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ESTIMAP: A GIS-BASED MODEL TO MAP ECOSYSTEM SERVICES IN THE EUROPEAN UNION

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ABSTRACT – Policies of the European Union which affect the use or protection of natural resources increasingly need spatial data on the supply, the flow and the demand of ecosystem services. The model ESTIMAP was developed to this purpose. ESTIMAP departs from land cover and land use maps to which it adds other spatial information with the objective to map various ecosystem services. This study introduces the ESTIMAP map as tool to support the mapping and modelling of ecosystem services at European scale. Examples are provided for three regulating ecosystem services, air quality regulation, coastal protection, and pollination and one cultural ecosystem services, recreation.

KEYWORDS: ECOSYSTEM SERVICES, MAPPING, EUROPEAN UNION, MODELLING

INTRODUCTION

In 2011 the European Union (EU) adopted the Biodiversity Strategy to 2020 which aims to halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and to restore them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss (European Commission, 2011). The Biodiversity Strategy includes six targets and 20 associated actions. Action 5 of the strategy requires Member States of the EU, with the assistance of the European Commission, to map and assess the state of ecosystems and their services in their national territory by 2014, assess the economic value of such services, and promote the integration of these values into accounting and reporting systems at EU and national level by 2020.

Mapping ecosystem services is becoming key to support decision making processes at different scales and policy levels (Maes et al., 2012; Pagella & Sinclair, 2014). The reason to include it as a special action of the EU Biodiversity Strategy related to need for robust, reliable and comparable spatial information of biodiversity and ecosystem services to help establish Europe's green infrastructure and to prioritize areas for ecological restoration. The latter action explicitly refers to a global biodiversity target, agreed under the new strategic plan of the convention of biological diversity, aiming to restore 15% of degraded ecosystems by 2020. Although Action 5 is formally associated with Target 2 of the EU Biodiversity Strategy, it is clear that its scope goes much further than this and that it underpins the achievement of several other policies. Mapping ecosystem services will also inform the development and implementation of related policies on water, climate, agriculture, forest and regional planning (Crossman et al., 2013).

A large body of research has recently become available to map ecosystem services (Martínez-Harms & Balvanera, 2012; Crossman et al., 2013). Mapping approaches are usually based on simple spreadsheet models linking land cover land use data to the provision of ecosystem services or on the spatial disaggregation of ecological data which may

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serve as proxies for ecosystem services (Maes et al., 2012). Recently, several authors have made proposals to achieve common standards and agreed procedures to operationalize this growing body of knowledge on ecosystem services (Crossman et al., 2013; Pagella & Sinclair, 2014). In addition to simple, proxy based mapping approaches, ecosystem services maps are more and more based on models and decision making tools that particularly address the mapping of multiple ecosystem services, usually with the aim to assess trade-offs that arise from certain decisions. Several tools to support decision making and implementation of the above mentioned policies that affect the use of natural resources are thus becoming increasingly available (Bagstad et al., 2013). Mostly, these models are built on current ecological knowledge of a particular system, for instance on quality and quantity of surface and ground water, on forest succession and carbon, nitrogen and water-cycling.

This paper introduces the Ecosystem Services Mapping tool (ESTIMAP), a collection of spatially explicit models to support the mapping and modelling of ecosystem services at European scale. The main objective of ESTIMAP is to support EU policies with spatial information on where ecosystem services are provided and consumed. The mainstreaming of biodiversity and ecosystem services into EU policy and decision making is indeed dependent on the capacity to assess how changes in policy will impact biodiversity and the supply of ecosystem services (Maes et al., 2013). A recent application of ESTIMAP supported the EU Cohesion Policy to help assess how budget allocations to European regions affect land use and ecosystem services (Batista E Silva et al., 2013). Land use is a key component for all models, which are designed to fit a scenario assessment approach using 2006 as a baseline. Hereto, ESTIMAP is dynamically integrated with a land use change model (Lavalle et al., 2011; Batista E Silva et al., 2013).

The remainder of the paper is structured as follows. Firstly, the design of ESTIMAP is briefly introduced. Next, we give examples of the kind of output the model produces. Finally, further developments and limitations of ESTIMAP are discussed.

Materials and Methods

Model design

The main goal of ESTIMAP is to provide an integrated assessment of the capacity of ecosystems to deliver ecosystem services with standardized output formats. It is developed in order to fit the continental scale to support European policies which impact on natural resources.

ESTIMAP is based on the ecosystem services cascade framework (Haines-Young & Potschin, 2010), which is used as a frame for mapping (Maes et al., 2012). This model links ecosystems in a stepwise manner to human wellbeing through the flow of ecosystem services. Ecosystems provide the necessary structures and processes that underpin ecosystem functions which are defined as the capacity or the potential to deliver services. Ecosystem services are derived from ecosystem functions and represent the realized or actual flow of services in relation to the benefits and values of people. Following the cascade model, ESTIMAP thus assesses the supply of ecosystem services, which refers to the potential or capacity to provide services as well as the demand for ecosystem services, which is the sum of all services that is used or consumed (Burkhard et al., 2012).

At present, ESTIMAP includes four complete models: outdoor recreation (Maes et al., 2011; Paracchini et al., 2014), crop pollination (Zulian et al., 2013a), coastal protection (Liquete et al., 2013) and air quality regulation. Several other modules are in development. Table 1 describes the main outputs of all the current models with output format and units of measure. Each model includes at least one supply and one demand indicator. ESTIMAP covers the EU-28 using a 1 ha model resolution, which is the mapping unit of the land use data. The outputs can be visualised using the original model resolution or they can be aggregated at any desired mapping unit (e.g., socio-economic areas, river basins, grids), to respond to the need of different stakeholders (Hein et al., 2006; de Groot et al., 2010). Hereafter, we briefly describe the models that are completed.

Outdoor recreation

Recreation, as an ecosystem service, refers to public, local, nature-based, outdoor recreational activities, which include a wide variety of practices ranging from walking, jogging or running in the closest green urban area or at the river/lake/sea shore, bike riding in nature, picnicking, observing flora and fauna, organizing a daily trip to enjoy the surrounding beauties of the landscape, among a myriad of other possibilities. These activities have an important role on human well-being and health, since they provide physical, aesthetic and cultural benefits and offer an opportunity to experience directly a relationship with nature. In addition, fruition of nature-based recreational activities may induce people's support for ecosystem protection.

ESTIMAP results in three indicators that can be used for a European assessment of nature-based recreation: the Recreation Potential (RP), the Recreation Opportunity Spectrum (ROS), and the share of the population that can potentially profit from nearby nature for recreation purposes.

Table 1. Currently available modules of ESTIMAP with their respective indicators, units and output formats.

Module	Supply or demand	Indicator	Units	Output format
Pollination	Supply	Relative Pollinator abundance (RPA)	Dimensionless indicator	Raster map
	Demand	Crop production deficit	Share of total production (%)	Statistics
		Pollination gap in the landscape	Share of cropland not covered by RPA (%)	Raster map and Statistics
Recreation	Supply	Recreation potential (RP)	Dimensionless indicator	Raster map
	Demand	Recreation Opportunity Spectrum (ROS)	Categories based on RP and proximity	Raster map
		Potential trips	Share of the population which has access to ROS classes (%)	Statistics
Air quality regulation	Supply	Removal of pollutants by urban vegetation	ton NO_2 ha-^{1} year-^{1}	Raster map and Statistics
	Demand	Population exposure to threshold pollutant concentration	Share of the population exposed to different levels of NO_2 (%)	Statistic
Coastal Protection	Supply	Coastal protection capacity Coastal protection exposure	Categorical indicator	Raster map
	Demand	Costal protection demand		

The RP is a composite model which estimates the capacity of sites to provide recreation services based on their naturalness, level of protection and distance to lakes or the sea. The ROS is a cross-tabulating model which overlays the RP to a proximity index. These two indicators are used to derive the third one through a zonal assessment. Parameters and scores were derived from national surveys, literature review and expert consultation. A full description of the model can be found in Zulian et al. (2013b).

Crop pollination

Pollination refers to the role ecosystems play in transferring pollen between flower parts. Pollination by insects is a key ecosystem service for many cultivated species of fruits, vegetables, seeds and herbs, which benefit from, or depend on insects to produce food for human consumption.

ESTIMAP considers one indicator to map supply and two indicators to map demand for pollination services by wild insects. Supply is expressed using an index of relative pollination potential (RPP), which is defined as the relative capacity of ecosystems to support crop pollination. The RPP is a composite mapping model based on the assumption that different habitats, but in particular forest edges, grasslands rich in flowers and riparian areas, offer suitable sites for wild pollinator insects. Insects' accessibility to these sites is estimated using the typical foraging range of wild solitary bees.

The demand side is estimated linking the RPP to regional statistics of crop production. This highlights where in the landscape pollination gaps occur and how these gaps accumulate to a regional crop production deficit, defined as the reduction in crop production in absence of animal pollination. Parameters and scores were derived from literature review and expert consultation. A full description of the model can be found in Zulian et al. (2013a).

Coastal protection

Coastal protection is defined as the natural defence of the coastal zone against inundation and erosion from waves, storms or sea level rise. In the same context, protection refers

to the physical defence of any asset present in the coastal zone (e.g. property, people) (Liquete et al., 2013).
ESTIMAP assesses coastal protection using three indicators. The supply indicator is the capacity of coastal ecosystems to protect the coast against inundation or erosion. This is based on geological and ecological characteristics including the morphology of the coast and the ecosystem type. A second indicator is the natural exposure of the coastal zone which refers to the predicted need for coastal protection based on the climatic and oceanographic conditions of each area. A third indicator assesses the human demand for coastal protection which is the estimated necessity of protection of the coastal populations based on the presence of residents and assets in the coastal zone. Parameters and scores were derived from literature review and expert consultation. A full description of the model can be found in Liquete et al. (2013).

Air quality regulation

Air quality regulation refers to the influence of ecosystems on air quality by emitting chemicals to the atmosphere or by removing chemicals from the atmosphere. In particular urban trees are known to capture particular matter and other others air pollutants and thus provide air quality regulation services (Nowak et al., 2006; Manes et al., 2012a; Manes et al., 2014). ESTIMAP uses NO_2 as a common indicator for air quality and calculates the annual NO_2 concentration of pollutants, according to the model provided by (Beelen et al., 2009). The concentration map is derived from a regression mapping exercise linking the concentration of air pollutants derived from European databases (maintained by the European Environment Agency and the European Monitoring and Evaluation Programme) to a list of spatial predictors. Based on this concentration map, ESTIMAP subsequently estimates two indicators for air quality regulation in Europe's large urban zones (Dijkstra & Poelman, 2012): the removal of NO_2 by urban vegetation and the exposure of urban population to threshold concentrations of NO_2. NO_2 removal is calculated by multiplying the deposition velocity of NO_2 on green urban areas with the resultant NO_2 concentration map.

Results and discussion

ESTIMAP is mainly developed to assess how changes in policies which affect land use have an impact on the supply and demand of ecosystem services. For the purpose of this paper, only the baseline situation is mapped. The reference year for ESTIMAP is 2006 which means that all input data to assess ecosystem services refer to this year. Note that the latest version of the Corine Land Cover dataset is also available for 2006. This dataset constitutes a major input to all ecosystem services modules of ESTIMAP.
Indicators for the supply of four ecosystem services, pollination, recreation, air quality regulation and coastal protection, were mapped at regional level for the EU-28. They can be used to compare the provision capacity of ecosystem services across Europe.
Air quality regulation considered the removal of NO_2 by vegetation in large urban zones in the EU. Figure 1 presents the average annual NO_2 removal per unit surface area of large urban zones at regional scale in the EU. The maps results in a patchy distribution caused by the interplay between the total surface size of urban vegetation and the ambient concentration of NO_2. Regions with high values for this surface have typically urban zones which are to a large extent covered by vegetation. This is particularly evident in Scandinavia. The strong linkage between green urban areas and human health warrants the future inclusion of other pollutants to ESTIMAP which are important determinants of air quality such as ozone and particulate matter. An important observation is that not only the quantity of urban green but also the composition of urban tree communities defines air pollutant removal capacities (Manes et al., 2012b).

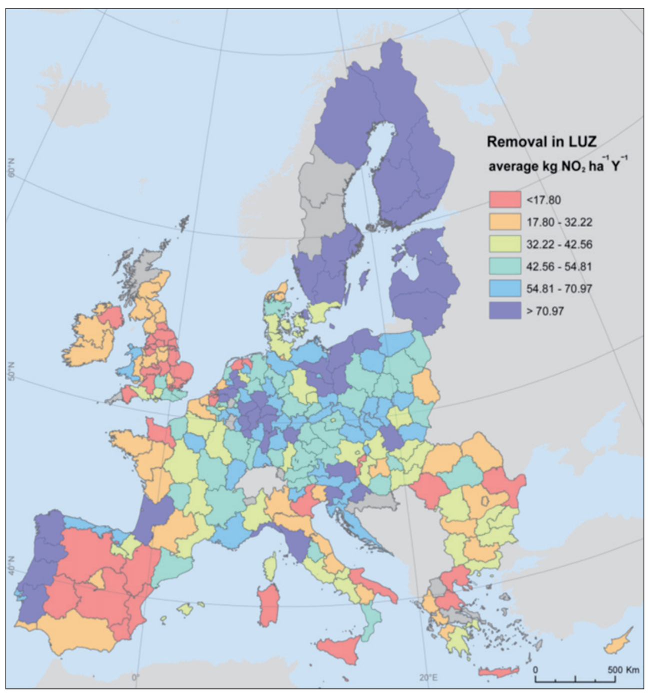

Figure 1. Air quality regulation service. The average annual NO_2 removal per ha in large urban zones (LUZ) estimated by ESTIMAP in the EU at the NUTS 2 level.

Clearly, such knowledge needs to be included to support urban planning.

Coastal protection capacity is mainly driven by geomorphology of the coastline, but also by the presence of certain habitats whose physical structure may disrupt water movements or adapt their form to it such as dunes and shallow wetlands along the coast. Low capacity is present in regions that border the north east Atlantic coastline as well as in regions along the northern part of the Adriatic Sea (Figure 2). These are regions where additional, man-made coastal protection is needed to protect populations and infrastructure. Typically, these regions are characterized by a high population density, which is linked to an increased pressure on the remaining ecosystems which act as natural defence against flooding. A next step is therefore to better value the contribution of these coastal habitats in delivering protection.

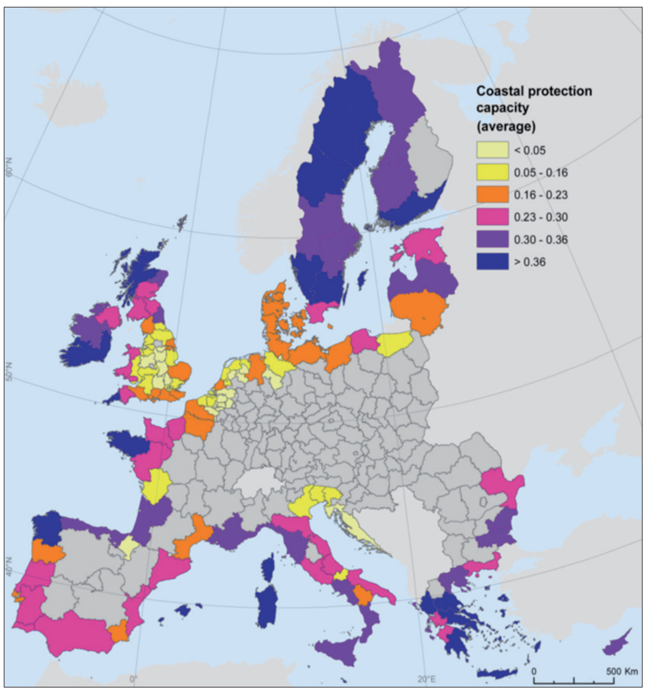

Figure 2. Coastal protection service. Average coastal protection capacity (dimensionless indicator between 0 and 1) estimated by ESTIMAP in the EU at the NUTS 2 level.

Pollination services, measured by relative pollination potential based on a generic model species with short foraging distance, increased along a gradient from north to south, mainly as a result of the influence of climate on the activity of pollinators (Figure 3). However, given the climate, regions with a predominantly intensive agriculture, had a lower potential than regions where agricultural landscapes are characterized by patchy distributions of woodland and semi-natural areas. ESTIMAP links pollination potential to crop production which makes the model useful to help identify areas where wild pollinators supply may not be sufficient to meet crop demands.

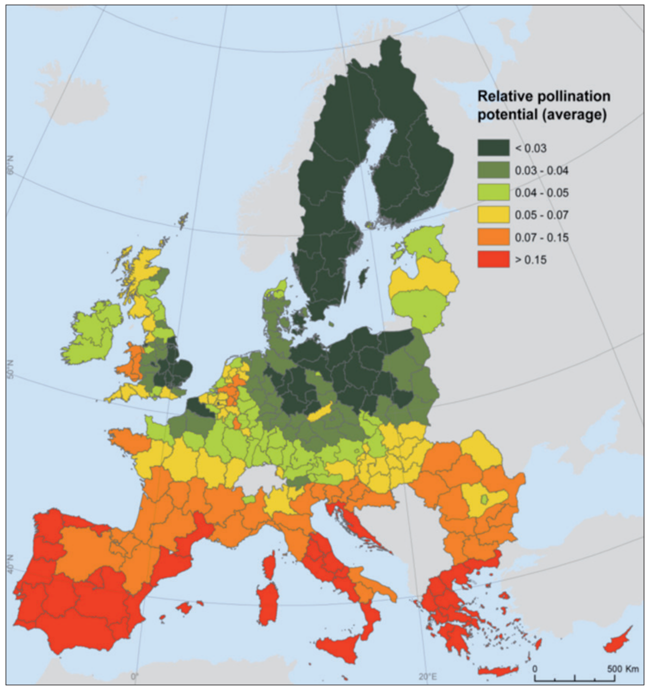

Figure 3. Pollination service. Average relative pollination potential (dimensionless indicator between 0 and 1) estimated by ESTIMAP in the EU at the NUTS 2 level.

Recreation potential, as modelled in ESTIMAP, has a patchy distribution across Europe. Figure 4 maps the capacity of ecosystems to support nature-based recreation. It is mainly determined by the naturalness of the landscape and the presence of the natural protected areas. This explains the high values for regions in Germany, a country which has a very dense network of relatively small protected areas. Regions where most of their land is converted to urban or agricultural land use score lower values. Further applications of the recreation model foresee assisting urban planning so as to appreciate better the role of green urban areas and nearby protected areas in delivering cultural ecosystem services.

Several more modules of ESTIMAP are under development. Further work includes the following ecosystem services: erosion control, water provision, water regulation, the extension of the air quality regulation module with other air pollutants, the extension to other cultural ecosystem services, and ecosystem services which rely directly on species diversity and abundance such as biological control, wild food provision, and or bird watching. Including more services allows examining trade-offs between ecosystem services that are the result of changes in land management (Raudsepp-Hearne et al., 2010).

In addition to these developments, further work will focus on handling uncertainty that is associated with ecosystem services maps produced by ESTIMAP. Particular interest goes to comparing outputs of ESTIMAP with local and regional assessment, which can often rely on more accurate input data or measurements (Dick et al., 2014), and to testing the flexibility of ESTIMAP models when applied to local and regional scales.

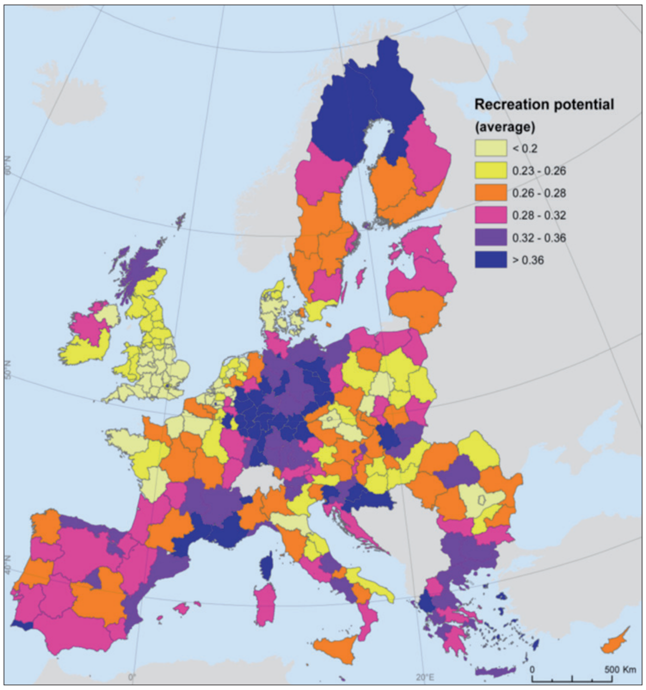

Figure 4. Recreation service. Average recreation potential (dimensionless indicator between 0 and 1) estimated by ESTIMAP in the EU at the NUTS 2 level.

CONCLUSIONS

Mainstreaming ecosystem services in EU decision making processes requires a solid conceptual and methodological framework for mapping and assessing ecosystem services that serve the multiple objectives addressed by policies. In particular, the EU Biodiversity Strategy to 2020 includes a target on ecosystem services. The inclusion of ecosystem services into biodiversity policies increased the demand for demonstrating the value of natural capital in order to justify investments in biodiversity protection. ESTIMAP provides a response to this call and aims to operationalize standardized European on land cover, land use, biodiversity, and other environmental variables to estimate biophysical flows of ecosystem services and their associated benefits. This paper is the first to report on the development and first outcomes of this pan-European model and may therefore act as a reference for further work and citations.

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