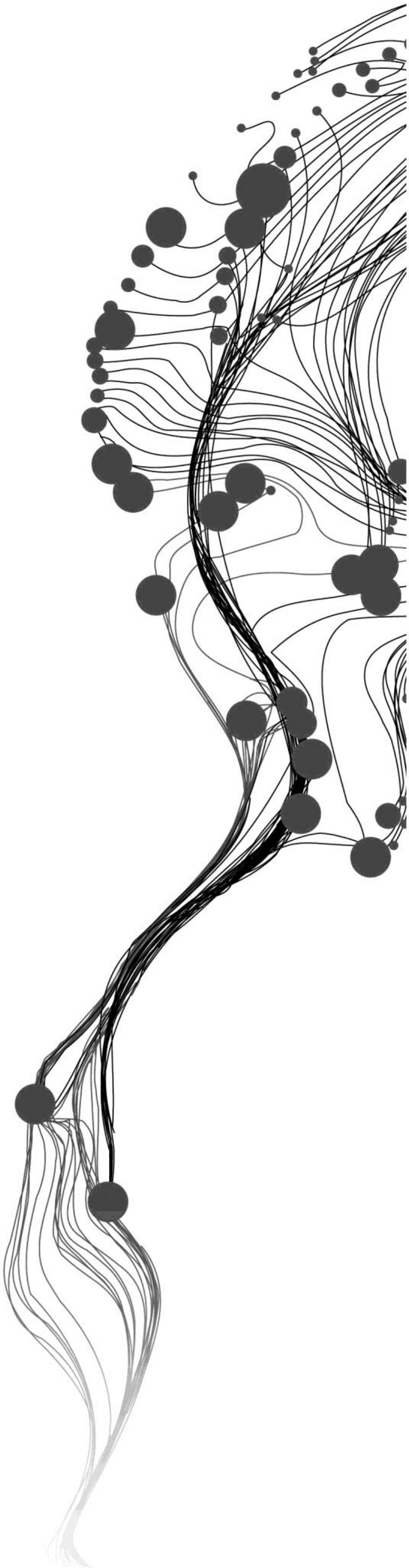
USE AND USER-CENTRED DESIGN OF ECOSYSTEM SERVICES MAPS

VENUS LORENA ROCHA GUTIERREZ
February, 2019

SUPERVISORS:
Dr. E. Drakou
Dr. C.P.J.M. van Elzakker



USE AN USER-CENTRED DESIGN OF ECOSYSTEM SERVICES MAPS

VENUS LORENA ROCHA GUTIERREZ
Enschede, The Netherlands, February, 2019

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfillment of the requirements for the degree of Master of Science in Geo-Information Science and Earth Observation.
Specialization: Geoinformatics

SUPERVISORS:
Dr. E. Drakou
Dr. C.P.J.M. van Elzakker

THESIS ASSESSMENT BOARD:
Prof. dr. Menno-Jan Kraak
Dr. Ir. C.J.E. Schulp; Vrije University of Amsterdam, Faculty of Science, Environmental Geography

ABSTRACT

This research proposes the design of ES maps using the User-Centred Design approach, to facilitate the communication of ES information to the decision-making process. In addition, it provides guidelines for map-makers, that can help improve their future use and inclusion in the decision-making process. The focus will be on the implementation of the second and the third stage of the User-Centred Design (UCD) approach, called "Produce design solutions" and "Usability evaluation" respectively. The process begins with the analysis of the information provided by the first stage of UCD executed by (Rühringer, 2018). This information will be the basic data for the design a set of preliminary solutions and subsequently in the definition of the testing methods, type of participants and the strategy of implementation of the usability test. In the second stage, the case study selection, type of improvements and map elements were defined based on the requirement analysis. As a result of the map design process, a set of three prototype maps at the national, sub-national and EU level were created. These set of maps were tested on the third stage "usability evaluation" of the UCD approach. This evaluation focused on knowing the use and design issues of the ES maps. To gain insight into the information displayed in the ES prototype maps and to know how effective was the visual representation, a set of geographic questions were conducted. The TPs of this usability evaluation were representative users identified as current or potential users or/and map-makers that belong to Europe and work with Ecosystem Services or take decisions regarding these of maps. As a result of the usability evaluation, the design and use issues were identified and based on this information the ES prototype maps were improved to obtain a suitable design of ES maps that satisfied the user requirements. Finally based on the improvements and the maps design process followed for ES maps a guideline for map makers was provided.

Keywords: Ecosystem Services, maps, usability research, User-Centred Design.1

ACKNOWLEDGMENTS

This research would not be possible without the support and help from my family and friends.

I would like to express my greatest gratitude to my first supervisor Dr. E. Drakou, for her guidance in my research, their patience, enthusiasm and help me to manage to finalized this thesis.

Also, thank you to my second supervisor Dr. C.P.J.M. van Elzakker, for helping me solve the technical problems I encountered through the development of my research and his valuable time.

I would like to express my greatest gratitude to the authors for their contribution to this thesis, for sharing their data to be used as examples of this research.

My sincere thanks to my Friends in especial to Felipe and Paola who supported me on this thesis.

I am forever grateful to my beloved family - my mother, my aunts, my sister and nephew for trusting, supporting and inspiring me as always.

In memory of Isabel, "Mi Guerrera".

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CICES Common International Classification of Ecosystem Services
IPBES Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
DG Directorate General
MA Millennium Ecosystem Assessment
MAES Mapping and Assessment of Ecosystems and their Services
NCP Nature's Contributions to People
TEEB The Economics of Ecosystems and Biodiversity
UCD User-Centred Design
MEA Millennium Ecosystem Assessment and updated
TEEB The Economics of Ecosystems and Biodiversity
FEGS-CS The Final Ecosystem Good and Services Classification
NCP Nature Contributions to People
NESCS National Ecosystem Services Classification System

1. INTRODUCTION

1.1. Motivation and problem statement

Ecosystem Services maps are used to analyze and communicate related spatial information, evaluate the state of ecosystems and support decision-making concerning biodiversity management and spatial planning (Crossman et al., 2013; Hauck et al., 2013; Malinga, Gordon, Jewitt, & Lindborg, 2015). To understand the importance of these maps and the challenges coming along with them, it is first necessary to introduce the concepts of Ecosystem Services.

Ecosystem Services (ES) are the benefits people obtain directly or indirectly from the ecosystems (Maes et al., 2012; Millennium Ecosystem Assessment, 2005), which have high importance for the survival and socio-economic development of the humanity (Fitter et al., 2010). According to the Common International Classification of Ecosystem Services (CICES) V5.1 (Haines-Young & Potschin, 2018), the ES are categorized in provisioning, regulating and maintenance and cultural services. Provisioning services are the products obtained from ecosystems such as food, energy, water, etc. Regulating and maintenance services are the benefits derived from the regulation of ecosystem processes such as climate regulation, pollination, air quality regulation and maintenance of life cycles of migratory species. Cultural services are the non-material benefits that people receive from ecosystems such as recreation and tourism (De Groot, Fisher, & Christie, 2010; Haines-Young & Potschin, 2018).

Over the past 50 years, the human impact on ecosystems and their biodiversity has increased and this is affecting the flow of ES to society (Fitter et al., 2010; MEA, 2005). An example of this situation is the increase of species extinction rates, the overexploitation of natural resources and the expansion of cultivated land at the expense of natural habitats. Additionally, the state of biodiversity has been affected by among others, the introduction of non-native species, pollution, climate change and over-harvesting (Burkhard & Maes, 2017). Consequently, these have resulted in the degradation of the capability of ecosystems to provide Ecosystem Services, which diminishes the prospects for sustainable development and increases the vulnerability of society's individuals, communities and nations (Rashid, Robert, & Scholes, 2005).

Nowadays, the concept of ES is widely discussed in scientific and environmental debates, because it can be considered as a suitable instrument for the implementation of the idea of sustainable preservation of natural resources (Grunewald & Bastian, 2015). Their inclusion into policy and decision making depends on the availability of spatially explicit information on the condition and tendency of ecosystems and their services, across different spatial and temporal scales. The European Union's (EU) Biodiversity Strategy to 2020 addresses the need to consider ES in decision making by means of biophysical mapping and its valuation (Maes et al., 2012). Through Action 5 of this strategy, the aim is to "improve knowledge of ecosystems and their services in the EU". To reach that aim it is required that Member States of the EU, map and assess the state of ecosystems and their services at national level by 2014 to assess the economic value of such services and integrate these values into accounting and reporting at EU and national level by 2020 (European Commission, 2011). Through ambitious research, the EU recognizes the high potential of mapping ES for policy support and decision making (Drakou et al., 2015; Maes et al., 2012; Wolff, Schulp, & Verburg, 2015).

The changes in flow, potential, demand, capacity and benefits that ES deliver, the variations of the ecosystems through time, and, additionally, the congruence between ES and conservation objectives can be usually represented performing ES mapping processes (Crossman et al., 2013; Malinga et al., 2015). Other procedures such as modeling tools can assess trade-offs and scenarios for multiple services. The supply-demand budgets cannot only be calculated but also mapped, and also bundles of ES or synergies can be assessed and mapped (Kruse, 2017).

Mapping of ES is known as an important step in the implementation of the ES, as a powerful tool to visualize, analyse and quantify complex phenomena that emerge from the human-nature interactions (Drakou et al., 2015). The purpose is to identify according to specific mapping objectives, type of study needs and the geographic or political scale of mapping, patterns of human activities over time and space but most importantly the capacities of different ecosystems to provide ES under changes of ecosystem use. Additionally, ES mapping can identify the location of the demand for these services, or the state of the ecosystems' condition to help prioritize where management interventions, e.g. green infrastructure could be implemented or where degraded ecosystems can be restored (Burkhard, Kroll, Nedkov, & Müller, 2012; Drakou et al., 2015; Maes et al., 2018; Nahuelhual et al., 2015).

There are a variety of methods or approaches for ES mapping, which are applied to all service categories (regulating, provisioning and cultural) to assess and visualize their flow, supply, and demand (Burkhard & Maes, 2017; Crossman et al., 2013). According to Burkhard et al. (2017), the use of GIS tools for ES mapping can be divided into the following approaches; 1. Analysis tools, 2. Biophysical Models for ES, 3. Advance models. This results in a broad range of types of maps with different levels of complexity addressing different needs (Drakou et al., 2015; Nahuelhual et al., 2015). This variety of methods, approaches and desired outputs generates challenges for the map makers, who have the responsibility to design well-constructed maps. For instance, some of the most common challenges faced in the use of ES maps by Palomo et al. (2018) and by Drakou, Kermagoret, et al. (2017), were the poor communication between map makers and map users, the differences in the use and understanding of ES concepts, their classification and terminology and insufficient skills and background of the people involved in the mapping process. Additional challenges are some other difficulties associated with the data such as the low availability of accurate and suitable spatial data, problems to find the adequate method to mapping ES, and an over-simplification of the outputs, among others.

These challenges limit the opportunities of use of ES maps, which leads to work and effort invested in the process of production is lost. To solve this, it is necessary to address some of these problems and propose solutions to make these maps more simple and easy to use, to incorporate scientific knowledge into decision-making (Burkhard & Maes, 2017; Drakou et al., 2017; Ruckelshaus et al., 2015). Thus, the focus of this research is to assess the use of ES maps and to use a User-Centred Design (UCD) approach to propose solutions, in order to address some of the difficulties mentioned above. UCD is a methodology that allows the mapping process to be focused on the users and keep their participation active during all stages of map production (Ioannis Delikostidis, 2011; Haklay, 2010; van Elzakker & Wetlands, 2007). This research will be based on the application of this approach, which consists of three stages. The first starts by identifying the user requirements and then during the second and third stage the design solutions are developed and evaluated. This process is repeated until the design will satisfy the user's needs (Schobesberger, 2010).

This research will concentrate on developing the second and third stage of the UCD approach, as the first stage (requirement analysis) has already been executed by Rühringer, (2018). The design and production of a selection of ES maps will be based on her elaboration of user requirements and recommendations. Thereafter, the resulting ES prototype maps (set of cartographic maps of Ecosystem Services) will be evaluated by different map users in a couple of iterative steps. Based on the outputs of these analyses, guidelines will be proposed to help the map makers to create suitable ES maps, ultimately aiming to improve their use in the decision-making process.

1.2. Innovation aimed at

Ecosystem services mapping has been addressed, through a large variety of research and studies on mapping processes, current mapping practices, benefits and the challenges of Ecosystem Services maps, only a limited amount has employed User-Centred Design to involve the user and improves the map outcomes for ES but neither has developed guidelines to support the visualisation design of this kind of maps. Given that, this research on the use of ES maps using a User-Centred Design approach is likely to be the first of its kind that proposes ES map designs based on user needs and evaluate them in terms of effectiveness, efficiency, and satisfaction, resulting into guidelines for designing ES maps. The outcomes of this research are intended to provide map-makers support to make maps more complete, understandable and easy to use by the users at different administrative levels of European Union countries.

1.3. Objectives and research questions

The main objective of this thesis research is to propose a design of cartographic map(s) of Ecosystem Services (ES) that satisfies the user requirements making use of the User-Centred Design (UCD) approach and to produce guidelines for map makers, that can help to improve the future use of ES maps and their inclusion in the decision-making process. The sub-objectives with the related research questions that have to be addressed to achieve the main objective are defined below:

i. To design prototypes of a set of Ecosystem Services maps that meet the user requirements.

   a) How can the map design recommendations, derived from the first stage of UCD executed by Rühringer (2018) help to determine types of improvements and methods to implement on the conceptual design of prototype ES maps, in order to accomplish the user needs?

   b) Which process can be applied to create understandable and usable ES maps, so that they can be used as support into scientific research and decision-making processes?

   c) What design characteristics can be improved to produce ES maps that can answer the geographic questions of the map users and accomplish the user needs and purpose?

ii. To determine use and design issues of the set of prototype Ecosystem Services maps, assessing the maps against their requirements, in order to be able to redesign and improve the prototypes.

   a) Which use and design issues can be identified in the proposed set of prototype ES maps?

   b) What types of difficulties do the users encounter when they try to carry out tasks with the set of prototype ES maps?

iii. To produce guidelines on the procedures and design elements associated with the final design of Ecosystem Services maps, that can help the map makers to enhance their outcomes and to support the use of these maps by users in their decision making

   a) Which procedures can be followed to achieve an ES map that accomplishes the user needs? And what are the steps to follow?
   b) How can the guidelines improve the future use and understanding of the ES maps by the map-users?

1.4. Structure of the thesis

This thesis is divided into seven chapters in order to answer the research questions. The description of the research and objectives are in **Chapter One**. **Chapter Two** contains information related to ES mapping, challenges, and existing ES maps. The methodology of the thesis is described in **Chapter Three**. The conceptual design of the prototype maps and the implementation is presented in **Chapter Four**; answering the first research question to reach *objective one (i).* In **Chapter Five,** describes the implementation of the usability evaluation, and the interpretation of the results phase I and II, in order to achieve the *objective (ii).* **Chapter Six** describes the improvements in the final ES maps. In **Chapter Seven** contains the discussion of results and guidelines for the map makers based on the procedures and design elements related to the final ES maps in order to achieve the *objective (iii)*, and limitations and recommendations for future work. The answers to research questions and conclusions are presented in **Chapter Eight**.

2. LITERATURE REVIEW

This chapter covers some relevant literature for the research. In Section 2.1., an overview of the Ecosystem Services concept is given and Section 2.2. describes Ecosystem Services Mapping. Section 2.3 presents the challenges to be faced in ES mapping and the limited amount of usability research that has already been executed.

2.1. Ecosystem Services concepts

As already indicated in Section 1.1., Ecosystems Services (ES) are the benefits people obtain directly or indirectly from the ecosystems (Maes et al., 2012; Millennium Ecosystem Assessment, 2005). The term "Ecosystem Services" emerged in the 1980s and became strong in the 1990s (Gómez-Baggethun, de Groot, Lomas, & Montes, 2010). In 2005, the Millennium Ecosystem Assessment (MEA), stated that the world depends entirely on the ecosystems and the services they provide, and that over the last 50 years ecosystems have changed more rapidly and extensively than in any other period in history (Burkhard & Maes, 2017; Millennium Ecosystem Assessment, 2005; Nemec & Raudsepp-Hearne, 2013).

Since the 1990s the usage of the ES concept has been growing tremendously. For example, an ES assessment has been used to estimate values of ES to inform where trade-offs in ES provision can affect people. Mapping and modeling are used to estimate biophysical quantities, to evaluate and establish trends, estimate costs, and place monetary value on biophysical quantities also to support the identification of priorities or future risks, etc. (Egoh, Drakou, Dunbar, Maes, & Willemen, 2012; Maes et al., 2016; Nemec & Raudsepp-Hearne, 2013). Nowadays, the ES concept has become a valuable tool for policy and decision making (Malinga et al., 2015; Vihervaara, Kumpula, Tanskanen, & Burkhard, 2010). This interest and the efforts made have helped to develop methods and tools for mapping, assessing, quantifying and valuing ES, contributing to attracting policy support for nature conservation (Gómez-Baggethun et al., 2010; Grêt-Regamey, Weibel, Kienast, Rabe, & Zulian, 2015).

In order to quantify, assess and map ES, these have been classified by the Millennium Ecosystem Assessment (MEA, 2005) with an update by The Economics of Ecosystems and Biodiversity, (TEEB, 2010), into four categories: provisioning, regulating, cultural and supporting services. Those categories were linked to the human well-being components security, health, basic material for good life and social relations, with the purpose to help the use of the concept of ES by different users. (De Groot et al., 2010). This classification was redesigned in the Common International Classification of Ecosystem Services (CICES), Version 5.1 (Haines-Young & Potschin, 2018) into a new structure divided into three categories, provisioning services, regulating and maintenance services and cultural services, as a standard to provide better guidance. This classification system does not recognise so-called supporting services because it does not attempt to identify or classify flows that have an intermediate status which operate alongside more basic ecological processes (Haines-Young & Potschin, 2018). CICES classification was selected because has been used in different studies to develop indicators, and guide valuation and mapping processes and also form part of the mapping framework to support the EU Biodiversity Strategy to 2020 (Burkhard & Maes, 2017; Haines-Young & Potschin, 2018; Maes et al., 2018). These are not the only classifications systems that currently exist for ES, others such as: The Final Ecosystem Good and Services Classification (FEGS-CS) (Landers & Nahlik, 2013), Nature Contributions to People (NCP) (Díaz et al., 2018) and National Ecosystem Services Classification System (NESCS) (EPA, 2015) also have been developed to identify, quantify, and value changes in ecosystems and their services.

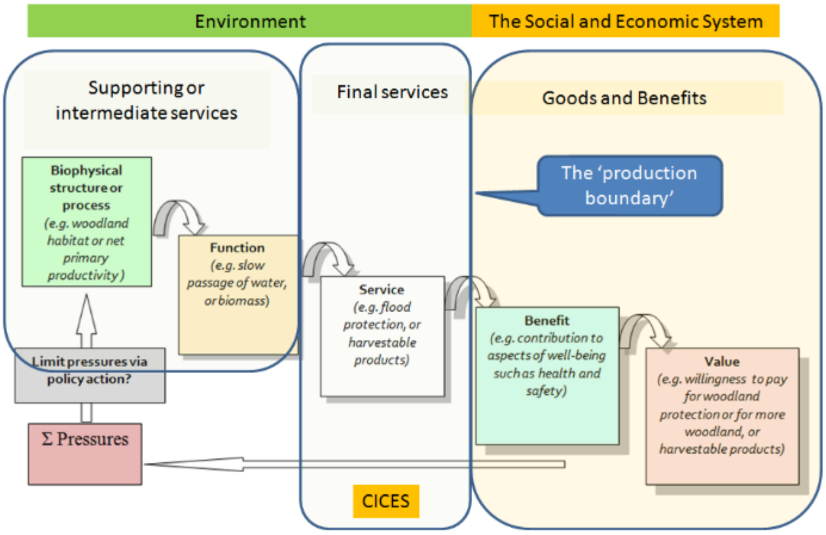


Figure 1. The cascade model, chain ES flow, processes, functions, services, benefits and values. Credit: Roy Haines-Young & Potschin, 2013.

In order to highlight the ways in which people and nature are connected. The cascade model in Figure 1 shows to the left side the important elements that help to determine the capacity of an ecosystem to supply and to the right side the aspects of the demand for them. This model helps to understand the delivering of ecosystem services, from ecological structures and processes through to the well-being of people at the other (Burkhard & Maes, 2017; Haines-Young & Potschin, 2016; Maes et al., 2012). The cascade framework has been adapted by Burkhard et al. (2017) to comprehend which multiple components of ES can actually be mapped (see Figure 2).

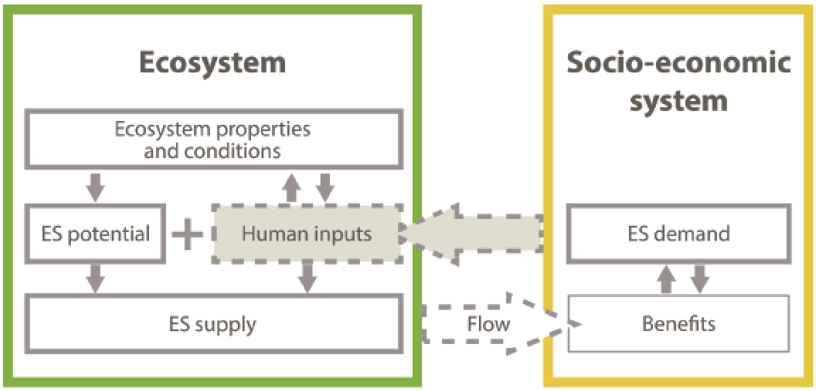


Figure 2. Mapping aspects of ES by Burkhard et al. (2017), Bold grey: subjects relevant for mapping; dashed: may be mapped; thin: additional aspects for which mapping could be developed

2.2. Mapping Ecosystem Services

Maps are the representation of spatio-temporal phenomena(Burkhard & Maes, 2017; Drakou et al., 2015). In ES mapping, these maps are produced through the use of different methods such as tiered approach, participatory GIS, land-cover based approach, modelling, Bayesian statistics, machine learning (Drakou et al., 2015; Willemen, Burkhard, Crossman, Drakou, & Palomo, 2015), This variety allow to assess and analyse the spatial congruence between ecosystems functions, services, synergies and trade-offs, trends, etc., (Burkhard & Maes, 2017; Malinga et al., 2015; Nemec & Raudsepp-Hearne, 2013). Recently, the effectiveness of ES maps in ES mapping was analysed and as a result, a set of seven recommendations to improve the effectiveness of ES maps was provided (Burkhard & Maes, 2017). 1) define the purpose for which mapping is needed, 2) the minimum parameters of reliability, accuracy and resolution of the input data, 3) asses the resources (the type of data, time and cost), 4) evaluate the limitations of the data and maps, 5) have clear the context of use "*maps are essential for many processes, but projects are never just maps*" (Burkhard & Maes, 2017), 6) the map maker needs to involve more map users into the process and 7) find the right balance between user demands and sources.

ES mapping applies a broad range of tools which can be divided into three categories each of which has different data needs and different outputs (Burkhard & Maes, 2017; Crossman et al., 2013; Egoh et al., 2012). **1)** *Analysis tools, software packages built to operate in GIS platforms* like ArcGIS, QGIS, GRASS GIS, Social Values for Ecosystem Services (Solves), Land Utilisation Capability Indicator (LUCI). These can be applied for simple land cover-based analyses and indicator-based ES mapping; **2)** *Biophysical Models for ES, created to apply in complex model-based analyses for specific topics*, e.g. for hydrology the Soil and Water Assessment Tool (SWAT), Integrated Model to Assess the Global Environment (IMAGE), Multiscale Integrated Models of Ecosystem Services (MIMES), the Global Unified Metamodel of the Biosphere (GUMBO); **3)** *Integrated modelling tools for ES assessment*, for example InVEST (the Integrate Tool to Value Ecosystem Services and their trade-offs), which has been widely applied for mapping and valuate ES and also the Artificial Intelligence for Ecosystem Services (ARIES). (Burkhard & Maes, 2017; Crossman et al., 2013). Indicators in terms of mapping and modeling were designed to assess the ecosystem condition and ES (Maes et al., 2018). These indicators describe how to map and evaluate the pressures on the ecosystem and their condition, besides, they can be used when the ES cannot be quantified. Some of the purposes of using these indicators were assigning monetary values to the biophysical service supply and an understanding of trade-offs versus costs (Egoh et al., 2012).

The complex relationship between nature and people have increased the use of a wide variety of tools for mapping and evaluating Ecosystems Services as an attempt to improve the understanding of this relationship. ES mapping in this context has turned into an essential tool to help scientists, land managers, practitioners, policy makers and users from public and private sectors, to visualize spatial and/or temporal information on how ecosystems contribute to human wellbeing, at the same time, support policies and decisions that have an impact on natural resources (Burkhard & Maes, 2017; Nemec & Raudsepp-Hearne, 2013; Palomo et al., 2018).

The use of ES maps as a communication tool in decision making, play an important role in processes where it is essential to determine the risks for ecosystem health, to detect unsustainable use to provide a service and, to identify spatial areas with a high or low provision and a high or low demand to make a comparison that helps to reveal areas under pressure (e.g. climate change, invasive species, fragmentation of the land, pollution, etc.) (Burkhard & Maes, 2017; Grêt-Regamey et al., 2015; Hauck et al., 2013; Maes et al., 2012; Maes, Paracchini, & Zulian, 2011). Different EU policies (e.g. the EU Biodiversity Strategy) integrate the ES concept into their design, implementation and management, in order to develop plans for conservation, restoration and monitoring of ecosystems aiming to inform decisions and improve the wellbeing of people and nature (Maes et al., 2012; Ruckelshaus et al., 2015). Since the ES concept and mapping entered the policy agenda, several important science-policy projects have been developed with the aim of encourage actions for sustainable use of biodiversity. For example, in 2005 the MEA carried out an assessment to determine the consequences of ecosystem change and to establish the scientific basis for actions to enhance the conservation and sustainable use of ecosystems. In 2010, The Economics of Ecosystems and Biodiversity (TEEB) project had the aim to provide data and a better understanding in economic terms about the effects of the depletion of ES and the consequences of policy inaction on halting biodiversity loss at various scales (global, regional and local) (De Groot et al., 2010). Recently, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2018) was created to synthesize the knowledge on biodiversity, ecosystems and their contributions, as well as tools and methods to protect and sustainably use this natural wealth. The "EU Biodiversity Strategy to 2020", through the Action 5, the encourage Member States with the assistance of the Commission, to use of ES mapping to assess the state of ecosystems and their services, 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. To helped to highlight the importance not only of the ES concept but also the ES mapping for conservation, monitoring, planning and policy (Bouwma et al., 2018; European Commission, 2011; Hauck et al., 2013; Maes et al., 2014; Maes et al., 2012; Rabe, Koellner, Marzelli, Schumacher, & Grêt-Regamey, 2016).

Maps also in other areas has been an important tool to help to make spatial analysis and support activities like conservation planning. Some examples of this, was the investigation on recreation in an urban and a rural forest in southern Germany during a summer and a winter. for the analysis was quantifying the recreational area, counting the number of visitors, mapped the visitors' paths and was asked to the visitors to rate Recreational behavior and perceived forest benefits and to name reasons for pathway choice. In the study was analysed visitors' patterns and the spatial behavior. As a results was determined a weak connection between recreational behavior and demand for specific forest characteristics (Meyer, Rathmann, & Schulz, 2019). Another research explored landscape values related to an iconic species using participatory mapping. This participatory mapping was used to provide means of compiling a wide range of landscape values by producing a visual representation to inform conservation planning. Through the use SoftGIS methodology, was mapped and quantified the overlap of bivariate biodiversity hotspots identifying value concurrence. The results showed an effective way to render explicit spatial variations in the values attributed to a landscape and identified concurrence of values, which allow the integration of multiple landscape values in conservation planning (Ernoul et al., 2018)

2.3. Challenges and Usability in Ecosystem Services mapping

Challenges in ES mapping refers to the problems the scientists, policy makers and stakeholders from public and private sectors have been facing during the mapping process (Maes et al., 2012; Palomo et al., 2018). ES mapping has become more relevant as a communication tool but, their implementation into decision-making processes is still limited because of some challenges in the mapping process (Hauck et al., 2013; Maes et al., 2018).

Nowadays, some of the most relevant challenges are related to topics such as 1) the limited availability or access to data; 2) discrepancies in ES classification and terminology; 3) a lack of consistency among methods to quantify, model and map ES due to the wide variety of existing ES definitions; 4) the difficulty in mapping non-spatial ES data; 5) difficulties to select a suitable method that can be applied in ES mapping; 6) the lack of communication between map makers and map users; 7) the low knowledge about tools and methods; 8) technical difficulties and over-simplification of ES data (Palomo et al., 2018). Moreover, not all ES can be represented in a map easily (e.g. some provisioning ES are not mapped as contributions of ecosystems to human well-being, demands for regulating ES are also not easy to define or to map, also cultural services related to the personal identities of people) (Burkhard & Maes, 2017; Hauck et al., 2013). Currently, the use of a wide range of tools allows users to build diverse types of ES maps that try to satisfy different target audiences (Drakou et al., 2015). For the growing number of new map makers, another important challenge is to produce and design aesthetic maps, which are easy to understand and well explain the ES (i.e. which are effective, efficient and satisfying). All these challenges limit in some way the use and impact of ES maps into the decision-making (Ruckelshaus et al., 2015). Therefore, it becomes relevant to tackle some of these challenges. In this regard, the implementation of user research methods and techniques such as the User-Centred Design approach can provide solutions for the challenge called

"Map-maker and map-user communication" (Palomo et al., 2018) which refers to the lack of communication between the mapmaker and the map user which result in maps that do not meet the users requirements.

Usability research up to now have carried out in a few studies; the first study is related to the analysis of the user behavior and cognitive processes while applying ES information integrated into a Decision Support System (DSS) (Klein, Drobnik, & Grêt-Regamey, 2016). This DSS displayed ES data through various types of representation (e.g. pie and bar chart) it was investigated first, what was the information most used and, second, how this information affected the user's cognitive processes and, third, how this information affected the reasoning in decision-making. This was done through an eye-tracking experiment focusing on the user's behavior. As a result, the study provided design recommendations for representing ES information based on the intended use, also identified critical representation characteristics that could influence the perception of ES information (Klein et al., 2016). The second study investigated the correspondence between the ES user needs and the data provided by the scientific community. This was performed testing stakeholders from 38 countries of sub-Sahara Africa using a targeted sampling strategy to determine the ES data needs. Their findings indicate they stakeholders are participating actively in ES research and using the information to support policy development mainl5y with information of provisioning and regulating services, although the information is not adequate in some cases for decision making. The results highlight the importance and the necessity for dynamic ES information for the different spatial and temporal scales. Also, was found gaps in ES research which need to be filled to increase the use of ES outputs in policy development. Increased efforts are needed to involve stakeholders who do not currently use ES information in the process, also recommended improving the capacity of researchers to improve ES research and thus support policy (Willcock et al., 2016). In 2018 was performed the use and user requirement analysis of ES maps at EU, national and sub-national level to understand the perspectives of the current map users and map makers of ES maps and to identify usability issues of this kind of maps. To develop the analysis of ES maps, exploratory user research methods were applied in an User-Centred Design approach. As a result, this research provided a set of descriptions of the use and user requirements of ES maps and some recommendations for future map design (Rühringer, 2018).

2.4. Existing ES maps

It is important for the analysis of ES maps and the selection of the case study, to understand first that map type is the result of a unique combination of graphical variables (size, value, grain, colour, orientation, shape), measurement scale of qualitative or quantitative data (nominal, ordinal, interval, ratio) and (dis)continuity of the data. As a result, nine different map types can be created from these combinations (Kraak & Ormeling, 2010).

1. Dot map
2. Choropleth map
3. Chorochromatic map
4. Isoline map
5. Statistical surface
6. Diagram map
7. Flowline map
8. Cartogram
9. Proportional point symbol map

According to Burkhard & Maes (2017), the most popular map types identified in ES are dot maps, choropleth maps, proportional point symbol map and isarithmic map. The data from modeling and quantifications derive in these different ES map types (Burkhard & Maes, 2017). To design this kind of maps it is necessary to apply "mapping methods" which are the organised way of applying graphic variables to represent information (Kraak & Ormeling, 2010). The popular ES maps types are described below.

Dot maps: Represent point data through symbols, showing quantity or the entity localization (see Figure 3). This map type has risen in popularity since it works in small scales and with very large numbers of features. In ES mapping are used to represent distribution patterns of entities or differences in densities (Burkhard & Maes, 2017; Kraak & Ormeling, 2010). Dot maps utilise mapping techniques such as "Dot-density and dasymetric mapping" and "One to one mapping".

Choropleth maps: Type of quantitative map in which statistical or administrative areas are colored, shaded or represented by symbols proportionally to the value represented (Borden, Jeffrey, & Thomas, 2008; Tyner, 2010). Also, it can describe as a map type that use the colour gradient to provide a view of quantitative spatial pattern across an area (Burkhard & Maes, 2017; Peterson, 2015a) (see Figure 3). Choropleth maps used mapping techniques such as "Choropleth mapping" and sometimes "Dasymetric mapping".

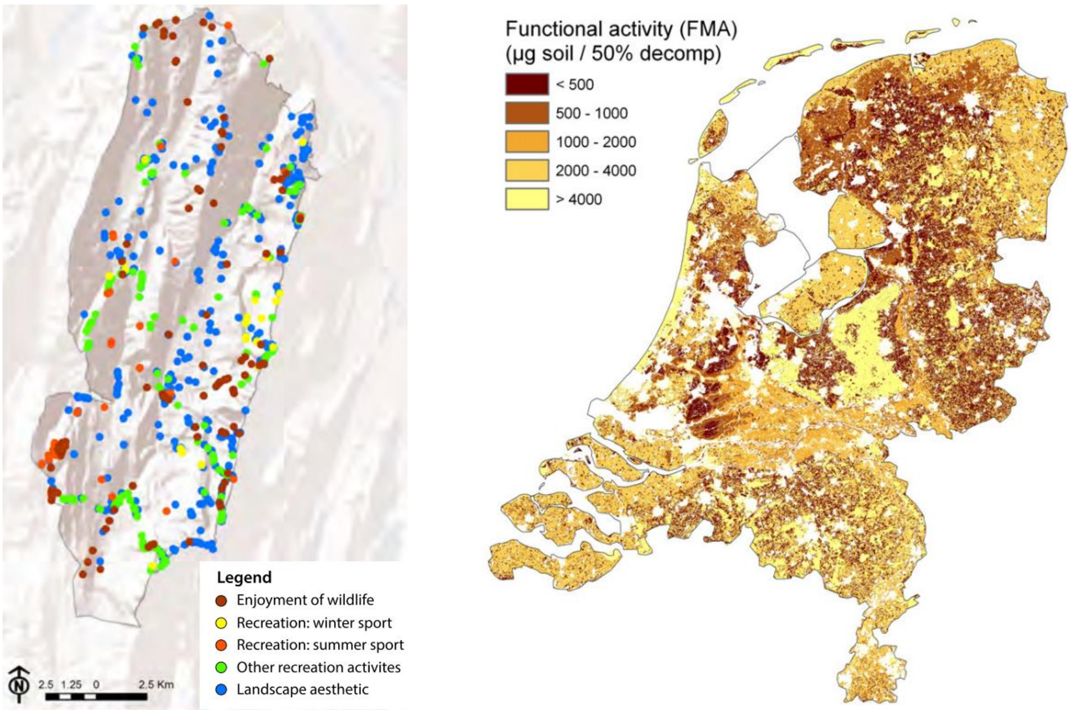


Figure 3. Right side: example of a dot map (Burkhard & Maes, 2017), Left side: example of a choropleth map (van Wijnen et al., 2012)

Proportional point symbol map: One of the most popular map types has been used to portray point data through symbols (circle, square, or triangle) that varies in size proportionally to the quantity it represents (Borden et al., 2008) (see Figure 4). Proportional point symbol maps used mapping techniques such as "Proportional point symbol mapping" and "Proportional symbols and choropleth maps".

Isoline map or Isarithmic map: Is a planimetric representation of the surface of a three-dimensional volume (e.g. contour lines in topographic maps). In ES, this type of map represents the gradual variation of Ecosystem services over the space (e.g. climate regulation) (Borden et al., 2008; Burkhard & Maes, 2017) (see Figure 5). Isarithmic maps used mapping techniques such as "Isarithmic Mapping".

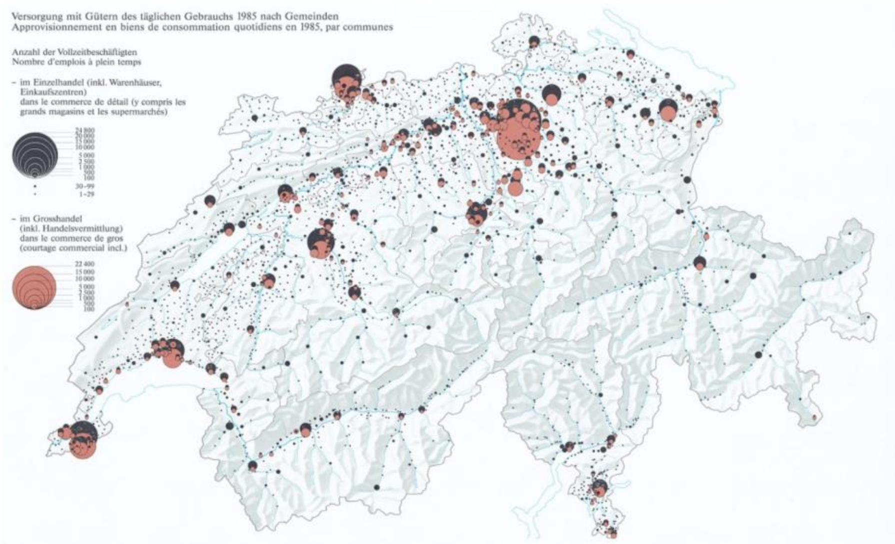


Figure 4. Example of proportional point symbol maps ("Atlas of Switzerland," n.d.)

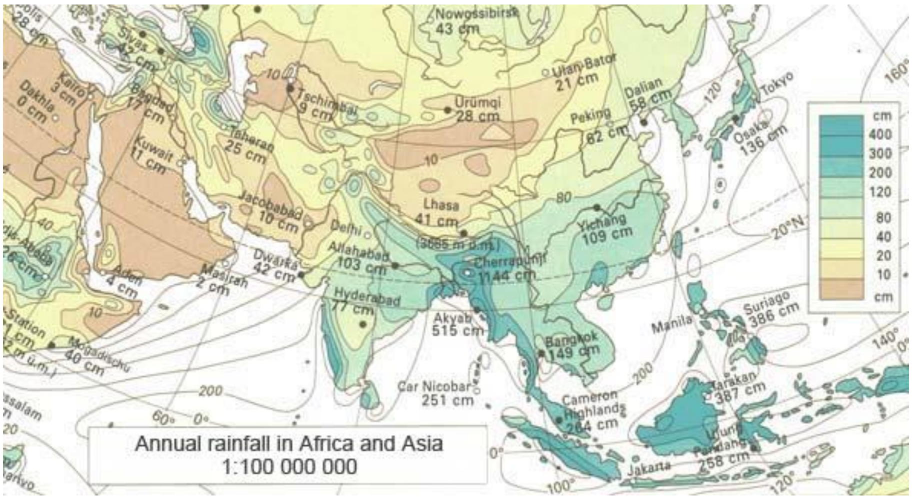


Figure 5. Example of an isoline map ("GITTA Geographic Information Technology Training Alliance," n.d.)

2.5. Summary

The ecosystems and their services are essential to human well-being. In recent decades the use of ES has been growing tremendously because the relationship between people and nature becomes essential for conservation and sustainable development. Consequently, ES mapping has made important progress in terms of the development of new methods and tools to map, assess the state, conservation and maintenance of the ecosystems and the multiples services they provide. ES maps can be used to facilitate the understanding of ES concepts and support research, policymakers, and stakeholders from public and private sectors in decision-making processes. But there are some ES mapping process challenges and solutions must be found for them. This thesis, through the use of the approach User-centred design (UCD), can address the challenge called *"Map-maker and map-user communication"* (Palomo et al., 2018) which refers to the lack of communication between the mapmaker and the map user which result in maps that do not satisfy the user's requirements. The UCD approach engages the users from the beginning of the map design process and also performed usability tests to able to know at early stages of the process what problems related to used and design need be solved. Designing ES maps that can meet the user needs also can improve the communication from the scientific knowledge to the users. Details about how it will follow this approach to meet the goals of this research are described below.

3. RESEARCH METHODOLOGY

The purpose of this chapter is to describe the methodology that will be used in this research. In order to get answers to the research questions formulated in the first chapter will apply the User-Centred Design (UCD) approach presented in van Elzakker & Wealands (2007). In this research, the focus will be on the implementation of the second and the third stage of the User-Centred Design (UCD) approach, called "Produce design solutions" and "Usability evaluation" respectively. The methodology in Section 3.1. describes the application of User-Centred Design in ES mapping process. Section 3.1.1. the first stage of UCD user requirement analysis by Rühringer (2018) is described. Section 3.1.2. describes the map design process, the second stage of UCD. Section 3.1.3. describes "Usability evaluation".

3.1. User-Centred Design in mapping process

In the early '80s, the User-Centred Design framework emerged as one of the guiding principles for designing usable technologies, digital and non-digital products (Haklay, 2010). For this framework, it is important to place the user at the centre of the process, while designers and developers focused on what the user needs (Haklay, 2010; Nielsen, 1993). The User-Centred Design (UCD) approach has been used as an iterative process to ensure that the most suitable product is developed before it is delivered (Kramers, 2007).

The mapping process according to Tyner (2010) is described as a process of four steps 1) planning, 2) analysis, 3) presentation and 4) production (see Figure 6). In ES mapping process, planning and analysis consist of the identification of the ES categories and indicators relevant to be mapped, the determination of methods and tools (e.g. SWAT, InVEST, ARIES) that can be applied, the identification of the potential users, the data collection (from field data, databases) and spatial analyses, etc., (Grêt-Regamey et al., 2015; Maes et al., 2012; Tyner, 2010). For the last two steps, presentation and production, the User-Centred Design takes place as the process to design and develop cartographic products based on the outputs generated in the analysis step of the mapping process with tools such as InVEST, ARIES, etc. This UCD approach is divided into three main stages, 1) analysis of requirements, 2) production of design solutions and 3) evaluation design (van Elzakker & Wealands, 2007). Each of these stages (Figure 6), provide information that helps to obtain a satisfactory design solution. The first stage identifies user needs and context of use. The second stage is related to the development of the conceptual design and the implementation of the prototypes. The third stage is associated with the prototype evaluation by representative users. To finalise the process the second and third stages iterate until they satisfy the user needs (Kramers, 2007; van Elzakker & Ooms, 2018; van Elzakker & Wealands, 2007).

In this research, I focus on developing the second and third stage of the UCD approach (see Figure 6), to obtain satisfactory design solutions of ES maps and to produce guidelines for map makers, that can help to improve the future use of ES maps and their inclusion in the decision-making process The details are explained in the sections that follow.

3.1.1. Analysis requirements

The user requirements are the *initial information* source of this research, derived from the first stage of the UCD approach. This data was provided by Rühringer (2018) as a product of her MSc thesis "Use and User Requirements of Ecosystem Service Maps". This research conducted the "analysis requirements" the first stage of the User-Centred Design approach (van Elzakker & Ooms, 2018). This aimed "to provide a detailed description of the use and user requirements of ecosystem service maps giving rise recommendations for future map design". This information will be the basic data for the design a set of preliminary solutions and subsequently in the definition of the testing methods, type of participants and the strategy of implementation of the usability test. The outcomes (see Section 4.1) of this research are organised and analysed to determine the aspects like user needs, use purpose, the context of use, usability issues, target audience, and recommendations.

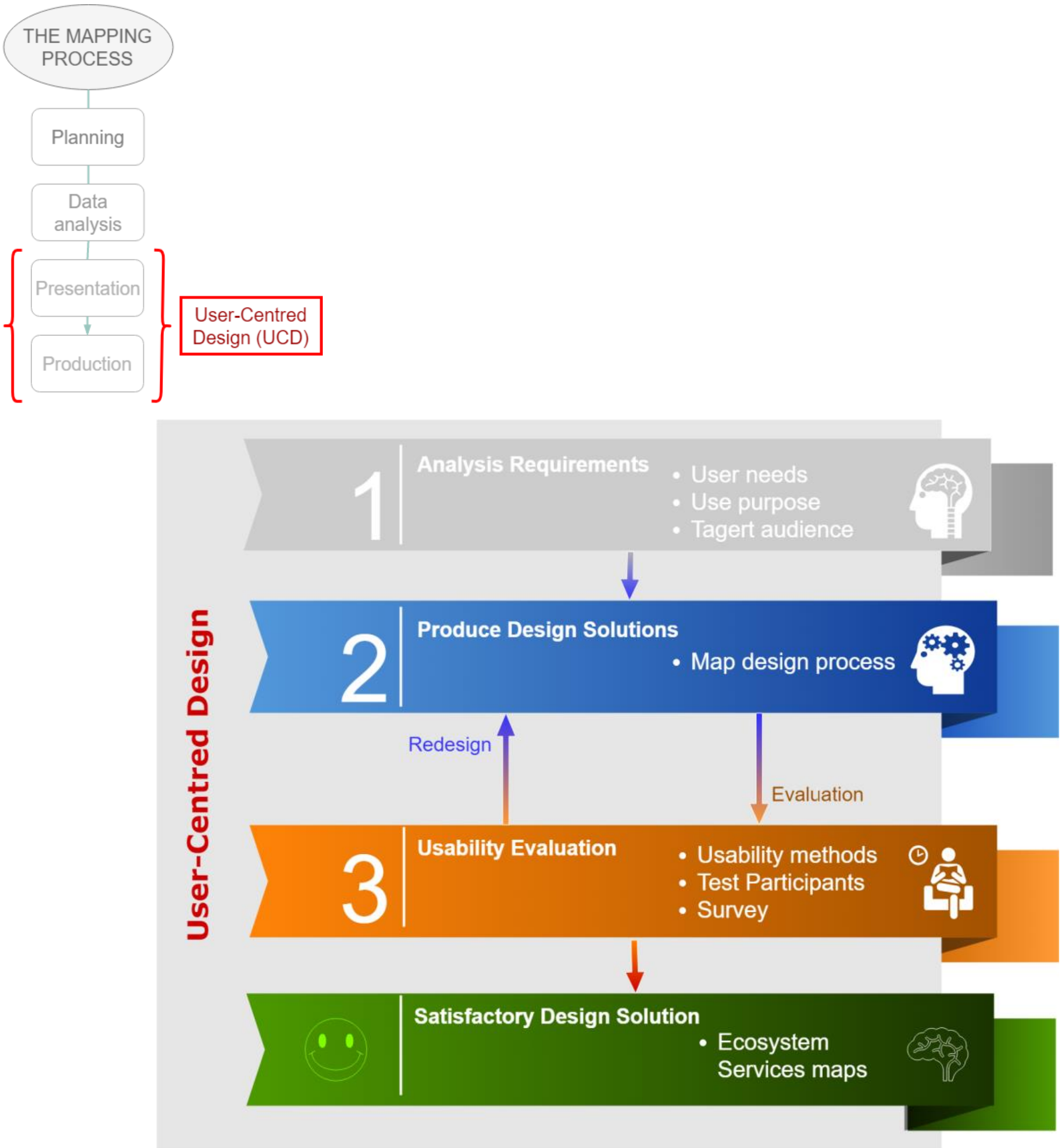


Figure 6. The mapping process by Tyner (2010) and The User-Centred Design Approach, Adapted from van Elzakker & Wealands (2007).

3.1.2. Produce design solutions

The second stage of the UCD process is called "Produce design solutions". The aim is to design ES maps easy to use by the users into the decision-making process. This stage uses the findings and recommendations identified in the first stage, to carry out the "Map design process" of ES maps and helping the case study selection, type of improvements and map elements.

The map design process (Figure 7) is the workflow in which the second stage of the UCD is based on to achieve a design of ES maps that satisfy the user requirements (see Chapter One). Step 1, is Identification of ES map type and method. Besides, will be select the case study which will consist in example maps to develop the conceptual design and the prototypes. Step 2, refers to the definition of technical aspects and selection of the cartographic elements contained in the map. Step 3, focuses on layout and preliminary maps. Step 4, is the creation of the maps using the case study. These design steps (see Figure 7), are described in the next section.

The process of mapping Ecosystem Services (ES) is essential to understand benefits ecosystems bring to human well-being and can support activities and policies which have an impact on natural resources (Burkhard & Maes, 2017; Hauck et al., 2013). Thus, it is necessary to highlight, that the accurate representation of the results also plays a significant role in understanding the outcomes derived from the ES analyses, so this aspect becomes one of the most important factors to guide users decide if they can use these maps to inform the decision-making process. The map products of the ES mapping process can be categorised as thematic maps. This type of maps is defined as a graphic display of attribute data or variables, qualitative or quantitative (Borden et al., 2008; Kraak & Ormeling, 2010; Tyner, 2010). This kind of maps are made to 1) provide information about quantity is in a specific location, 2) show characteristics of a geographic phenomenon and/or 3) present findings to an audience (Tyner, 2010). Every thematic map consists of three components:

1) **Base map:** Provide locational information
2) **Thematic overlay:** Is all the thematic information (results from the analysis, boundaries, etc.)
3) **Cartographic elements:** Are the elements that can be used to make up a map design (Titles, legend, inset maps, etc.)

In the map design process, these components must be integrated properly to create satisfactory graphics composition that the user can read and use in decision-making. Map design can be described as the aggregation of all processes that cartographers go through during the cartographic process to create solutions for specific problems. Also as a complex activity which involves intellectual and visual aspects (Borden et al., 2008). Mapmakers need to make important choices to create suitable graphical compositions, related to the selection of map type, proper mapping method or technique, base map, graphic variables, etc., and the cartographic elements (Borden et al., 2008; Brewer, 2005; Kraak & Ormeling, 2010).

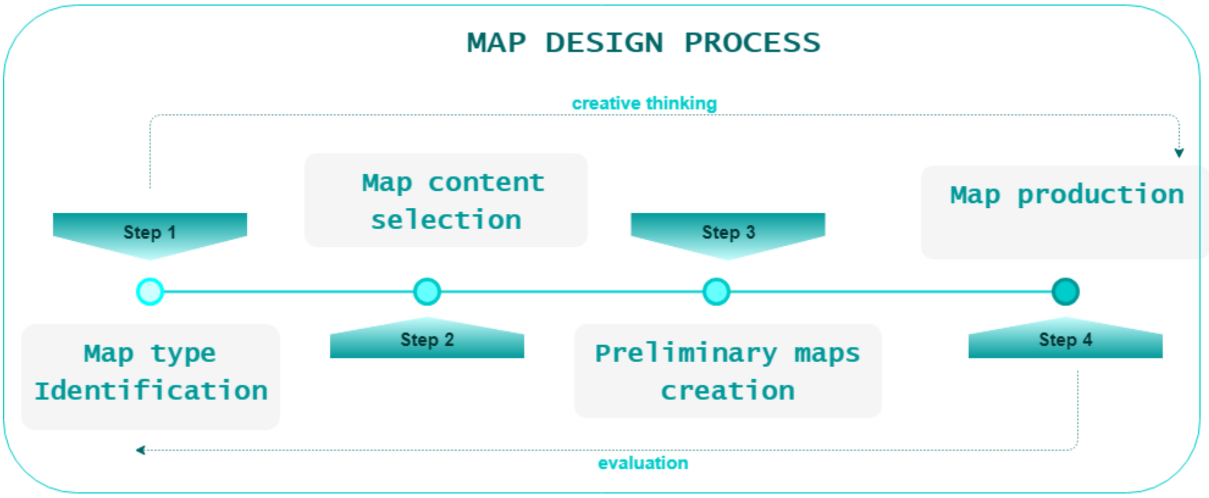


Figure 7. The map design process, Based on *Mapping process* by Tyner (2010), *The design process* by Borden, Jeffrey, & Thomas, 2008; Peterson (2015) and *Map design and production* by Kraak & Ormeling (2010).

Identification of map type and case study

This first step for this research consists initially in the identification of the ES map types. During this step, a selection of studies for different years will be carried out. This identification will help to identify the map type most commonly used in ES research. For the selection specific conditions have to be fulfilled i.e., having at least in their results one ES map. Also, have clear information related to scale, the approach applied to mapped ES, ES category (Provisioning, Regulating and Maintenance, Cultural), attribute ES (Capacity, Flow, Demand, Supply, Use, Potential), map type, location, the research name and year. From this information will analyse the maps to understand ES mapping and type of maps produced. As a result, the types of ES maps that are mostly used and the method suitable to be applied in the design will be determined. These results help to select the case study of this research.

Case study selection

This selection will consider the usability issues, users, use purpose identified in the first stage of UCD by Rühringer (2018) and the results of the map type analysis. The selection for this research consists of taking three examples of ES maps from the list of the map type analysis; these maps were chosen because they had unique characteristics as different scales, different problems with the map content, legend, colors and resolution. Then, the characteristics of the maps are placed in an excel table with the attributes such as scale, the number of maps, thematic map type, etc., and filtered crossing the attributes of thematic map type, based on approach method, legend units, scale, number of maps and year, this were compared between them and was remove the ES maps with the same attributes.

Attributes:

- Thematic map type: Choropleth map, dot map, proportional point symbol map, isarithmic map.
- Based on the approach: Land-cover based, PPGIS, Model-based.
- Legend units: Quantitative, qualitative.
- Scale: EU, national, sub-national
- Number of maps: single map, multiple maps
- Year

As a result, a list of three representative examples of ES maps, their characteristics, that will use in map design and implementation and usability evaluation will be put together (see Section 4.2.1).

Step 2: Identification of map content

The identification of the map content is the selection of the primary and secondary cartographic elements for ES maps and the identification of the technical aspects for the map design process. For the identification of the technical aspects, I will use a checklist of technical aspects to specify the technical details required in the map design process (Table 1). For the selection of cartographic elements, the findings of the first stage of UCD are necessary, such as the context of use and use purpose. Also, the results from the map type analysis and the technical aspects, that alongside the study "A blueprint for mapping and modeling Ecosystem Services" by Crossman et al. (2013) will contribute in the selection of the elements of the ES maps require. This task will be done by crossing the attributes of the templates ES mapping blueprint Table 3 and Table 4 provided by Crossman et al. (2013), and the lists of the cartographic elements (see Table 2) (Peterson, 2015b). The number of elements is determined based on the technical aspects and map examples of the case study, such as map size, the context of use, scale, type of map and number of maps. As a result, technical aspects and the minimum map content that will help the users to understand the map will be obtained (see Section 4.2.2).

Table 1. Technical aspects.

Aspects	*Description*
Type of map	Static / Interactive /Digital/ On paper
Scale	National/Sub-national/EU
Map size	Letter/A4/ Tabloid
Orientation	Vertical / Horizontal
Export resolution	300 to 600 DPI
Export formats	JPG, PNG or PDF
Common use	Reports, articles, slide presentations, poster
Print	Colour or B/N
Software	ArcGIS, QGIS, MapInfo, etc.
Number of maps	Individual / Multiple

Table 2. Layout checklist of cartographic elements by Peterson (2015).

Primary Elements	*Secondary Elements*	
Title	Neat lines	Graphics
Subtitle	Graticules	Map number, if series
Legend	Network path	Tables
Maps	Disclaimer	Copyright
North arrow	Data sources	Projection
Date	Data citations	Inset maps
Authorship	Logos	Descriptive text
Scale bars	Graphs	
Page border	Photographs	

The study "A blueprint for mapping and modeling Ecosystem Services" by Crossman et al. (2013), provided two lists of information needed in an ecosystem service modeling and mapping study as a guideline for those beginning to develop an ES study.

Table 3. Blueprint template for reporting ES mapping studies

Name of the mapping study	Purpose of the study
Localization of the study sites and biophysical type	Study duration
Administrative unit	Main investigators
References	Type of project
Funding source	Contact details

Table 4. Blueprint template for reporting Ecosystem Service mapping and modeling studies

Mapped Ecosystem Service	Provisioning/ Regulating/Cultural
Accounting definitions	Type/ Beneficiary
ES indicator	---------------------
Quantification Unit	Quantity/Area/ Time
Input data source	Quantification method
Spatial details	Scale/ Extend / Resolution
Mapped year or period	---------------------
Study objective met	---------------------
Comments	---------------------

For the scale selection, it is necessary to have clear the differences between large-scale maps and small-scale maps to design a proper visualisation in which can distinguish the information and the map content (text, legend, map, etc.). According to Peterson (2015), the scales in Table 5 give an overview of these differences and allow to establish the scale of the map. These scales were matched with the administrative levels used in the first stage of UCD by Rühringer (2018) to understand the differences between them.

Table 5. Type of scales

Type of Scale		*Scale*	*Level*
Small scale	1:250,000 and smaller	Sub-National	Comprise local and regional level mappings
Medium scale	1:50,000 to 1:250,000	National	Covers the nation level mapping
Large scale	1:50,000 and larger	EU	Covers European Union and global level mappings

Step 3: Preliminary maps

For the development of this component the elements for design, type of improvements, methods or cartographic rules to follow and will be designing the map composition (layout) and the first preliminary maps will be defined. All the decisions will be based on the following information; use purpose, the context of use, map type, technical aspects, cartographic elements, usability issues of example maps and the recommendations provided by the first stage of UCD, to design the cartographic elements, graphic variables correctly and to test different arrangements of map elements until obtaining a satisfactory, aesthetically and pleasing design that communicates well the information to the user. Elements like texts, colours, legend, content, that make up a map are not an easy task to design (Borden et al., 2008; Tyner, 2010). That is why it is important mapmaker has some knowledge about design principles or cartographic rules to make a proper design. As a result of this step, will provide a list of the type of improvements, the sketches of the elements arrangements for the maps and the cartographic rules that can be used to improve the usability issues related to texts, colours, legend and map content of the example maps.

Step 4: Map production

After the construction of the preliminary sketches, the map design process continues with the implementation of the map design. This means the creation of the prototype maps making use of the software selected. The map prototypes in this thesis are created using ArcGIS Desktop 10.6.1. This implementation uses the sketches of the element arrangements obtained from the preliminary maps step. Moreover, the cartographic rules to improve the usability issues related to font, colours, legend and content based on map type of the map examples will be applied. As an outcome of this step will obtain the descriptions about improvements and the map prototypes of ES in PDF format, which will be implemented in the usability evaluation by the users.

3.1.3. Usability evaluation

Usability evaluation will perform at the third stage of the UCD approach. This evaluation focuses on testing the product, in this case, the ES maps, to know how well the users can use the maps to achieve specific tasks. To ensure the maps meet the user requirements and to determine the effectiveness, efficiency and how well satisfied the users with the product (Crane & Still, 2016; Haklay, 2010; van Elzakker & Ooms, 2018). The usability methods provide tools to collect data about the users and the product used. These methods can provide quantitative or qualitative information about the usage of products (Haklay, 2010; van Elzakker & Wealands, 2007). In quantitative research, the aim is to obtained statistical data to evaluate the performance of the product after the delivery, while in qualitative research obtains qualitative data about a new product at early stages of UCD process, to identify the design problems and the usability issues identified by users (Li, 2017; van Elzakker & Ooms, 2018). Varied user research methods can be used in usability. According to Iohannis Delikostidis (2011) can divide into main categories analyse requirements (e.g. brainstorming, diary keeping), produce design solutions (e.g. surveys (online), heuristic evaluation) and evaluate design (e.g. satisfaction questionnaires, remote evaluation). This method must be selected based on the type of research (quantitative and qualitative) that will be performed, number of participants, environment, stage of UCD, advantage and disadvantages.

Usability evaluation in the context of this research refers to assess a cartographic product (maps) by testing it with representative users called "Test Persons (TPs). During the evaluation, the test participants will carry out a set of tasks with the aim to identify use and design problems of the map prototypes and determine effectiveness, efficiency and satisfaction with the product (Crane & Still, 2016; I. Delikostidis & C.P.J.M., 2011; Haklay, 2010; van Elzakker & Ooms, 2018). The test results will provide the way to know if the participants completed the tasks successfully, if they answered the geographic questions correctly, how long it takes to complete the survey, how satisfied the participants were with the product and the changes required to improve the maps. For this research, qualitative information will be collected. The TPs are representative users of the ES maps that are not in the same country. the usability methods will be those that will allow work with few participants and with flexible study conditions. Some suitable methods identify for this research were: the *remote unmoderated usability test* is a method fast and easy to carry out and does not need a moderator. It can reach out to broader audiences, involves real users, usually implies tasks can obtain immediate usability feedback. The *questionnaire* is a useful method for studying how users use the prototypes and which features particularly are working adequately in the solution of tasks and which not. This method requires a previous revision of the questions to ensure can be resolved by the users. The outputs allow collecting data from a large number of users by mean of mail or on paper. This can also be reused at later occasions to check and compare the replies from the users. Besides, questionnaires can have open and closed questions, the first ones allow the users reply in natural language and the second ones can be related with the functioning, task or opinion about the prototype, depending on the initial purpose. It is recommended to use shorter questionnaires in order to maximise the response rate (Nielsen, 1993). To measure the satisfaction of the user with the maps was include a satisfaction questionnaire a survey which consists of asking the users for their personal opinion of how satisfied are with the maps when they are used. (Haklay, 2010; Nielsen, 1993).

After completing the ES prototype maps, the use and design evaluation need to carried out. This test plan is to apply an online survey to be able to test current and potential users in all Europe that work in ES. For this qualitative research two methods will be applied to assess the maps 1) remote unmoderated usability test, 2) questionnaire and additionally 3) satisfaction questionnaire. The combination of these methods will allow testing TPs remotely, fast and easy without a moderator, through an online survey. The feedback will interpret to determine the use and design issues. This method also will allow assessing the effectiveness, efficiency, and satisfaction of prototype maps of ES.

Test persons for this usability evaluation, are representative users identified as current user or potential users or/and map-makers from Europe Union countries working in Ecosystem Services or take decisions with this kind of information. I decided to contact by email the TPs that belong to Ecosystem Services Partnership (ESP) a worldwide network of Ecosystem Services for conservation and sustainable development, which is a network to connect Ecosystem Services scientists, policy makers and practitioners of all West & Central Europe including Russia and South-East Europe. Also participants from Greece and Cyprus professionals that have worked with Ecosystem Services in different process, as a way to reach a broad audience of current and potential users of ES maps. These TPs will be divided into two groups to carry out the usability evaluation in the following way: Form Greece and Cyprus as TPs from National and sub-national level to test the initials prototypes, Form the ESP as TPs from the EU level to test the improved map prototypes. The reason for select TPS from Greece, Cyprus and EU is to continue the UCD process that started with the user requirement analysis of ES maps at EU-, national and sub-national level conducted by Rühringer (2018).

The usability evaluation will be carried out in two phases: The **first phase**, will assess the initial map prototypes of example maps one and two, and the **second phase** will assess the improve ES prototypes maps of example maps one and two and the initial prototype for example map three. At the end of this stage will be implementing the improvements derived from the use and design issues of the second phase of the usability evaluation with the aim to produce the final ES maps (satisfactory design solutions). The creation and implementation of the usability evaluation will use the platform called *Maptionnaire* ("Maptionnaire," n.d.), which is the first online survey tool with GIS functionality that provides a customised questionnaire to specific needs and data analysis functions.

For this survey, a set of geographic and user satisfaction questions to test the use of ES maps prototypes is developed. In exploratory cartography, maps are tools that communicate, analyse, synthesise and explore information and complex data efficiently. Also, these maps provide answers to the geographic questions to allow map makers to know how effective is the visual representation. The use of maps and geographic questions makes possible to understand and recognise patterns, trends, correlations or anomalies in the geographic data (van Elzakker, 2004). Thus, to gain insight into the information displayed in the ES prototype maps and to know how effective was the visual representation, a set of geographic questions were conducted. The questions are related to their corresponding map use task which also can be related to sequence, map reading, map analysis and map interpreting (Muehrcke & Muehrcke, 1992; van Elzakker, 2004). These questions will help identify the use and design problems of the map prototypes and determine effectiveness, efficiency and satisfaction of the map prototypes. The usability evaluation will provide the identification of the use and design issues which will be as the basis to determine the type of improvements to performed in the prototype maps. At the end of the process of producing design solutions and the usability evaluation, the guidelines for map makers that can help to improve the future use of ES maps will be produced based on the procedures and design elements of the final maps.

3.2. Summary

In this research, the aim is the design of cartographic maps of Ecosystem Services (ES) that satisfy the user requirements are based on the User-Centred Design (UCD) approach. Three stages are part of this process which will help to achieve this goal. The initial stage was executed by Rühringer (2018), which provides detail information about user needs, usability issues and recommendation of ES maps. This information will serve as a basis for determining the type of ES map improvements, technical aspects, methods and cartographic rules to be applied in the map design process. The map content as title, explanatory descriptions, scale, etc., is defined using the checklist of cartographic elements provided by Peterson (2015) and the blueprint template provided by Crossman et al. (2013). A case study will be selected for implementation, in which the improvements defined from the requirements analysis will be applied through the use of cartographic rules or methods. As a result of this implementation, a set of prototype maps will be tested by representative users of ES maps from the national, sub-national and EU levels. The use and design issues detected on these maps will allow redesigning the design elements of each map to improve their visualisation and use. Based on the final ES maps and procedures a set of guidelines for map makers will be provided. These guidelines can help to improve the future use of ES maps and their inclusion in the decision-making process. The implementation of this methodology is described in the following sections.

4. PRODUCE DESIGN SOLUTIONS AND IMPLEMENTATION

The focus of this chapter describes the process to design ES maps that meet the user's requirements and so, to complete the second stage of the User-Centred Design approach. This chapter is divided into two sections. Section 4.1 synthesizes the results of the requirements analysis stage provided by Rühringer (2018) as initial information for stage two and three of the UCD process in this research. In section 4.2. describes the map design process followed to design the ES prototype maps and the selection of case study.

4.1. Requirement analysis by Rühringer (2018)

The findings of the first stage of User-Centred Design approach carried out by Rühringer (2018), were organised by requirements and uses purpose, usability issues and recommendations. By analysing these results an overview of the user requirement of Ecosystem Services maps at EU-, national and subnational level is given. The analysis reveals challenges in current Ecosystem Services maps identified by the users for which a set of recommendations based on the results of this research is proposed. Based on these findings, the user needs, use purpose, the context of use, usability issues, the target audience for map design, implementation and usability evaluation were determined.

Requirements and use purpose

The following findings provide the characteristics of the user needs of ES maps from the map user perspective (see Table 6) and the map-maker perspective (see Table 7) at EU, national and sub-national levels. This information was translated into the user needs, the use purpose of the ES maps, the context of use and target audience to be used in stage two and three of the UCD process of this research.

Table 6. Needs and requirements from the map-user perspective (source: Rühringer, 2018).

	Map-users perspective
Needs and requirements	*European Union (EU)* o Develop and support European policies for conservation and biodiversity *National level* o Monitor the development of biodiversity and habitats o Design and implement national agricultural policies o Guidelines developments *Sub-national level* o Produce ES maps of biodiversity o Management protected areas (National parks)
Use purpose	*European Union (EU)* o To inform decision and policy development process, impact assessments and raising awareness. o To communicate ES content to others *National level* o To develop and support forest policies o To manage decisions and risk assessment o To locate spatial information *Sub-national level* o To develop Environmental Impact Assessment (EIA), economic valuation, future scenarios and regional forest policy o To monitor habitat types and species o Educational purpose and raising awareness o To support trade-off decisions

Table 7. Needs and requirements form the mapmaker perspective (source: Rühringer, 2018).

	Map-makers' perspective
Needs and requirements	*European Union (EU)* o Policy and EU Biodiversity strategy *National level* o Public administration and policies *Sub-national level* o Developing policies o Management of public administration and protected areas
Use purpose	*European Union (EU)* o To support policies o Impact assessments o To evaluate the success of policies *National level* o To monitor and manage areas o To make the Environmental Impact Assessment o To manage the agricultural area and priorities of conservation *Sub-national level*

	o Sustainable management of ecosystems o Educational purposes and raising awareness o To support trade-off decisions o To develop and manage policies and best practices o Forest management o Urban planning

Usability issues

The aim of the usability evaluation of the current ES maps at EU, national and subnational levels executed by Rühringer (2018), was identified the use issues related to colour, map content, resolution, etc., that affect maps and their use in the decision-making process. Based on these issues a set of recommendations for future map design and map creation processes was provided.

Table 8. Usability issues found by the map-users of ES maps (source: Rühringer, 2018).

Usability Issues at	o Information missing (Map description, units of the legend, uncertainties, explanation of technical terms, titles) o Difficult to distinguish (colours, font size, symbols) o Excessive content (text in the legend, the ramp of colours, categories) o Low image resolution o Unclear information (map content, scenario assumptions) o Interpreting difficulties (map content, colours, legend, map labels)

Recommendations

The recommendations given by Rühringer (2018), were classified by map design elements as colour, legend, resolution, content. The descriptions given per map design provided general guidelines to determine what type of improvements the ES map design needs and what cartographic rules can apply. This, along with the user needs and usability issues, is used in this thesis to create a suitable graphical composition of ES prototype maps.

Table 9. Selected recommendations derived from analysis of the map users assessments which are relevant to this work (source: Rühringer, 2018).

Map design	***Recommendations***
Colour	o Colour schemes and combinations, for the user to distinguish the variations in the results and categories.
Legend	o Include units and title o Minimum number of categories o Maximum of five hues o Sequential/diverging colour scheme o Qualitative colour scheme
Resolution	o Export maps (jpg, png formats) with a minimum of resolution between 300 – 400 dpi
Content	o Include map title to describe the map purpose o Add the necessary labels to be able the users understand the content and the geographical localization o Add thematic layers if is necessary o Add an explanatory description about the map content, focusing on the target audience o The legible font size of map texts (labels, legend, title, source, description, etc.)

	Other findings
o	The context of use of ecosystem service maps is more dominant in a desktop environment than interactive cartographic systems have not been used yet by the European users. Besides, ES maps have been using in the form of static screen maps.
o	ES maps are used to communicate the geographic position of the information but rarely used into the decision-making process.
o	The involvement of the user at the three levels was found insufficient; sometimes their participation occurs at the end of the process, some other times in the beginning and the end but rarely during the whole process.
o	The most common tools used to mapping Ecosystem Services were InVEST, ESTIMAP and R, others for map creation was ArcGIS and QGIS.

Other findings from this study are related to challenges encountered by the users in the mapping process (see Section 2.3). It is a fact that no clear mechanisms are yet in place to connect the maps produced by scientific research with the decision- and policymakers. There is still a lack of use of ES maps in decision-making and a lack of communication between science and policy. The analysis also showed that the users are not taken into account for all the phases of the mapping process and in many cases, the map makers have poor knowledge about tools to map ES.

The results above were the findings for the first stage of UCD, carried out in the MSc research by Rühringer (2018) resulting in the descriptions (see Table 10) about user needs, use purpose, the context of use, usability issues, target audience. These findings will be the support in the selection of the cartographic features, visualisations strategies, content, methods or cartographic rules of the following stages of the UCD process.

Table 10. Summary analysis requirements provided by the first stage of UCD (source: Rühringer, 2018).

User needs	Support the development of European law's, policies and guidelines for conservation and biodiversity, help to monitor activities for conservation and management protected areas.
Use purpose	Provide localization of the spatial analysis of Ecosystem Services information, to communicate ES content to others and also support processes such as the development policies, laws and guidelines and also activities such as monitoring, management and planning at EU, national and subnational levels.
Target audience	Map users: are scientists, government representatives, practitioners
	Map-makers: are Non-Cartographers (professionals with previous knowledge of GIS tools and basics in cartography)
The context of use	The context of use of ecosystem service maps has used in a desktop environment, in the form of static screen maps.

4.2. Map design

Map design is the section of the implementation of the second stage of the UCD process which is called "Produce design solutions" in the methodological framework of this thesis. In this section, the ES prototype maps were designed with the aim of being easy to use by the users in the decision-making process. The ES "Map design process" used the findings and recommendations identified during the usability analysis (see Section 4.1) and helped to determine the case study selection, type of improvements and map elements. The map design process described in Figure 7, is the workflow used to design the ES prototype maps. In this process, the map types of existing ES studies determined. Based on this analysis and the list of maps obtained the example maps for the case study was selected. Before to start the design of the preliminary ES prototype maps the technical aspects and the cartographic elements were defined. For the construction of ES maps, design methods, elements and improvements were applied to create suitable ES maps to be tested against the map users.

4.2.1. Type of map and case study

Map type identification

According to Egoh et al. (2012), ES mapping studies in 2009 doubled by 2011. This search used this period of time provide by Egoh to start the identification of ES maps and continue looking for different type of maps can be represented the variety produce in ES research. As a result, was identified a sample of 20 ES mapping studies for the years between 2012 to 2018, the period in which the increase in the use of ES maps in research was most evident. These maps provided an overview of the type of existing Ecosystem Services (ES) maps, the ES mapping approaches used, map types, a number of maps produced, category and attribute of ES used, place and scale of the studies. From this analysis choropleth maps based on land cover based approach was the most used representations at all scales, followed by dot maps used at the subnational scale. The units used were both qualitative and quantitative, as shown in Table 11.

Case study selection

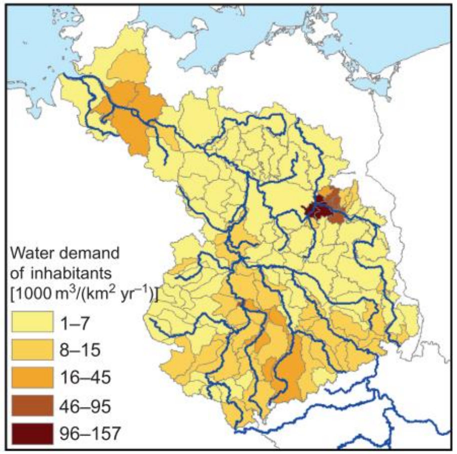
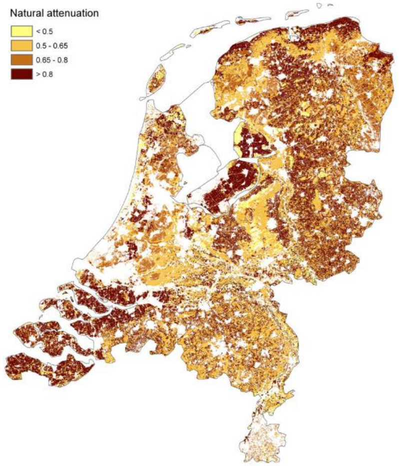
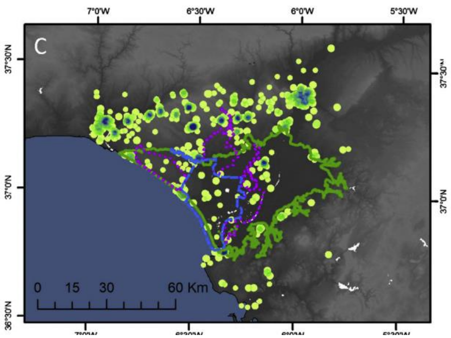
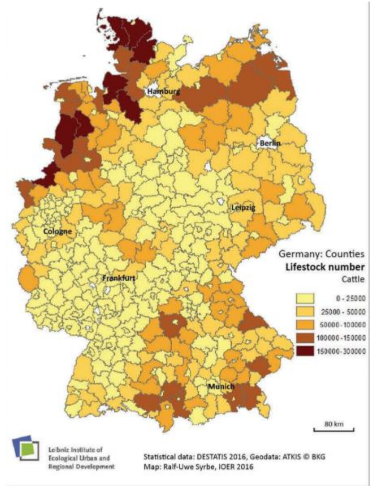
As a result, the case study for this research consists of three examples of ES maps. These maps will be improved in the map design process (see Table 12). These example of maps belong to the following studies and scale levels.

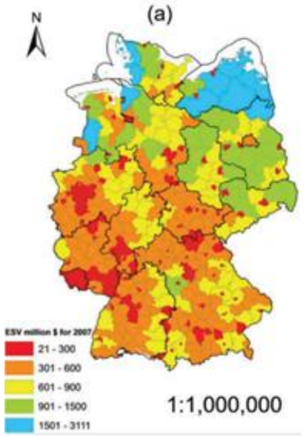
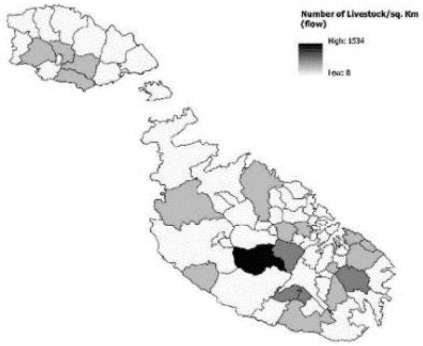
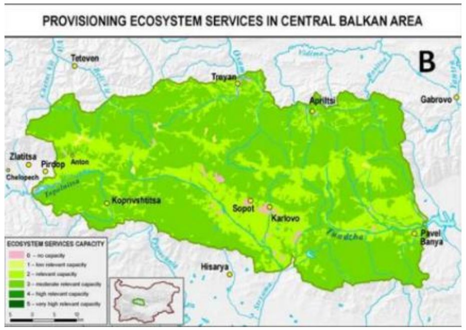
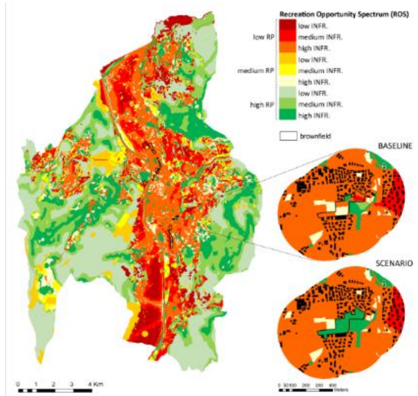
- *Study:* Ecosystem Services supply in protected mountains of Greece: setting the baseline for conservation management.
  Example map one at a national scale: Ecosystem Services supply in protected mountains of Greece (see Table 13).

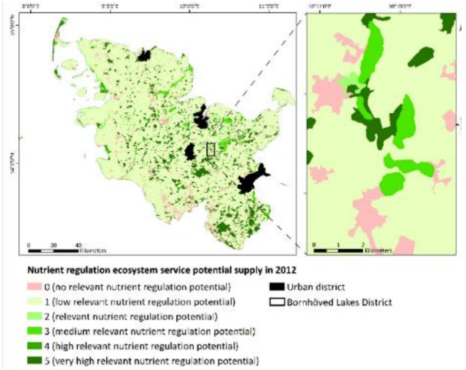
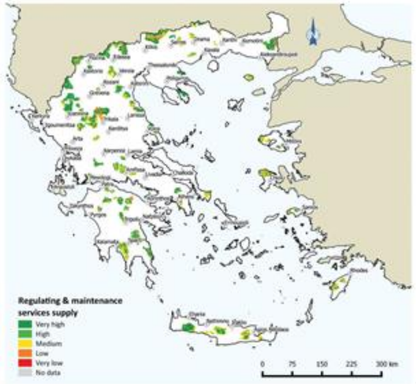
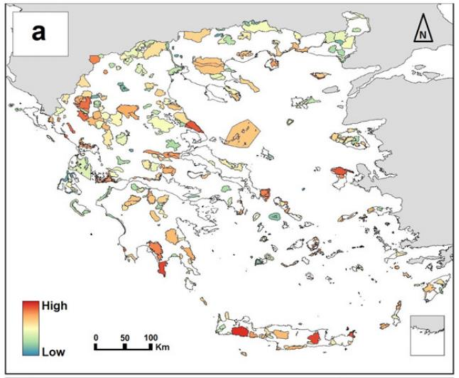
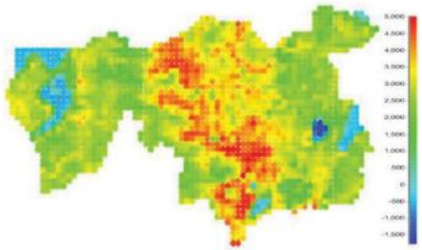
- *Study:* National Parks, buffer zones and surrounding lands: Mapping ecosystem service flows in Spain.
  Example map two at sub-national scale: National Parks, buffer zones and surrounding lands: Mapping ecosystem service flows in Spain (see Table 14)

- *Study:* Mapping ecosystem functions and services in Eastern Europe using global-scale data sets.
  Example map three at sub-national scale: Mapping ecosystem functions and services in Eastern Europe (see Table 15).

Table 11. Mapping ES, examples map

Example map	Description	Example map	Description
	*Title:* Mapping water quality-related ecosystem services: concepts and applications for nitrogen retention and pesticide risk reduction *ES Category:* Provisioning *ES Attribute:* Supply *Location:* The Elbe, Germany *Scale:* Sub-National scale *Type of map:* Choropleth map *Citation:* (Lautenbach et al., 2012)		*Title:* How to calculate the spatial distribution of ecosystem services Natural attenuation as the example from The Netherlands *ES Category:* Provisioning *ES Attribute:* Potential *Location:* Netherlands *Scale:* National scale *Type of map:* Choropleth map *Citation:* (Van Wijnen et al., 2012)
	*Title:* National Parks, buffer zones and surrounding lands: Mapping ecosystem service flow *ES Category:* Provisioning *ES Attribute:* Benefit *Location:* Spain *Scale:* Sub-National scale *Type of map:* Dot map *Citation:* (Palomo, Martín-López, Potschin, Haines-Young, & Montes, 2013)		*Title:* Ecosystem service supply and demand – the challenge to balance spatial mismatches *ES Category:* Provisioning *ES Attribute:* Benefit, supply, demand *Location:* Germany *Scale:* National scale *Type of map:* Choropleth map *Citation:* (Syrbe & Grunewald, 2017)

<table>
<tr>
<td>
</td>
<td>Title: Mapping ecosystem service value in Germany
ES Category: Economic valuation
ES Attribute: Value
Location: Germany
Scale: National scale
Type of map: Choropleth map
Citation: (Jiang, 2018)</td>
<td>
</td>
<td>Title: Assessing the capacity and flow of ecosystem services in multifunctional landscapes: Evidence of a rural-urban gradient in a Mediterranean small island state
ES Category: Provisioning
ES Attribute: Flow, Capacity
Location: Malta
Scale: National scale
Type of map: Choropleth map
Citation: (Balzan, Caruana, & Zammit, 2018)</td>
</tr>
<tr>
<td>
</td>
<td>Title: Towards integrated mapping and assessment of ecosystems and their services in Bulgaria: The Central Balkan case study
ES Category: Provisioning, regulation, cultural
ES Attribute: Capacity
Location: Central Balkan, Bulgaria
Scale: Sub- National scale
Type of map: Choropleth map
Citation: (Nedkov et al., 2018)</td>
<td>
</td>
<td>Title: Mapping and assessing ecosystem services to support urban planning: A case study on brownfield regeneration in Trento, Italy.
ES Category: Regulation, cultural
ES Attribute: Potential
Location: Trento, Italy
Scale: Sub-National scale
Type of map: Choropleth map
Citation: (Cortinovis & Geneletti, 2018)</td>
</tr>
</table>

<table>
<tr>
<td>
</td>
<td>Title: Mapping of nutrient regulating ecosystem service supply and demand on different scales in Schleswig-Holstein, Germany
ES Category: Regulation
ES Attribute: Potential, supply
Location: Holstein, Germany
Scale: Sub-National scale
Type of map: Choropleth map
Citation: (Bicking, Burkhard, Kruse, & Müller, 2018)</td>
<td>
</td>
<td>Title: Ecosystem services supply in protected mountains of Greece: setting the baseline for conservation management
ES Category: Provisioning, regulating
ES Attribute: Supply
Location: Greece
Scale: Sub-National scale
Type of map: Choropleth map
Citation: (Kokkoris, Drakou, Maes, & Dimopoulos, 2018)</td>
</tr>
<tr>
<td>
</td>
<td>Title: Cultural landscapes and attributes of “culturalness” in protected areas: An exploratory assessment in Greece.
ES Category: Cultural
ES Attribute: Potential
Location: Greece
Scale: National scale
Type of map: Choropleth map
Citation: (Vlami et al., 2017)</td>
<td></td>
<td>Title: The multifunctionality of the natural environment through the basic ecosystem services in the Florina region, Greece
ES Category: Provisioning, Regulation, cultural
ES Attribute: Potential
Location: Florina, Greece
Scale: Sub-National scale
Type of map: Choropleth map
Citation: (Kalfas, Zagkas, Raptis, & Zagkas, 2018)</td>
</tr>
</table>

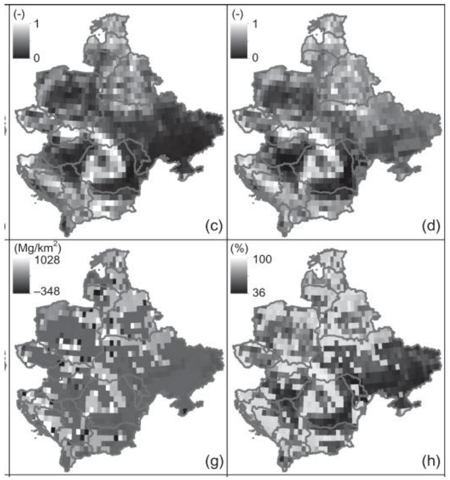
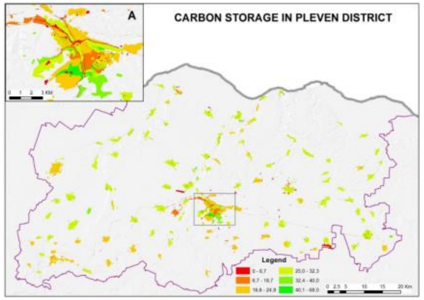
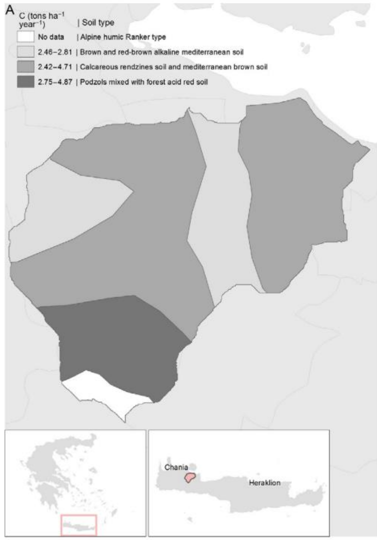
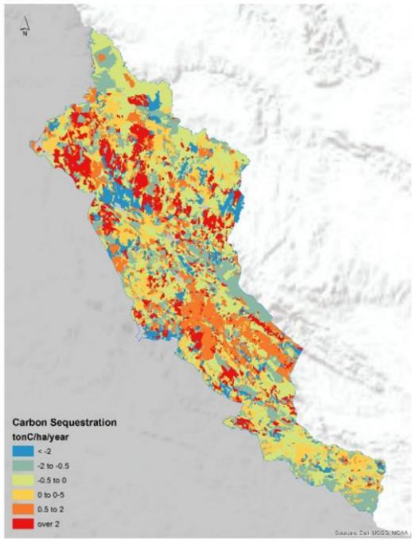
	*Title:* Mapping ecosystem functions and services in Eastern Europe using global-scale data sets *ES Category:* Provisioning, regulating, Cultural *ES Attribute:* Supply *Location:* Eastern Europe *Scale:* EU scale *Type of map:* Choropleth map *Citation:* (Schulp, Alkemade, Klein Goldewijk, & Petz, 2012)		*Title:* Mapping of carbon storage in urban ecosystems: a Case study of Pleven District, Bulgaria *ES Category:* Regulation *ES Attribute:* Supply *Location:* Pleven, Bulgaria *Scale:* Sub-National scale *Type of map:* Choropleth map *Citation:* (Nedkov, Zhiyanski, Nikolova, Gikov, & Nikolov, 2016)
	*Title:* Valuation of Soil Ecosystem Services *ES Category:* Regulation *ES Attribute:* Benefit *Location:* Koiliaris watershed on the Greek island of Crete *Scale:* Sub-National scale *Type of map:* Choropleth map *Citation:* (Jónsson, Davíðsdóttir, & Nikolaidis, 2017)		*Title:* Economic valuation and mapping of Ecosystem Services in the context of protected area management (Natural Park of Serra de São Mamede, Portugal) *ES Category:* Provisioning, regulating, Cultural *ES Attribute:* Benefit *Location:* Natural Park of Serra de São Mamede, Portugal *Scale:* Sub-National scale *Type of map:* Choropleth map *Citation:* (Nedkov et al., 2016)(Marta-Pedroso, Laporta, Gama, & Domingos, 2018)

Table 12. Case study selection

Name	Thematic map type		Based on Approach			Legend units			Scale			# of map		Year
	Dot	Choropleth	PPGIS	Landcover	Model	Quantitative	Qualitative	None	Local	National	EU	Single	Multiple	
Example 1														2018
Example 2														2013
Example 3														2012

Table 13. Example 1 (Ecosystem Services supply in protected mountains of Greece)

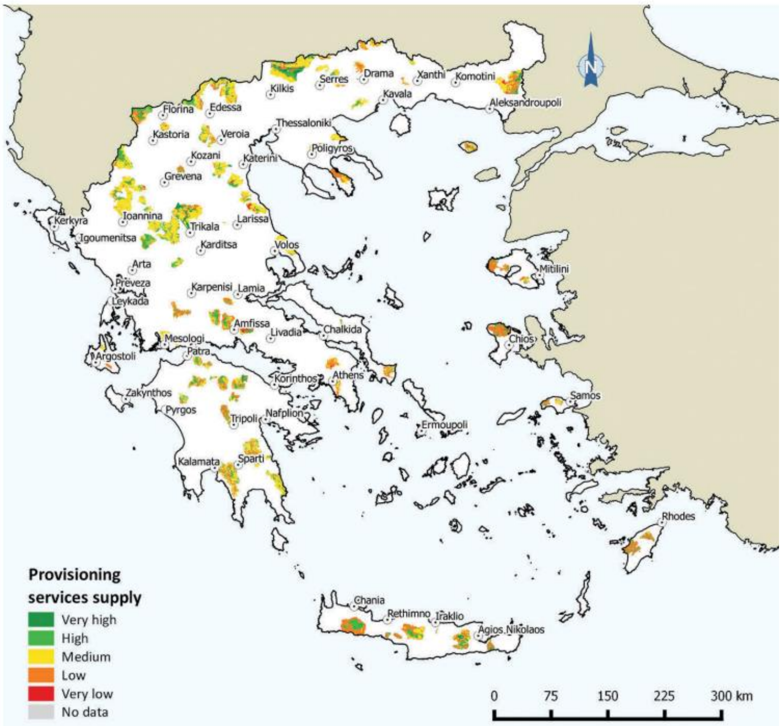
Example 1	
Country	○ Greece
Title of research	○ Ecosystem Services supply in protected mountains of Greece: setting the baseline for conservation management
Scale	○ National
ES category and attributes	○ Provisioning and Supply
Year	○ 2018
Thematic map	○ Choropleth map
Software used	○ GIS tools
Mapped based on the approach	○ Land cover based
Purpose of the study	○ To provide to stakeholders and decision-makers, baseline information for future applied research and conservation management actions
Purpose of the maps	○ Total ES supply map used to identify ES hot spot areas within the Greek Natura 2000 mountainous sites
Legend units	○ Qualitative
Citation	○ (Kokkoris et al., 2018)
Example map one	○ Figure: Spatial distribution of provisioning services at 91 mountainous sites (SACs) in Greece. The proximity to major urban centers is also indicated in the map. 

Table 14. Example 2 (National Parks, buffer zones and surrounding lands: Mapping ecosystem service flows in Spain)

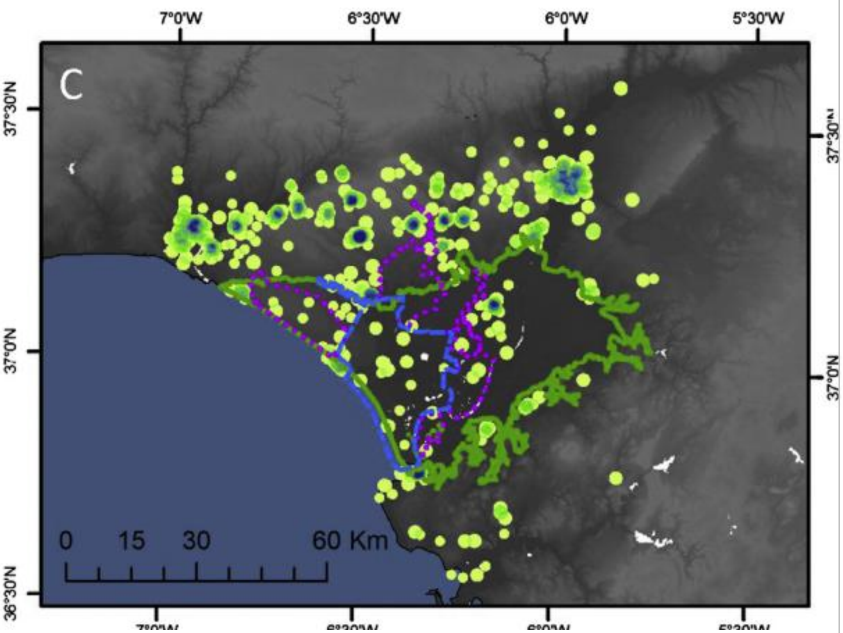
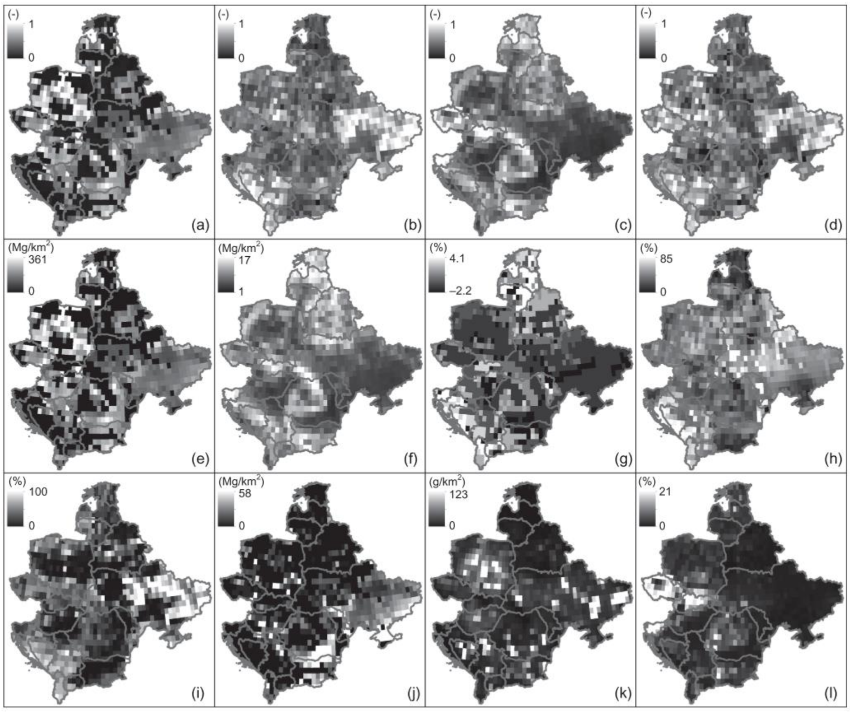
Example 2	
Country	o Spain
Title of research	o National Parks, buffer zones and surrounding lands: Mapping ecosystem service flows
Scale	o Sub-national
ES category and attributes	o Provisioning and Benefit
Year	o 2013
Thematic map	o Dot map
Software used	o GIS tools
Mapped based on the approach	o Participatory GIS
Purpose of the study	o Measure the benefits derived from protected areas and use of ecosystem service maps for conservation planning
Purpose of the maps	o Mapped service provision hotspots, (SPHs), degraded SPHs and service benefiting areas (SBAs).
Legend units	o Qualitative
Citation	o (Palomo et al., 2013)
Example map two	o Figure: Service benefiting areas (SBAs) in the Doñana protected  area, Spain.

Table 15. Example 3 (Mapping ecosystem functions and services in Eastern Europe)

Example 3	
Country	o Eastern Europe
Title of research	o Mapping ecosystem functions and services in Eastern Europe using global-scale data sets
Scale	o EU
ES category and attributes	o Provisioning, regulating, cultural
Year	o 2012
Thematic map	o Choropleth map

Software used	○ GIS tools and environmental assessment model framework
Mapped based on the approach	○ Model-based approach
Purpose of the study	○ To assess a set of models to distinguish changes between the functioning of the ecosystem (Ecosystem Functions - ESFs) and human use of such functions (Ecosystem Services - ESSs).
Purpose of the maps	○ Visualised the availability of ecosystem functions and supply of Ecosystem Services
Legend units	○ Qualitative and quantitative
Citation	○ (Schulp et al., 2012)
Example map three	○ Figure: Availability of ecosystem functions in Eastern Europe and Supply of Ecosystem Services in Eastern Europe 

4.2.2. Map content and technical aspects

Technical aspects

For the identification of the technical aspects Table 2 described in Section 3.2.was used, in which the technical details required in the map design process was specified. The aspects of common uses, type of map, map size, print, were determined based on the context of use "*the context of use of ecosystem service maps has used in a desktop environment, in the form of static screen maps*" (Rühringer, 2018). Scale and orientation were based on the scales of the example maps selected; these three maps were developed for the EU level for East Europe, National level for Greece and sub-national level for the protected areas of Doñana in Spain. The export resolution and export formats were based on the recommendation made in the requirement analysis; export maps (jpg, png formats) with a minimum of resolution between 300 – 400 DPI, and the software was defined based on the expertise of the map maker. As a result, was obtain Table 16 with all the technical aspects.

Table 16. Technical aspects

Aspects	*Description*
Type of map	Static Digital maps
Scale	Small/Medium/Large
Map size	Tabloid (43cm X 28cm)
Orientation	Vertical and Horizontal
Export resolution	300 - 600 DPI
Export formats	JPG, PNG or PDF
Common uses	Reports
Print	Colour
Software	ArcGIS 10.6.1
Number of maps	Individual / Multiple

The map content selection

This task was performed crossing the attributes of the template ES mapping blueprint (see Table 4) provided by Crossman et al. (2013), and the lists of the cartographic elements (see Table 1) Peterson (2015) to decide the main elements for the ES prototype maps. For example, was matched information like the title with the name of the mapping study, the legend with quantification unit, maps with ES maps and localization map. Besides, for this selection the list recommendations derived in the requirement analysis (see Table 9) was used to determine the main element required by the users. The number of elements was determined based on the technical aspects define in Table 16 such as map size, scale, type of map and number of maps and the use purpose of each example map. As a result, a list (see Table 17) with the minimum map content that helps the map-maker to emphasize important information and help the users to understand the map was obtained.

Table 17. Cartographic elements vs Standard attributes for mapping and modeling studies of ES

Primary Elements	***Items from Blueprint template to emphasized***
Title	Name of the mapping study
Subtitle	Mapped ecosystem service
Legend	ES indicator/Quantification unit
Maps	ES Maps and localization map
North arrow	Compulsory
Date	Optional
Authorship	Main investigator
Scale bars	Compulsory
Secondary Elements	
Disclaimer	Only if is required
Data sources	link of the article
Data citations	link of the article
Map number, if series	For multiple maps
Projection	Country projection
Inset maps	Only if is required
Descriptive text	Map explanatory content

4.2.3. Preliminary maps

In the preliminary maps, aspects like the elements for design, type of improvements, methods or cartographic rules to achieve the recommendations for map design provided in requirement analysis were defined, to develop the map composition (layout) and the ES prototype maps. As a result of this step, the preliminary maps of Ecosystem Services for each case study example was obtained.

Elements for design, type of improvements

The map design elements were defined based on the recommendations, usability issues provided by Rühringer (2018) in the requirement analysis, the first stage of UCD (see Section 4.1). According to these recommendations and the issues, the design elements were classified in colour, legend, text, map content, for which the *type of improvement* was determined.

Colour design

Colour has a strong visual impact, it attracts and directs the attention to the reader to the important elements on the map. Designing colours versatility, but it is necessary to be aware that the selection of dissonant colours do not allow the reader to look at the map for more than 10 seconds (Peterson, 2015a; Tyner, 2010). Colours are used to communicate information and for visualization (Borden et al., 2008). The colour scheme makes easier to read and understand the information on the map. This colours can be organised as a sequential, diverging and qualitative schemes to correspond to the data organisation and the ordered data can be numerical or ranked data (Borden et al., 2008; Brewer, 2005).

Issue: Colour vision impairment
Recommendation: use colour combinations that can be distinguished for the most common variations of colour-blindness
Type of improvement: Base the colour selection in the following pairs of hues which are not confused by people with the most common types of colour-blindness and avoid colour-blind confusion (Brewer, 2005):

- Red and blue
- Red and purple
- Brown and purple
- Brown and blue
- Brown and purple
- Yellow and blue
- Yellow and purple
- Yellow and grey
- Blue and grey
- Orange and blue

Issue: Colour scheme and data structure
Recommendation: Select a colour scheme that matches with the structure of the data and colour in the legend
Type of improvement: Apply sequential colour schemes with a hue with incremental changes in and saturation related to numerical range and number of classes. The most fully saturate colour represents higher data values and desaturated or lighter colours represent lower values of the data. As support has used the tool ColorBrewer 2.0.

Legend

The legend is a standard in all layouts to explain the content of the map. It provides the colour and details to help to understand the phenomena mapped; the legend needs to be clear and consistent, can be used as scheme colour to help the user to visualise the relation of the colours on the map. (Kraak & Ormeling, 2010; Peterson, 2015a; Tyner, 2010). In choropleth maps are one of the most important elements, to design can follow some guidelines and conventions (Borden et al., 2008). The number of categories recommended for the legend according to Peterson (2015) is five shades maximum if the hue is the same colour because is the range of the human eye can distinguish shades of the same hue and 10 – 12 maximum for separate colours(Peterson, 2015).

Issue: number of categories and colour in the legend.
Recommendation: select diverging or sequential colours schemes, use the maximum of five hues of the same colour, it is qualitative colour scheme use maximum 10-12 different colours.
Type of improvement: Select for choropleth maps five shades of the same colour or 10 – 12 maximum for separate colours

Issue: legend units
Recommendation: Include units (if available) in the legend.
Type of improvement: Include units in the legend and apply the legend design is the following way; For choropleth maps, the units were included, the legend was placed in boxes in a vertical presentation to allow the map user to read and interpret text and colours correctly. The box size was determined by the size of the texts, the class range units were placed on the right side and the data to the left side, from highest to lowest values from the top to the bottom box. The representation of the legend was in vertical with individual boxes for the colour in one of the maps and with the boxes compressing to give the sensation of data continuity in two of the maps (Borden et al., 2008).

Font
Font choice is important in map design, it can apply to titles, legend, and labels. Moreover, the criteria the map maker needs to select are related to typeface, letter height, width, line thickness, size and colour (Peterson, 2015).

Issue: font size
Recommendation: Legible font size of the map description, map labels, legend labels and title.
Type of improvement: Select a font size between 12 points and 14 for main text and 16 to 20 point for title text to obtain map descriptions, legend, titles legible and understandable according to the use purpose the typefaces Times New Roman and Arial are recommended.

Map content
The map content consists of the basic elements or cartographic elements the map can contain like title, the legend, the scale indicator, north arrow, explanatory texts, frame/border and insets. The task is to include the necessaries elements and to arrange these into a functional composition to achieve effective communication (Borden et al., 2008; Tyner, 2010).

Issue: title, map labels, thematic layers, descriptions
Recommendations: Include a title which describes the intent of the map, either on top or bottom of the layout. Add map layers if is necessary. Add map labels to enhance user understanding. Add explanatory description explaining the map content, adjust the descriptions and map content to the background knowledge of the audience.
Type of improvement: Include the cartographic elements defined in Table 17 which was selected on the basis of each element is necessary to communicate the use purpose and allow the users to perform the related tasks of reading, analysis, interpretation. The elements include are: title, subtitles, labels (only the necessary ones), authorship (the links of the articles and name of the first author) scale bars, projection, inset maps as area location and areas of interest, the descriptive text (map explanatory content) specific for each case and localisation map.

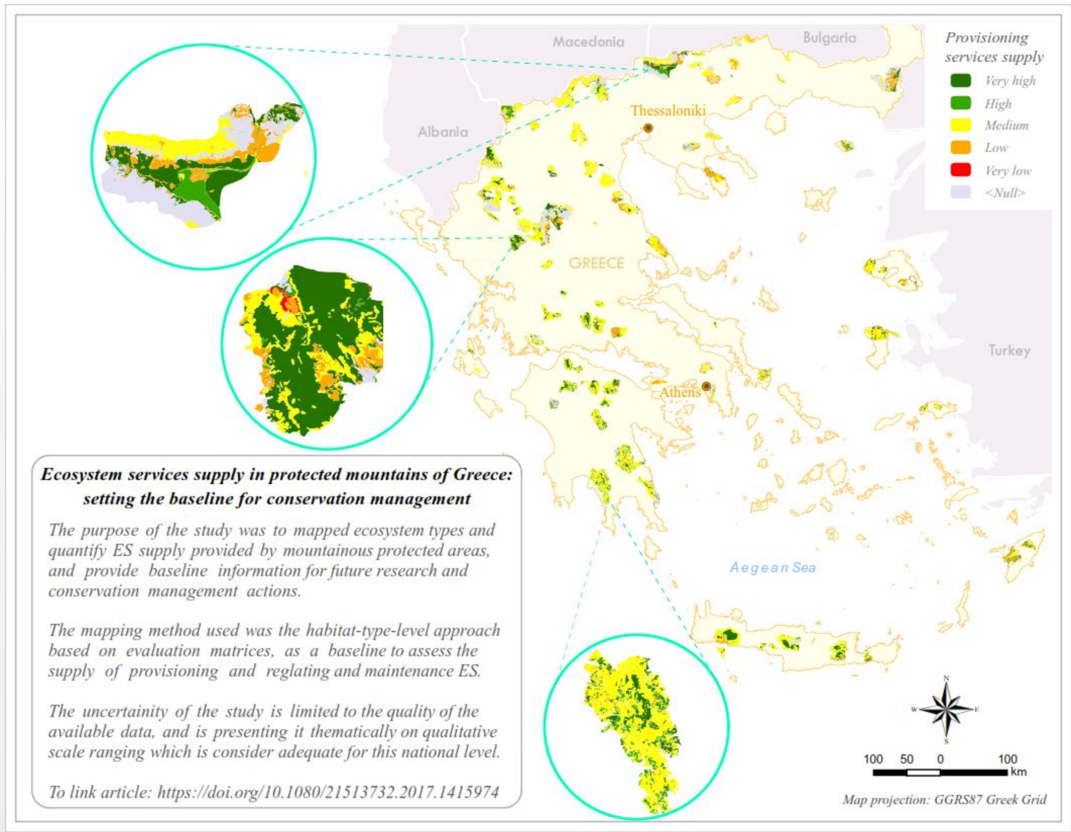
Map composition (layout) and preliminary maps.

The map composition design or layout needs special attention so that it can act as a showcase for all the cartographic elements and give to the users an adequate context of them with which can understand the map (Peterson, 2015b; Tyner, 2010). To evaluate a map aesthetically, it is required to look at these five components harmony, composition, clarity, contrast, balance (Borden et al., 2008; Tyner, 2010).

Taking this into account, the design of the map composition for the three example maps of the case study used all the information determined so far such as map type, cartographic elements, type of improvement, technical aspects. Therefore, the creation of the map composition in ArcGIS per map was possible, looking first "order" for the cartographic elements, which means for the distribution of the elements logically on a page of 43 X 28cm. The template created from these decisions is used for the construction of the three preliminary maps.

Figure 8. Template for the preliminary maps of ES

The creation of the preliminary maps was performed with the implementation of the template and the use of the information from the example maps one, two and three of this research. Each main map is placed on the template to the right side to gain more attention. The map space was larger than the space of the content to allow the user to visualise better the ES data. It was avoided leaving big white spaces without information, always trying to give a good balance and harmony to the map and all the elements together. The contrast and the clarity on the maps it handled, for example, emphasizing the important areas of interest, putting the names the urban areas to help the users to locate the information and make the relationship with the ES data. Different font size and varying the line thickness in the boundaries were used. As a result, three preliminary maps to be used in map production step to finalised the process (see Figure 9 and Figure 10).



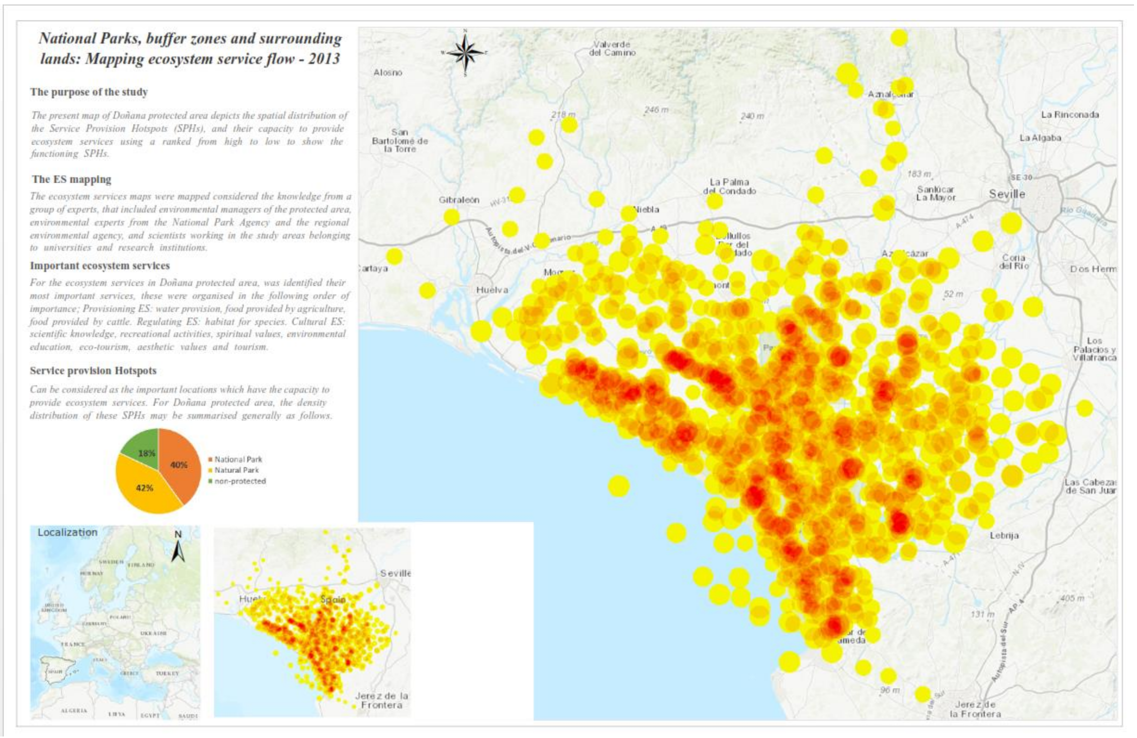


Figure 9. Preliminary maps produce for example map one (above) and example map two (below)

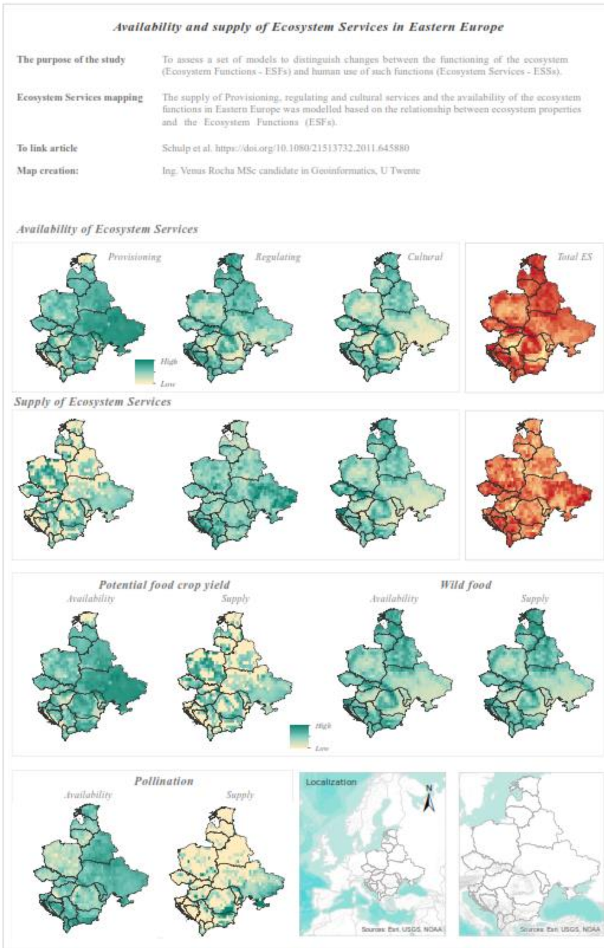


Figure 10. Preliminary map for example map three

4.2.4. Ecosystem Services map production

The map production is the step in which the ES map prototypes are elaborated. The creation of each example map used ArcGIS Desktop 10.6.1. and the sketches of the element arrangements obtained from the preliminary maps (step 3). Moreover, the cartographic rules were applied to improve the usability issues related to texts, colours, legend and map content based on the map type of the example maps. The outcomes of this section are the map prototypes in PDF format, that were tested by representative users of ES maps. Example maps one and two are used in phase one and example map three is tested in phase two of the usability evaluation.

Example map one – national scale

The first example is an individual map based on the data from the study "Ecosystem Services supply in protected mountains of Greece: setting the baseline for conservation management" by Kokkoris et al. (2018), the input data of this study correspond to the spatial distribution of provisioning services at 91 mountainous sites (SACs) in Greece (see Figure 11).

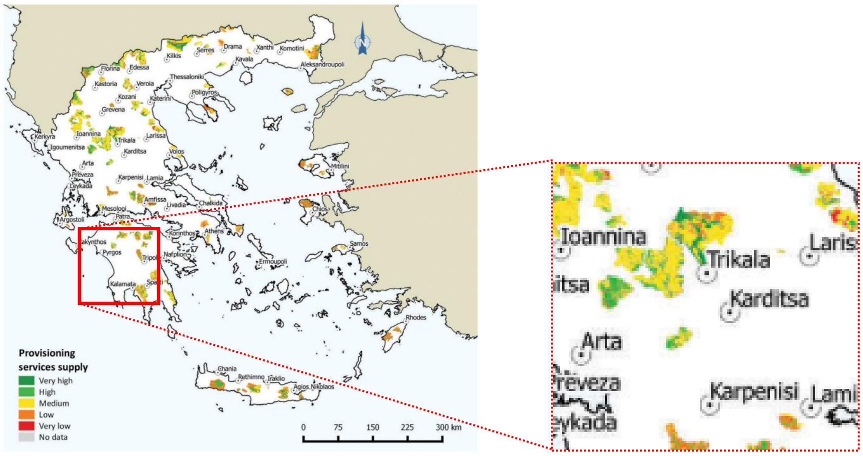


Figure 11 Example map one, by Kokkoris et al. (2018)

The type of improvements and methods applied were defined based on the Choropleth map type and the recommendations provided during the user requirement analysis.

The **colour** design was based on the choropleth technique which is usually used to depict bounded areal classified or aggregated data. Through the use of this technique, the map user can have the sense of the geographic pattern of the provisioning services supply with attention to high, medium and low capacity values associated to the protected mountain areas of Greece and also allow them to distinguish the individual values over the area when they read the map. The scheme colour selected was sequential with a hue with incremental changes in lightness and saturation corresponding to the qualitative range in this case high, medium, low and no data, associate to four classes. The dark colour represents areas with the high supply of provisioning services and lighter colours represent areas with the low supply of provisioning services. This task was supported by the tool online ColorBrewer 2.0.

Another important aspect regarding the improvement of this map was the **legend** which in a choropleth map is very important to provide the colour and details of the map. The legend design consisted in two steps: first, the reduction from six to four categories to facilitate the map reading to allow users to perceive better the differences between the areas with the high, medium and low supply of provisioning services. Second, the design of conventions as the box shape, size, orientation and range placement. For the box shape was chosen a rectangular form, their display in vertical, the class ranges and units were placed in the right side from the highest (dark colour) to lowest (light colour) from the top to the bottom box, which is a presentation that provides a visual anchor for the map user interpret the provisioning services supply and texts correctly.

The **map content** used the template organised in step 3, this template was modified as the design process moved forward. The cartographic elements were arranged in the following way: the main map of the supply of provisioning services at the centre of the page and the cartographic elements and explanatory text placed to the left side, around the main map the inset maps corresponding a set of circles with the maps of areas of highest provisioning Ecosystem Services supply. The selection of the inset maps which are usually used to clarify, gain scale and focus on these small areas, was the solution to point out the small areas and allow the map users to visualise some results in detail. The criterion to select these six maps was correspondence with six protected mountainous areas identified in the study as the important sites of the highest supply of provisioning Ecosystem Services. As a result, a static digital map in PDF format was obtained, which can be viewed well through the use of zoom tools (Borden et al., 2008; Burkhard & Maes, 2017). Map (prototype) "Ecosystem Services supply in protected mountains of Greece – 2018" can be viewed in Figure 12.

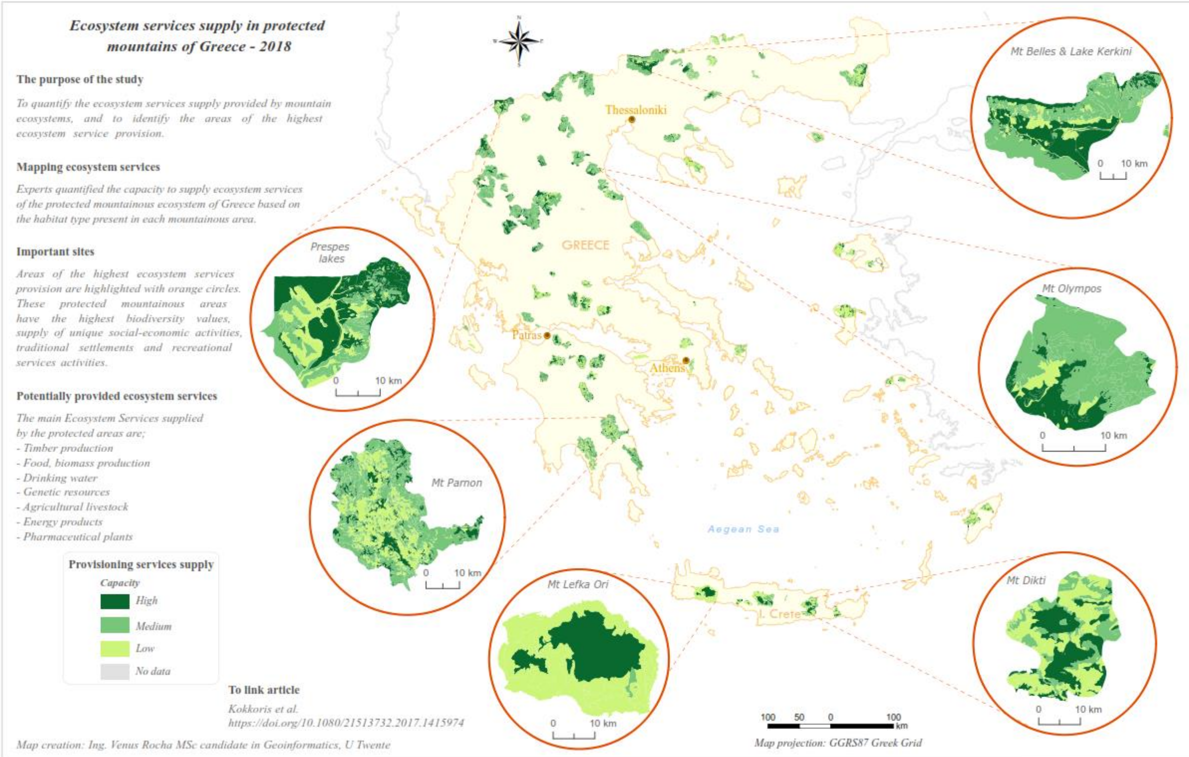


Figure 12. Example map 1 "Ecosystem Services supply in protected mountains of Greece – 2018"

Example map two – sub-national scale

The second example is an individual map which uses data from the study "National parks, buffer zones and surroundings lands: Mapping ecosystem service flows" by Palomo et al. (2013). The input data of this study was the perceived capacity of Ecosystem Services provision hotspots (SPHs) in Doñana protected area (National Park, Natural Park and the Greater Ecosystem of Doñana), resulted from the identification by experts through the use of participatory mapping techniques (PPGIS) in Spain. The study is located on the south-western coast of Spain at the sub-national scale (see Figure 13).

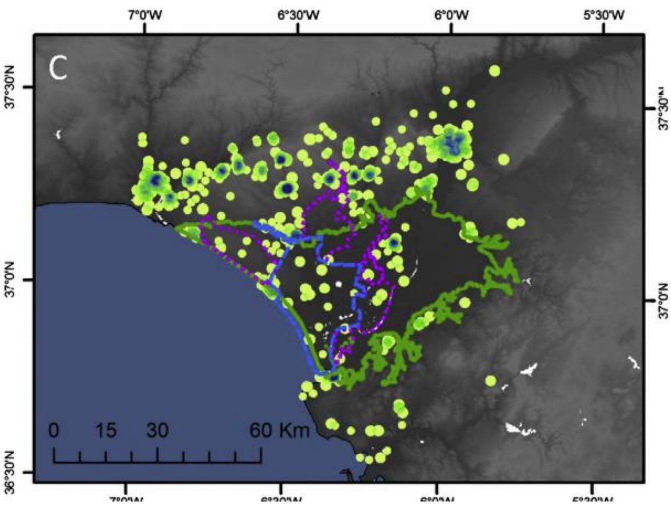


Figure 13. Example map 2 by Palomo et al. (2013)

The type of improvements and method applied were defined based on the Choropleth map type and the recommendations provided by the first stage of UCD.

The **colour** design was based in the choropleth technique which is usually used to depict bounded areal classified or aggregated data. Through the use of this technique, the map user can have the sense of the geographic pattern of the ES provision hotspots (SPHs) perceived capacity in Doñana protected area. With attention to high, medium and low capacity values associated to the perceived capacity in Doñana protected area in Spain and also allow them to find the differences between high and low perceived capacity over the protected area of Doñana. The scheme colour for this map also was sequential with a hue with incremental changes in lightness and saturation corresponding to the qualitative range, in this case, high and low. The most saturated colour represents areas with high perceive capacity of ES provision hotspots (SPHs) and desaturated colours represent areas with low perceive capacity of ES provision hotspots (SPHs).

Another aspect was the **legend** design which consisted of two steps: first, the distinction between class ranges was made to perceive better the differences in density of the hotspots between the areas with high, medium and low ES perceived capacity. Second, was designing the conventions as the box shape, size, orientation and range placement. The box shape also was chosen as rectangular, the class ranges and units were placed in the right side from the dark colour (High capacity) to the light colour (Low capacity), the colour scheme compressed to offer to the map a sense of continuity of the data. This type of presentation provides a visual anchor for the map user to read the texts correctly and interpret the density of the perceived capacity of ES provision hotspots.

The **map content** was based on the template performed in step 3; this template changed as implementation proceeded. The cartographic elements were organised in the following way: the main map of Ecosystem Services provision hotspots (SPHs) at the right side and the map content, map localization and cartographic elements were ordered to the left side of the map. This allowed to have content and map localization together and create a map composition that describes well the map to the map users and at the same time maintains the visual balance. The composition was established for each element of the map a visual hierarchy, to give unequal visual weight to the cartographic elements and allow the users to read the map easily (e.g. the data of the perceived capacity is the most attractive element on the map in comparison with the base map, because the colours are followed by the boundaries of the protected of Doñana which have a different colour, thickness and type of line to allow to read the different areas). Another aspect essential to improve in this map was the base map, necessary to provide locational information about the Ecosystem Service provision hotspots (SPHs) and the Doñana boundaries. Hence, it was important to select one that offered simplicity and clarity of the thematic information and facilitates the map reading, analysis and interpretation of the map users, this was selected from the catalog of the ArcGIS software. As a result, a static digital map in PDF format called Map prototype "Ecosystem Service map for Doñana National Park, Spain - 2013" was obtained, which can be viewed in Figure 14.

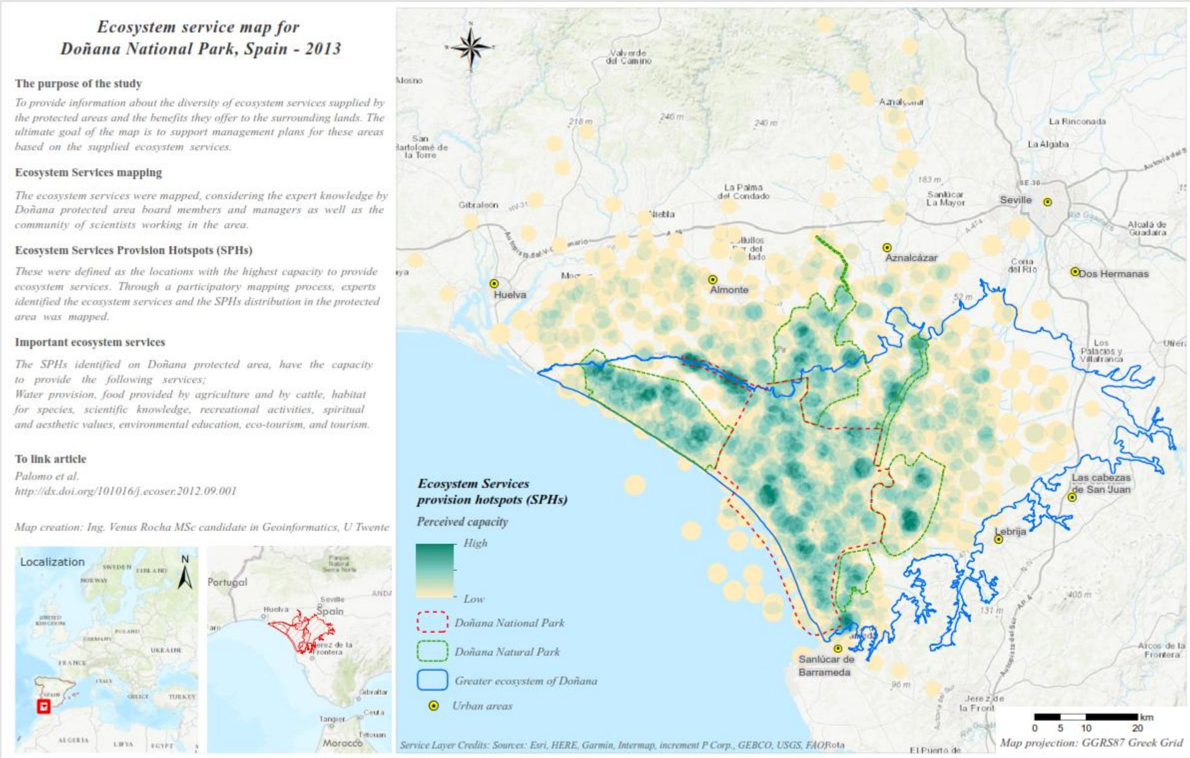


Figure 14. Example map 2 "Ecosystem Service map for Doñana National Park, Spain - 2013"

Example map three

The third example consists of multiple maps developed based on the data from the study "Mapping ecosystem functions and services in Eastern Europe using global scale datasets" by Schulp et al. (2012), the input data of this study was the availability of Ecosystem Functions (ESFs) and the supply of Ecosystem Services (ESSs) in Eastern Europe (see Figure 15).

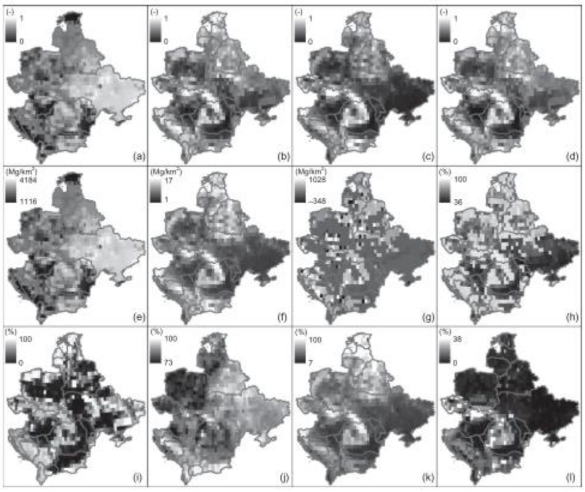


Figure 15. Example map 3 by Schulp et al. (2012).

The type of improvements and methods applied in this map were defined based on the Choropleth map type and the recommendations provided by the first stage of UCD.

The **colour** design was also based in the choropleth technique which is usually used to depict bounded areal classified or aggregated data. Through the use of this technique, the map user can have the sense of the geographic pattern of the availability of Ecosystem Functions (ESFs) and supply of Ecosystem Services (ESSs) in Eastern Europe, with attention to high and low values, which allows identification of following differences:

1) Between the high and low availability of Ecosystem Functions (ESFs).
2) Between the high and low supply of Ecosystem Services (ESSs).
3) Between the availability of (ESFs) and supply of (ESSs) per category and per service.
4) Between the overall availability of (ESFs) and overall supply of (ESSs).

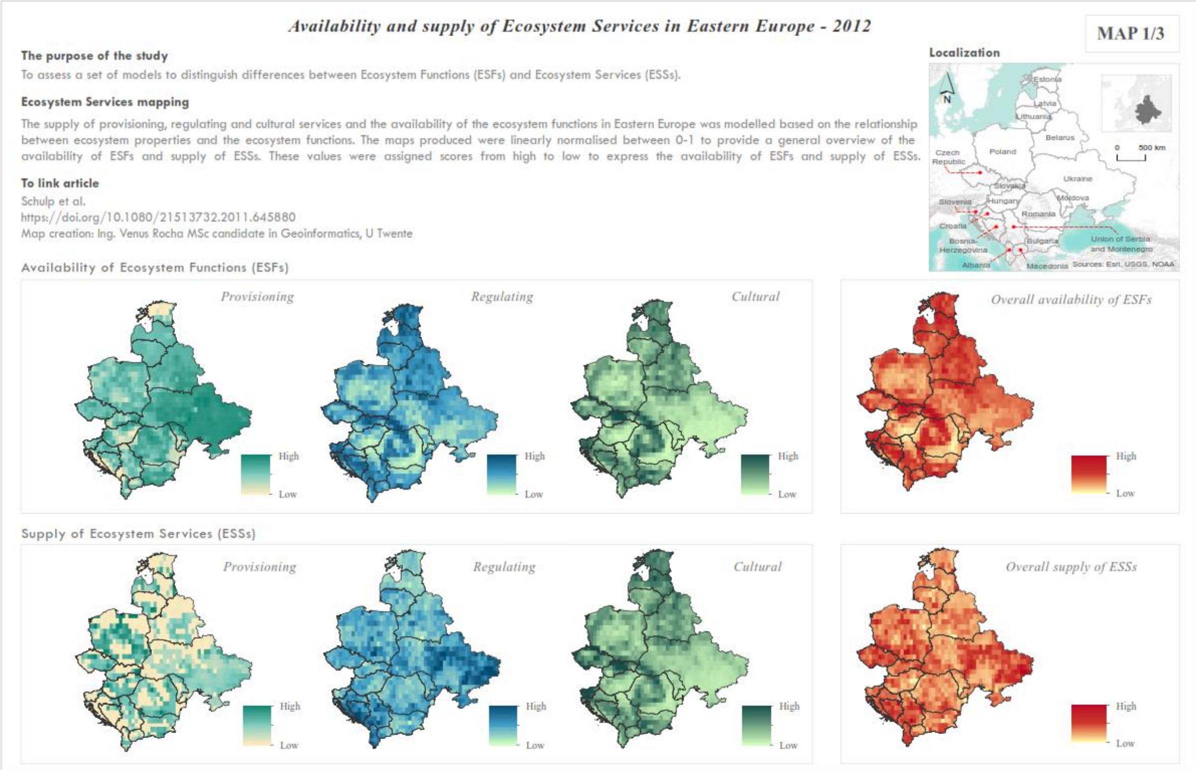
The scheme **colour** selected also was sequential for each map with a hue with incremental changes in lightness and saturation corresponding to the qualitative (ES categories and overall results) and numerical (input services) range according to the map. The dark colours represent areas with high availability or supply and lighter colours represent areas with low availability or supply. Furthermore, the scheme colour was associated with each ES category (provisioning, regulating, cultural) to facilitate the relationship between results and input services (e.g. erosion potential, air quality and pollination are input services of the regulating category).

The **legend** design consisted of two steps: first, the distinction between class ranges to perceive better the differences in the area with high and low values.
1) availability and supply of EFS and ESS,
2) availability between ES categories and services
4) supply between ES categories and services

Second, the conventions as the box shape, size, orientation and range placement was design. For the box shape was also chosen a rectangular form, the class ranges and units were placed in the right side from the highest values to lowest values (from the top to the bottom box), the colour scheme also was compressed to have a sense of continuity of the data. This type of presentation provides a visual anchor for the map user read the texts correctly and interpret the availability of ecosystem functions (ESFs) and the supply of Ecosystem Services (ESSs) per ES category and services.

The **map content** used the cartographic elements in the following way for the three maps: the main maps of the availability of ecosystem functions (ESFs) and the supply of Ecosystem Services (ESSs) at the bottom of the page and the explanatory description, map localization and cartographic elements were ordered on top of the page. This arrangement allowed me to have multiple maps and the content at the same time, to be able to describe both users without losing attention in the map content and maintaining the visual balance.

For the map design and implementation of this case was necessary three maps, the reason to divide the maps into three groups that the study has 24 individual maps between categories, overall results and input services, which not fit neatly into a map size of 43 x 28cm to make a good composition. The 24 maps were distributed into three maps to allow the users to understand and compare the spatial relationship between the availability of Ecosystem Functions (ESFs) and the supply of Ecosystem Services (ESSs). The first map (see Figure 12), consisted of the results of availability and supply for the ES categories and the overall result for availability (ESFs) and the supply of (ESSs). The second and third map (see Figure 13), consisted of the maps of availability and supply services, which are the input services that make up the ES categories. As a result, three static digital maps in PDF format called "Availability and supply of Ecosystem Services in Eastern Europe - 2012" were obtained, which can be viewed in Figure 16 and Figure 17.



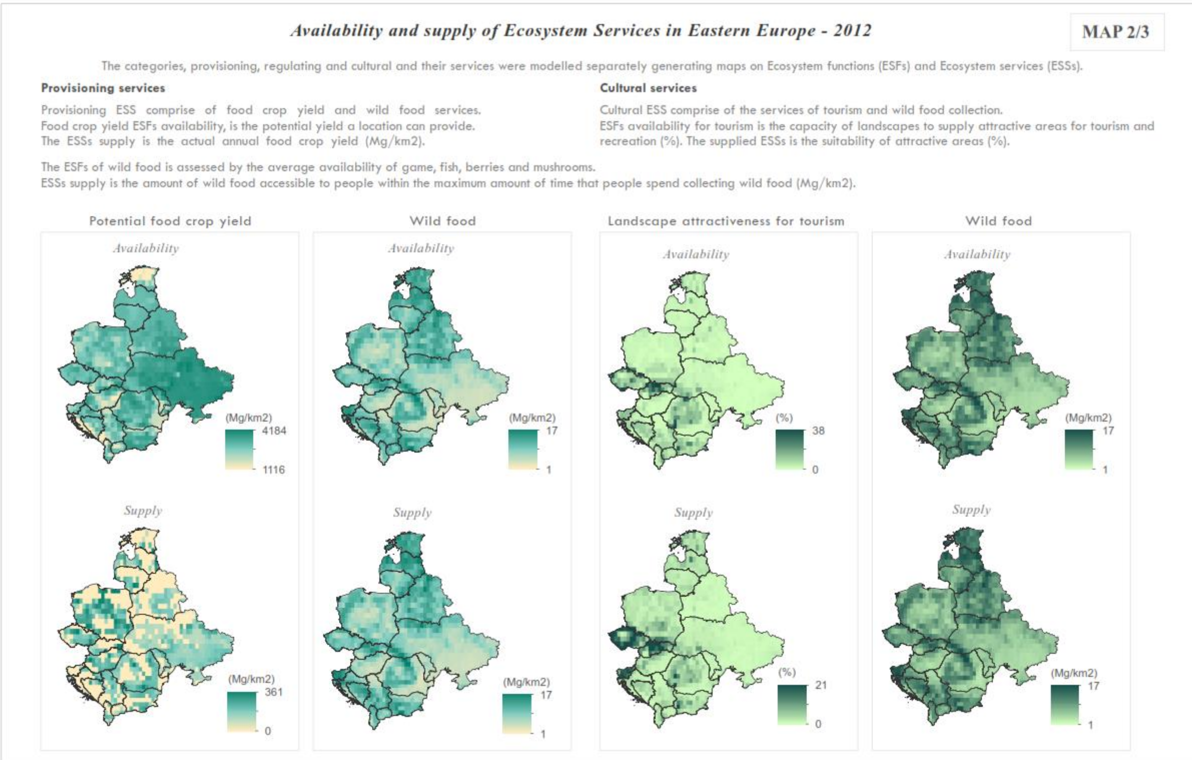


Figure 16. Example map 3, (above map 1 and below map 2)

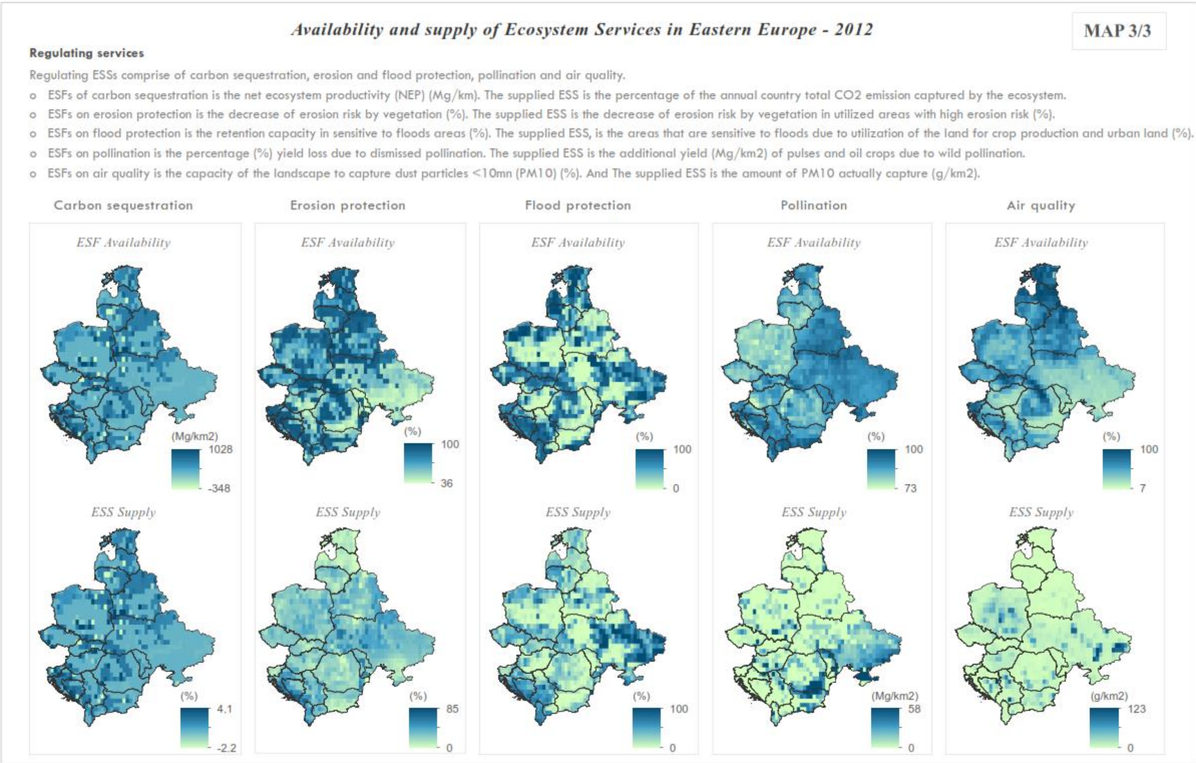


Figure 17. Example map 3 (map 3)

4.3. Summary

The design solutions and implementation used the information on the requirements analysis (first stage of UCD) executed by Rühringer (2018). The recommendations of this first stage were the basis to determine the improvements for the usability issues of the example maps of ES of the case study of this research. Based on these improvements the methods or cartographic rules that can help to improve the design elements of the ES prototypes were defined. The technical aspects were determined based on the context of use provided in the requirement analysis to define their characteristics, and the map content was determined with the help of the checklist of cartographic elements, the blueprint template for ES mapping and the recommendations. The ES prototypes maps were elaborate through the application of the type of improvements, methods and rules, technical aspects and cartographic elements. The creation of the ES prototypes maps was carried out in ArcGIS software and as an outcome three ES prototype maps were obtained and tested in the usability evaluation stage.

5. USABILITY EVALUATION (IMPLEMENTATION AND RESULTS)

The focus of this chapter is to describe the implementation of the usability evaluation and results of the online survey used to assess the prototype maps of Ecosystem Services and so determine the use and design issues. This chapter has three sections. Section 5.1 describes the implementation of the usability evaluation, participants, geographic questions and survey. Section 5.2 describes the results obtained from phase one and phase two of the usability evaluation. Section 5.3 is a summary of the chapter.

5.1. Usability evaluation (implementation)

Usability evaluation is the third stage of the UCD approach. This evaluation was qualitative research to assess a set of static maps of ES through a survey which was the result of the combination of the methods questionnaire and remote unmoderated usability test. These methods allowed to reach out to a broader audience of ES users remotely. The survey was created online in a maptionnaire and was carried out in two phases, the first to evaluated the initial prototype maps and the second to test the improve prototype maps. Each phase required at least 10 test persons (TPs) of representative users of ES maps.

Table 18. Usability evaluation characteristics

Type of user research	o Qualitative
The goal of the test	o To determine use and design issues of a set of cartographic maps (prototypes) of Ecosystem Services.
Type of maps to assess	o Static maps of Ecosystem Services
Usability method	o Combination (Questionnaire and Remote unmoderated usability test) o Satisfaction questionnaire
Environment	o Online and printed
Minimum of test persons	o 10 persons
Plan	o Test initial prototypes o Test improved prototypes

5.1.1. Implementation (Phase I)

Participants

For this usability evaluation, the TPs were representative users identified as current or potential users or/and map-makers that belong to Europe and work with Ecosystem Services or take decisions regarding these of maps. These TPs were divided into two instances to carry out usability evaluation. The first instance tested the initial ES prototype maps one and two at national and subnational scales that belong the studies "Ecosystem Services supply in protected mountains of Greece: setting the baseline for conservation management" by Kokkoris et al. (2018). And "National parks, buffer zones and surroundings lands: Mapping ecosystem service flows" by Palomo et al. (2013), by representative users from Cyprus (national level) and Greece at National and (sub-national level) (see Table 19).

Table 19. Test Persons (TPs) details in phase one of the usability evaluation.

User profile	o Hybrid (*participants acting as map-makers and map-users)* o Map-user (*Policymakers, decisionmaker in public administration, the scientific community, environmental managers*)
To test initials map prototypes of ES	o Workshop of Ecosystem Services, Cyprus (TPs from Greece and Cyprus)
Administrative level	o National o Sub-national

Geographic questions

The TPs for the online survey carried out a set of six tasks related to map use sequence: reading, analysis and interpreting, to solve the geographic questions developed of each map prototype. The geographic questions were organised by level of complexity, 1) elementary, 2) intermediate and 3) overall. These questions supported the identification of the use and design problems of the ES prototype maps. Likewise, helped to determine the effectiveness, efficiency and satisfaction of the maps. In table 20 the questions refer to phase one.

Table 20. The map questions, difficulty level and task-related for the prototype maps in phase one of the usability evaluation.

Map	Difficulty level	Geographic questions	Task	Map questions
Prototype map one at national scale	Elementary	What is there?	to **identify** objects	1) What types of Ecosystem Service (ES) are represented on the map?
	Elementary	Where is that geographic object?	to **locate** an object	2) Prespes Lakes was identified as one of the areas with the highest Ecosystem Services capacity of provision. Where is Prespes Lakes located?
	Intermediate	Where is the most / least?	to **quantify** spatial anomalies	3) Please consider the map of Greece only (i.e. do not look at the maps in the circles). In which part of Greece are most areas with a high provisioning service supply?
	Intermediate	Where is the most / least?	to **quantify** spatial anomalies	4) Please consider the map of Greece only (i.e. do not look at the maps in the circles). In which part of Greece are most areas with a low provisioning service supply?
	Overall	What are the region's geographic characteristics?	to **obtain** insight into an overview of the region	5) What is the protected mountain with the highest area (number of km2) of provisioning services?
Prototype map two at subnational scale	Elementary	What is there?	to **identify** objects	1) What types of Ecosystem Services (ES) are depicted on the map?
	Elementary	Where is that geographic object?	to **locate** an object	2) The area to the south of Almonte (between Almonte and the coast) is the area with the highest density of SPH's. Where is this area located?

	Intermediate	Where is the most / least?	to quantify spatial anomalies	3) Where is the area with the highest ecosystem SPHs located?
	Intermediate	Where is the most / least?	to quantify spatial anomalies	4) Where is the area with the lowest capacity to supply SPHs located?
	Intermediate	What is near that geographic object?	to position with respect to other objects	5) Which urban area is the closest to a SPHs with high capacity?
	Intermediate	What is near that geographic object?	to position with respect to other objects	6) Which urban area is the closest to a SPHs with a low capacity?

Survey

The ES survey was conducted in the ES workshop in Cyprus on 5 December and extended to 11 December 2018 to be able to have more surveys complete from the online survey. In this survey the test participants were divided into two groups: The first group corresponds to those TPs have their laptops at the moment of the event, these received by mail the following link (https://app.maptionnaire.com/es/5178/) to conducted the online survey. The second group consisted of the TPs did not bring their laptop to the event, for them was distributed the survey printed.

Figure 18. The Ecosystem Services maps survey in Maptionnaire, usability evaluation- Phase one.

5.1.2. Implementation (Phase II)

Participants

For this phase, the second instance tested the improve ES prototype maps of example map one and two and the initial prototype map three through the participation of TPs from Greece and the European ESP as representatives of the EU and national levels (see Table 21).

Table 21. Test Persons (TPs) details in phase two of the usability evaluation.

User profile	○ Hybrid (*participants acting as map-makers and map-users)* ○ Map-user (*Policymakers, decisionmaker in public administration, the scientific community, environmental managers*)
To test the improved map prototypes of ES	○ The Ecosystem Services Partnership (ESP) ○ University of Patras, Greece
Administrative level	○ EU ○ National

Geographic questions

In the following table 22, the questions make reference to phase two. Some of the questions from phase one were changed in the second phase of the usability evaluation to improve the responses from the TPs with the task assigned.

Table 22. The map questions, difficulty level and task-related for the prototype maps in phase two of the usability evaluation.

Map	Difficulty level	Geographic questions	Task	Map questions
Prototype map one at national scale	Elementary	What is there?	to **identify** objects	1) What types of Ecosystem Service (ES) are represented on the map?
	Elementary	Where is that geographic object?	to **locate** an object	2) Prespes Lakes was identified as one of the areas with the highest Ecosystem Services capacity of provision. Where is Prespes Lakes located?
	Intermediate	Where is the most / least?	to **quantify** spatial anomalies	3) Please consider the map of Greece only (i.e. do not look at the maps in the circles). In which part of Greece are most areas with a high provisioning service supply?
	Intermediate	Where is the most / least?	to **quantify** spatial anomalies	4) Please consider the map of Greece only (i.e. do not look at the maps in the circles). In which part of Greece are most areas with a low provisioning service supply?
	Overall	What are the region's geographic characteristics?	to **obtain** insight into an overview of the region	*5)* What is the protected mountain with the largest area (number of km2) of provisioning services?
Prototype map two at subnational scale	Elementary	What is there?	to **identify** objects	1) What types of Ecosystem Services (ES) are depicted on the map?
	Elementary	Where is that geographic object?	to **locate** an object	2) The area to the south of Almonte (between Almonte and the coast) is the area with the highest perceived capacity of SPH's. Where is this area located?
	Intermediate	Where is the most / least?	to **quantify** spatial anomalies	3) Within the greater ecosystem of Doñana, where is the area with the highest concentration of ecosystem SPHs with high

				capacity?
	Intermediate	Where is the most / least?	to **quantify** spatial anomalies	4) Within the greater ecosystem of Doñana, where is the area with almost only ecosystem SPHs with a low capacity?
	Intermediate	What is near that geographic object?	to **position** with respect to other objects	5) Which urban area is the closest to a SPHs with high capacity?
	Intermediate	What is near that geographic object?	to **position** with respect to other objects	6) Which urban area is the closest to a SPHs with a low capacity?
Prototype map three at EU scale	Elementary	What is there?	to **identify** objects	1) What categories of Ecosystem Functions are represented on the map?
	Elementary	What is there?	to **identify** objects	2) Which services were used as input for the provisioning ecosystem service map (ESSs) map? (select two please)
	Intermediate	Where is the most / least?	to **quantify** spatial anomalies	3) Which two countries can be identified in Eastern Europe with the highest overall supply of Ecosystem Services that approximately covers all national territory?
	Intermediate	Is that geographic object linked to other objects?	to **encounter** spatial linkages	4) Considering the whole of Eastern Europe, for which category of Ecosystem Services (provisioning, regulating or cultural) are the distribution patterns of the availability of ESFs and the supply of ESSs most similar?
	Intermediate	Is that geographic object linked to other objects?	to **encounter** spatial linkages	5) Please, look at the maps of ESF availability and ESS supply of air quality service. What of the following options describes the spatial relationship between the ESFs availability and ESSs supply of the air quality service?

Survey

In the second phase, TPs from Greece and the European ESP (representative users at national and EU level) tested the improved ES prototype maps one and two and the initial prototype map three belong to the study "Mapping ecosystem functions and services in Eastern Europe using global scale datasets" by Schulp et al. (2012). The online survey consisted of a set of geographic and satisfaction questions made to test the use of ES prototype maps, entirely online and was carried out between 28 January to 3 February 2019 with the TPs from Greece and 5 February to 11 February 2019 with the TPs form ESP. For this survey, the TPs were contacted by mail through an invitation. To have random answers of the ES survey, was create three surveys online with a different order for map sections. The surveys links were sent the TPs of ESP by mail. For Greece before sending it to the TPs, the three links of the online surveys were assigned randomly to each mail.

Figure 19. The Ecosystem Services maps survey in Maptionnaire, usability evaluation- Phase two.

5.2. Usability evaluation (Results)

5.2.1. Results phase I

The first phase of usability evaluation was performed in Cyprus during a workshop of Ecosystem Services 5 December to 11 December 2018. The initials prototypes example maps one and two of the case study were the focus of this first part. For this workshop was used two types of surveys online and printed. Performing the survey both online and printed, given the opportunity to compare the answers from the use of digital and printed maps and so determined if there are important differences between the answers.

Initial information

The usability evaluation part two was carried out by participants from Greece and the Ecosystem Services Partnership (ESP). The prototype maps of examples one and two for this part of the evaluation were adjusted according to the findings of the usability test part one. The online survey was carried out in total by 19 test persons (TPs), among whom 16TPs complete all the survey while 2TPs did not finish and 1TP did not answer. As shown in Figure 17, a high proportion of the TPs have Doctorate as the highest completed education level, followed by Master degree education level. Most of the TPs indicated they had experience producing them and using ES maps and those who do not have experience producing demonstrated interest to do it in the future. The 15TPs who has experience using this kind of maps has used these for policy decision but mostly for scientific consultation (see Figure 20).

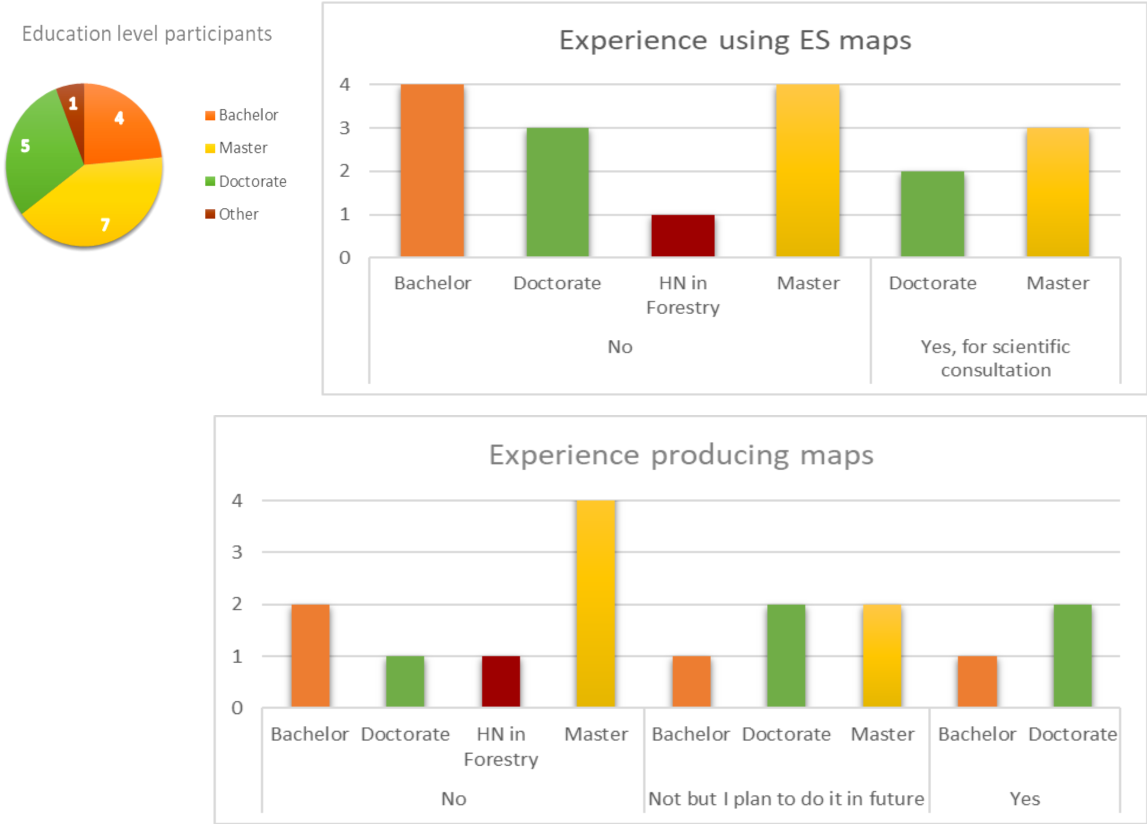


Figure 20. Education level, experience using and producing ES maps – Phase I

ES prototype map (example map one – National level)

The analysis of the answers related to the Geographic questions about the ES prototype map one called "Ecosystem Services supply in protected mountains of Greece – 2018", was performed observing the responses of each geographic question and interpreting how the Test Persons (TPs) answered the tasks assigned, as shall we see below.

- In the first two questions classified with an elementary level of complexity, the TPs were asked What types of Ecosystem Service (ES) categories are represented on the map? and Prespes Lakes was identified as one of the areas with the highest Ecosystem Services capacity of provision. Where is Prespes Lakes located?

The results showed that 11Test Persons (TPs) understood and recognised the provisioning as the ES represented on the map and 17TPs located Prespes Lakes closer to Thessaloniki than to Athens. While 6TPs answered the ES represented on the map were all the ES categories. These answers show that most of the TPs correctly answered both questions, but for some of them, the map in terms of what type of ES is still was not sufficiently clear. Perhaps some problems were, for instance, missing keywords in the explanatory text to clarify better what ES categories are represented on the map, or lack of attention by TPs to the details on the map like the legend title.

- Questions three and four with intermediate complexity level were asked the TPs, Please, consider the map of Greece only (i.e. do not look at the maps in the circles). In which part of Greece are most areas with a high provisioning service supply? and in which part of Greece are most areas with a low provisioning service supply?

These two questions were open-ended to allow the TPs to reply naturally about where the areas are located. The answers showed that most of the TPs locate the areas with high provisioning supply at North of Greece and the areas with low provisioning supply to the South of Greece which is the right answers. Other answers were: 1TP provided West of Greece as the location with the areas with high provisioning supply, 6TPs described the localization of the areas with general descriptions such as East, Central, Western and Eastern Islands of Greece and 2TPs provided no answer. Given the similarity of these answers, it can be said that the improvements of visual representation as the number of categories and colours, probably helped the TPs to perceive the same areas North for high provisioning and South for low provisioning, which means that most of the TPs analysed correctly the maps. Regarding, the other answers, could have been caused by the scale of the information (e.g. difficulties like distinguish on the map the details of the low quantity of provisioning services supply in the mountains of Greece), or lack of knowledge of how can answer to the question.

- The question five with an overall complexity, asked the TPs What is the protected mountain with the highest area (number of km2) of provisioning services?

The results showed four different answers, Mt. Belles & Lake Kerkini with 8TPs were identified as the mountain with the highest area (number of km2) of provisioning services followed by Mt. Lefka Ori with 5TPs. Other two mountains were also identified Prespes Lakes and Mt Olympos with two answers each, as the mountains with the highest area (number of km2) of provisioning services. These responses are the result of the individual analysis performed by TPs, from this variety of results it can be said that the TPs obtained the answer probably making use of the scale or through a visual interpretation. Some difficulties the TPs could find to answer the question were: difficulties in the use of the scale, lack of information about the quantity (total area, km^2, m^2, ha^2) of supply capacity of provisioning service and per area of interest (orange circles), or that the analysis only was supported by a visual interpretation.

ES prototype map (example map two –Sub-national level)

The analysis of the results are related to the Geographic questions about the ES prototype map two called "Ecosystem Service map for Doñana National Park, Spain - 2013" (Palomo et al., 2013), this was carried out analysing and interpreting the TPs answers for each geographic question and their related task, as shall we see below.

- The first two questions with an elementary level of complexity asked the TPs What types of Ecosystem Services (ES) are depicted on the map? and The area to the south of Almonte (between Almonte and the coast) is the area with the highest density of SPH's. Where is this area located?

The answers of the TPs showed that all 17TPs identified the ES categories of the Ecosystem Services represented on the map. But instead, the answers for the second question had more varied responses, for example, 3TPs answered the area with the highest density is located inside the Natural Park, 6TPs said inside the National Park, others 6TPs said inside the greater ecosystem of Doñana, and 4TPs said the area outside the National Park. This variety of answers might be due to a lack of understanding of the meaning the highest density of ES provision hotspots on the map, difficulties understanding the boundaries of Doñana protected area, or the question was not sufficiently specific or clear. For example, the TPs which answered inside the National Park and inside the greater ecosystem of Doñana both can be correct. This might occur because the highest density of ES provision of SPH does not fit totally inside of one area.

- Questions three and four with an intermediate level of complexity asked the TPs through open-ended questions, where is the area with the highest ecosystem SPHs located? and where is the area with the lowest capacity to supply SPHs located?

As a result of open-ended questions, there were different type of answers but they showed a common ground as follows: The area with the highest ecosystem SPHs was positioned inside the Doñana National Park by most of the TPs, only 2TPs located the area in the Doñana Natural Park and 1TP provided no answer. The localization of the area with the lowest capacity to supply ecosystem SPHs by 6TPs was located outside of Doñana National Park and Doñana Natural Park. 2TPs said close to the urban areas like Almonte, Lebrija, Las Cabezas de San Juan, etc., another 2TPs in the area of the Greater Ecosystem of Doñana and 1TP in the East part of the National Park, 5TPs gave vague answers such as East, Center, North, and East which were difficult to interpret and 1TP provided no answer. These multiple answers showed the different interpretations due to the boundaries of the protected area of Doñana was confusing, the question related to the area with the lowest capacity to supply ecosystem SPHs was quite general and the answers provided, were from the different point of views.

- The questions five and six also with an intermediate level of complexity asked the TPs, which urban area is the closest to an SPHs with high capacity? and Which urban area is the closest to an SPHs with a low capacity?

As a result, the answers showed that the urban areas called Almonte and Sanlúcar de Barrameda with 10TPs and 7TPS answers respectively were identified as the closest urban areas to an SPH with a high capacity. Both answers can be correct if the task is to find the urban area close to an SPH with high capacity. But the task asked to locate the urban area closest (shortest distance) to the SPH with high capacity (correct answer: Sanlúcar de Barrameda). Whereas the other answers showed the urban area closest to the SPHs with low capacity were located close to Seville, Aznalcázar, Huelva or Almonte, all the TPs chosen one of these options. Possibly this varied of answers were due to the question was general and the answers provided almost all were valid form different point of views. In this case, the question needs to be more specific due to the distribution of the SPHs with low capacity on the map.

5.2.2. Results phase II

The second phase was carried out online from 28 January to 3 February and 5 February to 11 February 2018. The example maps one, two for this phase are the results of the improvements derive from the usability test in phase one and the example map three in this phase is tested the initial prototype. The TPs from Greece and Ecosystem Services Network (ESP) were the representative users to test these three ES prototype maps.

Initial information

The usability evaluation part two was carried out by participants from Greece and the Ecosystem Services Partnership (ESP). The prototype maps of examples one and two for this part of the evaluation were adjusted according to the findings of the usability test part one. The online survey was carried out in total by 19 test persons (TPs), among whom 16TPs complete all the survey while 2TPs did not finish and 1TP did not answer. As shown in Figure 17, a high proportion of the TPs have Doctorate degree as the highest completed education level, followed Master degree. Most of the TPs indicated they had experience producing them and using ES maps and those who do not have experience producing demonstrated interest to do it in the future. The 15TPs who has experience using this kind of maps has used these for policy decision but mostly for scientific consultation (see Figure 21).

Figure 21. Education level, experience using and producing ES maps – Phase II

ES prototype map (example map one – National level)

The analysis of the answers related to the Geographic questions about the map "Ecosystem Services supply in protected mountains of Greece – 2018", was performed observing the responses of each geographic question and interpreting how the TPs answered the tasks assigned.

- In the first two questions classified with an elementary level of complexity, the TPs were asked to recognise the Ecosystem Service category represented on the map and to provide the location of the Prespes Lakes.

the TPs responses almost were completely the same, 15TPs identified the provisioning ES represented on the map and only 1TPs said all the ES categories are represented on the map. For the second question, all the 16TPs located Prespes Lakes closer to Thessaloniki than to Athens which is correct. Therefore, it is possible to say that, both tasks were carried out in this survey with a high rate of success.

- Questions three and four with intermediate complexity level were asked the TPs, to consider the map of Greece only (i.e. do not look at the maps in the circles) and to locate the areas with the low and high supply of provisioning services.

The questions here were a closed-ended question with multiple choices. As a result, most the TPs answered North of Greece as the area with high provisioning can be found, this indication was provided with more detail by 6TP by including the East of Greece and the Island of Crete in their descriptions which is correct. However, 2TPs identified the area with the following descriptions: In the North-East and South of Greece including the Island of Crete, and South-East of Greece including the Island of

Crete which is the wrong answer. The answers were correct for most of the TPs, but the answers which are not correct might occur for some of the TPs because of the scale of the areas of the mountains, which can make it hard to distinguish of where are the areas of high provisioning. On the other hand, the areas with low provisioning supply were located for most of the TPs in the South and East of Greece, and also in the Island of Crete for 2TPs which are correct, while only for 2TP the areas with low provisioning were located in the South, East, and West of Greece which is wrong answers. These last two answers may occur because of the lack of experience with the use of maps.

- Question five with an overall complexity asked the TPs to locate the mountain with the highest area (number of km2) of provisioning services. To do so, TPs needed to read, analyse and interpret the content of the map. They were required to look at the inset maps and through a visual interpretation and use of the scale to determine the highest area of provisioning.

From the analysis and interpretation of the areas highlighted in the orange circles by the TPs produced the following results: Mt. Belles & Lake Kerkini with 6TPs answers and Mt. Lefka Ori with 5TPs answers were the mountains identified with the highest area (number of km2) of provisioning services, while Mt. Olympos (3TPs), Mt. Parnon (1TPs) and Prespes Lakes (1TPs) were also determined as the mountains with the highest area (number of km2) of provisioning services.

ES prototype map (example map two –Sub-national level)

The analysis of the results is related with the Geographic questions about the ES prototype map two called "Ecosystem Service map for Doñana National Park, Spain - 2013" (Palomo et al., 2013), this was carried out analysing and interpreting the TPs answers for each geographic question.

- The first two questions with the elementary level of complexity asked the TPs to recognised on the map the ES represented and located the area to the south Almonte (between Almonte and the coast) with the highest density of ES provision hotspots (SPHs).

The results showed that 12 TPs replied that all the ES are depicted on the map, these answers are correct, whereas 3TPs indicated that the ES represented on the map were provisioning services and 1TP provided the answer regulating and maintenance as the ES represented on the map which is wrong. From these last answers, there seems to be a misconception of the terms in the map content and legend.

The content of the second question was adjusted according to the title of the legend, and also multiple answers were given to provide a clearer task to the TPs in this phase. Through this new question, was required to the TPs to locate the area to south Almonte with the highest perceived capacity of SPHs. The responses show interesting points of view due to the boundaries of the National Park and Natural Park of Doñana have two shapes difficult to understand their limits. Most of the TPs used the option partly inside the National Park to describe where is the area with the highest perceive capacity of SPHs; also they used the description outside the National Park. In this case, both answers can be correct due to areas of the SPHs are partly inside of the boundaries of the National Park and at the same time are partly outside which makes difficult to have a clear response of where is the area located. Two answers more by the TPs were provided for this question: 3TP located the area inside of the Natural Park and another 2TPs completely inside of the Greater Ecosystem of Doñana. Both responses can occur because the perception of the data was not fully understood, or another area with the highest perceived capacity of SPHs was located on the map.

- Questions three and four with an intermediate level of complexity were adjusted and changed to closed-ended questions. These now asked the TPs to locate inside the greater ecosystem of Doñana the area with the highest concentration of ecosystem SPHs with a high capacity and located the area with almost only ecosystem SPHs with a low capacity.

The area with the highest concentration of ecosystem SPHs with a high capacity of ES provision hotspots was located for the majority the TPs in the most western part of Doñana Natural Park. But the correct interpretation of the question corresponds to the answer the area is "*completely inside the National Park*". Only 4TPs understood the question and answered correctly. Also, in a lesser proportion other answers were obtained:

- The area is located to the North, East and West of Doñana Natural Park.
- The area is located in the East and West of the Doñana Natural Park,
- The area is inside of the Natural and National Park

In general, the TPs answers showed that Doñana Natural and Natural Parks contains the area with the highest concentration of ecosystem SPHs with a high capacity. From these varied of responses, it can be said that for test persons was difficult to determine where the area is located, due to the boundaries of the protected area of Doñana or difficulties to understand colour scheme compressed. Also, the question was not totally clear or not totally understood.

For the second question, was asked the TPs to locate the area with almost only ES provision hotspots (SPHs) with a low capacity inside of the Greater Ecosystem of Doñana. The results showed 6TPs answered correctly; they located the area close to Lebrija and Las Cabezas de San Juan urban areas and outside of the National and Natural Park of Doñana. Other TPs located the area "outside of the National and Natural Park of Doñana" and "the most eastern Doñana Natural Park area" and only 1TP gave a wrong answer. It can be said then that, the question still was not clear for most of TPs, the answers were not completely wrong, but the aim of the question was not fully achieve.

- The questions five and six also with an intermediate level of complexity asked the TPs, to identify the urban area closest to an SPHs with high/low capacity. For these questions, the TPs needed to analyse which urban area has the shortest distance to the areas of high/low SPHs.

The 9TPs located the urban area of Sanlúcar de Barrameda as the closest to an SPH with a high capacity which is the correct, whereas 5TP position Alameda urban area as the closest, this urban area is close but is not the closets one. Other 2TP responded Huelva and Aználcazar which are not correct. For the most TPs in this phase was more clear this question, but still, other answers showed that for some of them is more important locate the area with more high capacity than the area with the shortest distance to an urban area. In contrast, the responses for the area closest to an SPHs with low capacity does not show only one urban area as the closest, but all the urban areas as an option to be the closest to an SPH with low capacity. Thus, the question needs to be more specific to try to avoid these multiple answers.

ES prototype map (example map three – EU level)

The analysis of the results related to the ES prototype map three called "Availability and supply of Ecosystem Services in Eastern Europe-2012" (Schulp et al., 2012), was carried out analysing and interpreting the TPs responses for each geographic question and their related task.

- For the questions with elementary complexity level was asked the TPs to recognise and determine the ES represented on the map and also identify the input services used in the provisioning Ecosystem Services map.

The responses for both questions were answered correctly by most of TPs, only the second question showed two small differences in the answers, maybe because the TPs were not focussing on the details in the explanatory text. In the first question, all the TPs determined all ES categories were represented in the map. For the second question, they identified as inputs of provisioning Ecosystem Service map, the services of potential food crop yield and wild food which is the correct answer. Hence, the majority of TPs carried out well the reading of the map and interpreted the data, scheme colours and explanatory texts well.

- The following questions with intermediate complexity level requested the TPs to perform tasks related to quantify spatial anomalies and locate them based on the information on the map and to encounter spatial linkages between the information represented on the map. For question three the TPs needed to identified two countries in Eastern Europe with the highest overall supply of ES that approximately covers all national territory.

The common responses between 11TPs were Albania and Bosnia-Herzegovina which is the correct one, 3TP provided Romania as an answer and 2TPs answered only Bosnia-Herzegovina which are wrong. The question four considered the whole Eastern Europe and identified between ES categories which one has the distribution patterns of ESFs availability and ESSs supply more similar, the answers coincide in that the cultural services were the ES with similar pattern between ESFs availability and ESSs supply, only 2TP gave different opinions like provisioning or regulating. For the last question, the TPs were asked to select one option which better describes the spatial relationship between the ESFs availability and ESSs supply of the air quality service map. The answers showed 13 TPs chose the option "*Eastern Europe shows that the air quality service has high ESF availability that overlaps with areas of low ESS supply*" as the description which describes the relationship between availability and supply maps. Others 2TPs answered "*The air quality service for all areas in Eastern Europe has low ESF availability that overlaps with areas of high ESS supply*" and 1TP answered the "*Eastern Europe shows that the air quality service has high ESF availability that overlaps with areas of high ESS supply*". As a result, from these three questions, it can be said the tasks were well understood and the information on the map was clear for the majority of TPs, for others might be the patterns on the map was difficult to differentiate.

Satisfaction with ES maps

The fourth part "satisfaction questionnaire" was performed for the three ES prototypes maps in phase two. This questionnaire consisted of three questions about the maps, the use of the maps and further suggestions. As a result, the satisfaction was: *example map two* "Ecosystem Service map for Doñana National Park, Spain - 2013" was the prototype map that showed communicated very well the information in a clear manner. Furthermore, it was the easiest to use to respond to the questions. While, the opinion of most of the TPs about *example map one* "Ecosystem Services supply in protected mountains of Greece – 2018", was map communicate well the information and was easy to use and but for a few this map was difficult to use and communicate poorly the information. For the *example, map three* "Availability and supply of Ecosystem Services in Eastern Europe - 2012" the satisfaction about the map was: the map communicates well the information, and the map communicates poorly and very poorly the information. Interesting contrast since the answers to the geographic questions mostly was answered correctly. Besides, this map showed itself to be the most difficult to use as support to answer the questions (see Figure 23).

For further map improvements, a list of nine suggestions was provided. These suggestions were complete by 10TPs from the total of 16TPs. As a result, the option interactive map was the option with more answers, the second option more voted was the low resolution on the map, but the TPs did not give any detail about to which map need improve the resolution. In third place, 4TPs recommended improve the scheme colour of the map to make it easy to understand the map results but is not clear for which map. Only one TPs clarified that "I would prefer categorised data instead of continuous classification", but without more details. Also was suggested the maps need more explanatory text and less content. Only 1TP gave the suggestion about reducing the number of categories in the legend but is not clear for which map. An additional recommendation was clarifying the meaning of the units and thresholds in the legends for the Eastern Europe map (ES prototype three). In conclusion, these recommendations did not provide enough details but showed the interactive maps could be the next step for ES maps research.

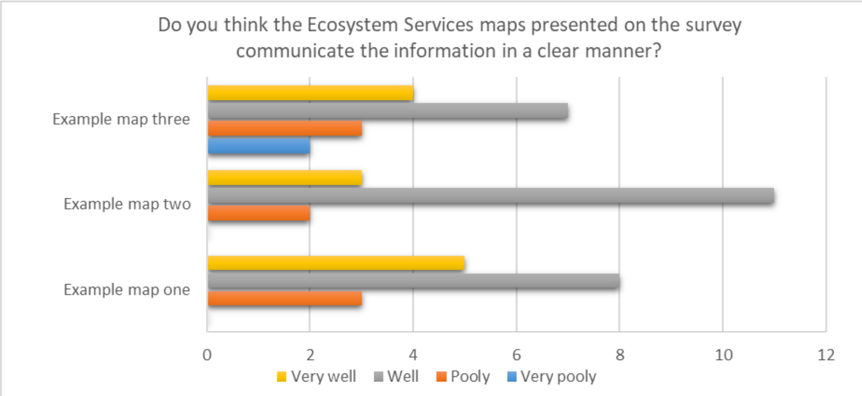


Figure 22. Results satisfaction questionnaire, ES communication

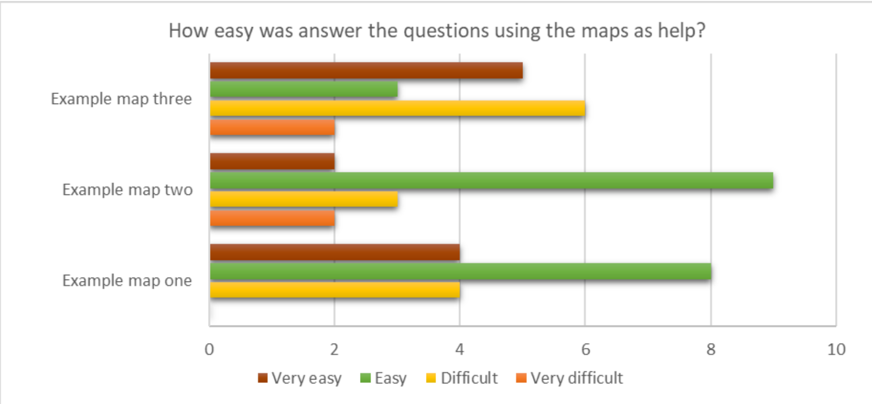


Figure 23. Results satisfaction questionnaire, ES difficulty

5.3. Summary

In this research, the usability evaluation was carried out to test a set of three ES prototype maps. The usability methods applied was the combination of a remote unmoderated usability test and questionnaire. To test representative users of ES maps remotely, fast and easy without a moderator, through an online survey created in Maptionnaire. The Test Persons were current and potential users of ES maps. These TPs were from Greece, Cyprus and the Ecosystem Services Partnership (ESP). The usability evaluation was performed in two phases: The first phase tested the initial ES prototype maps of example maps one and two through the participation of TPs from Cyprus and Greece as representatives of National and sub-national level. The second phase tested the improve ES prototype maps of example map one and two and the initial prototype map three through the participation of TPs from Greece and the European ESP as representatives of the EU level. The online survey consisted of a set of geographic and satisfaction questions was made to test the use of ES prototype maps. These questions supported the identification of the use and design problems of the ES map prototypes and also helped to determine the effectiveness, efficiency and satisfaction of the map prototypes. As a result, the usability evaluation was carried out in

December 2018 (phase one) and February 2019 (phase two). In total was 33TPs complete the survey. From the interpretation of the results the use and design issues related to the map content (explanatory text), the scheme colour in the legend (categories) were identified, also difficulties to perform visual interpretations, to understand well the thematic layers, etc. Besides, the satisfaction questionnaire identified the ES prototype map two as the map that communicated very well the information in a clear manner and the ES prototype map three was the most difficult to use.

6. FINAL ECOSYSTEM SERVICES MAPS

The final design of the ES maps was the result of the implementation of the improvements in the prototype maps. These improvements of the use and design problems were derived from the usability assessment responses (phase two). Each ES prototype map was evaluated based on the findings and improve its design elements. Some improvements could not be implemented due to the individual characteristics of the data. As a result, three final ES maps were obtained. These final maps are available in the APPENDIX G.

Final ES map called Provisioning Ecosystem Services supply in protected mountains of Greece - 2018 (Kokkoris et al., 2018). The design issues interpreted from the TPs answers indicate the map need more details in the explanatory descriptions about the ES represented and information related to the quantity of high, medium and low supply provisioning service to be able to interpret differences between mountainous sites. This issue can be solved with the implementation of an interactive map which allows quantifying the ES category per area or per region. In a static map is not an easy task and it can be too much information if this information is included. So, the final map has no changes that could be interpreted from the usability evaluation (phase two) (see Figure 24).

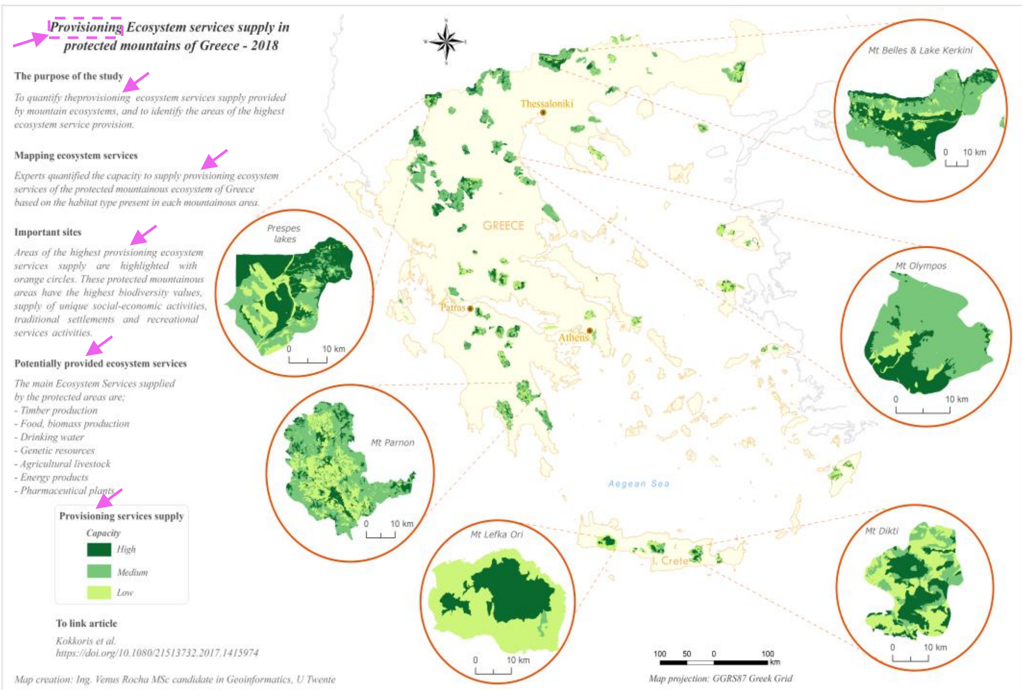


Figure 24. Final ES map called Provisioning Ecosystem Services supply in protected mountains of Greece -2018

Final ES map called Ecosystem service mapfor Doñana National Park, Spain – 2013 (Palomo et al., 2013). The improvements of this map derived for the design issues interpreted from the TPs of the survey phase two were: First, was added on the explanatory text the ES categories are represented on the map. Second, the ES provision hotspots (SPHs) was adjusted to the limits of the Doñana protected area. The intent to clarify the relation of the ES provision hotspots (SPHs) with their surroundings.

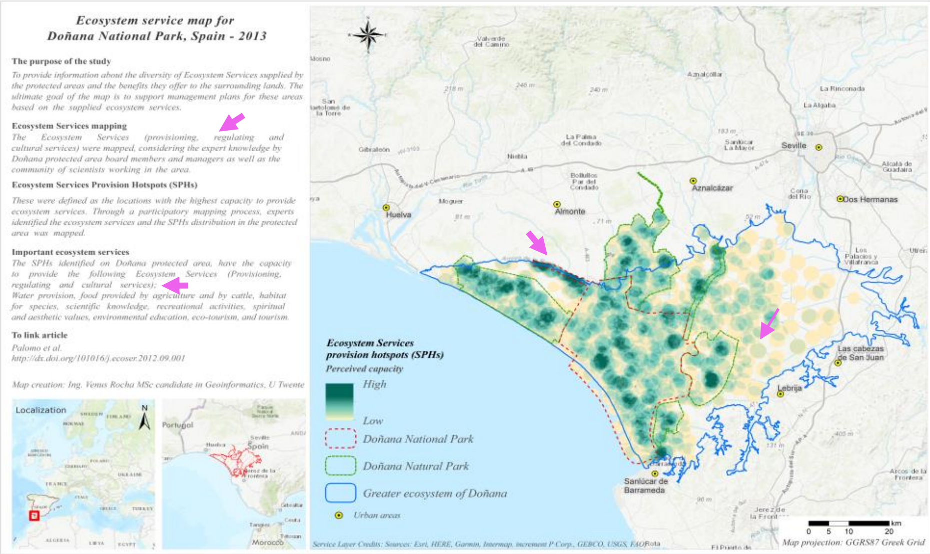


Figure 25. Final ES map called Ecosystem service mapfor Doñana National Park, Spain – 2013.

Final ES map called "Availability and supply of Ecosystem Services in Eastern Europe-2012" (Schulp et al., 2012). There were no improvements derived from the survey in phase two, due to the fact that most of the answers were answered correctly. But was suggested by one participant change the display of the legend from continues to categorised could not be carried out because each map it is the particular case with their own units and threshold to doing this some maps required 10 - 12 classes while in other maps can use the five classes. The legend represented in the maps was the most adequate option to have a good composition in the map which allowed to have a comparable scheme between ES maps.

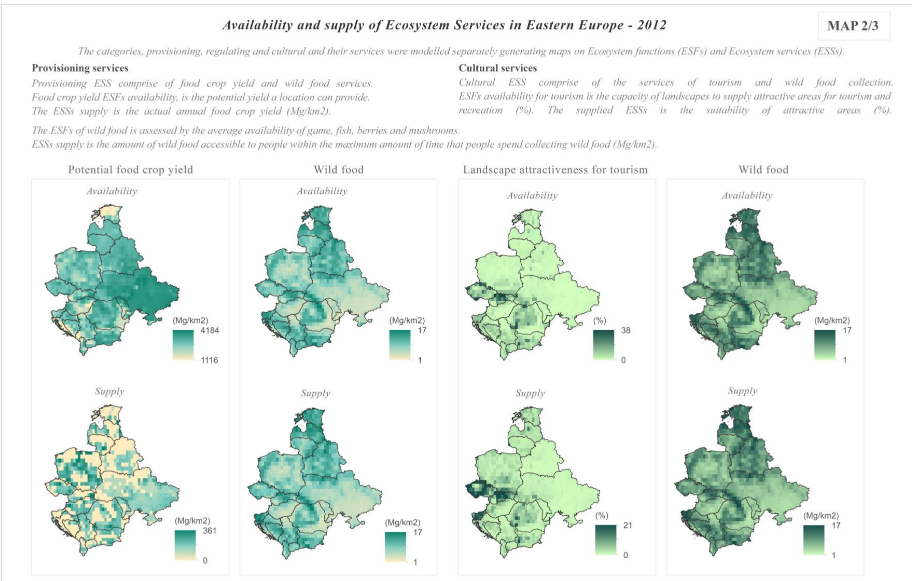


Figure 26. Final ES map called "Availability and supply of Ecosystem Services in Eastern Europe-2012"

7. DISCUSSION OF RESULTS AND GUIDELINES FOR MAP-MAKERS

7.1. Discussion

This research proposes a design of Ecosystem Services maps that can meet the user requirements making use User-Centred Design (UCD) approach and also produce guidelines for map-makers, that can help improve their future use in the decision-making process.

The UCD approache allowed to have previous knowledge of some recommendations for map design. These recommendations support the development process and provide the necessary information for the conceptual design and implementation of the ES prototype maps (Crane & Still, 2016; I. Delikostidis & C.P.J.M., 2011; Haklay, 2010). The improvements of the design elements (colour, text, legend, map content) through the use of methods or cartographic rules their arrangement in a suitable graphic composition are relevant to provide the map user with essential information about the map content and their purpose (Borden et al., 2008; Burkhard & Maes, 2017). The application of some cartographic rules and methods based on the nature of the data and communication objectives by map makers is recommended in order to ensure the communicative abilities of the maps (van Elzakker & Wealands, 2007). To develop suitable map designs that synthesize results correctly from the thematic analysis, geospatial operations and so, can communicate new geospatial knowledge easily understood for a wide audience (Kraak & Ormeling, 2010; Peterson, 2015; Tyner, 2010). The decisions about the method, the type of improvement and how applied in the conceptual design of the ES maps can vary depending on the mapmaker profile (e.g., their educational background, experience with ES maps). Mapmakers have a certain degree of freedom in the map design process (Borden et al., 2008) which allows them to make individual decisions, that at the end of the design process might not be the correct ones to improve design issues and create functional maps. Selecting the method and cartographic rules such as choropleth technique, legend, colour, text design before creating ES maps makes it possible to have the proper knowledge about how to make a good composition with ES information at the time of creating ES maps.

Map design is a complex activity in which a graphic representation that tried to reach the goals communication is obtained (Borden et al., 2008; Peterson, 2015a; Tyner, 2010). The proper design characteristics (e.g. Colour schemes, number categories, font size, labels, map insets) of the elements such as colour, text, legend and the map content are important to avoid misinterpretations, confusion or production of poor maps (Borden et al., 2008; Kruse, 2017). If these characteristics are not well designed, maps that cannot help solving geographic problems might be derived. The lack of knowledge about the cartographic rules or methods that can be applied in map design can increase the risk of making bad map designs which derive in misinterpretation by the map users about the map content and their purpose (Burkhard & Maes, 2017; van Elzakker, 2004). The map design is a process which involves many decisions each of which affects all the others; if the design characteristics result in a bad representation of ES data, the user needs cannot be meet (Borden et al., 2008). When the characteristics were designed, care was taken to ensure that the design was appropriate and able to communicate well the map information. It is important to remember the creation of maps goes beyond the look of a map. The correct design of elements increases the chances of providing maps understandable and appropriate for diverse map users. Maps have an "air of authority" (Hauck et al., 2013) and are something that the mapmakers need to be aware at the moment of designing a map.

The aim of testing was not to criticize the content of the ES maps but discover in the prototype ES maps their issues related to design and use (Crane & Still, 2016; Kraak & Ormeling, 2010; van Elzakker &

Ooms, 2018). It is important to perform this evaluation to determine how effective is the design to answering particular geographic questions and to know the map accomplish the user needs (Haklay, 2010; van Elzakker & Ooms, 2018). Through the usability evaluation, the ES prototype maps design had the opportunity to be adjusted based on the use and design issues (Haklay, 2010). Involved the map users which currently work with the ES maps was a good way to evaluate the cartographic designs and identify early in the process the map design issues to improve them. Perform the maps test with current users allowed the final ES maps product that fulfiled most of the requirements and user needs. The results related to the use and design issues were: the need in the explanatory text more details related to the ES represented, limited information in the map, difficult to distinguish details on the map, difficult to understand the thematic layers (e.g. Doñana boundaries), difficult to perform visual interpretations, difficult to understand units and thresholds in the legend. In addition, some of the difficulties encountered by map users when attempting to carry out tasks with prototype maps were determined, such as understand the geographic questions, the explanatory descriptions, distinguish differences in quantity between countries on the map, make the visual analysis, interpreted the ES represented, thematic layers, make comparisons between the maps, association between the explanatory descriptions and map content and the use the scale on the map, distinguish the areas with the high, medium and low supply of provisioning services on the map, lack of knowledge of how the analysis and interpretation of the map can be described (open-ended questions), may have some limitations because they were interpretations of the survey results without any follow-up or due to the usability methods implemented. The use of an ES map can be hindered by limited map reading, analysis and interpretation skills of the map user (Burkhard & Maes, 2017).

The use of one method that relies totally on written information or one source of information can be limiting the findings (Crane & Still, 2016; Nielsen, 1993; van Elzakker & Ooms, 2018). It is good practice in usability research to use at least three different methods, each of them must be different in the way it works. The combination of these methods take into account not only the performance of the map users with the tasks also allow remembering what the participants say and observe about the design, use and satisfaction with ES maps. The results from these methods allow to verify the findings and increase the chance to identify more issues on design and use of the ES maps that can be improved and also learn more about the difficulties encountered by users when they used the maps (Crane & Still, 2016).

The inclusion of ES maps into the decision-making process can increase with ES maps product of the use of User-Centred Design process. Because the UCD process not only requires to understanding who are the map users, what is the purpose of use of the maps, or the user needs, but it is essential to engage the ES map user in all process for design proper ES maps that meet the user needs. (Haklay, 2010). The use of the UCD process allows to test the maps in early stages in the process and so delivering maps that people want and can use (Crane & Still, 2016; van Elzakker & Ooms, 2018). The application of the usability evaluation using methods such as focus group, think aloud, interviews can be difficult to perform in the normal process of ES mapping. But a qualitative evaluation of the maps can be performed with a small number of participants to discover the most relevant use and design issues when the ES map user working with the ES maps (Nielsen, 1993; van Elzakker & Ooms, 2018) Through the use of a questionnaire method with geographic questions related to the maps, can be created in Maptionnaire a survey to test the ES maps and obtain fast feedback from the users about most relevant use and design issues and also about their satisfaction with the ES maps.

The map design process is a workflow in which was organized the process of the second stage of UCD to produce design solutions and provide sequential steps about the procedures followed to achieve the ES prototype maps in this research. The steps of the process can be followed in a specific order, or simultaneously depending on the map maker decisions (Tyner, 2010). The map design process is based on different interpretations about the steps can be carried out in the map design process (Borden et al., 2008;

Kraak & Ormeling, 2010; Tyner, 2010). Therefore, mapmakers may not follow the same workflow order or may decide to include more activities than described in the workflow. This process generally aims to help design more understandable maps as products of the UCD process. The guidelines were based on this process. First, the identification of the type of map provided the type of representation of the ES data required; this knowledge supported the definition of the methods or cartographic rules necessary for the design of the maps in the third step. The second step helped to defined the technical aspects and the cartographic elements of the map; this selection was useful to design ES maps because allowed to keep in mind only the elements that are part of the map and the important aspects of the implementation. In the third step, the method or cartographic rules defined for choropleth maps. In the last steps, the ES maps first as sketches then as prototypes applying the technical aspects, cartographic elements, cartographic rules to design ES maps. It is necessary to remember that this process begins with the definition of the user's needs and ends with the evaluation of the HE maps produced in order to know if these maps satisfied the user's needs initially considered. The guidelines give the chance to the mapmaker to take into account some important aspects in the map design process in order to provide proper maps for diverse map users (Babbar, Behara, & White, 2002; Crane & Still, 2016), but these indications do not ensure that the mapmaker design appropriate ES maps that can communicate well and meet the user needs. The good design also depends on the communication between the mapmaker and the map user and the good design applied during the map design process.

Apply the User-Centred design in ES mapping process provide a solution of the bottlenecks in which the ES maps do not meet the user needs because of the lack of communication between the mapmakers and map users (Palomo et al., 2018). The products produced through the use of this approach result in understandable and pleasant ES maps which can be used to support the decision-making process.

7.2. Guidelines

In this section, provide a set of guidelines based on the procedures and the ES map design results, these guidelines want to help map-makers to design Ecosystem Services maps that can be used into the decision-making process. The following indications are for ES choropleth maps (choropleth map was the visual representation used in the prototype of ES maps at national, sub-national and EU scales). These guidelines give a set of indications related to the map design process and the design elements that can be followed during map design and that can help to design ES choropleth maps.

Initially, it is necessary to have clear important information about the maps and the map users before starting the map design process. With help of the map users are necessary to define the a) *purpose of use*, b) *the user needs*, c) *target audience* and d) *the context of use* of the ES maps, this means to implement the first stage of UCD. This initial information provides the basis for all the process.

For example, the user needs can be the maps will be required to support the development of EU policies for conservation and biodiversity. The purpose of the ES maps is to provide localisation of the ES information and support monitoring activities. The context of use can be the ES map will use as a static map for consultation in digital form. The target audience can be decision makers from public or private sectors, practitioners, researchers, students, or government representatives.

When the initial information has been defined, it is possible to proceed with "Map type identification" the definition of the type of map to be represented. The mapmaker needs to define this map type based on the ES data results of the analysis (perform for example in InVEST) and the purpose of use. The purpose of this type of map is to help in the definition of the cartographic rules to apply in the design.

For example, the type of map represented of this research was the choropleth map, but the ES maps can also be a dot map, a proportional dot symbol map or an isarithmic map.

The process continues with "Map content selection" the determination of the technical aspects and the cartographic elements. To determine this was organized a list of aspects and their description that can help during the map design process (see Table 23).

Table 23. Recommendations for technical aspects.

Aspects	*Description*
Type of map	Static map or interactive map
Scale	National/Sub-national/EU
Map size	Tabloid (43 X 28 cm) this size was used in the ES maps in this research, is recommended for publications as reports different to articles because allow having enough space for all the elements on the map.
Orientation	Vertical / Horizontal, is the decision of the mapmaker oriented the information on the map, this depends on the ES information and the map content
Export resolution	The quality of an image depends on resolution, or the number pixels per inch (DPI). Therefore, all graphics must have a resolution between 300 and 600 dpi (at final size) ("Graphics Requirements - Publications," 2019)
Export Formats	JPG, PNG or PDF
Print	Colour or B/N is the decision of the mapmaker define the colour to be used based on the user needs and purpose of use.
Software	Is the software will use to create the ES maps (e.g. ArcGIS, QGIS, Tableau)
Number of maps	Individual / Multiple depends on the number of maps need to be represented

The minimum of cartographic elements or minimum map content that ES maps may have to provide a clear understanding of ES information is indicated below (see Table 24). These elements worked well as the minimum content to communicate the ES information according to the usability evaluation of this research. But can be complement with other elements (see Table 2) if is determine the ES map will be designed need others elements. But to add new elements is necessary to have into account also the information from the Blueprint Templates (see Table 3 and Table 4) to determine the relevance of the additional information.

Table 24. Recommendations for ES map content.

ES map content	
Title (Name of the mapping study)	This element is the main name of the map, it is recommended have clearly the ES category and/or attribute (supply, flow, capacity) describe in the title. This element together with the explanatory description facilitates the map users understand what ES is represented on the map.
Subtitle (Mapped ecosystem service)	First line highlight in each paragraph. the subtitles, help to point out an important topic for the US map (e.g. the paragraph about the purpose of the study).
Legend (ES indicator/Quantification unit)	The map legend needs to have a minimum content for an ES map: First, the title needs to describe the ES category or related ES information on the map (e.g. ES provision hotspots). Second, it needs to have a subtitle with the name of the units represented on the map (e.g. perceived capacity). Third, the scheme colour of the legend needs to be accompanied by its units (quantitative or qualitative) in order to be able the map users to make analyses in the interpretation of the ES data. And Fourth, the legend need to have all the elements mentioned on the map to facilitate the map reading.

Maps (ES map)	The main ES Map to be represented. Also, it is recommended to place a localization map if the target audience is international or not belong to the same region or country.
North arrow	Compulsory
Date	Optional
Authorship	Main investigator
Scale bars	Compulsory
Data sources (Link of the article)	It is recommended to include the study link to allow map users to review the details of ES information that may not have been placed on the map. Furthermore, it is useful for users to have some connection between the map and the complete study (article).
Map number, if series	This number is required when the production of ES maps include multiple maps connected.
Projection	Country projection is Compulsory
Inset maps	In ES maps it is recommended to use inset maps only to clarify, gain scale and focus on small areas that not are clear on the map or ES information that needs to be highlighted.
Descriptive text	The descriptive text it is an important part of ES maps. The descriptive text is the synthesis of the most important aspects of the study and the map. For example, the purpose of the study, mapping methods, explanation of the content in the legend and the inset maps. Is recommended to use a language easy to understand and try to avoid technical terms that cannot be easy to comprehend by different users. If the units in the legend are quantitative a brief explanation in the map content is required to clarify the meaning of the information of the map

The process continues with "Preliminary maps creation", to create the first preliminary maps is necessary the mapmaker to define the methods or cartographic rules to apply on the design elements (Colour, text, legend and map content) of the ES maps. The following table provides some indications about cartographic rules applied to produce the ES choropleth maps in this research. These indications might help understand the design characteristics need to be designed on the map properly to create an understandable and aesthetically map (see Table 25).

Additionally, I recommended to the mapmaker design different arrangements of the cartographic elements. Use the software you are most familiar with or easy to use to create the first preliminary maps, evaluate the preliminary maps with some map users and select the best option among others to continue work on it, after this initial evaluation edit possible design errors, in texts, colours, etc. when evaluating the preliminary maps try to make some geographic questions to the map users to test the maps meet the user needs. These are general indications that can help in the design process.

For end the process "map production" the mapmakers have the responsibility to create understandable and attractive ES maps that communicate ES information well to users and satisfy the user needs, making appropriate use of ES guidelines, cartographic rules and the ES data. The ES maps created after the map design process need to be tested by the map users, I recommend in a couple of iterative steps to find use and design issues to improve them before the final maps will be released.

Table 25. Recommendations for ES design elements.

Design element	Design characteristics	Recommendations
Colour	Hue, saturation and lightness Colour schemes Colour impairment	It is recommended to apply sequential colour schemes with a hue with incremental changes in and saturation related to numerical range and number of classes. This means the dark colours represent higher ES values and lighter colours represent lower ES values. The map maker can base the colour selection of the ES information in the following pairs of hues which can be distinguished without problem by the map users. o Red and blue o Red and purple o Brown and purple o Brown and blue o Brown and purple o Yellow and blue o Yellow and purple o Yellow and grey o Blue and grey o Orange and blue As support can be used the tool ColorBrewer 2.0 (http://colorbrewer2.org/)
Legend	Scheme colour Number of categories Design the conventions for the legend (box shape, size, orientation and range placement)	The number of categories recommended for the legend is five as a minimum if the hue is the same colour, it is different colour can be use 10-12 maximum (Peterson, 2015). For ES choropleth maps are recommended the following indications for the legend: Legend boxes in a vertical presentation to allow the map user to read and interpret text and colours correctly. The box size can be determined by the size of the texts. The class range units need to place on the right side and the data (scheme colour) to the left side. Organise the data from highest to lowest values from the top to the bottom box. Boxes compressing the colour give the sensation of data continuity but the map user can distinguish better between colours when these are categorised.
Text	Font size Lettering style (Typeface) Colour	It is recommended as a font size between 12 points and 14 for main text and 16 to 20 point for title text to obtain map descriptions, legend, titles legible and understandable (Tyner, 2010). The typefaces Times New Roman and Arial work well to give clarity to the explanatory ES content.

Map content	Explanatory text Title in legend and the map Visual hierarchy of the elements on the map Scale Map localization Labels Map and map insets	Some recommendations to achieve a good graphic composition of the cartographic elements: Place the ES main map to the right side of the page to gain more attention from the map user. Try to make the ES map occupy more space than the content, avoid leave big white spaces without information, in this way the ES map will see organised. Implement visual hierarchy between the design elements of the map. For example, make the ES information on the map appear dominant than the basemap, apply different font sizes for labels and varying the thickness and colour of the lines in the boundaries or thematic layers. Place in a visible position the north, and the graphical scale.

7.1. Limitations

In this research, the development and results of the conceptual design and implementation of the ES prototype maps and usability evaluation performed with the goal to design a set of prototype maps that meet the user needs were limited by some aspects such as

Static maps were the suitable choice to carried out for the first time usability evaluation of ES maps. The static maps in digital form were a good means to qualitatively evaluate the ES maps that are currently generated in the ES mapping process with representative users remotely. But the use of these statics maps limited the information can display and consult about the ES data like input ES data (e.g. land cover, ecosystems, habitats), explanatory descriptions, among other information and also, do not allow the map users interact with the ES information and thematic layers to have a better understanding of the ES data and their surroundings. According to the participants through the satisfaction questionnaire was suggested as a good improvement for the ES maps and to overcome such limitations, the interactive map as the next step to improve this kind of maps.

Choropleth maps were the type of map most used to represent EE data, according to the sample used from 20 maps belonging to ES research for the years 2009 to 2018. Therefore, this research only focused on choropleth maps, which limited the design and guidelines only on this type of map. But it should be considered that there are other types of maps as a product of the ES mapping process, such as dot maps, proportional point symbol map and isarithmic map.

The usability evaluation was carried out through a survey which was the combination of two usability methods (questionnaire and remote unmoderated usability test). The survey was completed by 33 representatives ES map users remotely, of whom 27 participants completed the online survey and 6 completed it in print. From these complete surveys, only a few interpretations could be made from the answers about the use and design issues because a couple of similar usability methods were used to evaluate ES maps, and the surveys did not have to follow up since the participation was anonymous and remotely, which limited the interpretation of the results. Maybe can improve the feedback from participants if is conduct some personal interview after the survey where participants can self-express about the maps and tasks in a session that can be recorded.

The guidelines were based on the procedures and the final ES map design. These set guidelines to give indications about the map design process and the design elements that can be followed during map design of ES choropleth maps. But the use of the guidelines does not ensure that the mapmaker designs appropriate ES maps that can communicate well and meet the user needs. The good design of ES maps also depends on the communication between the mapmaker and the map user and the form in which the mapmaker implements the guidelines, the cartographic rules to create a good composition for the map during the map design process.

7.2. Recommendations for future work

In this research, the use of ES maps using a User-Centred Design approach was investigated. From the results and limitations of this work, I recommend three main topics for future work.

Use interactive maps to visualize ES information and implement the UCD to create and evaluate results, is the next step in ES mapping research. Since the static ES maps produced in this research even though they satisfied the user needs considerably according to the results of the usability evaluation and the satisfaction questionnaire, limit the ES information on the map and the spatial analysis. The implementation of ES interactive maps can improve spatial analysis and allow the interaction with ES information and thematic information. Also, help to solve some difficulties the users in this research encountered such as difficulty in interpreting and quantifying data by region or areas of interest, and difficulties in analysing and interpreting data on maps to solve complex geographic tasks.

Use other types of usability methods to evaluate the ES maps. The use of different usability methods that allow knowing better the opinion and performance of the user with the ES maps. The interpretation of the issues can be more accurate in future studies if it includes methods such as think aloud, interviews, focus group. I also recommend conducting quantitative research to evaluate interactive maps so that the results will evolve from qualitative to statistical data.

From this research, I recommend the use of the User-Centred Design approach into the ES mapping process. Because through their use the map communication between the map maker and map users can improve so the ES maps have better opportunities to be designed properly and meet the user needs.

8. CONCLUSIONS

8.1. Answers to research questions

The main objective of this research was to propose a design of Ecosystem Services (ES) maps that satisfies the user requirements making use of the User-Centred Design (UCD) approach and produce guidelines for map-makers, that can help improve their future use and inclusion in the decision-making process. This objective was divided into three sub-objectives and the related research questions. The following chapter discusses the results of the research per research question in relation to scientific literature. The limitations of the research and recommendations for future work are provided at the end.

Sub-objective

i. To design prototypes of a set of Ecosystem Services maps that meet the user requirements.

a) How can the map design recommendations, derived from the first stage of UCD executed by Rühringer (2018) help to determine types of improvements and methods to implement on the conceptual design of prototype ES maps, in order to accomplish the user needs?

The recommendations identified during the usability analysis of the first stage of UCD provided detailed descriptions on solutions for design issues of the ES maps. These descriptions helped to determine the type of improvements required by each of the design elements (colour, text, legend and map content). The type of improvements identified supported the selection of methods or cartographic rules required in each aspect of the design elements. The following table shows each design issue identified during the analysis requirements in the first stage of UCD, the design element to which it belongs and types improvements and method or cartographic rule determined, which was implemented in the conceptual design and the ES prototype maps.

Table 26. Improvements and methods for ES maps

Design Element	Issue	Improvement
Colour	1. Colour vision impairment 2. Colour scheme and data structure	1. Apply pairs of hues which are not confused by people, avoid colour-blind confusion. 2. Apply sequential colour schemes with a hue with incremental changes in and saturation related to numerical range and number of classes.
Legend	3. Number of categories and colour 4. Legend units	3. For choropleth maps apply five shades of the same colour or 10 – 12 maximum for separate colours 4. Include units in the legend.
Text	5. Font size	5. Select a font size between 12 points and 14 for main text and 16 to 20 point for title text
Map content	6. The title, Map labels, Thematic layers, Descriptions	6. Include title, subtitles, labels, descriptive text, thematic layers and other cartographic elements 7. Apply layout design to all the cartographic elements.
Method or cartographic rules	Choropleth technique, five shade rule, colour-blind, contrast, design legend (the box shape, size, orientation and range placement), font design (point size, line thickness, typeface), layout design.	

b) Which processes can be applied to create understandable and usable ES maps, so that they can be used as support into scientific research and decision-making processes?

The process to be applied in order to create understandable and usable ES maps are the User-Centred Design (UCD) approach. Through the use of this approach in the ES mapping process, the design and development of cartographic products can be improved due to the continued presence of the ES map user. This continued participation can reduce the risk of the maps not meeting the map user needs. This process involves the map users in all the stages of the process, which allow in each stage of ES map production i.e., requirement analysis, producing design solutions and usability evaluation, to be transparent in relation to the decision-making process which will then use the produced information. As this is an iterative process, the produced ES maps have the opportunity to be tested before their use in scientific research and decision-making process which allows adjusting the maps in terms of design until the map users understand the purpose of use and be able to make a good analysis and interpretation of the information represented on the map.

c) What design characteristics can be improved to produce ES maps that can answer the geographic questions of the map users and accomplish the user needs and purpose?

The following design characteristics were improved to allow a better understanding of the map content of ES maps by the map users. The application of the cartographic rules properly to the design elements and their characteristics rise the possibilities to draw wide attention to the map users in the details of the maps. The latter can help them answer geographic questions and execute their related task. The table shows the design elements and their design characteristics, the tasks that can be performed if the characteristic is designed properly and the user needs that can be supported by a good representation of ES information.

Table 27. Design elements and characteristics, the tasks that can be performed if the characteristic is designed properly.

	Design characteristics	Task	ES map user needs
Colour	o Hue, saturation and lightness o Colour schemes o Colour blind	Select properly the colour design will allow to answer task related to estimate amounts, encounter spatial linkages, find a pattern, discover correlations, quantify anomalies	o Distinguish patterns between ES o Quantity of ES o The density of the ES information
Legend	o Scheme colour o Number of categories o Design the conventions (box shape, size, orientation and range placement)	Improve the legend allow to answer task related to identifying objects,	o Purpose of the ES map o Make clear the type of ES represented on the map o The distinction between classes or categories
Text	o Font size and Lettering style (Typeface) o Colour	Allow reading the explanatory texts, title, labels, title and units in the legend.	o Understand the ES units of the maps, the explanation of the content
Map content	o The explanatory text o The title in legend and map o The units in the legend o The number of cartographic elements o Visual hierarchy of the elements on the map o Scale, Map localization o Labels, Maps and map insets	Explained the location Locate an object	o Clarity of the Purpose of the ES map o Method used to map ES o Location of information on the map

Sub-objective

ii. To determine use and design issues of the set of prototype Ecosystem Services maps, assessing the maps against their requirements, in order to be able to redesign and improve the prototypes.

a) Which use and design issues can be identified in the proposed set of prototype ES maps?

The usability evaluation used a set of geographic questions to assess three prototype maps at three different scales national, sub-national and EU. The design issues interpreted from the answers were mainly associated with the map content and the scheme colour in the legend. The explanatory text did not provide enough clarity about the map content (e.g. ES category represented), the map did not provide specific data about the quantity of ES per class neither per area. The TPs might have found difficulties in distinguish details on the map because of the scale of the data, or due to difficulties in the use of the graphic scales provided. Others might be related to visual interpretation, lack of clarity about the units meaning and their thresholds represented in the legend, and difficulties to comprehend the thematic layers on the map.

Table 28. Use and design issues determine in the usability evaluation.

Map	Design Issues	Use issues
"One" National level	o Missing keywords in the explanatory text can relate the content, purpose of map and ES represented. o limited information on the map, cannot consult other data (e.g. quantity of high, medium or low provisioning per mountain)	o Difficulty to distinguish details on the map because of the scale of the information o Difficulties to use the scale on the map to quantified (number of km2) o Difficulties to perform visual interpretations
"Two" Sub-national level	o Need more details in the explanatory text related to ES represented on the map	o Difficulties to understand well the thematic layers (e.g. Doñana boundaries protected areas) o Misunderstood of the terms in the map content and legend
"Three" EU level	o Difficulties to understand units in the legend	o Legend units, lack of understanding of thresholds and units.

b) What types of difficulties do the users encounter when they try to carry out tasks with the set of prototype ES maps?

From the TPs answers, some difficulties in task execution were detected. These difficulties can be related mainly to the understanding of geographic questions and their tasks related to reading, analysing, interpreting the information on the maps (explanatory descriptions, map and legend), the complexity of some tasks, interpretation of the thematic layers and the use of tools like the scale.

Table 29. Difficulties encountered by the users.

ES Maps	Difficulties encountered by the users
Example map one	o To understand the geographic questions. o To read the map and make the visual analysis o To perform the association between the explanatory descriptions and map content (legend, colours). o To read the map and distinguish the areas with the high, medium and low supply of provisioning services.

	○ Lack of knowledge of how the analysis and interpretation of the map can be described (open-ended questions). ○ To use the tools on the maps (e.g. graphic scale).
Example map two	○ To read the map and interpreted the thematic layers (e.g. boundaries of the protected area of Doñana). ○ To read the explanatory description. ○ To read the map and interpreted the ES represented. ○ To understand the geographic question and the related task.
Example map three	○ To understand the explanatory descriptions. ○ To understand and distinguish differences in quantity between countries on the map. ○ To read the map and make the visual analysis and comparisons between the maps of ESFs availability and ESS supply. ○ To understand the geographic question and the related task. ○ Difficulties to make comparisons among maps.

Sub-objective

iii. To produce guidelines on the procedures and design elements associated with the final design of Ecosystem Services maps, that can help the map makers to enhance their outcomes and to support the use of these maps by users in their decision making

a) Which procedures can be followed to achieve an ES map that accomplishes the user needs? And what are the steps to follow?

The map design process as part of the second stage of User-Center design approach provides sequential steps that can follow in the design process of the ES maps, which is especially useful to the map makers to create ES maps meeting the user needs. These procedures are: the identification of the type of map to be represented (e.g. choropleth map, dot map), the selection of the method or cartographic rules to apply in the design elements (e.g. choropleth technique, five shade rule) the definition of technical aspects (e.g. map size, software) and the selection of the cartographic elements (e.g. title, inset maps) that are part of the ES map. The layout design to created preliminary ES prototype maps and the implementation of the ES prototype maps

c) How can the guidelines improve the future use and understanding of the ES maps by the map-users?

The guidelines developed in this thesis are a first attempt to improve the ES map design according to the user needs. They could help map makers which are not cartographers, to have an idea of some important aspects involved in the map design process which might not be evident or known. This can be a support for the mapmaker, in terms of giving an organized procedure to allow them to take better decisions and probably save time when the design process starts. These guidelines are not rigorous linear steps to follow in the exact order, but give an interpretation of how the workflow is, and which elements can be part of it. As mapmakers of ES maps have the responsibility to create ES maps that not only communicate well the ES information but are also aesthetically attractive that can really capture the user attention.

8.2. Conclusions

The process applied to design understandable and usable ES maps in this thesis is the User-Centred Design (UCD) approach. This approach focuses on continuous participation of the ES map user in the mapping process in order to reduce the risk that the maps do not meet the map user needs. This process involved the map users in all the stages, requirement analysis conducted (Rühringer, 2018), produce design solutions and usability evaluation.

The recommendations of the requirement analysis (first stage of UCD) provided was used as a guide to help to determine the type of improvements for the ES maps and was the support to the selection of methods or cartographic rules required by the design elements. The application of the cartographic rules properly in the design elements and their characteristics increased the understanding of the ES map content and as well as the possibility to draw wide attention to the map users in important details of the maps. The main improvements implemented in the existing ES maps (as those emerged from the user-requirement analysis) related to colour, texts, map content and legend improved the understanding of the map users on the ES information represented on the maps. This good understanding was verified from the correct answers given by the users to the geographical questions.

The design and use issues detected on ES maps from the usability evaluation were mainly associated with the explanatory text, the limited information in the map, the difficulty to distinguish details on the map and difficulty to understand the thematic layers on the map. Some of the difficulties the participants encountered during the survey were the difficulty of making a visual analysis of the information because the scale in the information made it difficult to see details on the map, difficult to use the map scale due to lack of experience, or lack of knowledge on how the map analysis and interpretation can be described (open-ended questions).

The map design process implemented on the second stage provided sequential steps that can be followed to produce ES maps that can achieve the user needs. The improved ES maps at national, subnational and EU scales product from map design process of this research, meet the user needs considerably according to the results of the usability evaluation and the satisfaction questionnaire performed by representative ES map users of national, subnational and EU levels.

The set of guidelines were produced to help to map makers who are not cartographers to create a suitable design of choropleth maps of ES. These guidelines were related to the design elements and the ES design map process which can be followed during the design of the ES choropleth map. However, it is necessary to emphasise that mapmakers have the responsibility to create understandable and attractive ES maps that communicate ES information well to users, making appropriate use of ES guidelines, cartographic rules and ES data.

The user-Centred design applied into the ES mapping process produced understandable ES maps which can be used to support the decision making process. The proposed guidelines for the map design process can be followed to design and achieve suitable ES maps that meet the user needs.

LIST OF REFERENCES

Atlas of Switzerland. (n.d.). Retrieved March 13, 2019, from http://www.atlasderschweiz.ch/

Balzan, M. V., Caruana, J., & Zammit, A. (2018). Assessing the capacity and flow of ecosystem services in multifunctional landscapes: Evidence of a rural-urban gradient in a Mediterranean small island state. *Land Use Policy*, *75*(March), 711–725. https://doi.org/10.1016/j.landusepol.2017.08.025

Bicking, S., Burkhard, B., Kruse, M., & Müller, F. (2018). Mapping of nutrient regulating ecosystem service supply and demand on different scales in Schleswig-Holstein, Germany. *One Ecosystem*, *3*, e22509. https://doi.org/10.3897/oneeco.3.e22509

Borden, D., Jeffrey, T., & Thomas, H. (2008). *Cartography : Thematic Map Design* (6th ed.).

Bouwma, I., Schleyer, C., Primmer, E., Winkler, K. J., Berry, P., Young, J., … Vadineanu, A. (2018). Adoption of the ecosystem services concept in EU policies. *Ecosystem Services*, *29*, 213–222. https://doi.org/10.1016/J.ECOSER.2017.02.014

Brewer, C. A. (2005). *Desining better maps: a guide for GIS users*.

Burkhard, B., Kroll, F., Nedkov, S., & Müller, F. (2012). Maps of ecosystem services, supply and demand. *Ecological Indicators*, 17–29. https://doi.org/10.1016/j.ecolind.2011.06.019

Burkhard, B., & Maes, J. (2017). *Mapping Ecosystem Services*. *Advanced Books* (Vol. 1). Pensoft Publishers. https://doi.org/10.3897/ab.e12837

Cortinovis, C., & Geneletti, D. (2018). Mapping and assessing ecosystem services to support urban planning: A case study on brownfield regeneration in Trento, Italy. *One Ecosystem*, *3*, e25477. https://doi.org/10.3897/oneeco.3.e25477

Crane, K., & Still, B. (2016). *Fundamental of User Centered Design, a Practical Approach*.

Crossman, N., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., … Maes, J. (2013). A blueprint for mapping and modelling ecosystem services. *Ecosystem Services*, *4*, 4–14. https://doi.org/10.1016/j.ecoser.2013.02.001

De Groot, R., Fisher, B., & Christie, M. (2010). Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation. In G. K. Kadekodi (Ed.), *The economics of ecosystems and biodiversity: The ecological and economic foundations* (pp. 1–40). https://doi.org/10.1017/s1355770x11000088

Delikostidis, I. (2011). *Improving the usability of pedestrian navigation systems*. *ITC Dissertation number 181*. University of Twente.

Delikostidis, I., & C.P.J.M., van E. (2011). Usability Testing of a Prototype Mobile Navigation Interface for Pedestrians. *ICC 2011: 25th International Cartographic Conference*, (Figure 1).

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R. T., Molnár, Z., … Shirayama, Y. (2018). Assessing nature's contributions to people. *Science*, *359*(6373), 270–272. https://doi.org/10.1126/science.aap8826

Drakou, E., Crossman, N., Willemen, L., Burkhard, B., Palomo, I., Maes, J., & Peedell, S. (2015). A visualization and data-sharing tool for ecosystem service maps: Lessons learnt, challenges and the way forward. *Ecosystem Services*, *13*, 134–140. https://doi.org/10.1016/j.ecoser.2014.12.002

Drakou, E., Liquete, C., Beaumont, N., Boon, A., Viitasalo, M., & Agostini, V. (2017). Mapping marine and coastal ecosystem services. In *Mapping Ecosystem Services* (pp. 252–257). https://doi.org/10.3897/ab.e12837

Egoh, B., Drakou, E., Dunbar, M., Maes, J., & Willemen, L. (2012). *Indicators for mapping ecosystem services: a review*. *Victoria*. https://doi.org/10.2788/41823

EPA. (2015). *National Ecosystem Services Classification System (NESCS): Framework Design and Policy Application*. Retrieved from https://www.epa.gov/sites/production/files/2015-12/documents/110915_nescs_final_report_-_compliant_1.pdf

European Commission. (2011). *Impact Assessment Accompanying the Document "Our life insurance, our natural capital: an EU biodiversity strategy to 2020."* Retrieved from https://eur-lex.europa.eu/legal-content/EN/

Fitter, A., Elmqvist, T., Haines-Young, R., Potschin, M., Rinaldo, A., Seta¨ La¨, H., … Murlis, J. (2010). An Assessment of Ecosystem Services and Biodiversity in Europe. In R. E. Hester & R. M. Harrison (Eds.), *Ecosystem Services* (pp. 1–28). Cambridge: Royal Society of Chemistry 2010.

https://doi.org/10.1039/9781849731058
GITTA Geographic Information Technology Training Alliance. (n.d.). Retrieved March 16, 2019, from http://www.gitta.info/ThematicCart/en/html/TypogrDesign_learningObject7.html
Gómez-Baggethun, E., de Groot, R., Lomas, P. L., & Montes, C. (2010). The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. *Ecological Economics*, *69*(6), 1209–1218. https://doi.org/10.1016/J.ECOLECON.2009.11.007
Graphics Requirements - Publications. (2019). Retrieved February 24, 2019, from https://publications.agu.org/author-resource-center/graphics/
Grêt-Regamey, A., Weibel, B., Kienast, F., Rabe, S. E., & Zulian, G. (2015). A tiered approach for mapping ecosystem services. *Ecosystem Services*, *13*, 16–27. https://doi.org/10.1016/j.ecoser.2014.10.008
Grunewald, K., & Bastian, O. (2015). *Ecosystem Services - Concept, Methods and Case Studies*. (K. Grunewald & O. Bastian, Eds.). Berlin Heidelberg: Springer-Verlag. https://doi.org/10.1007/978-3-662-44143-5
Haines-Young, R., & Potschin, M. (2016). Defining and measuring ecosystem services. In *Routledge Handbook of Ecosystem Services* (pp. 25–47). https://doi.org/10.1017/CBO9781107415324.004
Haines-Young, R., & Potschin, M. (2018). *Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure*. Retrieved from www.cices.eu
Haklay, M. (2010). *Interacting with geospatial technologies* (1st ed). Oxford: John Wiley & Sons Ltd.
Hauck, J., Görg, C., Varjopuro, R., Ratamäki, O., Maes, J., Wittmer, H., & Jax, K. (2013). "Maps have an air of authority": Potential benefits and challenges of ecosystem service maps at different levels of decision making. *Ecosystem Services*, *4*, 25–32. https://doi.org/10.1016/j.ecoser.2012.11.003
IPBES. (2018). Regional Assessment of Biodiversity and Ecosystem Services for Europe and Central Asia. Summary for Decision-Makers., 2–9.
Jiang, W. (2018). Mapping ecosystem service value in Germany. *International Journal of Sustainable Development & World Ecology*, *25*(6), 1–17. https://doi.org/10.1080/13504509.2018.1430623
Jónsson, J. Ö. G., Davíðsdóttir, B., & Nikolaidis, N. P. (2017). Valuation of Soil Ecosystem Services. *Advances in Agronomy*, *142*(December 2017), 353–384. https://doi.org/10.1016/bs.agron.2016.10.011
Klein, T. M., Drobnik, T., & Grêt-Regamey, A. (2016). Shedding light on the usability of ecosystem services-based decision support systems: An eye-tracking study linked to the cognitive probing approach. *Ecosystem Services*, *19*, 65–86. https://doi.org/10.1016/j.ecoser.2016.04.002
Kokkoris, I. P., Drakou, E. G., Maes, J., & Dimopoulos, P. (2018). Ecosystem services supply in protected mountains of Greece: setting the baseline for conservation management. *International Journal of Biodiversity Science, Ecosystem Services and Management*, *14*(1), 45–59. https://doi.org/10.1080/21513732.2017.1415974
Kraak, M.-J., & Ormeling, F. (2010). *Visualization of Spatial Data Third Edition. Pearson Education*.
Kramers, R. E. (2007). The atlas of Canada - User Centred Development. In *Multimedia Cartography*.
Kruse, M. (2017). Regional Ecosystem Service Mapping Approaches. In B. Burkhard & J. Maes (Eds.), *Mapping Ecosystem Services* (pp. 234–236).
Landers, D. H., & Nahlik, A. M. (2013). *Final Ecosystem Goods and Services Classification System (FEGS-CS)*.
Lautenbach, S., Maes, J., Kattwinkel, M., Seppelt, R., Strauch, M., Scholz, M., … Dormann, C. F. (2012). Mapping water quality-related ecosystem services: Concepts and applications for nitrogen retention and pesticide risk reduction. *International Journal of Biodiversity Science, Ecosystem Services and Management*, *8*(1–2), 35–49. https://doi.org/10.1080/21513732.2011.631940
Li, Q. (2017). *Use of maps in indoor wayfinding*. University of Twente.
Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J. P., … Bidoglio, G. (2012). Mapping ecosystem services for policy support and decision making in the European Union. *Ecosystem Services*, (1), 31–39. https://doi.org/10.1016/j.ecoser.2012.06.004
Maes, J., Liquete, C., Teller, A., Erhard, M., Paracchini, M. L., Barredo, J. I., … Lavalle, C. (2016). An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020. *Ecosystem Services*, *17*, 14–23. https://doi.org/10.1016/j.ecoser.2015.10.023
Maes, J., Paracchini, M.-L., & Zulian, G. (2011). *A European assessment of the provision of ecosystem services - Towards an atlas of ecosystem services*. *Joint Research Centre, Publications Office of the European Union* (Vol.

JRC63505). https://doi.org/10.2788/63557
Maes, J., Teller, A., Erhard, M., Grizzetti, B., Barredo, J. I., Paracchini, M. L., … Werner, B. (2018). *Mapping and Assessment of Ecosystems and their Services: An analytical framework for mapping and assessment of ecosystem condition in EU*. Luxembourg. https://doi.org/10.2779/41384
Maes, J., Teller, A., Erhard, M., Murphy, P., Paracchini, M., José, B., & Grizzetti, B. (2014). *Mapping and assessment of ecosystems and their services:Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. Publications office of the European Union, Luxembourg.* https://doi.org/10.2779/75203
Malinga, R., Gordon, L. J., Jewitt, G., & Lindborg, R. (2015). Mapping ecosystem services across scales and continents - A review. *Ecosystem Services*, *13*, 57–63. https://doi.org/10.1016/j.ecoser.2015.01.006
Maptionnaire. (n.d.). Retrieved March 13, 2019, from https://maptionnaire.com/
Marta-Pedroso, C., Laporta, L., Gama, I., & Domingos, T. (2018). Economic valuation and mapping of Ecosystem Services in the context of protected area management (Natural Park of Serra de São Mamede, Portugal). *One Ecosystem*, *3*, e26722. https://doi.org/10.3897/oneeco.3.e26722
MEA. (2005). *Ecosystems and Humand Well-Being: Synthesis a Report of the Millennium Ecosystem Assessment Core*. (M. E. Assessment, Ed.). Washington, DC., USA. https://doi.org/10.1196/annals.1439.003
Muehrcke, P. C., & Muehrcke, J. O. (1992). *Map use: Reading, Analysis, Interpretation*. Madison, Wisconsin: JP Publications.
Nahuelhual, L., Laterra, P., Villarino, S., Mastrángelo, M., Carmona, A., Jaramillo, A., … Burgos, N. (2015). Mapping of ecosystem services: Missing links between purposes and procedures. *Ecosystem Services*, *13*, 162–172. https://doi.org/10.1016/j.ecoser.2015.03.005
Nedkov, S., Borisova, B., Koulov, B., Zhiyanski, M., Bratanova-Doncheva, S., Nikolova, M., & Kroumova, J. (2018). Towards integrated mapping and assessment of ecosystems and their services in Bulgaria: The Central Balkan case study. *One Ecosystem*, *3*, e25428. https://doi.org/10.3897/oneeco.3.e25428
Nedkov, S., Zhiyanski, M., Nikolova, M., Gikov, A., & Nikolov, P. (2016). Mapping of carbon storage in urban ecosystems : a Case study of Pleven District , Bulgaria.
Nemec, K. T., & Raudsepp-Hearne, C. (2013). The use of geographic information systems to map and assess ecosystem services. *Biodiversity and Conservation*, *22*(1), 1–15. https://doi.org/10.1007/s10531-012-0406-z
Nielsen, J. (1993). *Usability Engineering. Morgan Kaufmann Pietquin O and Beaufort R* (Vol. 44). https://doi.org/10.1145/1508044.1508050
Palomo, I., Martín-López, B., Potschin, M., Haines-Young, R., & Montes, C. (2013). National Parks, buffer zones and surrounding lands: Mapping ecosystem service flows. *Ecosystem Services*, *4*, 104–116. https://doi.org/10.1016/j.ecoser.2012.09.001
Palomo, I., Willemen, L., Drakou, E., Burkhard, B., Crossman, N., Bellamy, C., … Verweij, P. (2018). Practical solutions for bottlenecks in ecosystem services mapping. *One Ecosystem*, *3*, 2–17. https://doi.org/10.3897/oneeco.3.e20713
Peterson, G. N. (2015a). *GIS cartography: A guide to effective Map Design. A guide to effective map design*.
Peterson, G. N. (2015b). *GIS cartography A guide to effective map design*.
Rabe, S.-E., Koellner, T., Marzelli, S., Schumacher, P., & Grêt-Regamey, A. (2016). National ecosystem services mapping at multiple scales ⊠ The German exemplar. *Ecological Indicators*, *70*, 357–372. https://doi.org/10.1016/j.ecolind.2016.05.043
Rashid, H., Robert, A., & Scholes, N. (Eds.). (2005). Ecosystems and Human Well-being: Current State and Trends, Volume 1. In *Millennium Ecosystem Assessment* (pp. 25–36). (Island Press. https://doi.org/10.1079/PHN2003467
Ruckelshaus, M., McKenzie, E., Tallis, H., Guerry, A., Daily, G., Kareiva, P., … Bernhardt, J. (2015). Notes from the field: Lessons learned from using ecosystem service approaches to inform real-world decisions. *Ecological Economics*, *115*, 11–21. https://doi.org/10.1016/j.ecolecon.2013.07.009
Rühringer, M. (2018). *Use and user requeriments of ecosystem services maps*. Twente University.
Schobesberger, D. (2010). *Mapping Different Geographies*. Vienna. https://doi.org/10.1007/978-3-642-15537-6
Schulp, C. J. E., Alkemade, R., Klein Goldewijk, K., & Petz, K. (2012). Mapping ecosystem functions

and services in Eastern Europe using global-scale data sets. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *8*(1–2), 156–168. https://doi.org/10.1080/21513732.2011.645880

Syrbe, R.-U., & Grunewald, K. (2017). Ecosystem service supply and demand – the challenge to balance spatial mismatches. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *13*(2), 148–161. https://doi.org/10.1080/21513732.2017.1407362

Tyner, J. A. (2010). *Principles of Map Design*.

van Elzakker, C. (2004). *The use of maps in the exploration of geographic data*. *Netherlands Geographical Studies 326*. Enschede.

van Elzakker, C., & Ooms, K. (2018). The Routledge Handbook of Mapping and Cartography. In K. A.J. & V. P (Eds.), *The Routledge Handbook of Mapping and Cartography* (pp. 55–67). London: Routledge.

van Elzakker, C., & Wealands, K. (2007). Use and Users of Multimedia Cartography. In W. Cartwright, M. P. Peterson, & G. Gartner (Eds.), *Multimedia Cartography* (2nd ed, pp. 487–504). New York: Springer-Verlag Berlin Heidelberg. https://doi.org/10.15713/ins.mmj.3

van Wijnen, H. J., Rutgers, M., Schouten, A. J., Mulder, C., de Zwart, D., & Breure, A. M. (2012). How to calculate the spatial distribution of ecosystem services — Natural attenuation as example from The Netherlands. *Science of The Total Environment*, *415*, 49–55. https://doi.org/10.1016/j.scitotenv.2011.05.058

Van Wijnen, H. J., Rutgers, M., Schouten, A. J., Mulder, C., de Zwart, D., & Breure, A. M. (2012). How to calculate the spatial distribution of ecosystem services - Natural attenuation as example from The Netherlands. *Science of the Total Environment*, *415*, 49–55. https://doi.org/10.1016/j.scitotenv.2011.05.058

Vihervaara, P., Kumpula, T., Tanskanen, A., & Burkhard, B. (2010). Ecosystem services-A tool for sustainable management of human-environment systems. Case study Finnish Forest Lapland. *Ecological Complexity*. https://doi.org/10.1016/j.ecocom.2009.12.002

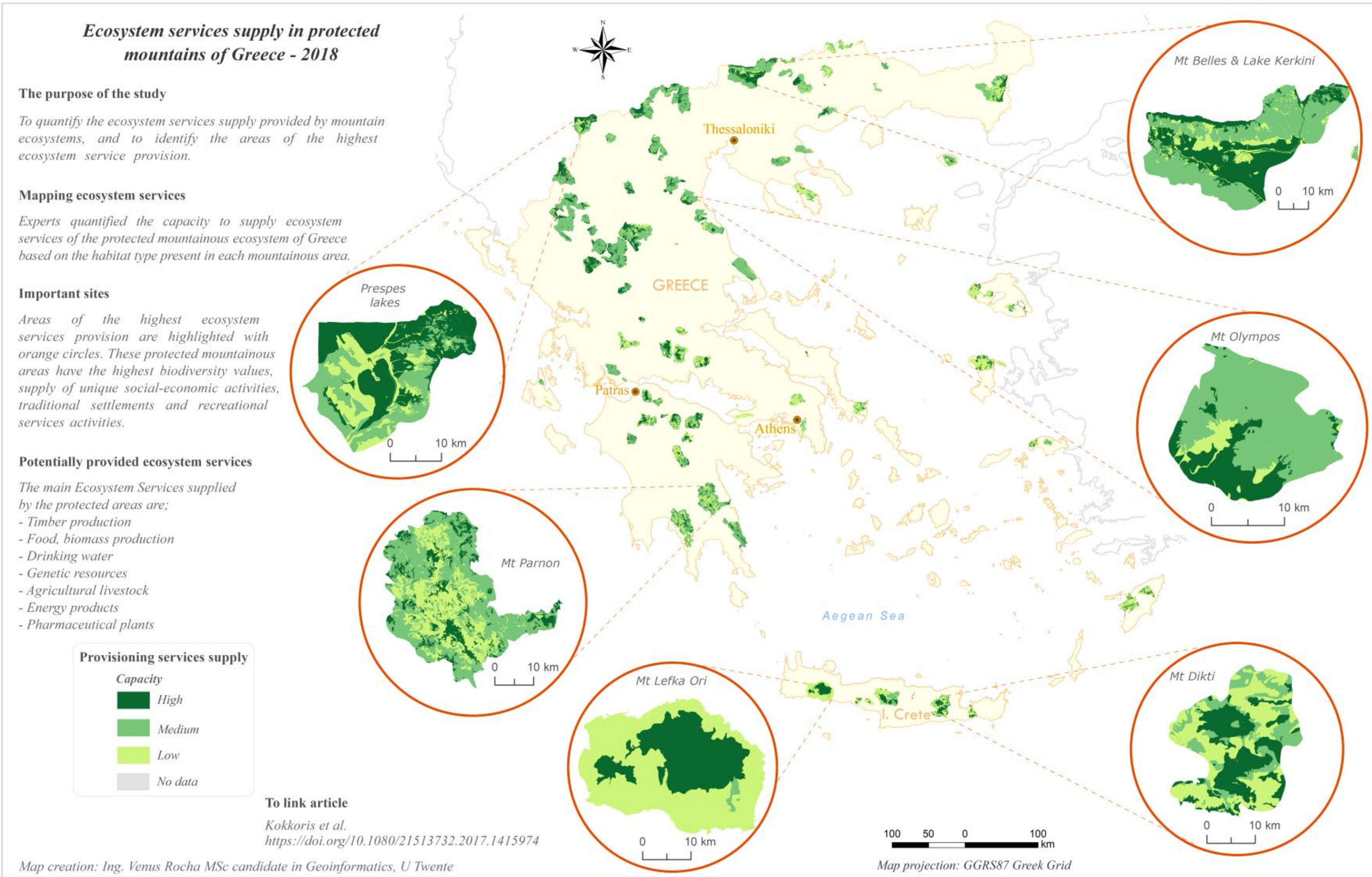
Vlami, V., Kokkoris, I. P., Zogaris, S., Cartalis, C., Kehayias, G., & Dimopoulos, P. (2017). Cultural landscapes and attributes of "culturalness" in protected areas: An exploratory assessment in Greece. *Science of the Total Environment*, *595*(October), 229–243. https://doi.org/10.1016/j.scitotenv.2017.03.211

Willcock, S., Hooftman, D., Sitas, N., O'Farrell, P., Hudson, M. D., Reyers, B., … Bullock, J. M. (2016). Do ecosystem service maps and models meet stakeholders' needs? A preliminary survey across sub-Saharan Africa. *Ecosystem Services*. https://doi.org/10.1016/j.ecoser.2016.02.038

Willemen, L., Burkhard, B., Crossman, N., Drakou, E. G., & Palomo, I. (2015). Editorial: Best practices for mapping ecosystem services. *Ecosystem Services*, *13*, 1–5. https://doi.org/10.1016/j.ecoser.2015.05.008

Wolff, S., Schulp, C. J. E., & Verburg, P. H. (2015). Mapping ecosystem services demand: A review of current research and future perspectives. *Ecological Indicators*, *55*, 159–171. https://doi.org/http://dx.doi.org/10.1016/j.ecolind.2015.03.016

APPENDIX A


Ecosystem services supply in protected mountains of Greece - 2018
The purpose of the study
To quantify the ecosystem services supply provided by mountain ecosystems, and to identify the areas of the highest ecosystem service provision.
Mapping ecosystem services
Experts quantified the capacity to supply ecosystem services of the protected mountainous ecosystem of Greece based on the habitat type present in each mountainous area.
Important sites
Areas of the highest ecosystem services provision are highlighted with orange circles. These protected mountainous areas have the highest biodiversity values, supply of unique social-economic activities, traditional settlements and recreational services activities.
Potentially provided ecosystem services
The main Ecosystem Services supplied by the protected areas are;
- Timber production
- Food, biomass production
- Drinking water
- Genetic resources
- Agricultural livestock
- Energy products
- Pharmaceutical plants
Provisioning services supply
Capacity
High
Medium
Low
No data
To link article
Kokkoris et al.
https://doi.org/10.1080/21513732.2017.1415974
Map creation: Ing. Venus Rocha MSc candidate in Geoinformatics, U Twente
Prespes lakes
Mt Parnon
Mt Lefka Ori
Mt Belles & Lake Kerkini
Mt Olympos
Mt Dikti
0 10 km
Thessaloniki
GREECE
Patras
Athens
Aegean Sea
I. Crete
100 50 0 100 km
Map projection: GGRS87 Greek Grid

APPENDIX B

Ecosystem service map for Doñana National Park, Spain - 2013

The purpose of the study

To provide information about the diversity of ecosystem services supplied by the protected areas and the benefits they offer to the surrounding lands. The ultimate goal of the map is to support management plans for these areas based on the supplied ecosystem services.

Ecosystem Services mapping

The ecosystem services were mapped, considering the expert knowledge by Doñana protected area board members and managers as well as the community of scientists working in the area.

Ecosystem Services Provision Hotspots (SPHs)

These were defined as the locations with the highest capacity to provide ecosystem services. Through a participatory mapping process, experts identified the ecosystem services and the SPHs distribution in the protected area was mapped.

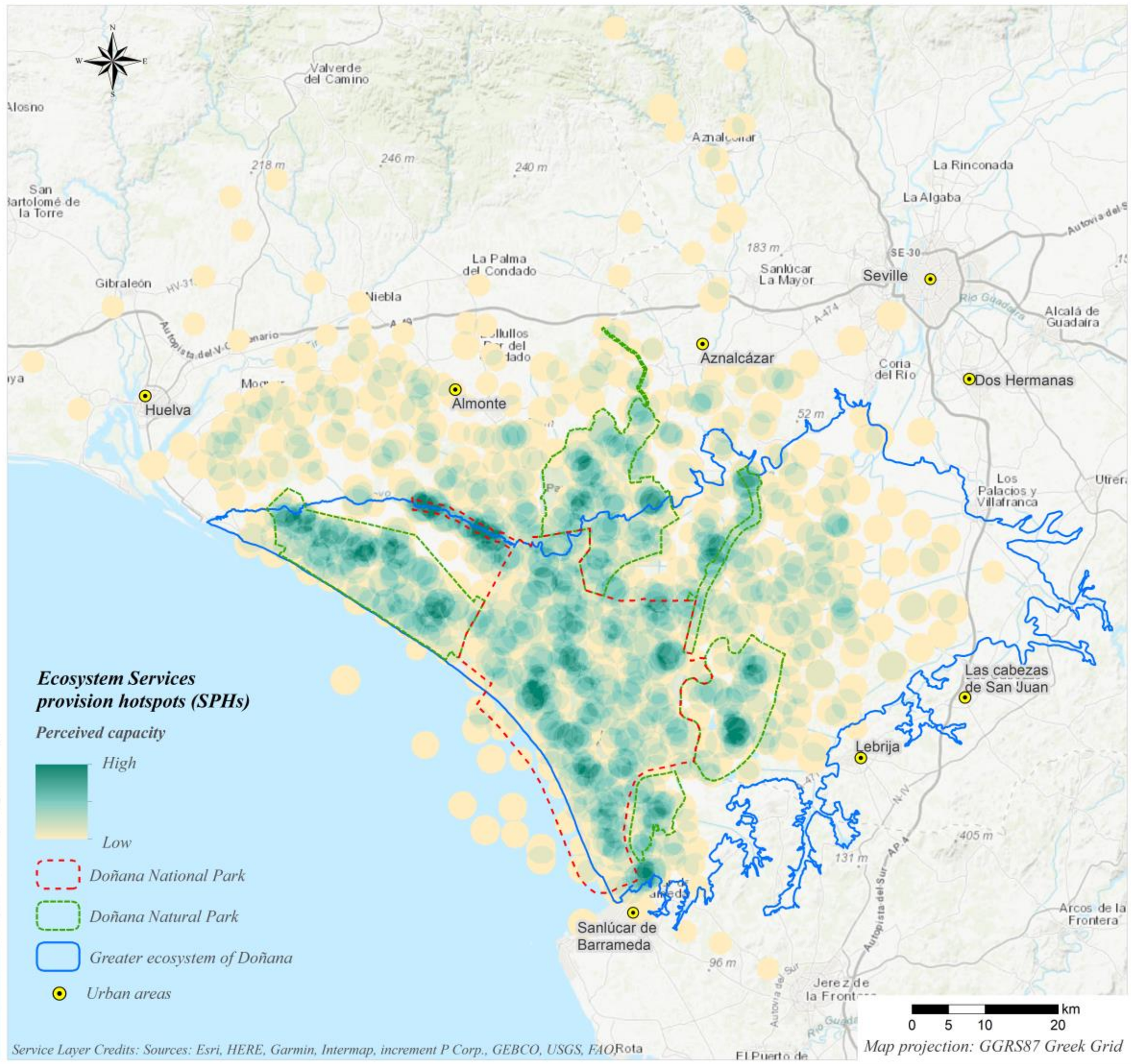
Important ecosystem services

The SPHs identified on Doñana protected area, have the capacity to provide the following services;
Water provision, food provided by agriculture and by cattle, habitat for species, scientific knowledge, recreational activities, spiritual and aesthetic values, environmental education, eco-tourism, and tourism.

To link article

Palomo et al.
http://dx.doi.org/101016/j.ecoser.2012.09.001

Map creation: Ing. Venus Rocha MSc candidate in Geoinformatics, U Twente



APPENDIX C

Availability and supply of Ecosystem Services in Eastern Europe - 2012

MAP 1/3

The purpose of the study

To assess a set of models to distinguish differences between Ecosystem Functions (ESFs) and Ecosystem Services (ESSs).

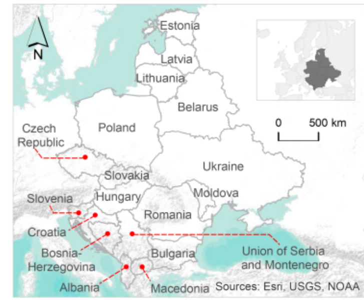
Ecosystem Services mapping

The supply of provisioning, regulating and cultural services and the availability of the ecosystem functions in Eastern Europe was modelled based on the relationship between ecosystem properties and the ecosystem functions. The maps produced were linearly normalised between 0-1 to provide a general overview of the availability of ESFs and supply of ESSs. These values were assigned scores from high to low to express the availability of ESFs and supply of ESSs.

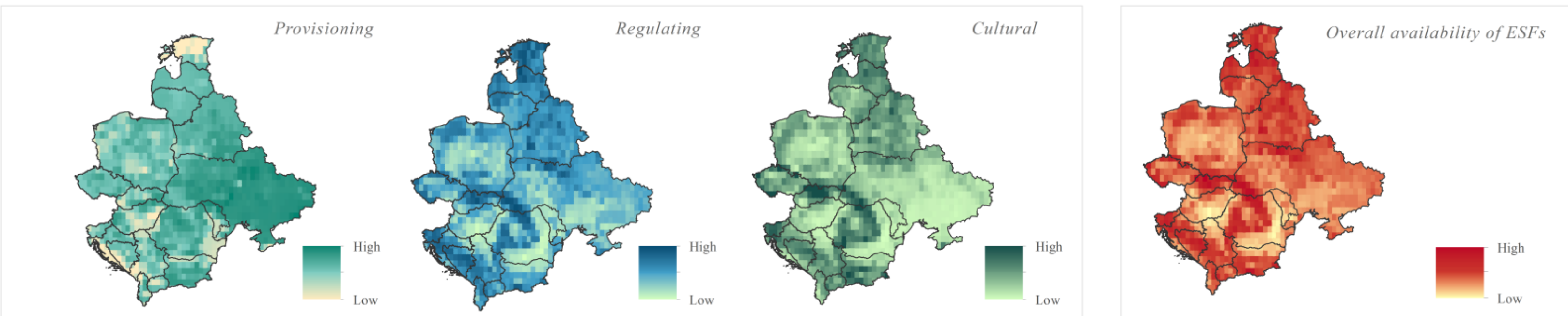
To link article

Schulp et al.
https://doi.org/10.1080/21513732.2011.645880
Map creation: Ing. Venus Rocha MSc candidate in Geoinformatics, U Twente

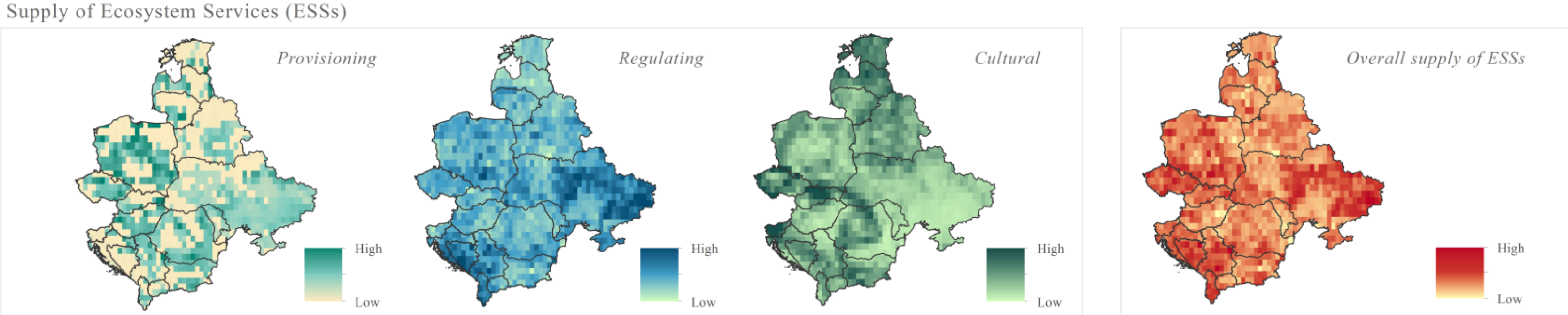
Localization



Availability of Ecosystem Functions (ESFs)



Supply of Ecosystem Services (ESSs)



Availability and supply of Ecosystem Services in Eastern Europe - 2012

MAP 2/3

The categories, provisioning, regulating and cultural and their services were modelled separately generating maps on Ecosystem functions (ESFs) and Ecosystem services (ESSs).

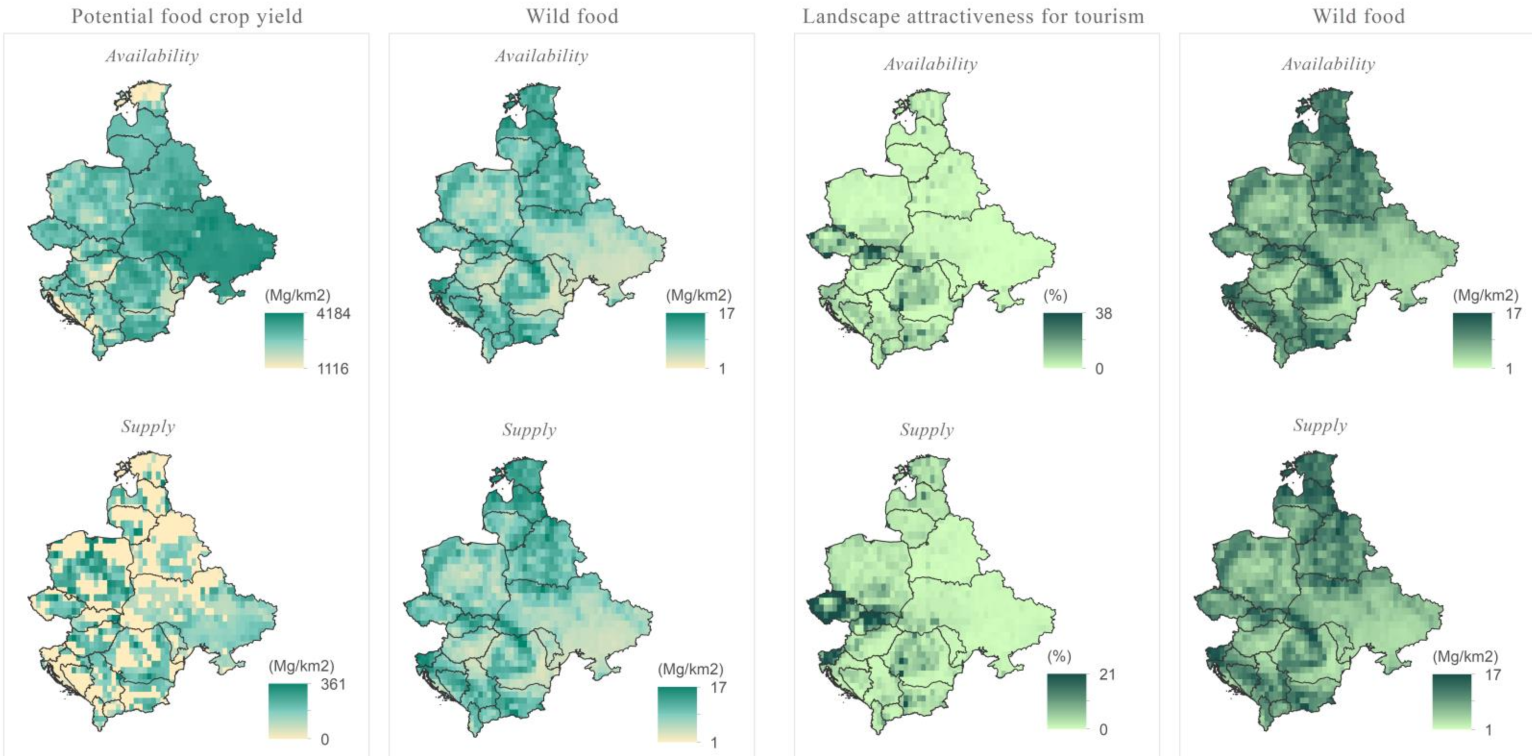
Provisioning services

Provisioning ESS comprise of food crop yield and wild food services. Food crop yield ESFs availability, is the potential yield a location can provide. The ESSs supply is the actual annual food crop yield (Mg/km2).

Cultural services

Cultural ESS comprise of the services of tourism and wild food collection. ESFs availability for tourism is the capacity of landscapes to supply attractive areas for tourism and recreation (%). The supplied ESSs is the suitability of attractive areas (%).

The ESFs of wild food is assessed by the average availability of game, fish, berries and mushrooms. ESSs supply is the amount of wild food accessible to people within the maximum amount of time that people spend collecting wild food (Mg/km2).



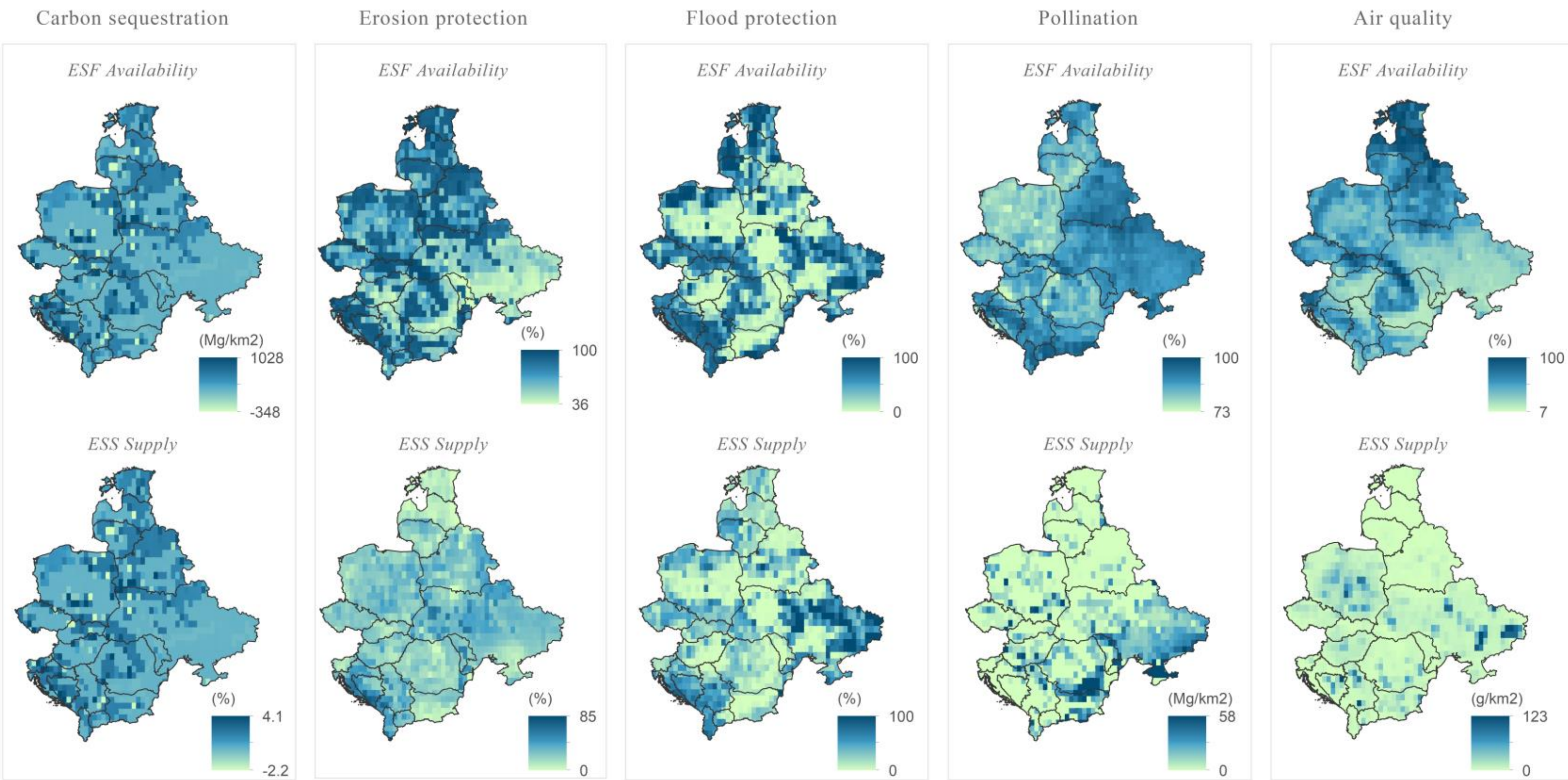
Availability and supply of Ecosystem Services in Eastern Europe - 2012

MAP 3/3

Regulating services

Regulating ESSs comprise of carbon sequestration, erosion and flood protection, pollination and air quality.

- *ESFs of carbon sequestration is the net ecosystem productivity (NEP) (Mg/km). The supplied ESS is the percentage of the annual country total CO2 emission captured by the ecosystem.*
- *ESFs on erosion protection is the decrease of erosion risk by vegetation (%). The supplied ESS is the decrease of erosion risk by vegetation in utilized areas with high erosion risk (%).*
- *ESFs on flood protection is the retention capacity in sensitive to floods areas (%). The supplied ESS, is the areas that are sensitive to floods due to utilization of the land for crop production and urban land (%).*
- *ESFs on pollination is the percentage (%) yield loss due to dismissed pollination. The supplied ESS is the additional yield (Mg/km2) of pulses and oil crops due to wild pollination.*
- *ESFs on air quality is the capacity of the landscape to capture dust particles <10mn (PM10) (%). And The supplied ESS is the amount of PM10 actually capture (g/km2).*



APPENDIX D

Survey link: https://app.maptionnaire.com/es/5178

Welcome to the Ecosystem Services maps survey (Phase I)

Dear participant

Thank you for participating in this survey that is part of the MSc thesis that investigates the use of ecosystem services maps by different users.

The objective of this research is to propose a design of cartographic map(s) of Ecosystem Services that satisfy the user requirements and to produce guidelines for map makers.

In this survey, you will find two ecosystem services maps that you will use to accomplish different tasks related to map-reading and map-use. But first, we will start with some questions about your background, which are needed to be able to interpret the outcomes of the task execution.

I would like to inform you, that all information collected will be kept confidential. Your name will not be disclosed to anyone, nor in the research reports. For any further information, please contact Ms. Venus Rocha at v.l.rochagutierrez@student.utwente.nl

Initial information

Please complete the following information before the start of the usability test of the Ecosystem Services maps.

1. Choose the device you will use to perform the test.
   - Tablet
   - Laptop
   - Paper map
   - Desktop
   - Other (please specify)
2. What is your highest completed education level?
   - University Bachelor
   - University Master
   - Doctorate
   - Other (please specify)
3. What was your main field of study or the highest level of education completed?
4. What is the type of your employer's organization (government, university, company, NGO etc.)?
5. What position do you hold?
6. At which administrative level does your organization operate?
   - European Union
   - National
   - Sub-national/Local
7. Do you have any experience producing ecosystem services maps?
   - Yes
   - No
   - Not but I plan to do it in future
8. If you answer was yes, how often do you do produce such maps?
   - Every day
   - Every week
   - Every month
   - Maybe a few times per year
   - Rarely

Do you ever use Ecosystem Services maps?

- Yes, for policy
- Yes, for scientific consultation
- No

If you answer was yes, how often do you do use Ecosystem Services maps?

- Every day
- Every week
- Every month
- Maybe a few times per year
- Rarely

If your answer was yes, at which administrative levels do these maps usually belong? You can select more than one option.

- European Union
- National
- Sub-national

Map example 1

This prototype map was made using data from the study "Ecosystem services supply in protected mountains of Greece: setting the baseline for conservation management" by Kokkoris et al. (2018), to mapped the multiple ecosystem services (ES) supply by the protected mountains of Greece.

Please, follow the next steps to accomplish the survey related to this map.

FIRST STEP:

Please click on the box "Ecosystem services map for example 1" and download the map.

SECOND STEP

For the next steps, you will need to use the map previously downloaded. Please, open the Ecosystem Services map in another window.

THIRD STEP:

Now look at the map carefully, read the title, descriptions, legend, try to understand all the information it contains before you start to answer the questions. Take one or two minutes to do this revision.

Questions Map example one

Carefully read every question below and continue answering the questions making use of the map.

1. What types of Ecosystem Service (ES) are represented on the map?
    - Regulation and maintenance
    - Provisioning
    - Cultural
    - All of the above
2. What protected mountainous areas of all Greece have the highest supply of provisioning ES?
3. Which protected mountainous areas of all Greece offer the lowest supply of provisioning ES?
4. Which areas with the highest ecosystem services of provision (Orange circles) of the following list have the highest supply of provisioning ES? You can select more than one option.
    - Mt. Taigetos
    - Mt. Olympos
    - Mt. Parnitha
    - Mt. Parnon
    - Prespes lakes
    - Mt. Belles and Lake Kerkini
5. What is are the provisioning area that can provide most benefits?
    - Mt. Belles and Lake Kerkini
    - Prespes lakes
    - Mt. Lefka Ori
    - All of the above

Map example two

This prototype map was made using data from the study "National parks, buffer zones, and surrounding land: Mapping ecosystem service flows" by Palomo et al. (2013). Research conducted for two protected areas, Doñana and Sierra Nevada both National and Natural Parks, of great ecological importance as Biosphere Reserve, in which Doñana also as World Heritage Site and Ramsar Wetland. Both protected areas are located on the southwestern coast of Spain.

The Ecosystem Services map, for Doñana, show the spatial distribution of the Ecosystem Service Provision Hotspots (SPHs) supply capacity.

Please, follow the next steps to accomplish the survey related to this map.

FIRST STEP:

Please click on the box "Ecosystem services map for example 2" and download the map.

SECOND STEP

For the next steps, you will need to use the map previously downloaded. Please, open the Ecosystem Services map in another window.

THIRD STEP:

Now look at the map carefully, read the title, descriptions, legend, try to understand all the information it contains before you start to answer the questions. Take one or two minutes to do this revision.

Questions Map example two

Carefully read every question below and continue answering the questions making use of the map.

1. What types of Ecosystem Service (ES) are represented on the map?
   - o Regulation and maintenance
   - o Provisioning
   - o Cultural
   - o All of the above
2. Higher density of Ecosystem Service Provision Hotspots (SPHs) shows the highest ES capacity supply. Where is this located?
   - o Doñana National Park
   - o Doñana Natural Park
   - o Greater ecosystem of Doñana
   - o Non-protected area
3. Where the zones with a low capacity of SPHs are located?
   - o Doñana National Park
   - o Doñana Natural Park
   - o Greater ecosystem of Doñana
   - o Non-protected area
4. What urban areas are closest to the zones with the highest values of SPHs?
   - o Huelva
   - o Seville
   - o Almonte
   - o Sanlúcar de Barrameda

5. Which urban areas can be affected by a low provision of Ecosystem Services?
   - o Huelva
   - o Seville
   - o Almonte
   - o Sanlúcar de Barrameda

6. What capacity has Doñana to provide Ecosystem Services?
   - o High
   - o Medium to high
   - o Medium
   - o Medium to low
   - o Low

APPENDIX E

RESULTS USABILITY EVALUATION (PHASE ONE)

The first part of the "Ecosystem Services maps survey" consist in the initial information.

Initial information of the Test Persons (TPs), Ecosystem Services maps survey realised for phase one.

TPs	Choose the device you will use to perform the test	What is your highest completed education level?	What is the field of study of your highest level of education completed? Example. Biology, Forestry	What is the type of your employer's organization (government, university, company, NGO etc.)?	At which administrative level does your organization operate?	Do you have any experience producing ecosystem services maps?	how often do you do produce such maps?	Do you ever use Ecosystem Services maps?	How often do you do use the ecosystem services maps?	At which administrative levels do these maps usually belong? You can select more than one option.
45	Paper	Bachelor	Civil engineering	goverment	Sub-National	Yes	Maybe a few times per year	No		
24	Laptop	Bachelor	Agronomist	government	National	No		No		
25	Desktop	Bachelor	Agriculturist	goverment	National	No		No		
28	Laptop	Bachelor	Forestry	Goverment	National	Not but I plan to do it in future		No		
42	Paper	HND in Forestry	Forestry	Government	National	No		No		
40	Paper	Master	Archeology	Government	National	No		No		
41	Paper	Master	Environmental and natural resources management	NGO	National	Not but I plan to do it in future		Yes, for scientific consultation	Rarely	National
43	Paper	Master	Nature conservation	NGO	National	No		No		
21	Desktop	Master	Marine Biology	Government	National	No		Yes, for scientific consultation	Maybe a few times per year	EU, National
23	Desktop	Master	Biology	Government	National	No		No		
27	Laptop	Master	Forestry	Government	National	No		Yes, for scientific consultation	Every week	Sub-national (regional and local)
32	Laptop	Master	Biology	University	National	Not but I plan to do it in future		No		
44	Paper	Doctorade	Ecology	government	National	No		No		
19	Tablet	Doctorate	Forestry	university	National	Not but I plan to do it in future		Yes, for scientific consultation	Maybe a few times per year	National, Sub-national (regional and local)
22	Laptop	Doctorate	Conservation planning	Government	National	Not but I plan to do it in future		No		
30	Desktop	Doctorate	Ecology	Government	National	Yes	Rarely	No		
31	Laptop	Doctorate	Environmental protection	University	European Union	Yes	Every month	Yes, for scientific consultation	Every week	National

The section two correspond to the geographic questions related with the example map one "**Ecosystem Services supply in protected of Greece" – 2018**. The geographic questions were organised by the difficulty level, first elementary, second intermediate and at last overall, as shown in Table 20.

What types of Ecosystem Service (ES) are represented on the map?

Answers	# TP (Online)	# TP (On Paper)
Regulating and maintenance	0	0
Provisioning	8	3
Cultural	0	0
All of the above	3	3

Prespes Lakes was identified as one of the areas with the highest Ecosystem Services capacity of provision. Where is Prespes Lakes located?

Answers	# TP (Online)	# TP (On Paper)
Closer to Athens than to Thessaloniki	0	0
Closer to Patras than to Thessaloniki	0	0
Closer to Thessaloniki than to Athens	11	6

Please consider the map of Greece only (i.e. do not look at the maps in the circles). In which part of Greece are most areas with a high provisioning service supply?

Answers **TP (Online)**
– North of Greece and Crete – North of Greece – No answer – mid-North to North – North of Greece – Central-North Greece – North of Greece – It is difficult to find easily the highest provisioning service area, one the first look I would say north but also considerable area is in the central part of Greece but also in the south at Crete. – North East of Greece – North of Greece – North-West
Answers **TP (On Paper)**
– North of Greece and partly the island of Crete – North – North of Greece – North of Greece and Crete – North – West of Greece

Please consider the map of Greece only (i.e. do not look at the maps in the circles). In which part of Greece are most areas with a low provisioning service supply?

Answers TP (Online)
– South of Greece and island – East of Greece – No answer – Central to South – Central of Greece – South and East of Greece – Islands – I would more easily say in Peloponisos area and in the eastern islands – South of Greece – South East of Greece – South-West
***Answers* TP (On Paper)**
– Part of the central Greece, Eastern part of Greece and the Peloponnese area – Western – South-west of Greece – South of Greece and islands (except Crete) – South – East of Greece

What is the protected mountain with the highest area (number of km2) of provisioning services?

Answers	# TP (Online)	# TP (On Paper)
Prespes lakes	2	0
Mt. Parnon	0	0
Mt. Lefka Ori	2	3
Mt. Dikti	0	0
Mt. Olympos	2	0
Mt. Belles & Lake Kerkini	5	3

The next section corresponds to the geographic questions related with the example map two **"Ecosystem service map for Doñana National Park, Spain" – 2013**. The geographic questions were organised by the difficulty level, first elementary, second intermediate and at last overall, as was shown in Table XX.

What types of Ecosystem Services (ES) are depicted on the map?

Answers	# TP (Online)	# TP (On Paper)
Regulating and maintenance	0	0
Provisioning	0	0
Cultural	0	0
All of the above	11	6

Where is the area with the highest ecosystem SPHs located?

Answers **TP (Online)**
– **The Doñana boundaries south of Almonte** – **West** – **In the Doñana National and Natural Parks** – **South of Almonte where the Greater ecosystem of Doñana line is** – **Inside the natural park** – **Central and west-southwest** – **Doñana National Park plus Doñana Natural Park, although outside these areas might serve as a protection zone and edge effects** – **At the thin line south of Almonte, where Doñana NFP boundary crosses the blue line of Greater Ecosystem of Doñana** – **west part of the National Park** – **Doñana natural park** – **No answer**
Answers **TP (On Paper)**
– **South of A**lmonte, border between Doñana National park **and the Greater Ecosystem of Doñana and W**est of Lebrija in the Doñana Natural Park – **The northern** part of Doñana National Park – Doñana National Park – The Doñana boundaries south of Almonte – Inside Doñana National Park – Doñana National Park

Where is the area with the lowest capacity to supply SPHs located?

Answers **TP (Online)**
– **East** – **Center** – **In the Urban areas and the eastern part of the greater ecosystem of Doñana** – **All areas outside Doñana Natural Park** – **Outside of natural and national parks** – **North and east** – **Outside Doñana National Park plus Doñana Natural Park** – **Outside Doñana NFP and Natural Park near the road that join Sevilla with Las Cabezas de San Juan** – **East part of the National Park** – **Outside the park** – **No answer**
Answers **TP (On Paper)**
– In the region of Almonte and the areas… or Los **Palacios y** Villafranca, las Cabezas de San Juan, and Lebrija – Eastern part – Greater Ecosystem of Doñana – East – Outside National Park – Greater Ecosystem of Doñana

The area to the south of Almonte (between Almonte and the coast) is the area with the highest density of SPH's. Where is this area located?

Answers	# TP (Online)	# TP (On Paper)
Inside the Natural Park	1	2
Inside the National Park	3	3
Inside the greater ecosystem of Doñana	4	2
Outside the greater ecosystem of Doñana	0	0
Outside the National Park	3	1

Which urban area is the closest to a SPHs with high capacity?

Answers	# TP (Online)	# TP (On Paper)
Huelva	0	0
Seville	0	0
Almonte	5	5
Sanlúcar de Barrameda	6	1
Aznalcázar	0	0

Which urban area is the closest to a SPHs with a low capacity?

Answers	# TP (Online)	# TP (On Paper)
Huelva	2	2
Seville	4	2
Almonte	3	1
Sanlúcar de Barrameda	1	0
Aznalcázar	1	4

APPENDIX F

Survey link: *https://app.maptionnaire.com/es/5458/*

Welcome to the Ecosystem Services maps survey V1.0 (Phase II)

Dear participant

Thank you for participating in this survey that is part of the MSc thesis that investigates the use of Ecosystem Services maps by different users.

The objective of this research is to propose a design of cartographic map(s) of Ecosystem Services that satisfy the user requirements and to produce guidelines for map makers.

In this survey, you will find three Ecosystem Services maps that you will use to accomplish different tasks related to map-reading and map-use. It will start with questions about your background to be able to interpret the outcomes the execution of the task. The test duration per map is maximum 15 minutes.

All information collected will be kept confidential. Your name will not be disclosed to anyone, nor in the research reports. For any further information, please contact Ms. Venus Rocha at v.l.rochagutierrez@student.utwente.nl

Initial information

Please complete the following information before the start of the usability test of the Ecosystem Services maps.

Choose the device you will use to perform the test.

- o Tablet
- o Laptop
- o Paper map
- o Desktop
- o Other (please specify)

What is your highest completed education level?

- o University Bachelor
- o University Master
- o Doctorate
- o Other (please specify)

What was your main field of study or the highest level of education completed?

What is the type of your employer's organization (government, university, company, NGO etc.)?

At which administrative level does your organization operate?

- o European Union
- o National
- o Sub-national/Local

Do you have any experience producing ecosystem services maps?

- o Yes
- o No
- o Not but I plan to do it in future

If you answer was yes, how often do you do produce such maps?

- o Every week
- o Every month
- o Maybe a few times per year
- o Rarely

Do you ever use Ecosystem Services maps?

- o Yes, for policy
- o Yes, for scientific consultation
- o No

If you answer was yes, how often do you do use Ecosystem Services maps?

- o Every week
- o Every month
- o Maybe a few times per year
- o Rarely

If your answer was yes, at which administrative levels do these maps usually belong? You can select more than one option.

- o European Union
- o National
- o Sub-national

Map example 1

This prototype map was made using data from the study "Ecosystem services supply in protected mountains of Greece: setting the baseline for conservation management" by Kokkoris et al. (2018), to mapped the multiple ecosystem services (ES) supply by the protected mountains of Greece.

Please, follow the next steps to accomplish the survey related to this map.

FIRST STEP:

Please click on the box "Ecosystem services map for example 1" and download the map.

SECOND STEP

For the next steps, you will need to use the map previously downloaded. Please, open the Ecosystem Services map in another window.

THIRD STEP:

Now look at the map carefully, read the title, descriptions, legend, try to understand all the information it contains before you start to answer the questions. Take one or two minutes to do this revision.

Questions Map example one

Carefully read every question below and continue answering the questions making use of the map.

What types of Ecosystem Service (ES) are represented on the map?

- o Regulation and maintenance
- o Provisioning
- o Cultural
- o All of the above

Please consider the map of Greece only (i.e. do not look at the maps in the circles). In which part of Greece are most areas with a high provisioning service supply? (Choose one or more options)

- o North of Greece
- o South of Greece
- o Island of Crete
- o East of Greece
- o West of Greece

Other (please specify)

Please consider the map of Greece only (i.e. do not look at the maps in the circles). In which part of Greece are most areas with a low provisioning service supply? (Choose one or more options)

- o North of Greece
- o South of Greece
- o Island of Crete
- o East of Greece
- o West of Greece

Other (please specify)

Prespes Lakes was identified as one of the areas with the highest Ecosystem Services capacity of provision. Where is Prespes Lakes located?

- o Closer to Athens than to Thessaloniki
- o Closer to Patras than to Thessaloniki
- o Closer to Thessaloniki than to Athens

What is the protected mountain with the largest area (number of km2) of provisioning services?

- o Prespes lakes
- o Mt. Parnon
- o Mt. Lefka Ori
- o Mt. Dikti
- o Mt. Olympos
- o Mt. Belles & Lake Kerkini

Map example two

This prototype map was made using data from the study "National parks, buffer zones and surrounding land: Mapping Ecosystem Service flows" by Palomo et al. (2013). Research conducted for two protected areas, Doñana and Sierra Nevada both National and Natural Parks, of great ecological importance as Biosphere Reserve, in which Doñana also as World Heritage Site and Ramsar Wetland. Both protected areas are located on the southwestern coast of Spain.

The Ecosystem Services map, for Doñana, show the spatial distribution of the supply capacity of Ecosystem Service Provision Hotspots (SPHs).

Please, follow the next steps to accomplish the survey related to this map.

FIRST STEP:

Please click on the box "Ecosystem Services map for example 2" and download the map.

SECOND STEP:

For the next steps, you will need to use the map previously downloaded. Please, open the Ecosystem Services map in another window.

THIRD STEP:

Now look at the map carefully, read the title, descriptions, legend, try to understand all the information it contains before you start to answer the questions.

Questions Map example two

Carefully read every question below and continue answering the questions making use of the map.

What types of Ecosystem Services (ES) are depicted on the map?

- o Regulation and maintenance
- o Provisioning
- o Cultural
- o All of the above

Within the greater ecosystem of Doñana, where is the area with the highest concentration of ecosystem SPHs with a high capacity? (Choose one or more options)

- o Completely inside the National Park
- o Most Western Doñana Natural Park area
- o Outside of the National and Natural Park
- o Most Eastern Doñana Natural Park area
- o North part Doñana Natural Park area

Other (please specify)

Within the greater ecosystem of Donana, where is the area with almost only ecosystem SPHs with a low capacity? (Choose one or more options)

- o Completely inside the National Park
- o Most Western Doñana Natural Park area
- o Outside of the National and Natural Park
- o Most Eastern Doñana Natural Park area
- o North part Doñana Natural Park area
- o Close to Lebrija and Las Cabezas de San Juan urban areas

Other (please specify)

The area to the south of Almonte (between Almonte and the coast) is the area with the highest perceived capacity of SPH's. Where is this area located? Huelva

- o Inside the Natural Park
- o Partly inside the National Park
- o Completely inside the greater ecosystem of Doñana
- o Completely outside the greater ecosystem of Doñana
- o Outside the National Park

Which urban area is the closest to a SPH with a high capacity?

- o Huelva
- o Seville
- o Almonte
- o Sanlúcar de Barrameda
- o Aznalcázar

Which urban area is the closest to a SPHs with a low capacity?

- Huelva
- Seville
- Almonte
- Aznalcázar

Map example 3

This set of three prototype maps were made using data from the study "Mapping ecosystem functions and services in Eastern Europe using global-scale datasets" by Schulp et al. (2012). On this research were modeled a large and diverse set of Ecosystem Functions (ESFs) and Ecosystem Services (ESSs) in Eastern Europe, using global-scale data, with the purpose of assessment and compared the availability of Ecosystem Functions (ESFs) and the supply of Ecosystem Services (ESSs) for the categories of provisioning, regulating, and cultural services.

Please, follow the next steps to accomplish the survey related to this set of maps.

FIRST STEP:

Please click on the box “Ecosystem Services map for example 3” and download the pdf file that has the set of three maps.

SECOND STEP:

For the next steps, you will need to use the map previously downloaded. Please, open the Ecosystem Services map in another window.

THIRD STEP:

Now look at the map carefully, read the title, descriptions, legend, try to understand all the information it contains before you start to answer the questions.

Carefully read every question below and continue answering the questions making use of the downloaded map.

What categories of Ecosystem Functions are represented on the map?

- Regulating
- Provisioning
- Cultural
- All of the above

Which two countries can be identified in Eastern Europe with the highest overall supply of Ecosystem Services that approximately covers all national territory?

- Poland
- Bosnia-Herzegovina
- Romania
- Albania

Considering the whole of Eastern Europe, for which category of Ecosystem Services (provisioning, regulating or cultural) are the distribution patterns of the availability of ESFs and the supply of ESSs most similar?

- Regulating
- Provisioning
- Cultural

Please, answer the following question looking at the second map (MAP 2/3), of the set of maps you downloaded previously for example 3.

Which services were used as input for the provisioning ecosystem service map (ESSs) map? (select two please)

- Erosion protection
- Potential food crop yield
- Pollination
- Wild food

Now, answer the following question looking at the third map (MAP 3/3), of the set of maps you downloaded previously for example 3.

Please, look at the maps of ESF availability and ESS supply of air quality service. What of the following options describes the spatial relationship between the ESFs availability and ESSs supply of the air quality service?

- Eastern Europe shows that the air quality service has high ESF availability that overlaps with areas of high ESS supply.
- Eastern Europe shows that the air quality service has high ESF availability that overlaps with areas of low ESS supply.
- The air quality service for all areas in Eastern Europe has low ESF availability that overlaps with areas of high ESS supply.

SATISFACTION QUESTIONNAIRE

How was your experience?

1. Do you think the Ecosystem Services maps presented on the survey communicate the information in a clear manner?

For Map example 1 (Greece) / Map example 2 (Spain) / Map example 3 (Eastern Europe)

1	2	4	5
Very poorly	Poorly	Well	Very well

2. How easy was answered the questions using the maps as help?

For Map example 1 (Greece) / Map example 2 (Spain) / Map example 3 (Eastern Europe)

1	2	4	5
Very difficult	Difficult	Easy	Very easy

3. Do you have any suggestions for further map improvements?
   - YES
   - NO

If your answer was yes, which of the following options are related to your suggestions for map improvements? (You can select more than one)

- Excessive content in the map
- The map needs more explanatory text
- The font size is small
- The colour scheme makes difficult to understand the map results
- It is difficult to distinguish colour combination
- Too many categories in the legend
- Low image resolution
- An interactive map would work better
- I do not have all the information I need to understand the map
- Other (please specify) or explain briefly your choice

Participation in this Survey

Thank you for participating in this survey, if you have comments or further questions please let us know below, or you can contact Ms. Venus Rocha at v.l.rochagutierrez@student.utwente.nl

APPENDIX F

RESULTS USABILITY EVALUATION (PHASE TWO)

The first part of the "Ecosystem Services maps survey" consists of the initial information.

TPs	Choose the device you will use to perform the test	What is your highest completed education level	What is the field of study of your highest level of education	What is the type of your employer's organization	Do you have any experience producing ecosystem	How often do you do produce such maps?	Do you ever use Ecosystem Services maps?	How often do you do use the Ecosystem Services maps?	At which administrative levels does these maps usually belong? (You can select more than one option.)
S3	Laptop	Bachelor	Forestry	Government	Yes	Rarely	No		National
T16	Laptop	Doctorate	Biology (Ecology)	Government, univ	Yes	Maybe a few times p	Yes, for scientific c	Maybe a few times	National
T20	Laptop	Doctorate	Environmental Eng	University	Yes	Maybe a few times p	Yes, for scientific c	Maybe a few times	National, Sub-national (regional
T21	Desktop	Doctorate	forestry	University	Yes	Maybe a few times p	Yes, for scientific c	Maybe a few times	EU, National, Sub-national (regio
T22	Laptop	Doctorate	Landscape Archite	University	Yes	Maybe a few times p	Yes, for scientific c	Maybe a few times	Sub-national (regional and local)
T23	Desktop	Doctorate	Forestry	Government	Not but I plan to do it in future		Yes, for scientific c	Maybe a few times	EU
T24	Laptop	Doctorate	Ecology	NGO	Yes	Maybe a few times p	Yes, for policy deci	Every month	EU, National
T28	Laptop	Doctorate	spatial planning	University	Yes	Maybe a few times p	Yes, for policy deci	Maybe a few times	Sub-national (regional and local)
P4	Desktop	Doctorate	Rangeland manage	University	Not but I plan to d	European Union, Na	Yes, for scientific c	Maybe a few times	EU, National
P11	Desktop	Doctorate	Geography	University	Yes	National, Sub-nation	Yes, for scientific c	Every week	EU, National, Sub-national (regio
S4	Laptop	Doctorate	Biology	International Orga	Yes	Maybe a few times p	Yes, for scientific c	Every month	European Union
S5	Desktop	Doctorate	Biology	University	Yes	Maybe a few times p	Yes, for scientific c	Maybe a few times	European Union, National, Sub-n
T10	Laptop	Master	Forestry	State officer	Not but I plan to do it in future		Yes, for policy deci	Every month	National, Sub-national (regional
T18	Laptop	Master	Natural Resource I	public funded rese	Not but I plan to do it in future		Yes, for scientific c	Maybe a few times	National, Sub-national (regional
T25	Laptop	Master	Ecology	NGO	Yes	Maybe a few times p	Yes, for policy deci	Maybe a few times	National, Sub-national (regional
T26	Desktop	Master	forestry	University	Yes	Maybe a few times p	Yes, for scientific c	Every month	EU, Sub-national (regional and lo

Questions Map example one

What types of Ecosystem Service (ES) are represented on the map?

Regulating and maintenance	0
Provisioning	15
Cultural	0
All of the above	1

Please consider the map of Greece only (i.e. do not look at the maps in the circles). In which part of Greece are most areas with a high provisioning service supply? (Choose one or more options)

North of Greece	14
South of Greece	5
Island of Crete	5
East of Greece	2
West of Greece	5

Please consider the map of Greece only (i.e. do not look at the maps in the circles). In which part of Greece are most areas with a low provisioning service supply? (Choose one or more options)

North of Greece	0
South of Greece	7
Island of Crete	2
East of Greece	9
West of Greece	3

Prespes Lakes was identified as one of the areas with the highest Ecosystem Services capacity of provision. Where is Prespes Lakes located?

Closer to Athens than to Thessaloniki	0
Closer to Patras than to Thessaloniki	0
Closer to Thessaloniki than to Athens	16

What is the protected mountain with the largest area (number of km2) of provisioning services?

Prespes lakes	1
Mt. Parnon	1
Mt. Lefka Ori	5
Mt. Dikti	0
Mt. Olympos	3
Mt. Belles & Lake Kerkini	6

Map example two

This prototype map was made using data from the study "National parks, buffer zones and surrounding land: Mapping Ecosystem Service flows" by Palomo et al. (2013). Research conducted for two protected areas, Doñana and the Sierra Nevada both National and Natural Parks, of great ecological importance as

Questions Map example two

What types of Ecosystem Services (ES) are depicted on the map?

Regulating and maintenance	1
Provisioning	3
Cultural	0
All of the above	12

Within the greater ecosystem of Doñana, where is the area with the highest concentration of ecosystem SPHs with high capacity? (Choose one or more options)

Completely inside the National Park	6
Most Western Doñana Natural Park area	10
Outside of the National and Natural Park	1
Most Eastern Doñana Natural Park area	5
North part Doñana Natural Park area	5
Other (please specify)	Both inside the National and Natural Parks the small corridor in the northwest of the area

Other (please specify)
Within the greater ecosystem of Donana, where is the area with almost only ecosystem SPHs with a low capacity? (Choose one or more options)

Completely inside the National Park	1
Most Western Doñana Natural Park area	0
Outside of the National and Natural Park	9
Most Eastern Doñana Natural Park area	5
North part Doñana Natural Park area	0
Close to Lebrija and Las Cabezas de San Juan urban areas	6
Other (please specify)	the land strip just south of the area with the highest capacity

The area to the south of Almonte (between Almonte and the coast) is the area with the highest perceived capacity of SPH's. Where is this area located? Huelva

Inside the Natural Park	3
Partly inside the National Park	8
Completely inside the greater ecosystem of Doñana	2
Completely outside the greater ecosystem of Doñana	0
Outside the National Park	3

Which urban area is the closest to an SPH with high capacity?

Huelva	1
Seville	0
Almonte	5
Sanlúcar de Barrameda	9
Aznalcázar	1

Which urban area is the closest to an SPHs with a low capacity?

Huelva	3
Seville	6

Almonte	3
Aznalcázar	4

Map example 3

What categories of Ecosystem Functions are represented on the map?

Regulating	2
Provisioning	1
Cultural	1
All of the above	15

Which two countries can be identified in Eastern Europe with the highest overall supply of Ecosystem Services that approximately covers all national territory?

Poland	0
Bosnia-Herzegovina	13
Romania	3
Albania	11

Considering the whole of Eastern Europe, for which category of Ecosystem Services (provisioning, regulating or cultural) are the distribution patterns of the availability of ESFs and the supply of ESSs most similar?

Regulating	1
Provisioning	1
Cultural	14

Please, answer the following question looking at the second map (MAP 2/3), of the set of maps you downloaded previously for example 3.
Which services were used as input for the provisioning ecosystem service map (ESSs) map? (select two please)

Erosion protection	1
Potential food crop yield	16
Pollination	1
Wild food	14

Please, look at the maps of ESF availability and ESS supply of air quality service. What of the following options describes the spatial relationship between the ESFs availability and ESSs supply of the air quality service?

Eastern Europe shows that the air quality service has high ESF availability that overlaps with areas of high ESS supply.	1
Eastern Europe shows that the air quality service has high ESF availability that overlaps with areas of low ESS supply.	13
The air quality service for all areas in Eastern Europe has low ESF availability that overlaps with areas of high ESS supply.	2

SATISFACTION QUESTIONNAIRE RESULTS

Do you think the Ecosystem Services maps presented on the survey communicate the information in a clear manner?	Very poorly	Poorly	Well	Very well
Greece map	0	3	8	5
Spain map	0	2	11	3
Eastern Europe map	2	3	7	4

How easy was answered the questions using the maps as help?	Very difficult	Difficult	Easy	Very easy
Greece map	0	4	8	4
Spain map	2	3	9	2
Eastern Europe map	2	6	3	5

Do you have any suggestions for further map improvements?	Count
Yes	10
No	6

If your answer was yes, which of the following options are related to your suggestions for map improvements? (You can select more than one)	Count
Excessive content in the map	3
The map needs more explanatory text	4
The font size is small	1
The colour scheme makes difficult to understand the map results	4
It is difficult to distinguish colour combination	0
Too many categories in the legend	1
Low image resolution	5
An interactive map would work better	6
I do not have all the information I need to understand the map	1

If your answer was yes, which of the following options are related to your suggestions for map improvements? (You can select more than one)---Other (please specify) or explain briefly your choice
R1: relates to eastern Europe maps: no explanation of Mg/km, g/km, why percentage thresholds were set to a certain level (I assume highest available value)
R2: The formulation of the questions made it difficult to follow. The questions were asked for visual confirmation for comparisons while the differences were not so evident.
R3: I would prefer categorised data instead of continuous classification.

FINAL ECOSYSTEM SERVICES MAPS

Provisioning Ecosystem services supply in protected mountains of Greece - 2018

The purpose of the study

To quantify theprovisioning ecosystem services supply provided by mountain ecosystems, and to identify the areas of the highest ecosystem service provision.

Mapping ecosystem services

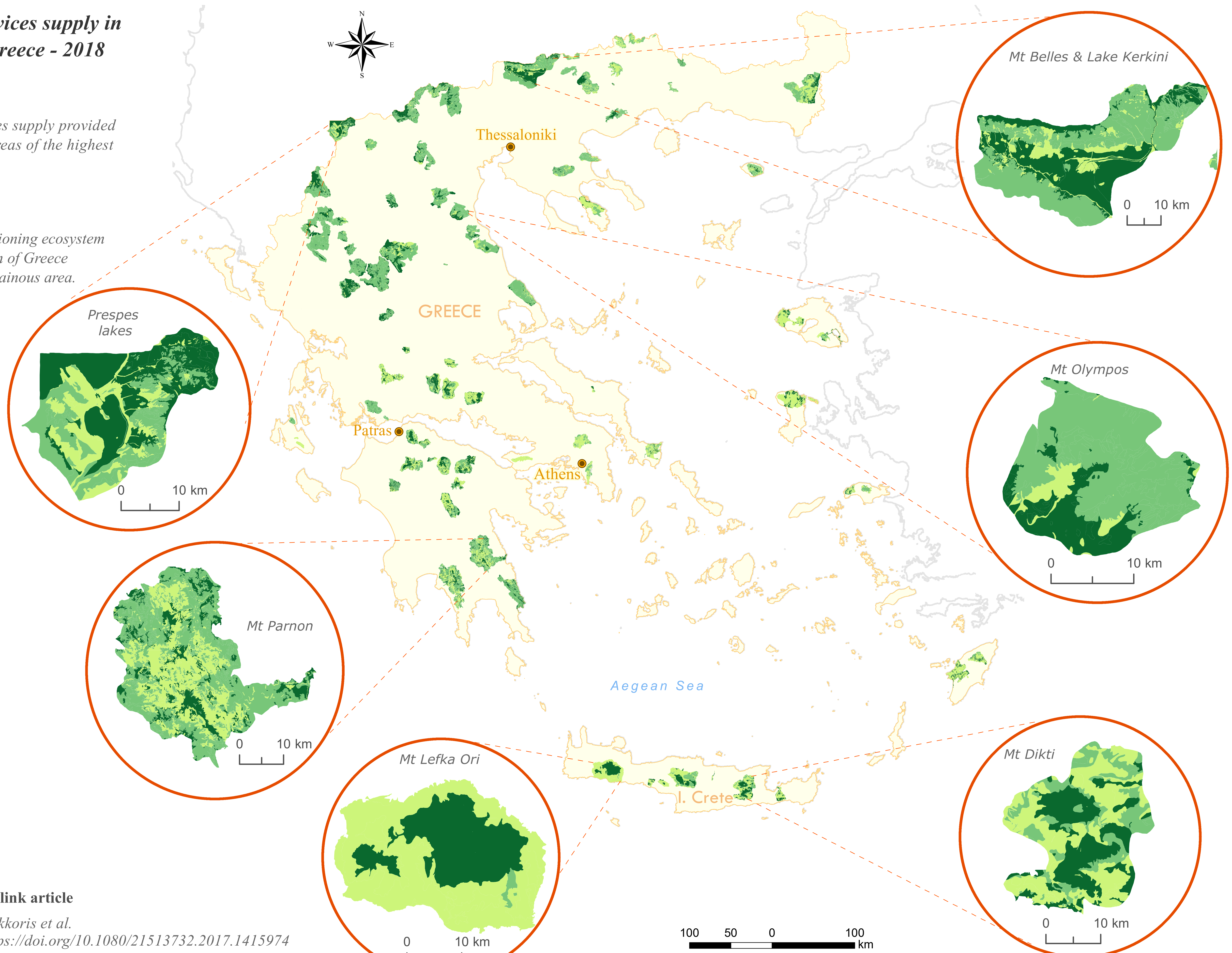
Experts quantified the capacity to supply provisioning ecosystem services of the protected mountainous ecosystem of Greece based on the habitat type present in each mountainous area.

Important sites

Areas of the highest provisioning ecosystem services supply are highlighted with orange circles. These protected mountainous areas have the highest biodiversity values, supply of unique social-economic activities, traditional settlements and recreational services activities.

Potentially provided ecosystem services

The main Ecosystem Services supplied by the protected areas are;
- *Timber production*
- *Food, biomass production*
- *Drinking water*
- *Genetic resources*
- *Agricultural livestock*
- *Energy products*
- *Pharmaceutical plants*



Provisioning services supply

Capacity
- *High*
- *Medium*
- *Low*
- *No data*

To link article

Kokkoris et al.
https://doi.org/10.1080/21513732.2017.1415974

Map creation: Ing. Venus Rocha MSc candidate in Geoinformatics, U Twente

Map projection: GGRS87 Greek Grid

Ecosystem service map for Doñana National Park, Spain - 2013

The purpose of the study

To provide information about the diversity of Ecosystem Services supplied by the protected areas and the benefits they offer to the surrounding lands. The ultimate goal of the map is to support management plans for these areas based on the supplied ecosystem services.

Ecosystem Services mapping

The Ecosystem Services (provisioning, regulating and cultural services) were mapped, considering the expert knowledge by Doñana protected area board members and managers as well as the community of scientists working in the area.

Ecosystem Services Provision Hotspots (SPHs)

These were defined as the locations with the highest capacity to provide ecosystem services. Through a participatory mapping process, experts identified the ecosystem services and the SPHs distribution in the protected area was mapped.

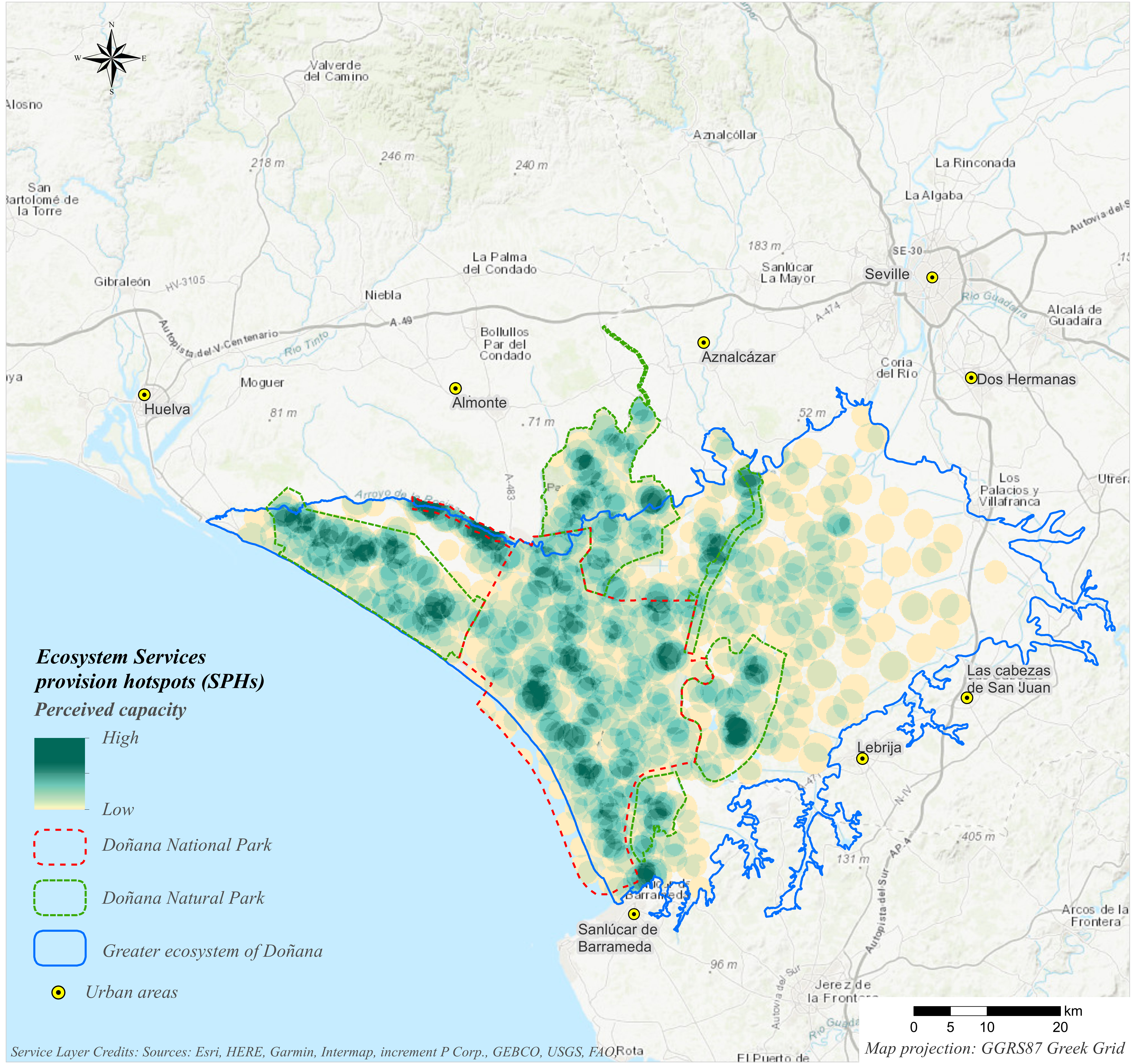
Important ecosystem services

The SPHs identified on Doñana protected area, have the capacity to provide the following Ecosystem Services (Provisioning, regulating and cultural services);
Water provision, food provided by agriculture and by cattle, habitat for species, scientific knowledge, recreational activities, spiritual and aesthetic values, environmental education, eco-tourism, and tourism.

To link article

Palomo et al.
http://dx.doi.org/101016/j.ecoser.2012.09.001

Map creation: Ing. Venus Rocha MSc candidate in Geoinformatics, U Twente



Availability and supply of Ecosystem Services in Eastern Europe - 2012

MAP 1/3

The purpose of the study

To assess a set of models to distinguish differences between Ecosystem Functions (ESFs) and Ecosystem Services (ESSs).

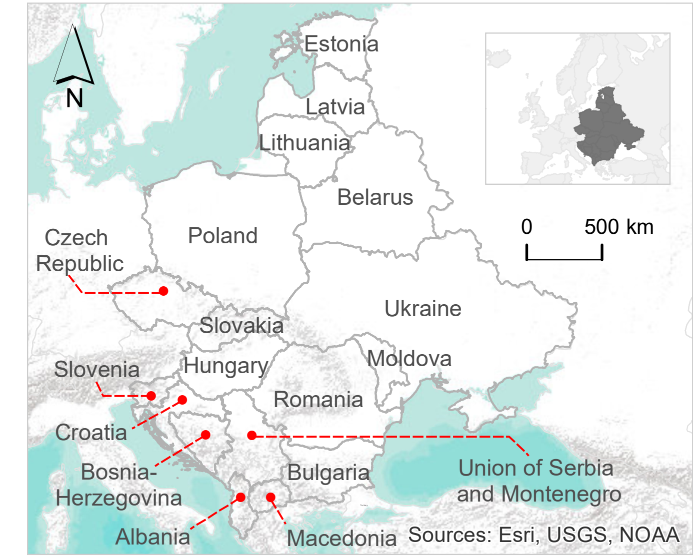
Ecosystem Services mapping

The supply of provisioning, regulating and cultural services and the availability of the ecosystem functions in Eastern Europe was modelled based on the relationship between ecosystem properties and the ecosystem functions. The maps produced were linearly normalised between 0-1 to provide a general overview of the availability of ESFs and supply of ESSs. These values were assigned scores from high to low to express the availability of ESFs and supply of ESSs.

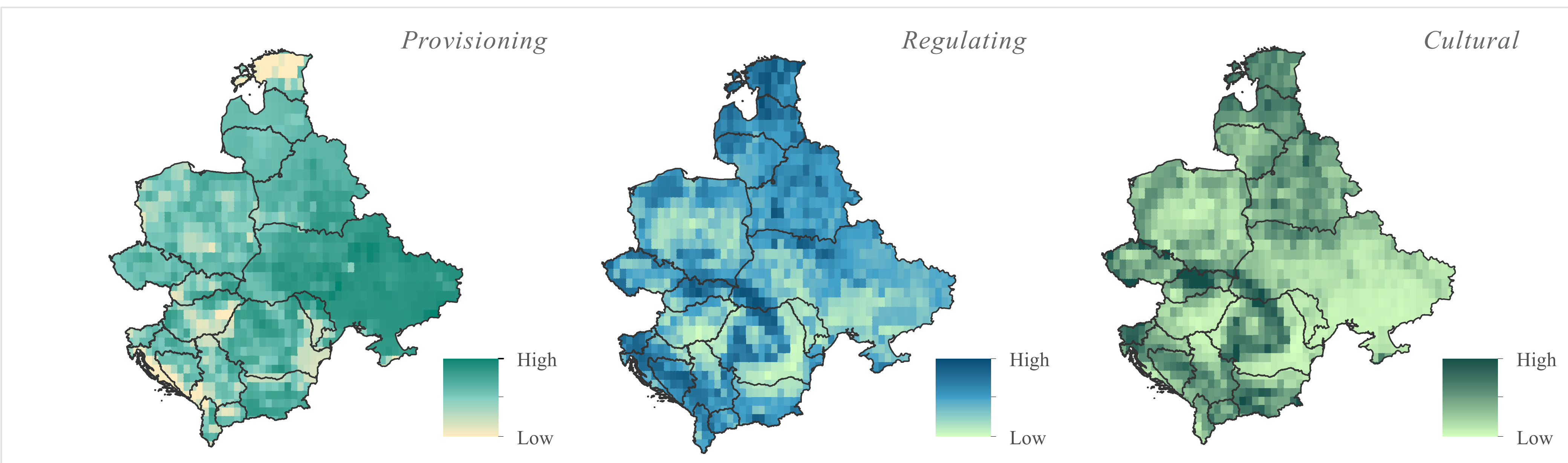
To link article

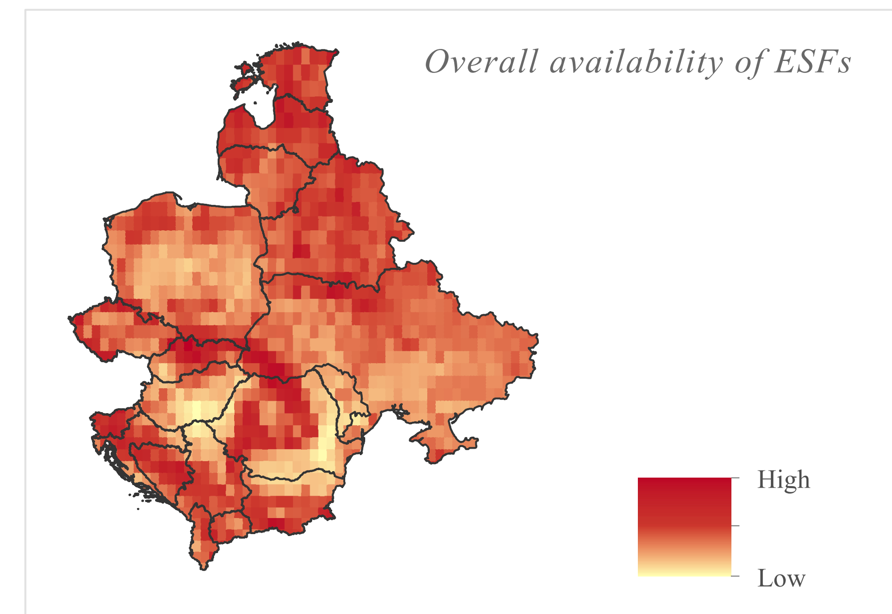
Schulp et al.
https://doi.org/10.1080/21513732.2011.645880
Map creation: Ing. Venus Rocha MSc candidate in Geoinformatics, U Twente

Localization

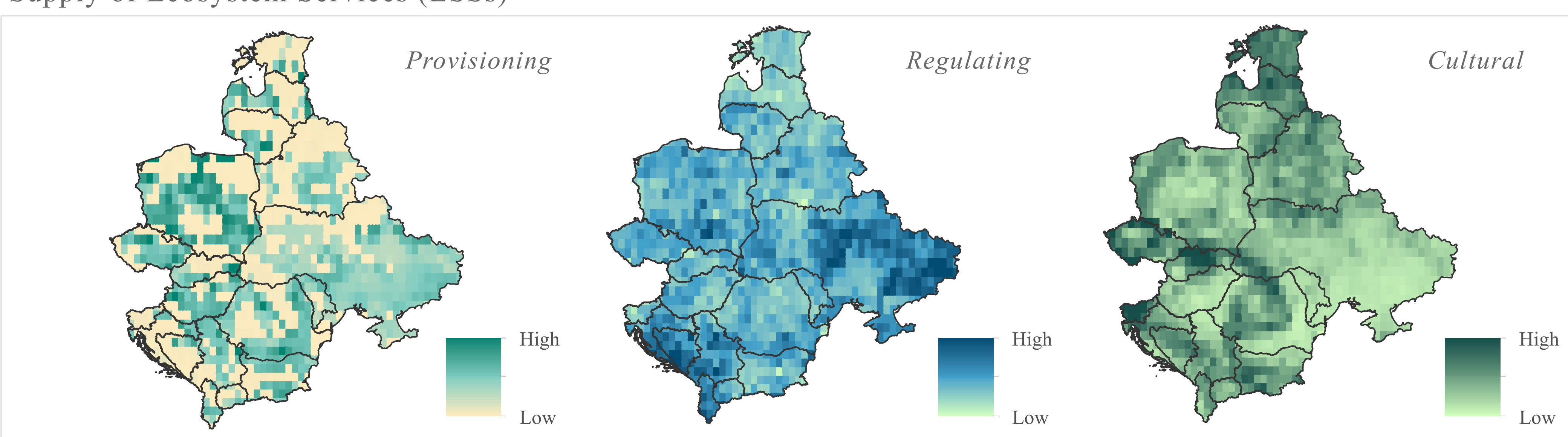


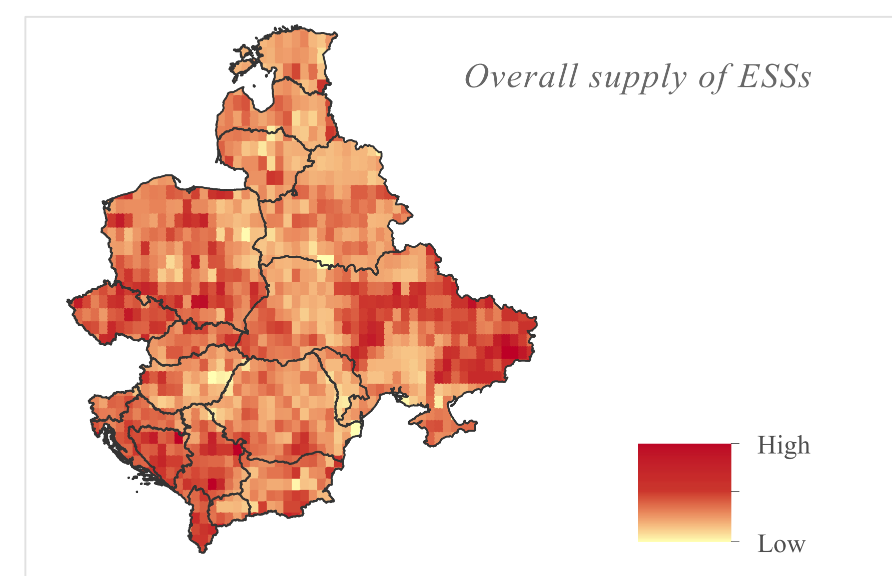
Availability of Ecosystem Functions (ESFs)





Supply of Ecosystem Services (ESSs)





Availability and supply of Ecosystem Services in Eastern Europe - 2012

MAP 2/3

The categories, provisioning, regulating and cultural and their services were modelled separately generating maps on Ecosystem functions (ESFs) and Ecosystem services (ESSs).

Provisioning services

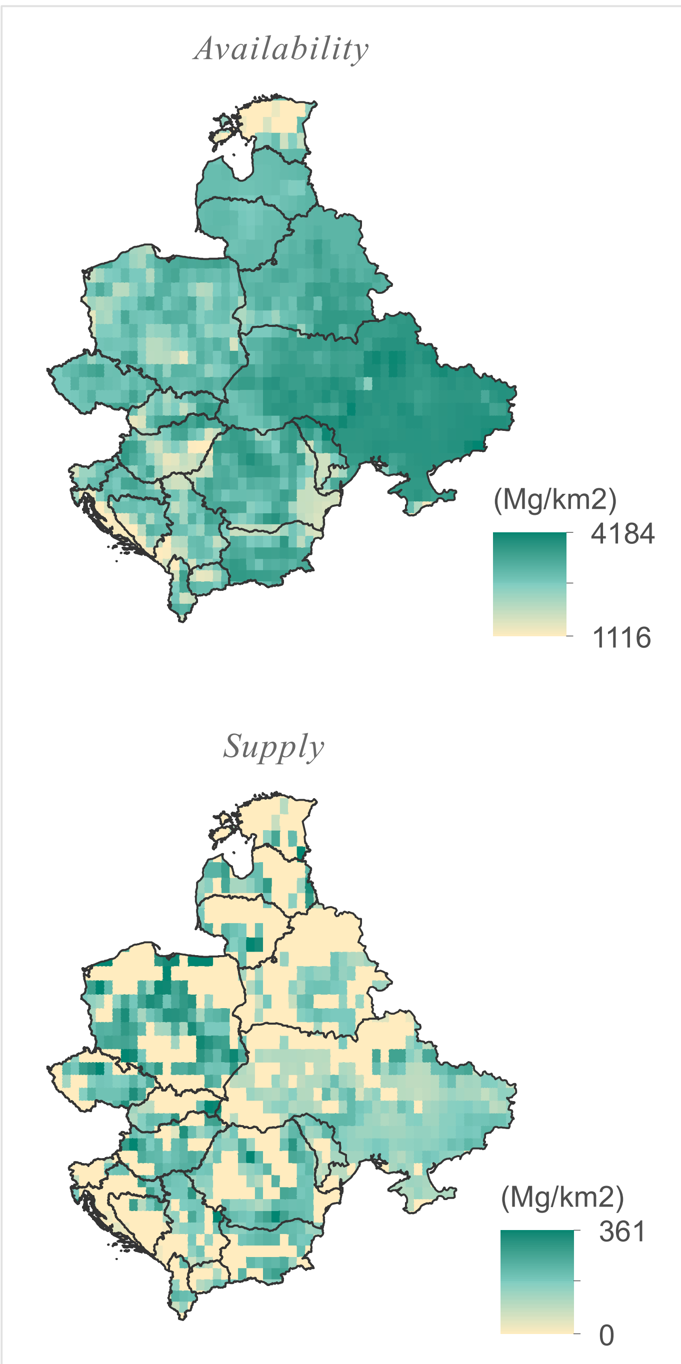
Provisioning ESS comprise of food crop yield and wild food services. Food crop yield ESFs availability, is the potential yield a location can provide. The ESSs supply is the actual annual food crop yield (Mg/km2).

The ESFs of wild food is assessed by the average availability of game, fish, berries and mushrooms. ESSs supply is the amount of wild food accessible to people within the maximum amount of time that people spend collecting wild food (Mg/km2).

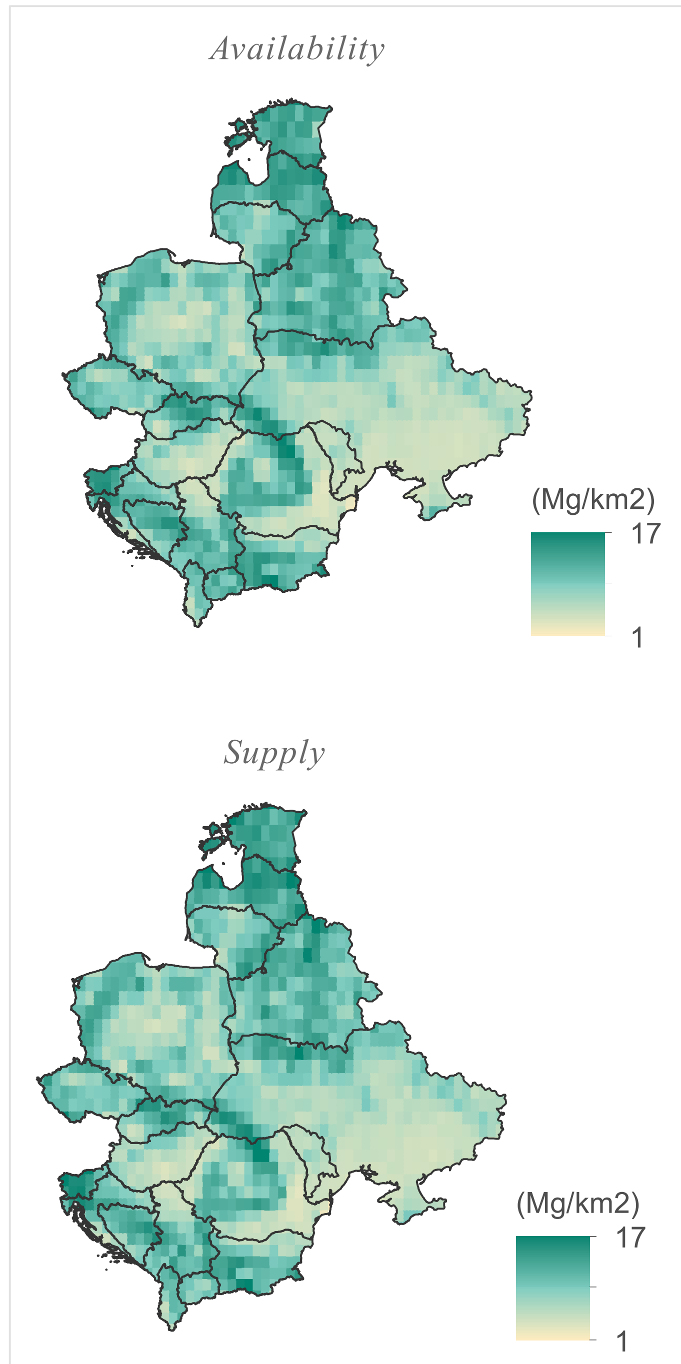
Cultural services

Cultural ESS comprise of the services of tourism and wild food collection. ESFs availability for tourism is the capacity of landscapes to supply attractive areas for tourism and recreation (%). The supplied ESSs is the suitability of attractive areas (%).

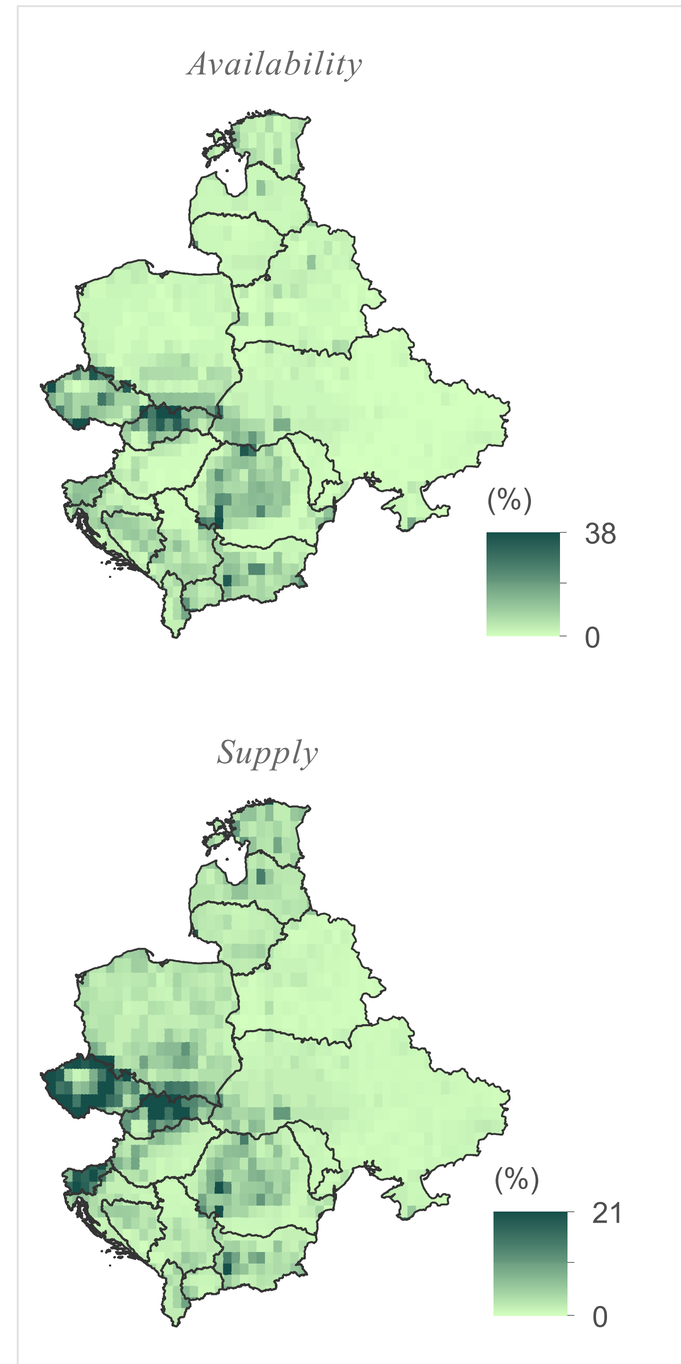
Potential food crop yield



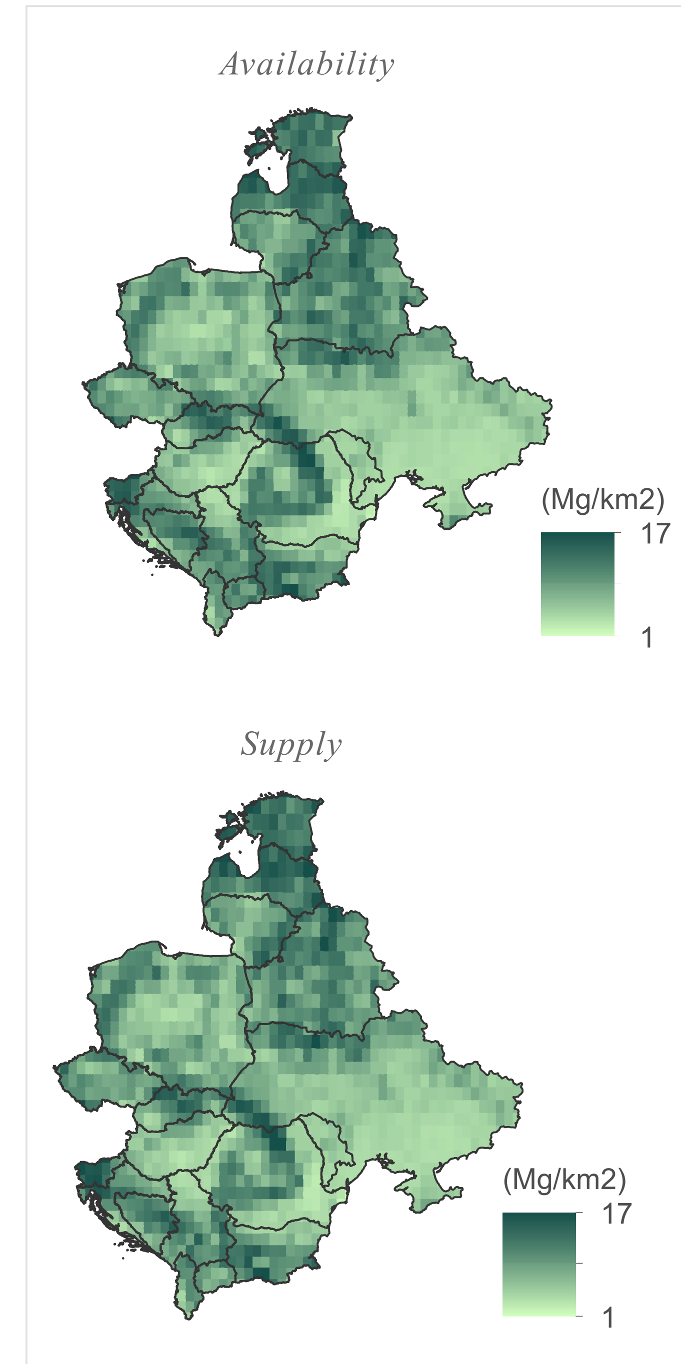
Wild food



Landscape attractiveness for tourism



Wild food



Availability and supply of Ecosystem Services in Eastern Europe - 2012

MAP 3/3

Regulating services

Regulating ESSs comprise of carbon sequestration, erosion and flood protection, pollination and air quality.

- *ESFs of carbon sequestration is the net ecosystem productivity (NEP) (Mg/km). The supplied ESS is the percentage of the annual country total CO2 emission captured by the ecosystem.*
- *ESFs on erosion protection is the decrease of erosion risk by vegetation (%). The supplied ESS is the decrease of erosion risk by vegetation in utilized areas with high erosion risk (%).*
- *ESFs on flood protection is the retention capacity in sensitive to floods areas (%). The supplied ESS, is the areas that are sensitive to floods due to utilization of the land for crop production and urban land (%).*
- *ESFs on pollination is the percentage (%) yield loss due to dismissed pollination. The supplied ESS is the additional yield (Mg/km2) of pulses and oil crops due to wild pollination.*
- *ESFs on air quality is the capacity of the landscape to capture dust particles <10mn (PM10) (%). And The supplied ESS is the amount of PM10 actually capture (g/km2).*