.

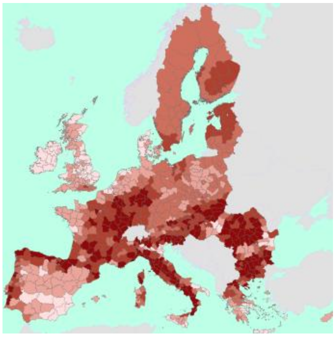
Health and wellbeing services bundle

CAPACITY INDICATORS

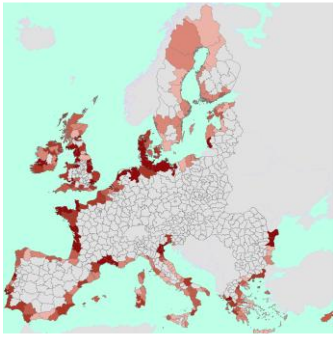
Climate regulation
Carbon stock (ton C)



Air quality regulation capacity
(dry deposition velocity m year^{-1})



Coastal protection against storms
Share of coastal habitats (%)



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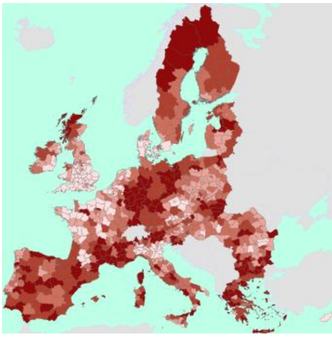
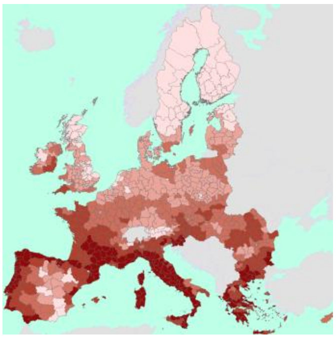
Recreation potential
Index



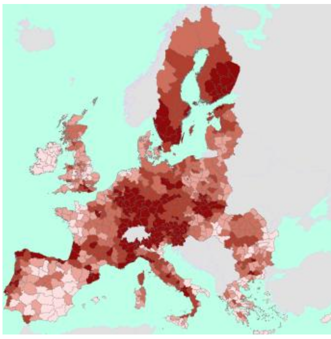
Capacity to protect against other natural disasters such as landslides, avalanches and floods

FLOW INDICATORS

Climate regulation
Carbon sequestration (ton C year^{-1})



Atmospheric cleansing by vegetation
Removal of NOx (ton year^{-1})



Indicators measuring the contribution of ecosystems in protection against natural distasters

Visitor statistics measuring the flow of recreational and cultural services

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7 CONCLUSIONS AND FINAL REMARKS

The spatial indicators for ecosystem services that are presented in this report represent only a first spatially explicit baseline for assessing the state of ecosystem services in Europe. Clearly, further developments are necessary to extend the analysis to services for which currently no spatial information is available or at least, difficult to obtain. In this context, it is useful to refer to the PRESS project. PRESS stands for PEER Research on Ecosystem Services and is an initiative endorsed by PEER (Partnership for European Environmental Research) to develop methodologies for mapping ecosystem services at different spatial scales. Case studies for mapping timber production and forest services, water purification and recreation are under development and reports will be available in 2011.

Besides adding high resolution data and validation of results against alternative estimates of ecosystem services, there is additional need to use the maps of ecosystem services in scenario assessment (for instance see Schröter et al. 2005; Metzger et al 2008). The purpose is to evaluate different scenarios with respect to land use, biodiversity or human inputs against a set of baseline maps in order to detect areas where ecosystem services increase or decrease. Such assessment necessitates the development of a model methodology coupled to a geo spatial database as well as of story lines for different scenarios. Possible approaches for ecosystem service model development are currently under consideration.

The role of biodiversity

The EU biodiversity policy introduces the concept of ecosystem services as a means of mainstreaming biodiversity into other policies, notably agriculture, fisheries, forestry and regional development. The argument is that these policies are dependent on biodiversity resources and are therefore partly responsible for some of the declines that are observed in biodiversity. The assumption is that the provision of ecosystem services is underpinned by and hence, correlated to biodiversity. As a consequence, maintaining ecosystem services is assumed to contribute to conservation of habitats and species.

Although it is evident the biodiversity underpins ecosystem services, the exact mechanisms remains poorly understood. Studies based on experiments, maps overlaying indicators for biodiversity with indicators for ecosystem services, field observations or meta-analysis of published data often report weak correlations between biodiversity and ecosystem services. Several arguments are put forward to frame the lack of correlation between ecosystem services and biodiversity.

In November 2010, Alter-Net organized a workshop which aimed to review the state of the art of present knowledge on the link between ecosystem services and biodiversity. Key to this debate is how to define biodiversity. A narrow definition puts biodiversity equal to species richness or relative species abundance. The dominance of few species in ecological communities which are consuming and transferring the bulk of the energy and material flows in ecosystems often lead to weak relationships between ecosystem services and biodiversity. A broader definition of biodiversity including also structural and functional traits of species as well as landscape and ecosystem diversity may therefore result in much better relations between biodiversity and ES.

A second argument is that ecosystem service indicators are often based on models which do not include biodiversity as a parameter in the model. An example is nitrogen retention that is mapped in this study as an indicator for water quality regulation by rivers and streams. Aquatic biodiversity, in particular river bed bacteria, macrophytes and plankton, are the main consumers of in stream nitrogen. Yet, this service is modeled using physical properties only and therefore, it is meaningless looking for correlations between service and biodiversity underpinning the service.

REFERENCES

Bouraoui F, Grizzetti B, Aloe A. (2009) Nutrient Discharge from Rivers to Seas for Year 2000 . EUR 24002 EN. Luxembourg (Luxembourg): European Commission; 2009. JRC54459

Britz W, Witzke P (2008) CAPRI model documentation 2008: Version 2. http://www.capri-model.org/docs/capri_documentation.pdf.

Burkhard B, Kroll F, Müller F, Windhorst W (2009) Landscapes' capacity to provide ecosystem services: a concept for land cover based assessments. **Landscape online** 15, 1-22.

Costanza R, Pérez-Maqueo O, Martinez ML, Sutton P, Anderson SJ, Mulder K. (2008) The value of coastal wetlands for hurricane protection. **Ambio** 37:241-248.

De Groot RS, Alkemade R, Braat L, Hein L, Willemen L (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. **Ecological Complexity** 7, 260-272.

Escobedo FJ, Nowak DJ (2009) Spatial heterogeneity and air pollution removal by an urban forest. **Landscape and Urban Planning** 90, 102-110.

European Commission (2010) Options for an EU vision and target for biodiversity beyond 2010. COM(2010) 4 final. Brussels.

FAO (2007) Gridded livestock of the world 2007, by G.R.W. Wint and T.P. Robinson. Rome, pp 131.

Gallai N, Salles JM, Settele J, Vaissière BE (2009) Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. **Ecological Economics** 68, 810-821.

Galluan H, Zanchi G, Nabuurs GJ, Hengeveld G, Schardt M, Verkerk PJ (2010) EU-wide maps of growing stock and above-ground biomass in forests based on remote sensing and field measurements.**Forest Ecology & Management** 260, 252-261.

Grizzetti B, Bouraoui F, Aloe A. (2007) Spatialised European Nutrient Balance. EUR 22692 EN. 2007. JRC36653.

Grizzetti B, Bouraoui F, De Marsily G, Bidoglio G (2005) A statistical method for source apportionment of riverine nitrogen loads. **Journal of Hydrology**, 304: 302-315.

Grizzetti B, Bouraoui F, De Marsily G (2008) Assessing nitrogen pressures on European surface water. **Global Biogeochemical Cycles**, 22 GB4023, doi:10.1029/2007GB003085.

Joyce K, Sutton S (2009). A method for automatic generation of the Recreation Opportunity Spectrum in New Zealand. **Applied Geography** 29, 409–418.

Karl T, Harley P, Emmons L, Thornton B, Guenther A, Basu C, Turnipseed A, Jardine K (2010) Efficient atmospheric cleansing of oxidized organic trace gases by vegetation. **Science** 330, 816-819.

Kienast F, Bolliger J, Potschin M, de Groot R, Verburg PH, Heller I, Wascher D, 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

Klein AM, Vaissière BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C (2007) Importance of pollinators in changing landscapes for world crops. **Proceedings of the Royal Society: Biological sciences** 274, 303-313.

Layke, C. 2009. Measuring Nature's Benefits: A Preliminary Roadmap for Improving Ecosystem Service Indicators. WRI Working Paper. World Resources Institute, Washington DC. Available online at http://www.wri.org/project/ecosystem-service-indicators.

Metzger MJ, Schröter D, Leemans R, Cramer W (2008) A spatially explicit and quantitative vulnerability assessment of ecosystem service change in Europe. **Regional Environmental Change** 8, 91-107.

Mulholland, P.J. , Helton, A.M. , Poole, G.C. , Hall Jr., R.O. , Hamilton, S.K. , Peterson, B.J. , Tank, J.L., Ashkenas, L.R., Cooper, L.W., Dahm, C.N., Dodds, W.K., Findlay, S.E.G., Gregory, S.V., Grimm, N.B., Johnson, S.L., McDowell, W.H., Meyer, J.L., Valett, H.M., Webster, J.R., Arango, C.P., Beaulieu, J.J., Bernot, M.J., Burgin, A.J., Crenshaw, C.L., Johnson, L.T., Niederlehner, B.R., O'Brien, J.M., Potter, J.D., Sheibley, R.W., Sobota, D.J., Thomas, S.M. (2008) Stream denitrification across biomes and its response to anthropogenic nitrate loading. Nature 452, 202-205.

Naidoo R, Balmford A, Costanza R, Fisher B, Green RE, Lehner B, Malcolm TR, Ricketts TH (2008) Global mapping of ecosystem services and conservation priorities. **Proceedings of the National Academy of Sciences of the United States of America** 105, 9495-9500.

Nowak DJ, Crane DE, Stevens JC (2006) Air pollution removal by urban trees and shrubs in the United States. **Urban Forestry and Urban Greening** 4, 115-123.

Pistocchi A, Bouraoui F, Bittelli M. (2008) A Simplified Parameterization of the Monthly Topsoil Water Budget. **Water Resources Research** 44, Article number W12440.

Pistocchi A, Zulian G, Vizcaino P, Marinov D (2010) Multimedia Assessment of Pollutant Pathways in the Environment, European Scale Model (MAPPE-EUROPE). EUR 24256 EN. Luxembourg (Luxembourg): Publications Office of the European Union; 2010. JRC56335.

Pistocchi A (2008) A GIS-Based Approach for Modeling the Fate and Transport of Pollutants in Europe. **Environmental Science and Technology** 42, 3640-3647.

Ricketts TH, Regetz J, Steffan-Dewenter I, Cunningham SA, Kremen C, Bogdanski A, et al. (2008) Landscape effects on crop pollination services: Are there general patterns? **Ecology Letters** 11, 499-515.

Schröter D, Cramer W, Leemans R, Prentice IC, Araújo MB, Arnell NW, et al. (2005) Ecology: Ecosystem service supply and vulnerability to global change in Europe. **Science** 310, 1333-1337.

TEEB (2010) Chapter 5: The economics of valuing ecosystem services and biodiversity. http://www.teebweb.org/EcologicalandEconomicFoundation/tabid/1018/Default.aspx

UNEP-WCMC (in preparation) Developing ecosystem indicators: experiences and lessons learned from sub-global assessments and other initiatives.

Veroustraete F, Sabbe H, Eerens H (2002) Estimation of carbon mass fluxes over Europe using the C-Fix model and Euroflux data. **Remote Sensing of Environment** 83, 376-399.

Wesely ML, Hicks BB (2000) A review of the current status of knowledge on dry deposition. **Atmospheric Environment** 34, 2261-2282.

Wriedt G, Bouraoui F (2009) Towards a General Water Balance Assessment of Europe. EUR 23966 EN. Luxembourg (Luxembourg): OP; 2009. JRC53258.

ANNEX 1. ECOSYSTEM SERVICE MAPS AT HIGH RESOLUTION

This annex contains the data and maps that have been used to make aggregated maps at NUTSX statistical level.

Provisioning and regulating services:
Indicators based on land cover data

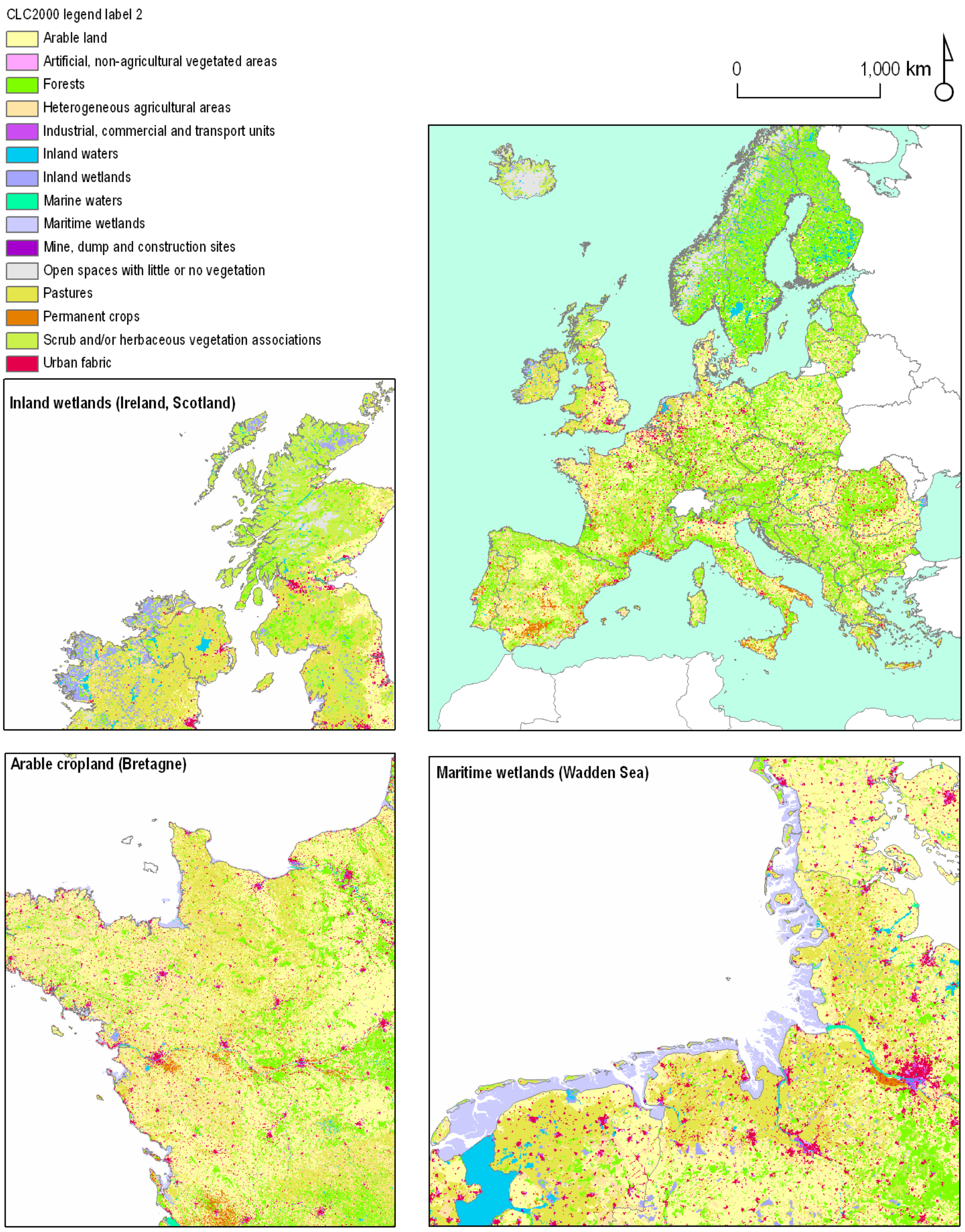

Fig A1. The capacity of ecosystems to provide food, water and protection against seaborne storms was approximated using CORINE land cover data of arable land, inland wetlands and water bodies and maritime wetlands. Data source: Corine Land Cover 2000 raster data - version 13, EEA.

Provisioning services:
Livestock services

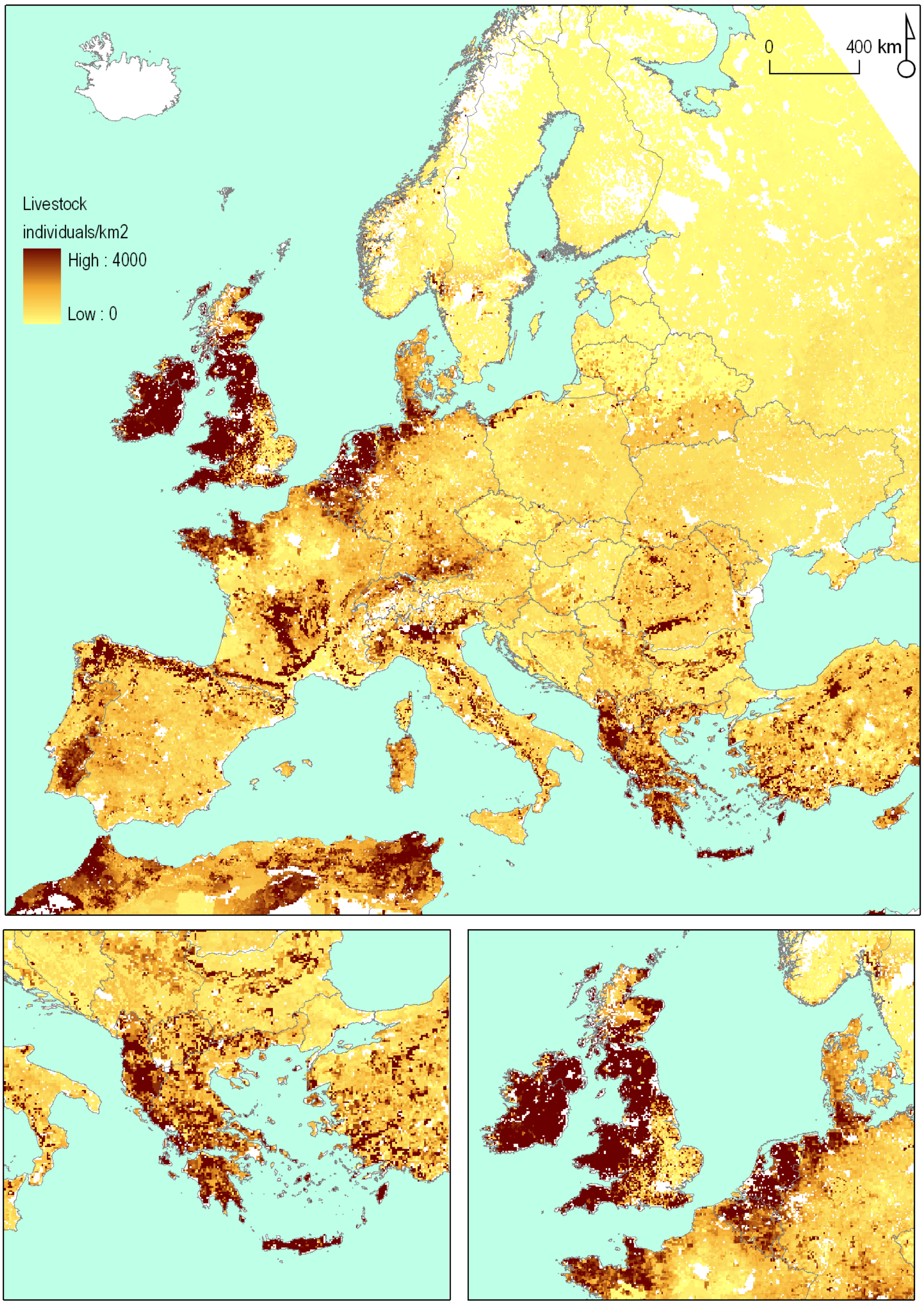

Fig. A2. Livestock density was mapped based on the FAO gridded livestock data. Numbers of cattle, sheep and goat are summed and expressed per km². Zoom areas above the North Sea and Greece. The resolution of the data is 0.05°.

Provisioning services:
Water provision

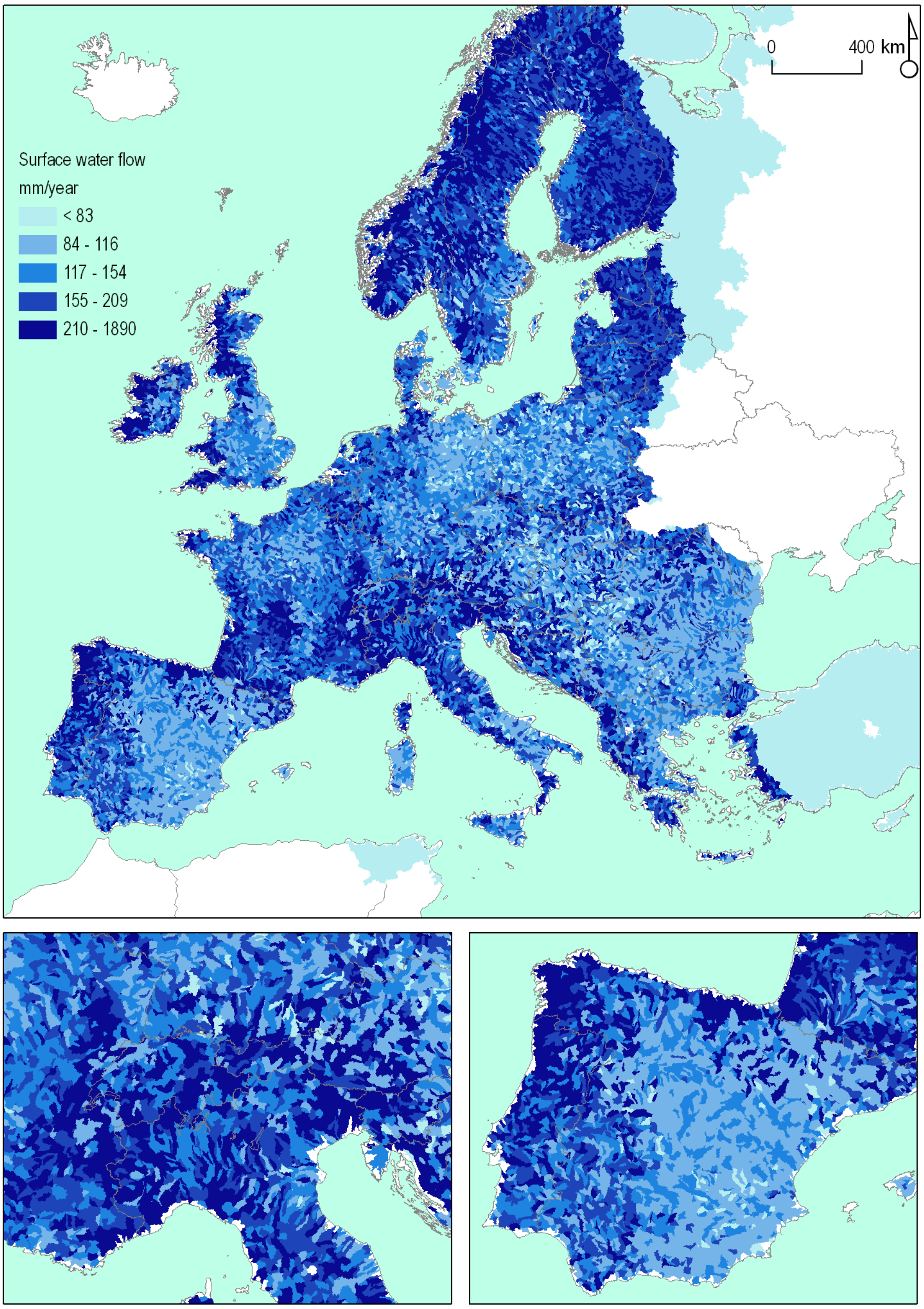

Fig. A3. Surface water flow is used as proxy to estimate the annual contribution of inland water bodies and wetlands to fresh water provision. To this end, Europe is sub divided over 30 thousand sub catchments for which a water balance was made. The resolution of the data is 10 km, on average. Data source: Wriedt and Bouraoui (2009).

Regulating services:
Water regulation

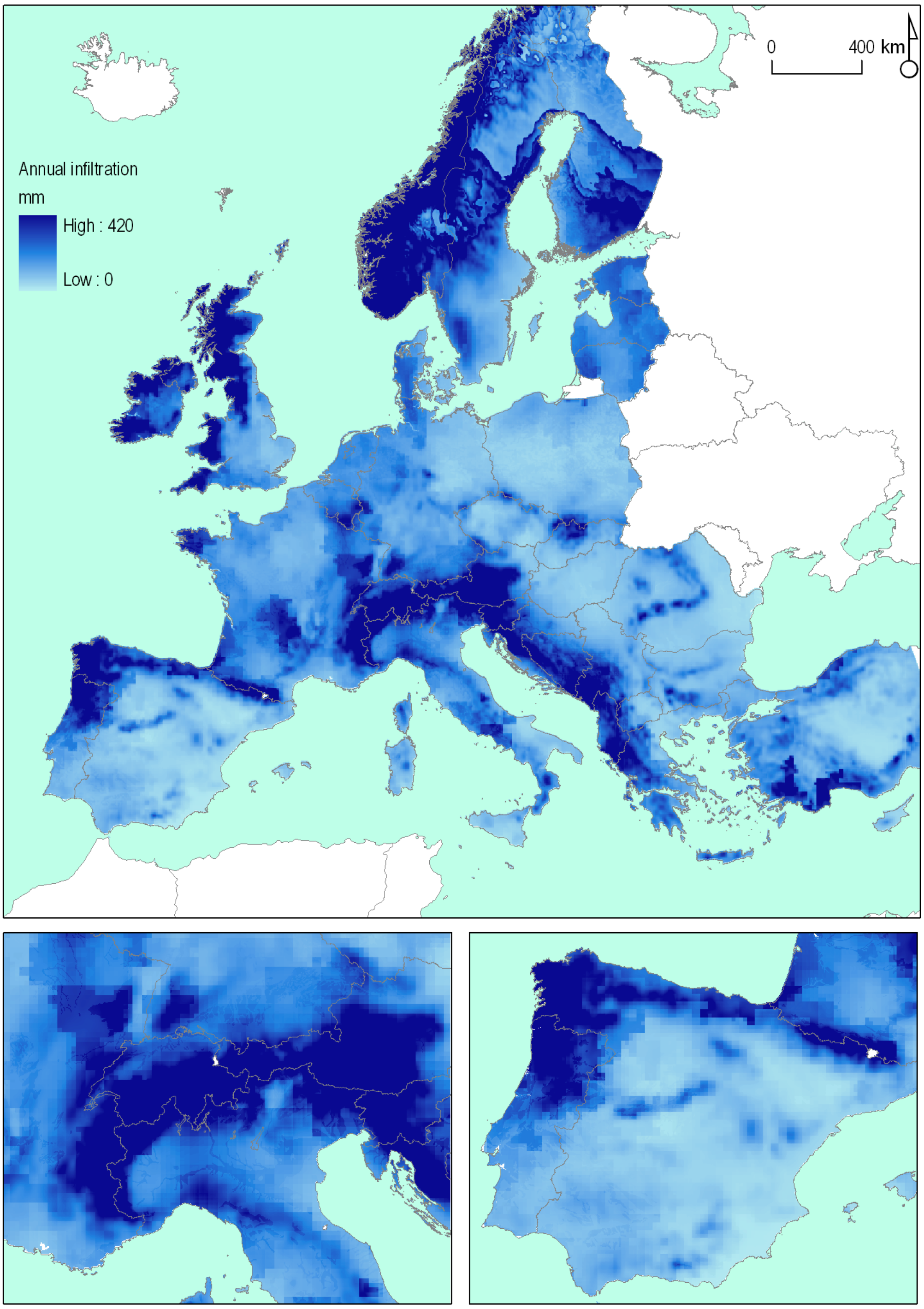

Fig. A4. Infiltration is used as proxy to estimate the capacity of terrestrial ecosystems to (temporarily) store fresh water. The data used are derived from the MAPPE model (Pistocchi et al. 2008; Pistocchi et al. 2010). The resolution is 1 km.

Regulating services:

Water regulation

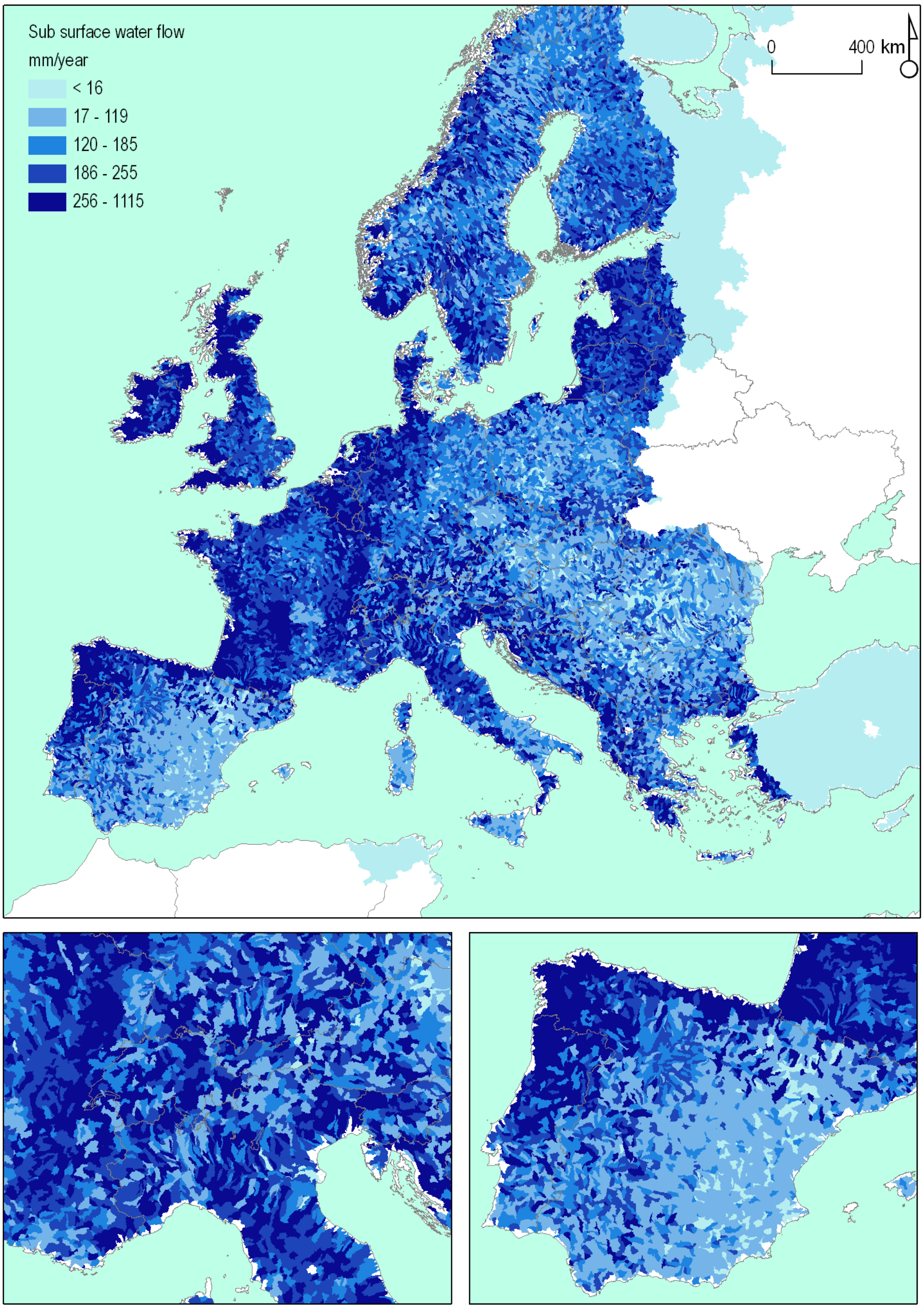

Fig. A5. Sub surface water flow is used as proxy to estimate the annual contribution of terrestrial ecosystems to fresh water regulation. Europe is sub divided over 30 thousand sub catchments for which a water balance was made. The resolution of the data is 10 km. Data source: Wriedt and Bouraoui (2009).

Regulating services:

Water purification indicated by nitrogen retention and removal (1)

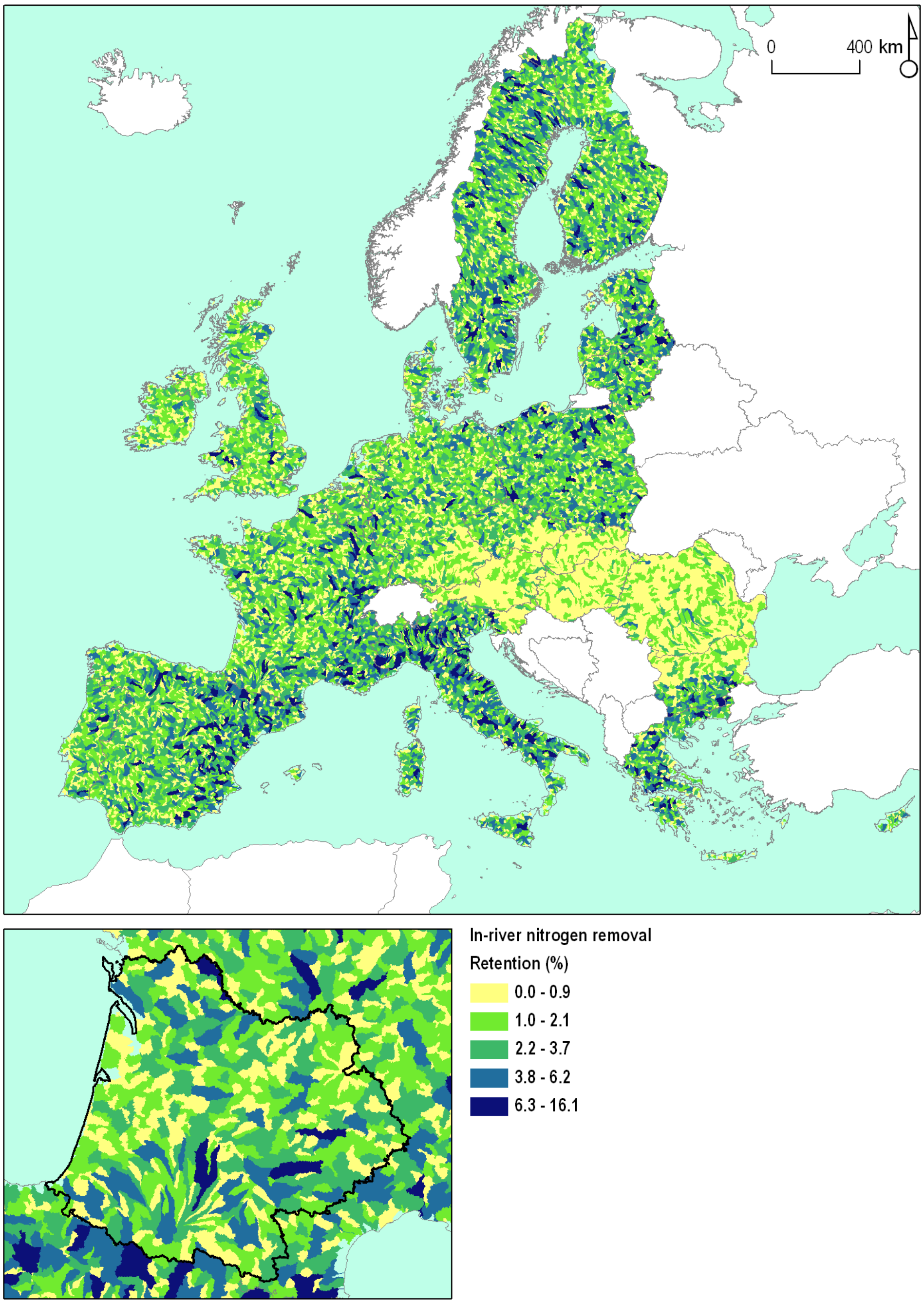

Fig. A6. Nitrogen services by rivers and streams. The maps show the nitrogen retention (%) by retention processes in rivers and large lakes. The map is based on the model GREEN which assesses at European scale the fate and transport of nitrogen (Grizzetti et al. 2005). Europe is sub divided over 30 thousand sub catchments. The resolution of the data is 10 km. The zoom represents the river basin district of the Garonne – Ardour (France)

Regulating services:

Water purification indicated by nitrogen retention and removal (2)

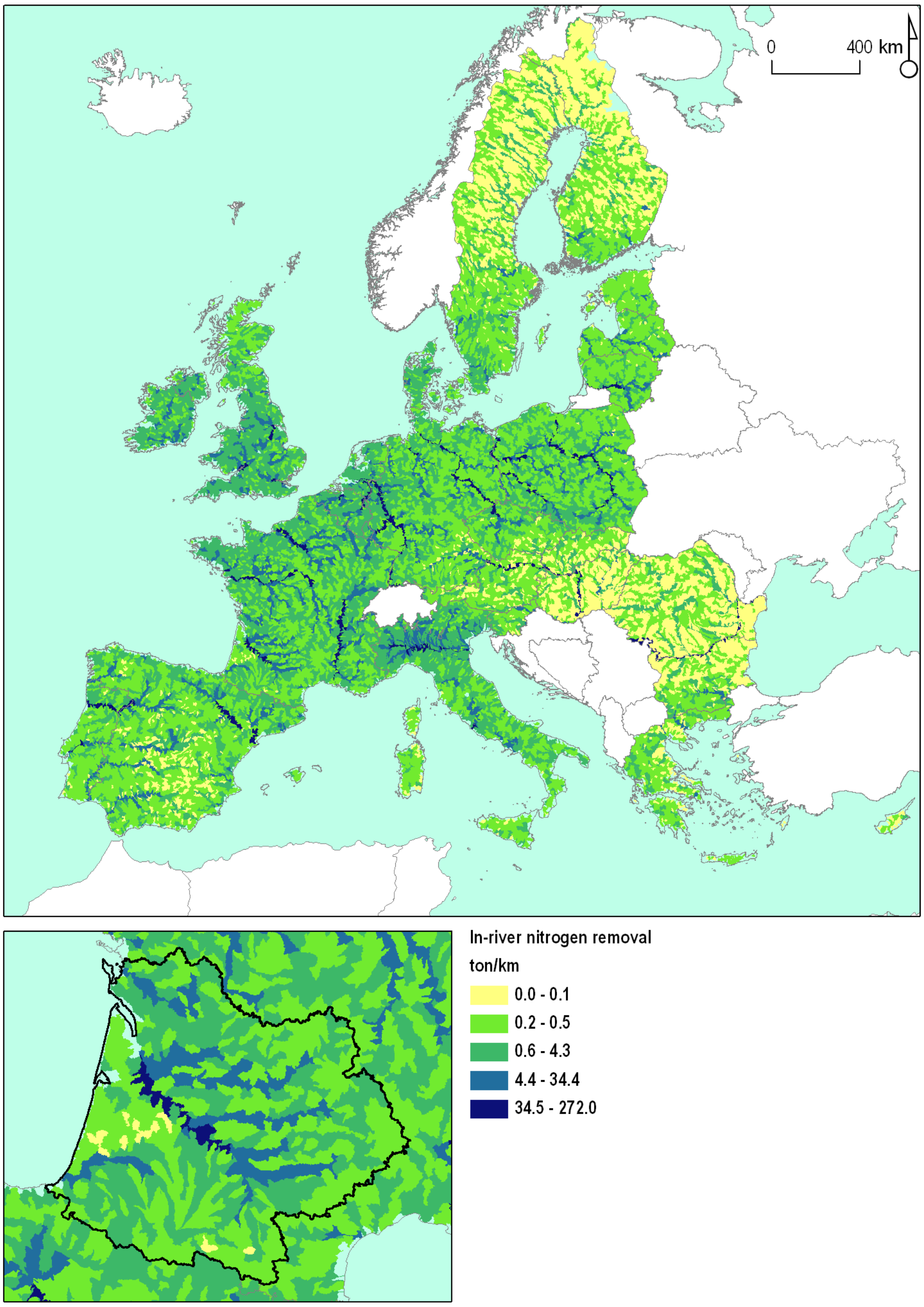

Fig. A7. Nitrogen services by rivers and streams. The maps show the nitrogen removal (ton km^{-1}) by retention processes in rivers and large lakes. The map is based on the model GREEN which assesses at European scale the fate and transport of nitrogen (Grizzetti et al. 2005). Europe is sub divided over 30 thousand sub catchments. The resolution of the data is 10 km. The zoom represents the river basin district of the Garonne – Ardour (France)

Regulating services:

Climate services: Carbon storage and carbon sequestration (1)

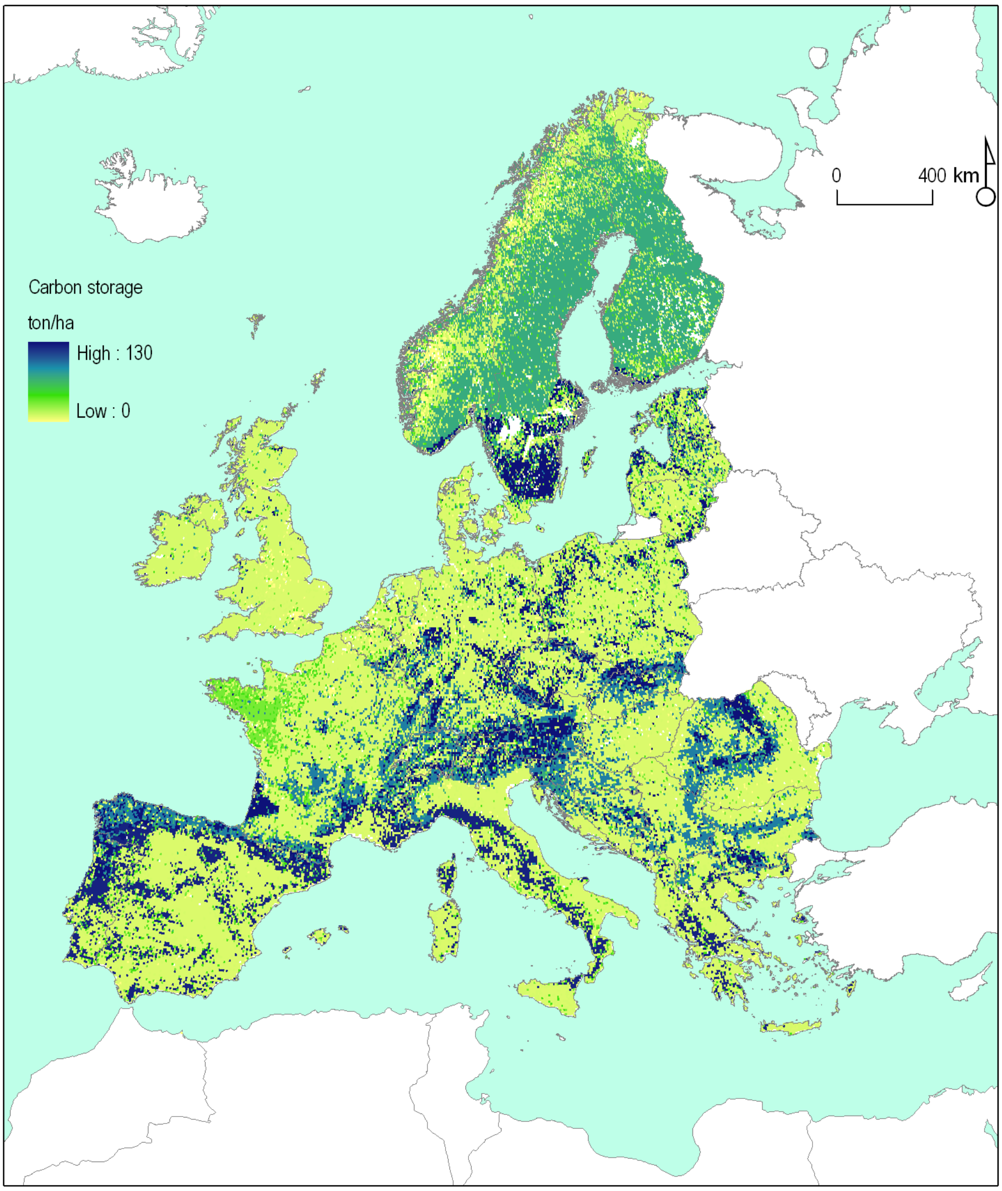

Fig. A8. Estimate of above- and below-ground carbon stored in living plant material. Source: CDIAC and Global land cover data 2000.

Regulating services:

Climate services: Carbon storage and carbon sequestration (2)

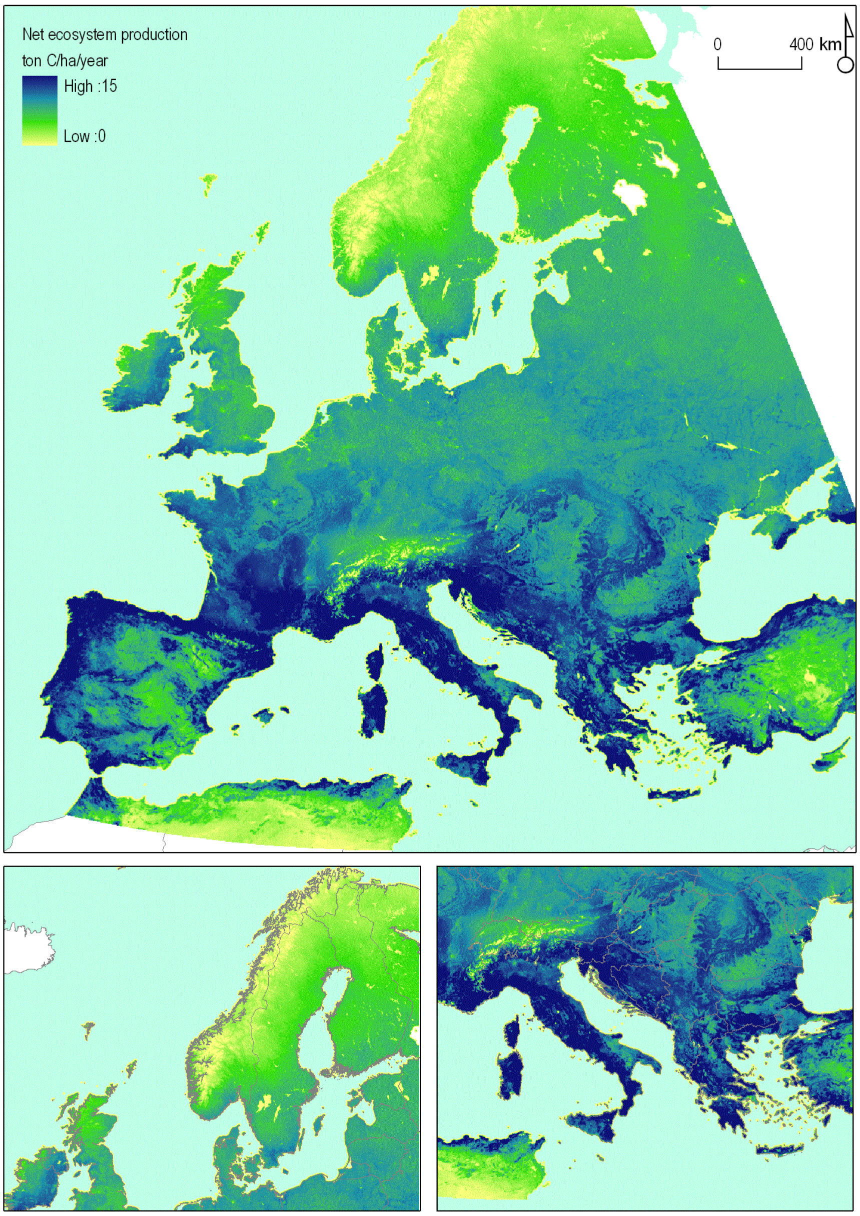

Fig. A9. Carbon fixation approximated by net ecosystem productivity (NEP). The NEP takes into account the soil respiratory flux originating from heterotrophic decomposition of soil organic matter. These carbon fluxes are quantified using the C-Fix model which is a remote sensed-based carbon balance product efficiency model wherein the evolution of the radiation absorption efficiency in the PAR (Photosynthetically Active Radiation) band (or fAPAR) of vegetation is directly inferred from space observations, SPOT-VEGETATION S10 (SPOT VGT S10) images, using the Normalized Difference Vegetation Index (NDVI). Zoom areas: North Europe (left) and the east Mediterranean (right). The resolution is 1/112°. Data source: VITO.

Regulating services:
Air quality services

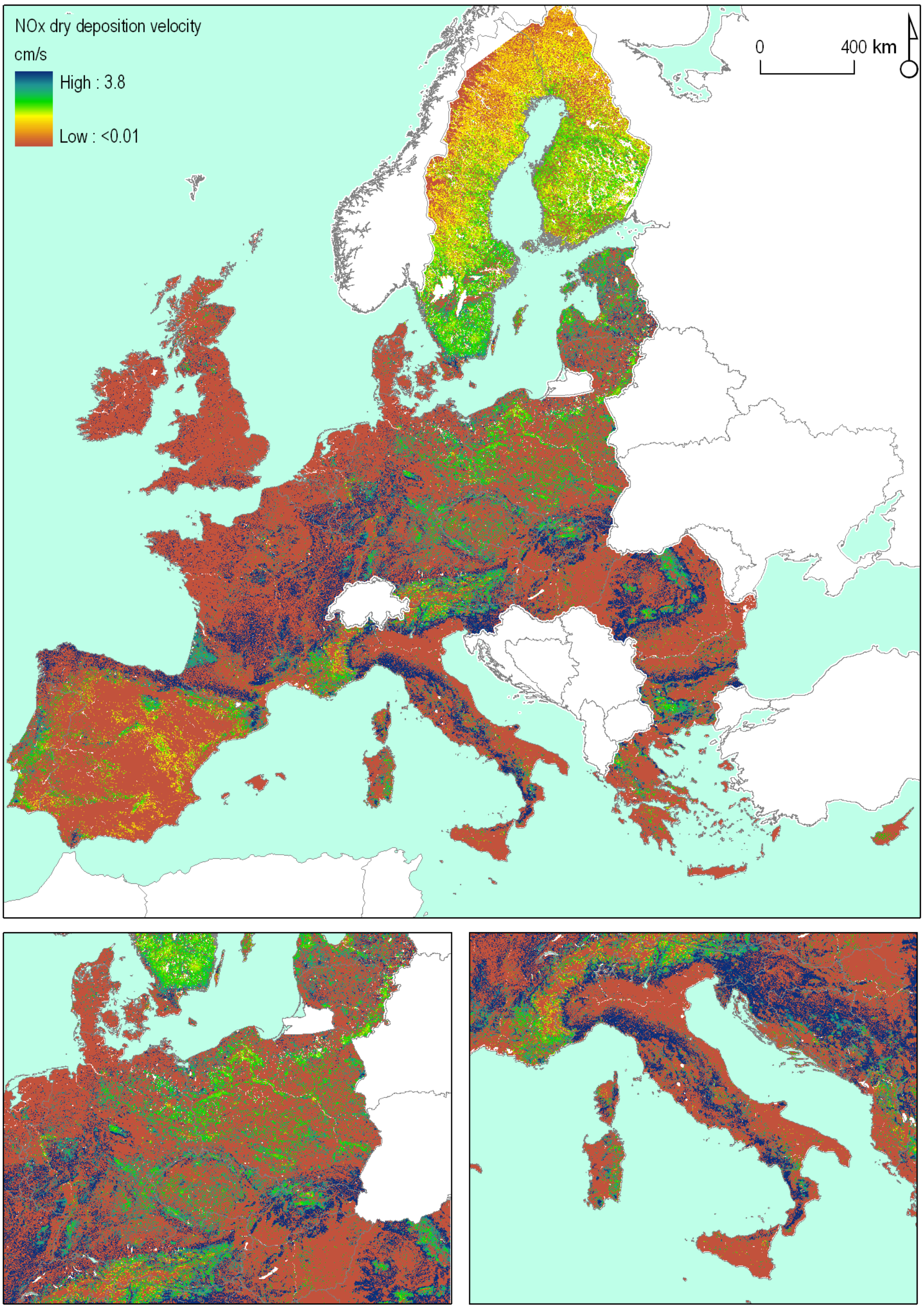

Fig. A10. NOx dry deposition velocity as indicator for the capacity of vegetation to capture and remove air pollutants. Data modeled for the MAPPE model (Pistocchi 2008).

Regulating services:
Erosion control

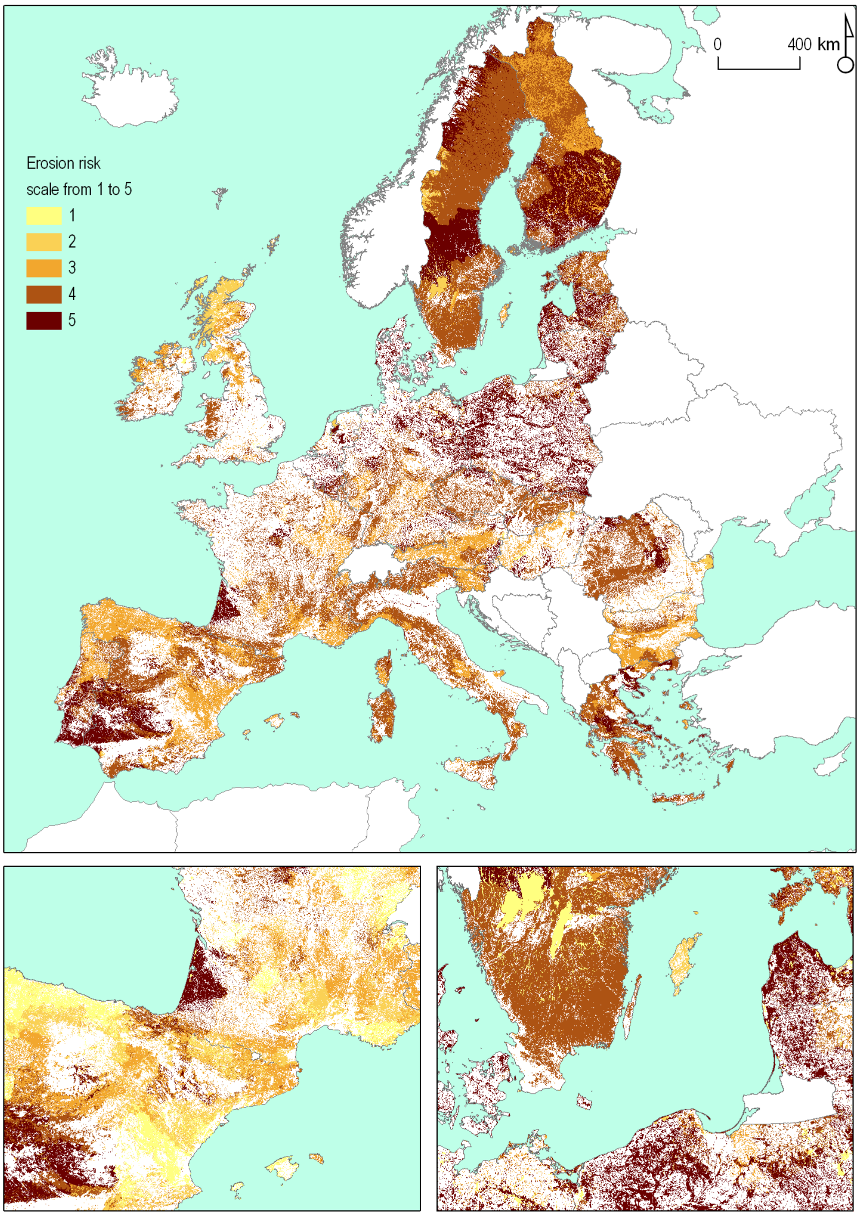

Fig. A11. Erosion control services by forests and ecosystems. This indicator is the result of the overlay of an erosion risk map (using 5 classes of increasing erosion risk, MESALES (Le Bissonais et al. 2002) with a CLC2000 map retaining forests and semi-natural ecosystems. Vegetation present in areas of high erosion risk is given a high relative value. The resolution of the map is 1 km. The zoom areas are North-Spain and South-West France (left) and the Baltic Sea (right). Sources: ESDAC and CLC2000 (EEA).

Regulating services:
Soil quality regulation

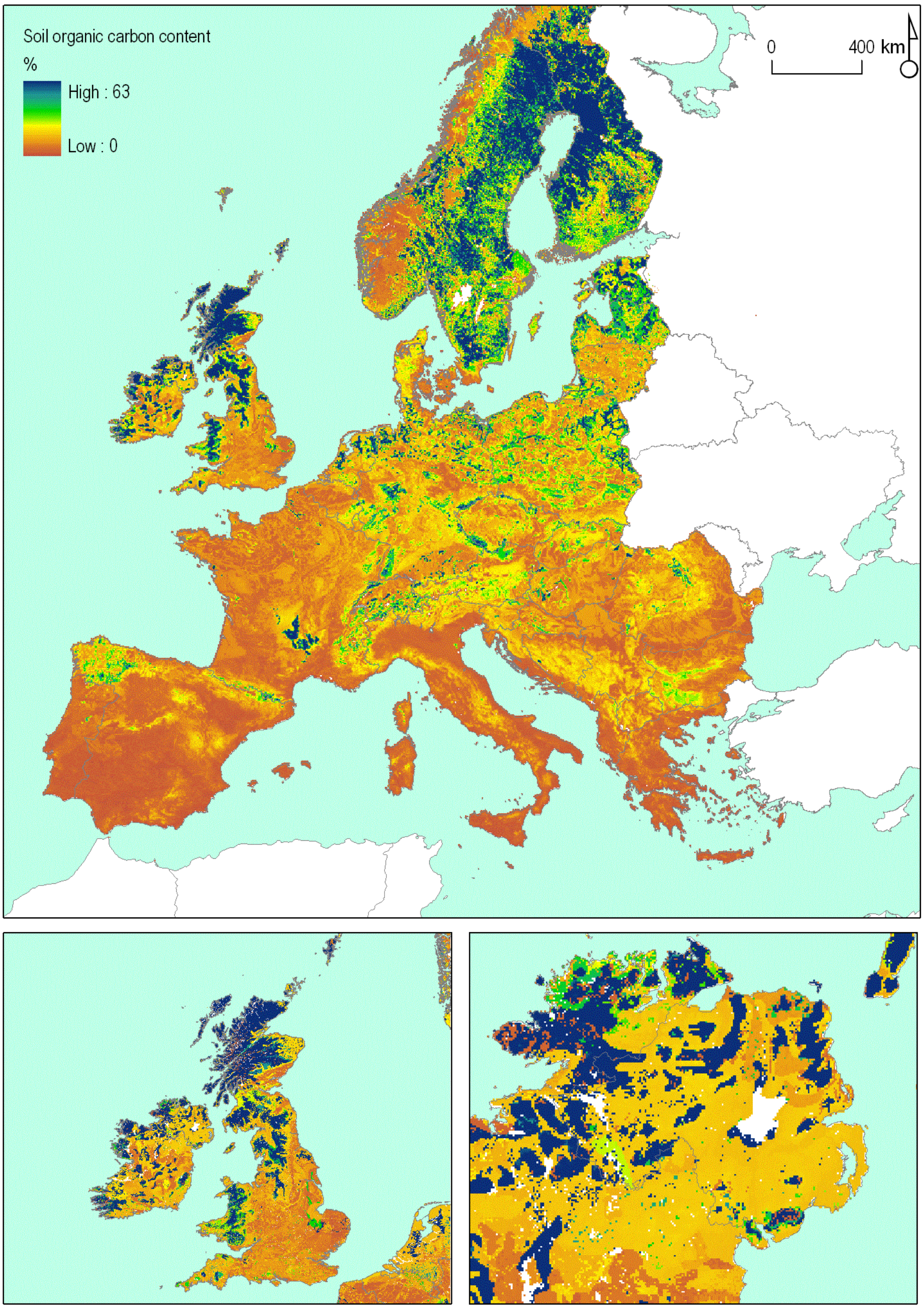

Fig. A12. Topsoil organic carbon content as surrogate for the capacity of ecosystems to maintain the quality of soils. Zoom areas: The UK and Ireland (left) and Northern Ireland (right). Data source: ESDAC.

Regulating services:

Pollination potential

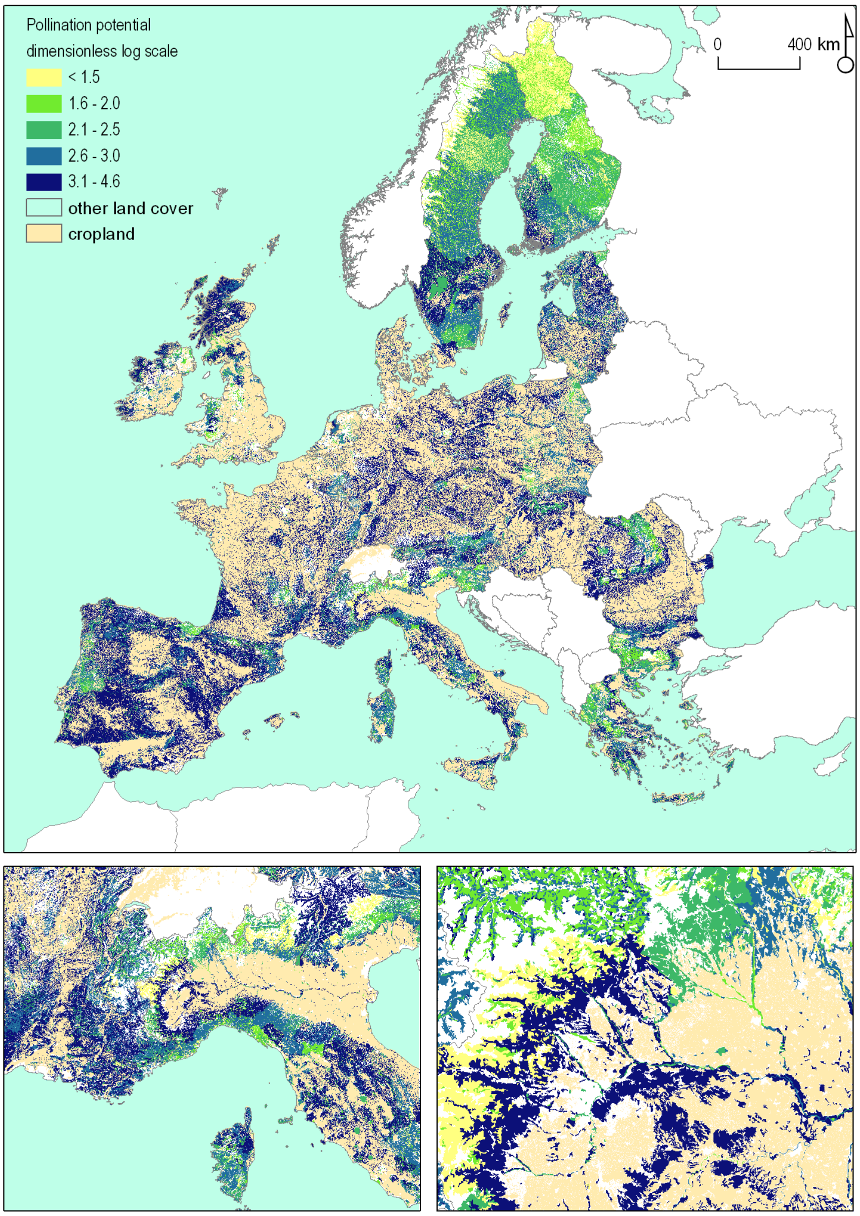

Fig. A13. Pollination potential of ecosystems adjacent to cropland. Crop pollination is modeled for each cropland pixel as the product of crop dependency and visitation rate. Visitation rate is modeled as a function of distance to the nearest land cover pixel representing forest, semi natural area, wetland or inland water body. The pollination potential of ecosystems is then assigned by taking the sum over all the nearest cropland pixels. Spatial data sources: Land use map based on Grizzetti et al. (2007). The resolution is 1 km. Zoom areas: Northern Italy (Left) and the Northern part of Piemonte (right).

Cultural services:

Recreation potential

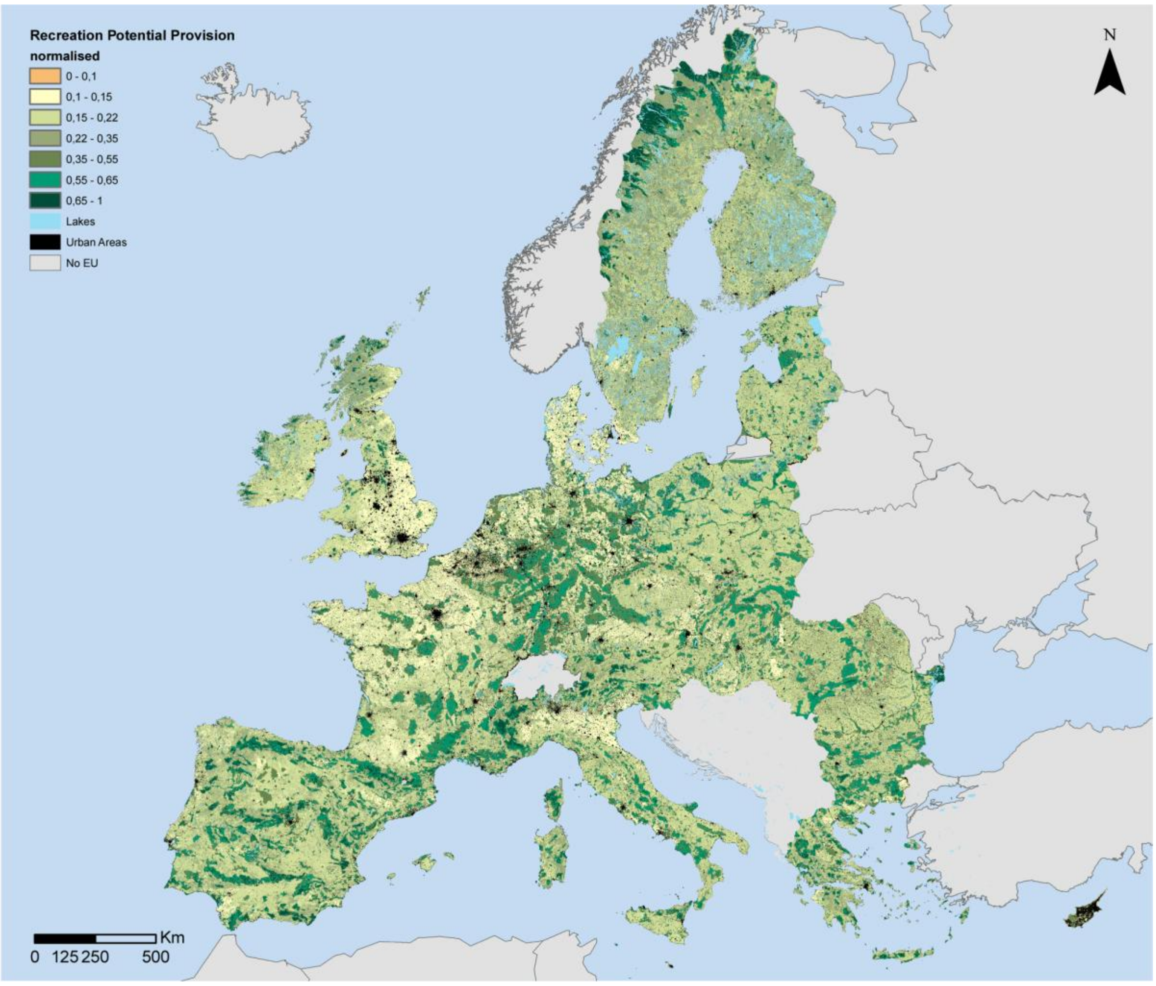

Fig. A14. Recreation potential index (RPI). The RPI is a combined index based on degree of naturalness, presence of protected areas, presence of coastlines (lakes and sea) and quality of bathing water. Data sources: CLC2000, CAPRI model, EEA bathing water quality database, Natura 2000 database and CDDA database.

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Abstract

Until recently, biodiversity policies were essentially driven by conservation of rare and endangered habitats and species. Although substantial efforts have been undertaken to protect nature, the 2010 target of stopping the loss of biodiversity has not been met. New policies at global and European level have therefore complemented conservation based biodiversity targets using the argument of ecosystem services. Ecosystem services are the benefits people receive from nature. So far, data for mapping such services are strongly biased towards provisioning services such as food and timber production while spatial information of so called regulating and cultural ecosystem services is, largely lacking. This report summarizes the key data needed for mapping ecosystem services at a European scale and presented a first set of maps showing the capacity of ecosystems to provide services.

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