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Mapping and assessment of forest ecosystems and their services

Applications and guidance for decision making in the framework of MAES

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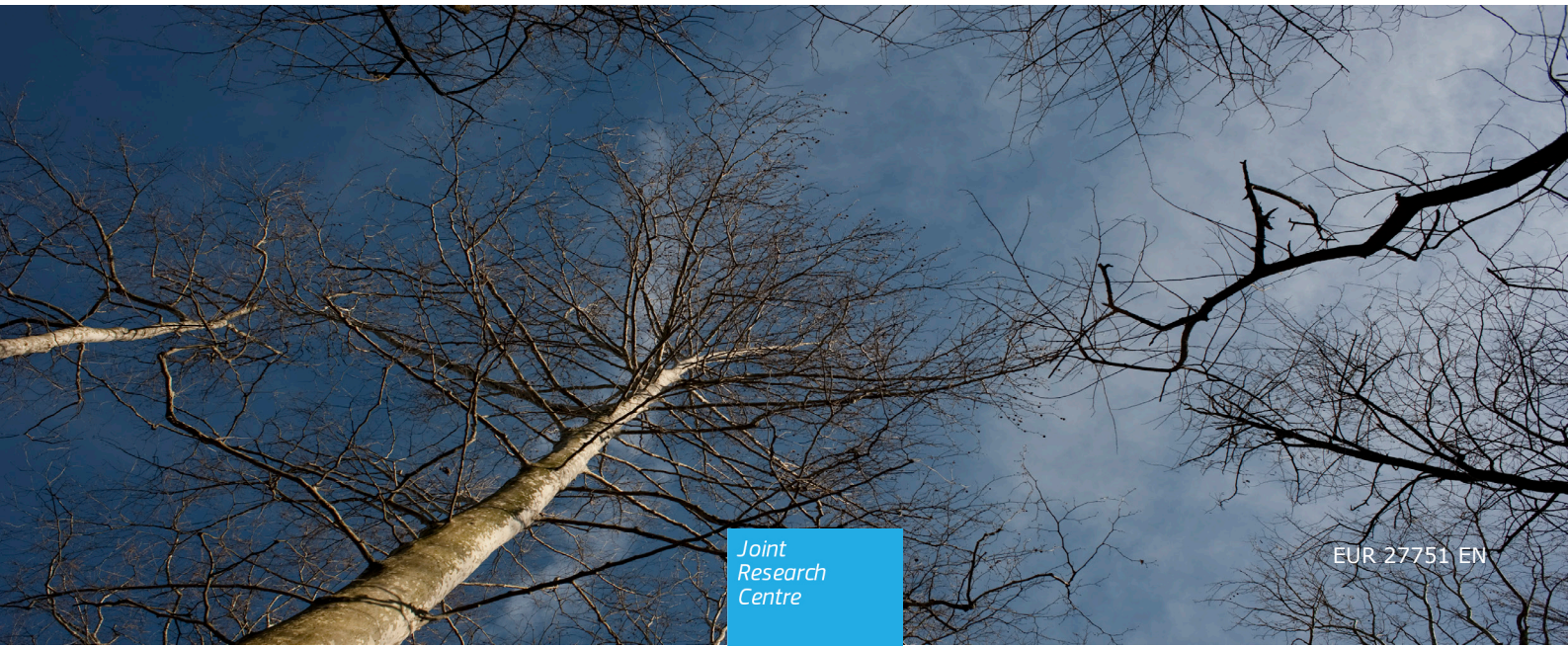

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Abstract

Mapping and assessment of forest ecosystems and their services – Applications and guidance for decision making in the framework of MAES

The aim of this report is to illustrate by means of a series of case studies the implementation of mapping and assessment of forest ecosystem services in different contexts and geographical levels. Methodological aspects, data issues, approaches, limitations, gaps and further steps for improvement are analysed for providing good practices and decision making guidance. The EU initiative on Mapping and Assessment of Ecosystems and their Services (MAES), with the support of all Member States, contributes to improve the knowledge on ecosystem services. MAES is one of the building-block initiatives supporting the EU Biodiversity Strategy to 2020.

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Executive summary

Forest is the largest terrestrial ecosystem in the EU covering more than 40% of the total land cover and is home to much of European biodiversity. Forests provide timber and a multiplicity of important ecosystem services to society such as clean air, fresh water, carbon sequestration, food, opportunities for recreation and many others. However, despite their importance, the knowledge on forest ecosystems and their services still needs to be substantially improved. The EU initiative on Mapping and Assessment of Ecosystems and their Services (MAES), with the support of all Member States, contributes to improve the knowledge on ecosystem services. MAES is one of the building-block initiatives supporting the EU Biodiversity Strategy to 2020.

In 2014, the MAES Working Group launched a forest pilot study aiming to identify available knowledge that can be used to map forest ecosystems and assess their condition and the services they provide, including forest biodiversity. On 2nd December 2014, a dedicated workshop on "Mapping and Assessment of Ecosystems and their Services (MAES) in the forest environment" was held with wide participation from the private and public sector and stakeholders. In the workshop, it was agreed: first, to test the MAES framework and indicators with real forest data and maps and provide feedback for improvement; and second, to develop a guidance document to map and assess forest ecosystems and their services in the EU. This report is a contribution to these tasks.

The aim of this report is to illustrate by means of a series of case studies the implementation of mapping and assessment of forest ecosystem services in different contexts and at three geographical levels: i.e. regional, national and European-wide. Methodological aspects, data issues, approaches, limitations, gaps and further steps for improvement are analysed for providing good practices and decision making guidance from the experience gained.

By analysing the case studies and relevant literature we provide an overview of the array of mapping approaches resulting from the combination of data sources, type of data sources, scales and methods. The number of approaches and options for mapping poses difficulties to decision makers for having a complete understanding of the strengths and weaknesses of each approach. The last part of the report provides an overview of the main approaches using the case studies as examples for providing a more robust basis for informed decisions, including options for model and data validation, and uncertainty measures which are inherent to each method and dataset used for mapping and assessment. We provide a synthesis for understanding the potentials and limitations of the mapping approaches analysed and their capacity for conveying useful information to territorial decision processes. The report closes proposing best practices for forest ecosystem services mapping and assessment.

1. Introduction

Forest is the largest terrestrial ecosystem in the EU covering more than 40% of the land surface and is a main repository for European biodiversity. Additionally, forests provide important ecosystem services to society such as clean air, fresh water, carbon sequestration, soil protection from water and wind erosion, habitats for animal and plant species; forests offer opportunities for recreation and are a source of biomass and wood for multiple uses. However, despite their importance, the knowledge on forest ecosystems and their services still needs to be substantially improved. "Environmental policy is dependent upon good science and reliable data" and achieving the ambitious goals for biodiversity protection in the EU will be possible only by investing in "a strong knowledge base to support and inform actions on the ground" (Janez Potočnik, Brussels, 22 May 2014).

Some preliminary results (Maes et al., 2015) indicate that forest ecosystems are increasing in area while cropland and grassland are decreasing in Europe. There are some positive trends in several ecosystem services, especially provisioning services, which are driven by a complex interaction of changes in agricultural production, afforestation, higher ecosystem productivity and increased nature protection, but decreasing services directly related to biodiversity. Between 2000 and 2010, the increasing extent of forest resulted in positive influences on regulation services (i.e. erosion control, carbon storage, water retention, air quality regulation and recreation). But pollination and habitat quality are the most degraded service for woodland, forest, heathland, shrub and grassland.

The achievement of the objectives of enhancing forest biodiversity and forest multifunctionality of the EU Forest Strategy (European Commission, 2013a) as well as the achievement of the EU 2020 Biodiversity Strategy (European Commission, 2011) and Targets (e.g. 15% restoration of degraded ecosystems, deployment of green infrastructure, ensuring no net loss, payment for forest ecosystem services), will strongly benefit from the outcomes of the EU initiative on Mapping and Assessment of Ecosystems and their Services (MAES)[1], with the support of all Member States. Likewise the development and synergies with related processes within and outside the EU also need to be strengthened.

In 2014, the MAES Working Group launched a forest pilot study aiming to identify available knowledge that can be used to map forest ecosystems and assess their condition and the services they provide, including forest biodiversity (MAES, 2014). On 2nd December 2014, a dedicated workshop on "Mapping and Assessment of Ecosystems and their Services (MAES) in the forest environment" was held with the participation of representatives from Member States (i.e. Standing Forestry Committee, Civil Dialogue Group on Forestry and Cork, Forest & Natura 2000 ad hoc working group, MAES Working Group), selected experts, forest owners representatives, NGOs, and experts from related international groups/processes outside EU (e.g. UN). In this workshop it was agreed to:

- Test the MAES framework and indicators with real forest data and maps and provide feedback for improvement, and
- Develop a guidance document to map and assess forest ecosystems and their services in EU.

The present report is a contribution to these tasks. Therefore the aim of this report is to illustrate by means of a series of case studies the implementation of mapping and assessment of forest ecosystem services in different contexts and at three geographical levels; i.e. regional, national and European-wide. Methodological aspects, data issues,

[1] http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/index_en.htm

approaches, limitations and gaps will be analysed for providing good practices and decision making guidance from the experience gained.

The report is structured in five chapters. The second chapter is a brief description of the policy drivers addressing forest ecosystems and the services they provide. Chapter 3 describes the main concepts about maps, mapping and the different dimensions of forest ecosystem services mapping. Chapter 4 describes ten case studies on mapping and assessment of forest ecosystem services in different environments and at three geographical levels. The final chapter analyses the case studies and provides guidance and good practices for decision making using maps and assessments of forest ecosystem services.

2. Policy framework for European forest, ecosystem services and biodiversity

There are no treaties in the EU for a common forest policy. The responsibility for forest policy lies primarily with the Member States under the subsidiarity principle, as stated in the Treaty of Lisbon. The role of the EU is limited and designed principally to add value to national forest policies and programs by monitoring and possibly reporting on the state of EU forests, anticipating global trends and drawing MS' attention to emerging challenges, and proposing and possibly coordinating or supporting options for early action at EU scale.

Nevertheless, there is an increasing recognition of the role of forests for protection of biodiversity and of the dependency of human well-being on natural capital from forest ecosystems. At the same time, ecosystems, habitats and species that provide this natural capital are reported degraded or lost due to human activity.

The urgent need to protect and enhance this natural capital is recognised in the EU's 7th Environmental Action Programme, which sets out the priorities for environmental policy until 2020 (EU, 2013). The EU and its Member States are requested to implement existing strategies to protect natural capital, to fill gaps where legislation does not yet exist and to improve existing legislation.

Key strategies include the EU Biodiversity Strategy to 2020 (European Commission, 2011), which mirrors the global Aichi targets of the Convention on Biological Diversity (CBD, 2010), the EU Forest Strategy (European Commission, 2013a), and the Blueprint to Safeguard Europe's Water Resources (European Commission, 2012). These are supported by a number of earlier measures including legally-binding commitments; in particular the Habitats and Birds Directives, the Water Framework Directive and the Air Quality Directives.

2.1. The EU Biodiversity Strategy 2020

The European Commission and Council adopted in 2011 the EU Biodiversity Strategy to 2020 (European Commission, 2011), which also implies the time lines to meet the Aichi targets of the Convention of Biodiversity (CBD, 2010). The Aichi biodiversity targets complement the previous, conservation-based biodiversity targets with the addition of ecosystem services as an element to be considered in the global expansion of protected areas (Target 11), as well as a component of priority for protection and restoration (Target 14).

The EU Biodiversity Strategy for 2020 aims to halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020. It also aims to restore them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss.

The Biodiversity Strategy has six mutually supportive and inter-dependent targets and 20 supporting actions (Figure 2.1). Target 2 calls for better protection and restoration of ecosystems and their services. Within target 2, Action 5 pleas for all Member States to map and assess the state of ecosystems and their services, their economic value and to promote the integration of these values into accounting and reporting systems at EU and national level by 2020. This knowledge base will support the Green Infrastructure Strategy (European Commission, 2013b), and the establishment of ecosystem capital accounting. It also underpins other targets of the Biodiversity Strategy and related EU initiatives and highlights the importance of an integrative view in decision making processes. A robust knowledge base is key to address synergies and trade-offs of policy impacts on ecosystems and their services. The Biodiversity Strategy implies two timelines for their targets. For 2020, it states that ecosystems and their services are

maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems. For the long-term target in 2050, the EU biodiversity and the ecosystem services it provides —its natural capital— are protected, valued and appropriately restored for biodiversity's intrinsic value and for their essential contribution to human wellbeing and economic prosperity, so that catastrophic changes caused by the loss of biodiversity are avoided.

A Working Group was set-up to develop the concept and methodologies for Action 5 of Target 2. The MAES initiative includes the European Commission in collaboration with the Joint Research Centre of the European Commission, European Environment Agency and Member States. Two reports propose a common analytical framework for mapping and assessment across Europe in order to assess the state of ecosystems, and a set of indicators that can be used at European and Member State levels to map and assess biodiversity, ecosystem condition and ecosystem services (MAES, 2013, 2014). This work aims to ensure consistency in approaches and comparability of data across Member States.

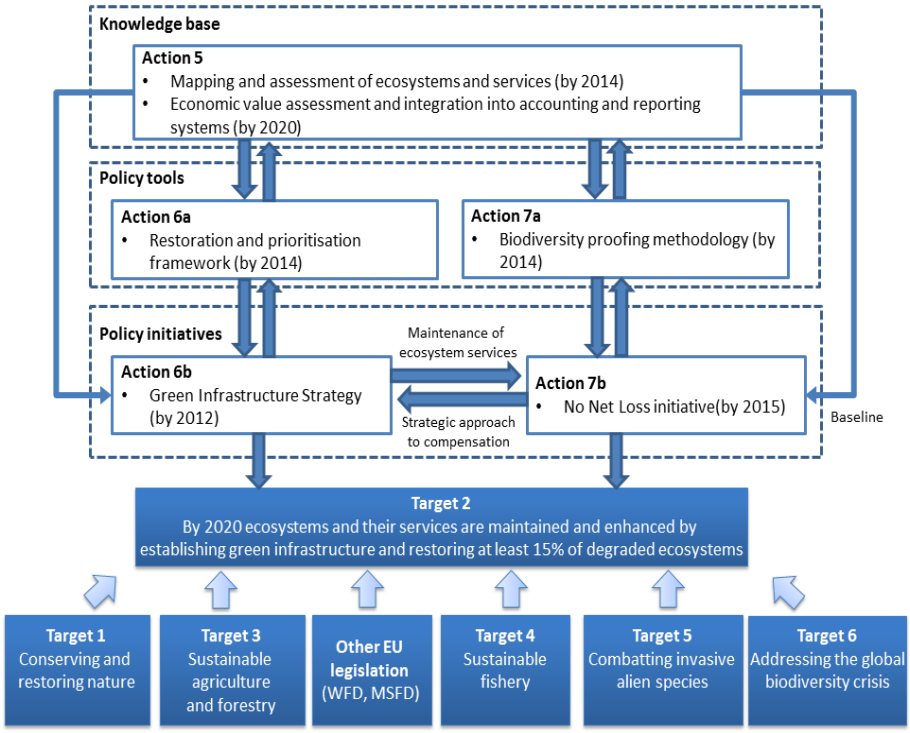

Figure 2.1. Importance of Action 5 in relation to other supporting actions under Target 2 and to other targets of the EU Biodiversity Strategy (Source: MAES, 2013).

2.2. EU Forest Strategy

The present EU Forest Strategy was adopted in 2013 (European Commission, 2013a). In common with the previous EU Forestry Strategy (European Commission, 1998) and EU Forest Action Plan 2007–2011 (European Commission, 2007), the Forest Strategy focusses strongly on sustainable forest management and the multifunctional nature of forests delivering multiple ecosystem services. The role of ecosystem services from forests is recognised for overall economic and social development, especially in rural areas. The Forest Strategy also emphasises the need for protection of the forest, notably in relation to biodiversity and climate change. Resource efficiency would optimise the contribution of forests and the forest sector to rural development, growth and job creation. Finally the Strategy aims at promoting global forest responsibility, sustainable production and consumption of forest products.

The recently adopted Forest Multi-Annual Implementation Plan of the EU Forest Strategy (or "Forest MAP")(European Commission, 2015c) is a follow-up of the 2013 Forest Strategy, updating the challenges which the sector faces, while still balancing the economic, social and environmental benefits of forests. The Forest MAP provides a concrete list of actions in order to ensure a coherent, coordinated approach to the various policies and initiatives relating to the forest sector, with the particular involvement of stakeholders. The plan also includes actions to enhance essential ecosystem services provided by forests - such as flood, landslide and erosion protection, carbon sink, climate stabilisation, habitat for animals and plants, genetic resource, and recreational space - and to provide both experts and the public with comprehensive and harmonised information on EU forests through the Forest Information System for Europe (FISE).

2.3. Nature legislation

The EU Nature policy comprises the Birds Directive and the Habitats Directive, indicating the EU target species and habitats that are to be protected while establishing the EU-wide Natura 2000 network under the 1992 Habitats Directive. The aim of the network is to assure the long-term survival of Europe's most valuable and threatened species and habitats, and combines both the areas designated under the Birds Directive as the ones designated under the Habitat Directive. Member States have a legal obligation to manage Natura 2000 sites and achieve favourable conservation status for those habitats and species within their borders. Over 27,000 sites have been included in the Natura 2000 network and cover 18% of the European land area. Around 21% of the total forest area in the EU belongs to Natura 2000.

Under the Habitats Directive, adopted in 1992, Natura 2000 sites are selected on the basis of national lists proposed by the Member States. The Commission adopts a list of Sites of Community Importance (SCI) which then become part of the network. Finally, the SCI are designated at the national level as Special Areas of Conservation (SAC). There are a total of 81 forest habitats listed in Annex 1 of the Habitats Directive out of a total of 230 habitat types. Twenty eight of these forest habitats are considered priority habitats. Under the Birds Directive, adopted in 1979, Member States select the most suitable sites and designate them directly as Special Protection Areas (SPAs). These sites then automatically become part of the Natura 2000 network. Ninety one out of the 195 birds listed in Annex I of the Birds Directive are considered to be key forest species. Since 2011, the Natura 2000 Biogeographical Process helps to ensure coherent and effective management of the Natura 2000 protected sites in the nine biogeographical regions: Alpine, Artic, Boreal, Black Sea, Continental, Macaronesian, Mediterranean, Pannonian and Steppic (see: European Commission, 2015b, a).

The two strategies, the Biodiversity Strategy and the Forest Strategy, both request that Member States achieve a significant and measurable improvement in the conservation status of forest species and habitats by fully implementing EU nature legislation and ensuring that national forest plans contribute to the adequate management of the Natura 2000 network by 2020.

3. Maps, mapping and the dimensions of ecosystem services

Maps have been produced since the beginning of human history and have had multiple uses during all this time; from military, cadastral and road maps to present-day web-mapping tools with multiplicity of thematic applications. A map can be thought of as a model representing the whole earth or a certain space (Cauvin et al., 2013). From this perspective, map (model) creation should follow very precise rules: in other words, should follow the scientific method, including characteristics of reproducibility, validation and uncertainty assessment. In summary, a map can be defined as "a graphic model of the spatial features of reality" (Kraak and Ormeling, 1996), thus allowing communication and further analysis in GIS post-processing and modelling.

Within the scope of MAES, maps of ecosystem services are useful for several purposes (MAES, 2013):

- Spatially explicit representation of synergies and trade-offs among different ecosystem services, and between ecosystem services and biodiversity;
- Communication tool to initiate discussions with stakeholders;
- Visualisation of the locations where valuable ecosystem services are produced or used;
- Tools for communicating the relevance of ecosystem services to the public in their territory;
- Planning and management of biodiversity protection areas and implicitly of their ecosystem services at sub-national level;
- Support to decision makers to spatially identify priority areas, and relevant policy measures.

Maps of ecosystem services can represent different biophysical dimensions of the services: i.e. ecosystem services flow, potential, demand and stock. Each dimension uses a specific approach and data type and therefore mapping each dimension produces a different output. Here we present a brief description of the subject mapped on these four dimensions. First, ecosystem services are the benefits that people obtain from ecosystems (MA, 2005): the direct and indirect contributions of ecosystems to human wellbeing (TEEB, 2010). Specifically, ecosystem services flow (supply) refers to the part of the services actually used (MAES, 2013). Second, ecosystem services potential is the potential capacity of an ecosystem (or area) to provide services independently of being used or not. For example, usually forest volume increases by more than the amount taken out by felling. In this case the volume increment is the potential and the felled part is the ecosystem service flow (supply). Third, ecosystem service demand is the quantity of a given service desired by people per time period. In analysing ecosystem services demand it is important to consider scale dependency factors, as some services are transported over long distances (e.g. timber) while others have a local level demand (e.g. soil protection) (MAES, 2013). Finally, stocks are for example the total amount of carbon or timber stocked in forest at a given time period, whereas the supply is a flow having units per time period.

In addition to the mapping of the biophysical output of ecosystem services, mapping of ecosystem services values is an option increasingly used. For instance, after having produced maps of ecosystem services, e.g. flow or stock, it is feasible to map ecosystem service values. In this case the monetary value of the service is represented spatially showing how values vary across space (Schägner et al., 2013). The following chapter illustrates the mapping dimensions of forest ecosystem services in case studies.

4. Cases studies on forest ecosystem services mapping and assessment

This chapter illustrates through ten case studies different approaches to mapping and assessing forest ecosystem services. The case studies are grouped in three geographical levels: local/regional, national and European-wide (Figure 4.1). The case studies include the approach used and a brief methodological description with the scope of showing the main differences regarding methods and models, availability of data and type of data used for mapping and assessment. Although the case studies follow a common structure (abstract, methods and results, discussion, and conclusions) there is some flexibility in the content due to differences in approaches. Each case study is a summary of a previous peer-reviewed publication; therefore readers interested in further methodological details are suggested to consult the original publication (Table 4.1).

Case study - Title	Scale	Reference/Project
CS 4.1 - Highlighting synergies and trade-offs between biodiversity, carbon storage and water flow regulation using spatial analysis: Basque Country forests (Spain)	Regional	Onaindia et al. (2013)
CS 4.2 - Mapping production of biomass by annual plants in Mediterranean evergreen woodlands: Portuguese woodlands	Regional	Ramos et al. (2015)
CS 4.3 - On the importance of integrating expert knowledge into mapping ecosystem services: Swiss Alps forests	Regional	Grêt-Regamey et al. (2013)
CS 4.4 - Mapping green infrastructure based on ecosystem service supply and demand: Helsinki-Uusimaa Region, Finland	Regional	Kopperoinen et al. (2014); Kopperoinen et al. (2015); (Itkonen et al., 2015)
CS 4.5 - Mapping timber production and carbon storage forest ecosystem services from a case study in the Mediterranean region (Molise Region, Italy)	Regional	Chirici et al. (2014)
CS 4.6 - Site-based ecosystem services mapping and assessment in Portuguese montado agro-forests – comparing the InVEST and TESSA tools	Regional	OPERAs and Lter Montado Projects
CS 4.7 - How is biodiversity changing in Spanish forest ecosystems?	National	Spanish National Ecosystem Assessment (2014); Santos-Martín et al. (2013)
CS 4.8 - Mapping multiple ecosystem services (Sweden)	National	Gamfeldt et al. (2013); Snäll et al. (2015); Snäll et al. (2014)
CS 4.9 - Developing a spatially-explicit pan-European map of forest biomass provision	European -wide	Busetto et al. (2014)
CS 4.10 - Mapping forest carbon stock distribution in European forest	European -wide	Thurner et al. (2014)

Table 4.1. Case studies for mapping forest ecosystem services and source references.

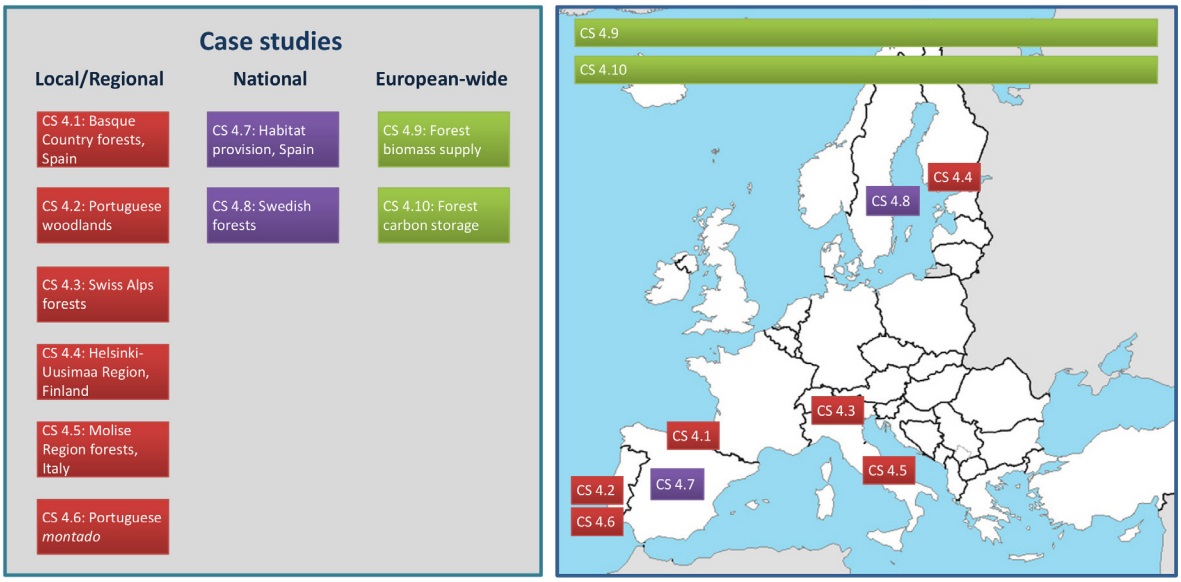

Figure 4.1. Three geographical levels of the case studies: Local/Regional, National and European-wide; and distribution map (Source of base map: GISCO).

Local and regional case studies

4.1. Highlighting synergies and trade-offs between biodiversity, carbon storage and water flow regulation using spatial analysis: Basque Country (Spain) forests

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Abstract

Trade-offs between biodiversity, carbon storage and water flow regulation were analysed in a biosphere reserve in Biscay (Basque Country, northern Spain) within the Millennium Ecosystem Assessment in this county aiming to propose criteria for conservation plans that included biodiversity and ecosystem services. A Geographic Information System (GIS)-based approach was designed to estimate and map the biodiversity and ecosystem services. The current protected areas, namely coastal ecosystems and Cantabrian evergreen-oak forests, were found to be important for the overall biodiversity, and included some important portions of ecosystem services. The non-protected natural forests, such as mixed-oak forests, were biodiversity hotspots, and contributed to carbon storage and water flow regulation services. Thus, this native forest, nowadays not protected, should be considered in conservation proposals. While

pine and eucalyptus plantations contributed to carbon storage and water flow regulation, they had negative effects on biodiversity and caused environmental problems. As a result of this study, the new Plan for Management of Natural Resources will include mixed-oak natural forests as protected areas. Our study highlights that the inclusion of ecosystem services in conservation planning has a great potential to provide opportunities for biodiversity protection; nevertheless, strategies of conservation based only on specific ecosystem services

Methods and discussion

Study area

The study was conducted in the Urdaibai Biosphere Reserve (UBR), Biscay, northern Spain, declared as Biosphere Reserve in 1984. In 1989 was established a legislation to protect the core areas, namely coastal ecosystems and evergreen-oak forests, and to promote a sustainable development. In recent years this legislation has been a focus of controversy between stakeholders. Actually, the Natural Resources Management Plan is under revision in order to try to reconcile the conservation of the natural resources with their sustainable use. Therefore, this area is an appropriate place to define strategies for land management that are based on both biodiversity and ecosystem services.

Mapping ecosystem services

A GIS-based approach was designed to spatially estimate the value of biodiversity and the provision of two important services in the study area: carbon storage and water flow regulation. For the mapping we used as base data of land uses the EUNIS (European Nature Information System) map of the Basque Country, in 1:10,000 scale [source: Eusko Jaurlaritza/Gobierno Vasco (2015)]. For this study, the 86 habitats present in the area were aggregated into the 10 environmental units most relevant to the region: coastal habitats (2%), grassland and hedges (21%), bushes, shrubs and heaths (3.5%), riparian forest (0.5%), beech forest (0.001%), mixed oak forest (9%), Cantabrian green oak forest (7%), broadleaves plantations (2%), eucalyptus plantations (7%), coniferous plantations (48%).

We made a quantitative valuation of biodiversity and the ecosystem services provision. After that, different areas were assigned as hotspots and ranges, where hotspots identified those areas with a high value of biodiversity or ecosystem service, and ranges identified areas that provided medium amounts of biodiversity or service (Egoh et al., 2008).

Mapping Biodiversity

The biodiversity value integrated information on several levels of biodiversity as a function of the plant richness, successional level and existence of a legally protected feature. $B = f(r, q, p)$

Where B: Biodiversity; r: richness, as the number of native plant species; q: habitat quality (successional level); p: protection status (based on relevant flora, fauna and singular landscapes).

The number of native vascular plant species (richness) was used as a proxy of biodiversity and was calculated based on the literature (see: Onaindia et al., 2013). Plant richness values were ranged on a scale from 1 to 4, using equal intervals from the maximum value to the minimum value. The assigned values for the successional level were: 4: forests and coastal habitats, 3: bushes, 2: grasslands, and 1: others. Finally the assigned value for protection status was 1 (legally protected by European directives or regional laws) or 0 (non-protected).

Mapping Carbon storage

We mapped the amount of carbon stored in biomass (living trees) and soil in the study area. C stored in living trees (aboveground and belowground), was obtained as follows (IPCC, 2003): CB = V*BEF*(1+R)*D*CF

Where CB: the carbon stocks in living biomass, tonnes C ha^{-1}; V: the merchantable volume, m3 ha^{-1}; BEF: the biomass expansion factor, without units; R: the root-to-shoot ratio, without units; D: the basic wood density, tonnes d.m. m^{-3} merchantable volume, and CF: the carbon fraction of dry matter, tonnes C (tonne d.m.)$^{-1}$.

The merchantable volume data for the different forests were obtained from the Forest Inventory of the Basque Country (see: Onaindia et al., 2013). For the valuation of C stored in the soil, we used the "Inventory of organic C stored in the first 30 cm of the soil" of the Basque Country (Neiker-Ihobe, 2004).

Water flow regulation

We used the fraction of the annual water flow stored in the soil to measure the water flow regulation service: WC: Hu/R, where WC: the water flow regulation.

R = P – Etc; Hu: the water storage in the soil (mm/year); R: the annual water flow (mm/year); P: the annual rainfall (mm/year); Etc: the corrected annual potential evapotranspiration (mm/year).

The potential evapotranspiration was modified by correction factors for the different vegetation types used in the InVEST-Integrated Valuation of Ecosystem Services and Trade-offs (Tallis et al., 2011). The water storage in the soil map and the annual potential evapotranspiration map were supplied by the Water Agency of the Basque Government. The annual rainfall map was supplied by the Meteorological Agency of the Basque Government.

Discussion of methodology

One of the proxies used to calculate biodiversity was the number of native vascular plant species, but data on relevant fauna species were not included because there was not available geo-referenced information at regional scale. Nevertheless, fauna was taken into account indirectly through the inclusion of the protection status of land that includes the presence of significant fauna species.

Regarding the valuation of C store in biomass, we focused on the C stored in living trees. We couldn't estimate ecosystems other than forests, neither C stored in the understory, herbaceous layers and dead organic matter in forests. The reason was that there were not evaluations for these environmental units. However, the C contained in these units is low compared with other components. In relation to the calculation of water cycle control, the data available on evapotranspiration were just for potential evapotranspiration, however, in order to obtain a more realistic value of the real evapotranspiration the data for each different vegetation type were modified by a correction factor. The correction factors used were global indexes used at international level, as we do not have data at regional scale.

Conclusions

Biodiversity, carbon storage and water flow regulation hotspots are coincident on 4% of the total surface of the biosphere reserve, and the whole area is covered by natural forest. Results highlight synergies among biodiversity, carbon storage and water flow regulation in natural forests, and trade-offs between biodiversity and ecosystem services in forest plantations (Figure 4.2). While natural forests are fundamental for biodiversity and for all the studied ecosystem services, pine and eucalyptus plantations contribute to ecosystem services, but have negative effects on biodiversity and cause environment problems.

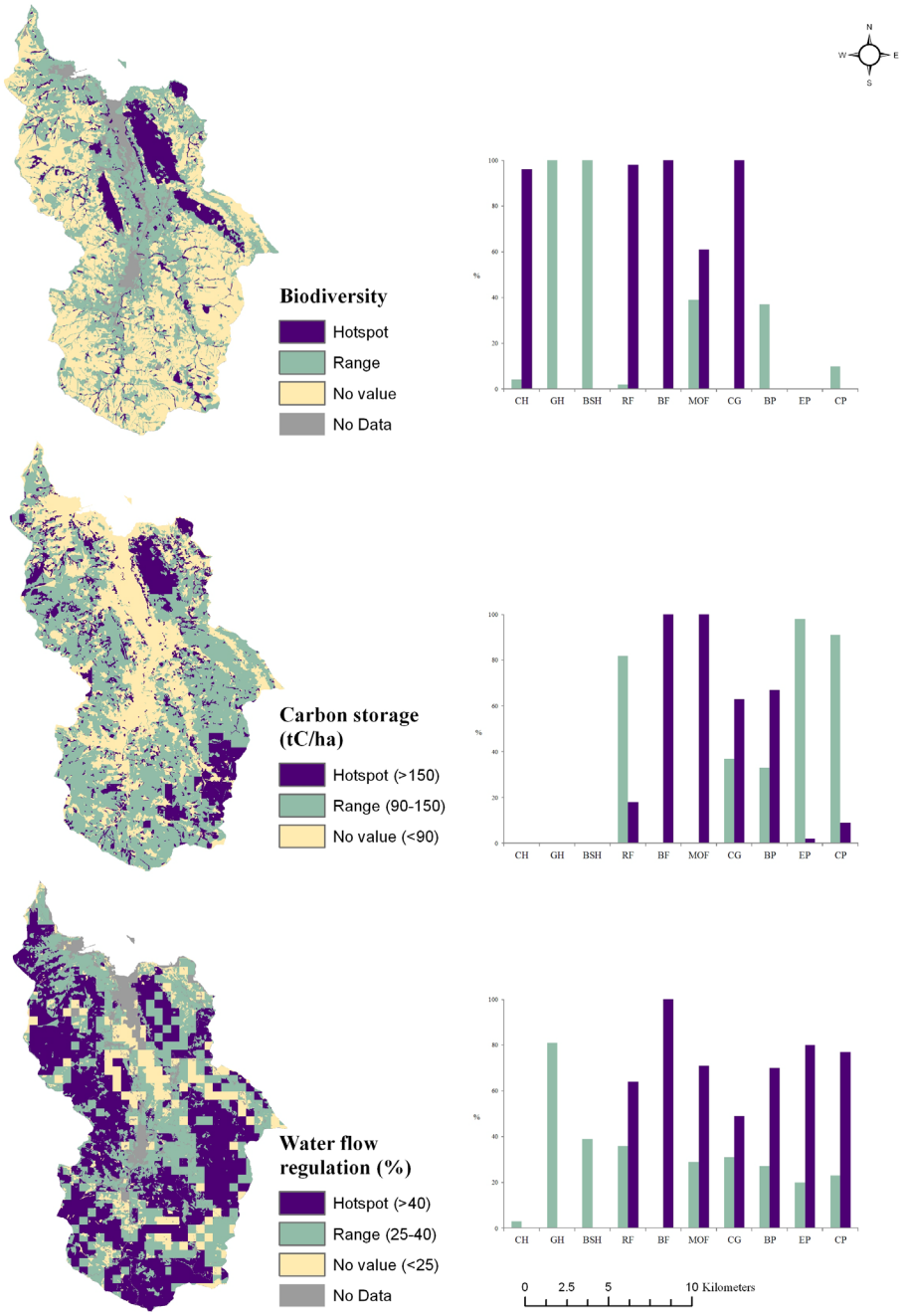

Figure 4.2. Maps of ranges and hotspots of biodiversity, carbon storage and water flow regulation, and graphics indicating the percentage of each ecosystem that is included in range and hotspot. CH (coastal habitats), GH (grassland and hedges), BSH (bushes, shrubs and heaths), RF (riparian forest), BF (beech forest), MOF (mixed oak forest), CG (cantabrian green oak forest), BP (broadleaves plantations), EP (eucalyptus plantations), CP (coniferous plantations).

Conservation of biodiversity will ensure the provision of a considerable portion of the studied ecosystem services. The most important contribution to biodiversity and ecosystem services is within the current protected areas, however the non-protected natural forests also have a significant contribution. Thus, the small and fragmented areas of mixed-oak forests have a high input to biodiversity, carbon storage and water regulation. Even if they are small, the protection of areas covered by mixed-oak, beech

and riparian forests will enhance the studied biodiversity and services. In consequence mixed-oak forests will be considered in conservation proposals together with new strategies of regeneration in the New Natural Resources Management Plan of the UBR.

Our study shows that the consideration of ecosystem services can optimise the conservation strategies for multiple ecosystem services and that a biodiversity network would protect a considerable supply of ecosystem services. The inclusion of ecosystem services in conservation planning has a great potential to deliver opportunities for biodiversity protection, whereas strategies of conservation based only on specific ecosystem services may be detrimental to biodiversity and may cause environmental problems.On the one hand the fine grain of the data used in this study has the advantage that the results can be used for management strategies by decision-makers. On the other, the limitations of the results are also in relation to the scale, because if we have had more detailed data we would have come to more accurate results. Thus, further work is necessary to obtain more accurate data on environmental variables at local level in order to have more reliable results to implement specific management measures.

4.2. Mapping production of biomass by annual plants in Mediterranean evergreen woodlands: Portuguese woodlands

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Abstract

Mediterranean evergreen woodlands are sparsely forested areas, where trees occur mingled with patches of shrubland and grassland dominated by annual plants. While the standing biomass (trees and perennial shrubs) is often calculated in ecosystem services studies, the production of biomass by annual plants remains to be addressed due to its temporal dynamic. This biomass is commonly used as pasture for cattle grazing. Although it could be assumed that its production value is the same for the entire ecosystem range, previous work has shown that annual biomass strongly depends on the local climate and land-use (Ramos et al., 2015), thus this assumption cannot be taken and the production of biomass by annual plants must be measured in a spatial explicit way. Here we have focused in Holm-oak (*Quercus ilex*) woodlands, because they are located between the semi-arid and dry sub-humid climates, strongly limited by water availability and affected by the effects of desertification and land degradation. To characterize the production of biomass by annual plants in Mediterranean evergreen woodlands we used satellite measures provided by MODIS and calculated several metrics related to the annual variations. In selected sites, we also measured in the field the annual biomass production. A model was then built relating satellite and field data, and then used to extrapolate the biomass values production over the entire study area. A map showing the production of the biomass produced by annual plants within Mediterranean woodlands was then built using geostatistics.

Using this approach we could calculate the production of biomass by annual plants within Holm-oak woodlands. The values differ greatly between sites, from less than 50 g m^{-2} to 350 g m^{-2} or more. These values were spatially aggregated, with a spatially continuity of 6,500 m, which allowed mapping using geostatistics. The most productive regions were located in the center of the distribution area of *Q. ilex*, while less productive regions were located in the mountains areas to the north and south.

This work highlighted that the production of biomass by annual plants within woodlands can be accessed by associating satellite and field data. These measures must be mapped with high resolution, rather than assuming a value for the entire region, due to the large differences between sites.

Methods and discussion

Holm-oak woodlands are an important ecosystem in southern Europe, since they provide several ecosystem services, in particular related to biomass production. Plant biomass in these savanna-like areas systems is located mainly in evergreen plants (mostly trees) and in annual plants, which exist mingled under the trees canopy. Although trees are frequently taken into account when measuring ecosystem services such as carbon sequestration, annual plants are overlook because they are not the main component of the ecosystem. However, the annually produced biomass is an important part of the overall ecosystem produced biomass, and it is consumed locally (by extensive grazing), harvested and stored to be consumed elsewhere as forage (in livestock production units) or stays in the system contributing to soil organic matter.

The objective of this study was to quantify and map the production of biomass by annual plants that exist within Mediterranean woodlands. This was done by modelling field measures of annual plants biomass with satellite based measures. Using this model a map was built for the entire national distribution of this ecosystem.

This work was based on the project DesertWarning, which aimed at developing early warning indicators for the effects of Desertification and Land Degradation. Within this project the Portuguese national forest inventory (AFN, 2006) was chosen for sampling sites selection. Of c. 336,000 points distributed across the country, we selected only the ones with Holm-oak woodlands as main land-use type. Afterwards, environmental factors were homogenized in order to ensure that their effects were small. This was done by selecting from all possible sampling sites available the ones having: altitude between 150 and 300 m, inclination smaller than 5°, soil dominantly acidic (pH<6.5), within lithosols or luvisols type and dominated by sedimentary and metamorphic lithology and for which there was no record of fire for the last 40 years (which represented the dominant conditions on the study area). This homogenization resulted in 6,242 sampling sites distributed along a climate gradient.

Using a random stratified sampling (stratified by average annual precipitation, to ensure sampling along the entire environmental gradient) 15 sites were selected for field sampling in 2014. In each of these sites, three 30x30 cm quadrates were sampled, and the above-ground biomass of annual plants growing within them was collected by clipping at ground level. Each quadrate was considered a replicate, resulting in three replicates per site. Harvesting was done after the final of the growing season at the peak of live biomass. Plant biomass was then oven dried at 60°C for 48 h to calculate dry biomass, which was further used in the analysis.

For the selected sites, satellite data was obtained from MODIS normalized difference vegetation index (NDVI) product. Maximum NDVI for each 16 days period was considered. Ten vegetation phenology variables were determined using a double logistic least squares fitted function using TIMESAT software (Jönsson and Eklundh, 2004). When calculated over large regions these metrics can be used to characterize the current status of the studied ecosystem or its response over time to environmental pressures, such as climate change or desertification and land degradation (Ivits et al., 2012). These variables were collected annually for each growing season from 2000 to 2012 and then averaged for each sampling site. See Ramos et al. (2015) for further details.

A model was built relating field and satellite data. The satellite driven variable with the strongest relationship with field data was selected, and a linear regression was used, after transforming the variables to ensure a linear relationship. Using this model, the values of yearly production of biomass by annual plants (g m^{-2}) were calculated for all sites. For visual interpretation these values were interpolated using ordinary kriging after

variogram analysis. The maximum range of the variogram was considered as the visualization limit in the output map.

Of the ten phenology variables tested the one with the most significant relationship with field data was amplitude, which represents the maximum NDVI amount added by the annual vegetation to the base level NDVI (which is the amount of NDVI given by the perennial trees and shrubs). Amplitude was modelled with the biomass of annual plants measured in the field, which explained c. 54% of its variance. Higher field biomass resulted in higher amplitude values measured by satellite, although a sill was observed for NDVI values for high field of biomass measured in the field (i.e. when a very high production of biomass was observed in the field, the measured NDVI increment was not the same as for lower values). This resulted in a logarithmic relationship.

Using this model, the production of biomass by annual plants was estimated for all sampling points. The distribution of these values showed that most sites presented medium-low productivity, between 100 g m^{-2} to 150 g m^{-2}, although values from less than 50 g m^{-2} to more than 350 g m^{-2} could be found (Figure 4.3).

The variogram of the estimated production of biomass by annual plants showed a spatial continuity of 6,500 m, no anisotropy and c. 1/3 of the total variance as the nugget effect. This model was used to interpolate the production of biomass by annual plants along the study area, which corresponds to the extent of the Holm-oak woodlands in the country. The highest values were found in the centre of the distribution, while lowest values were found in the more mountainous areas to the south and north, in the north-south limits of the distribution of the ecosystem.

This work allowed mapping the production of biomass by annual plants in Holm-oak woodlands. Because Mediterranean evergreen woodlands are also composed of other tree species, most notably cork-oak (*Quercus suber*), further work is necessary to include these areas in the model. Cork-oak is mostly restricted to coastal areas, where it replaces Holm-oak, and these areas are characterized by more precipitation and lower temperatures, thus a different productivity is expected.

Conclusions

In this work, we could provide a map of the production of biomass by annual plants within Holm-oak woodlands, a frequently overlooked component of this ecosystem. This could be done relating satellite and field data. The results highlighted that a single value of production of biomass by annual plants cannot be assumed for the entire range of distribution of the woodlands, because of the large differences between sites.

Acknowledgment

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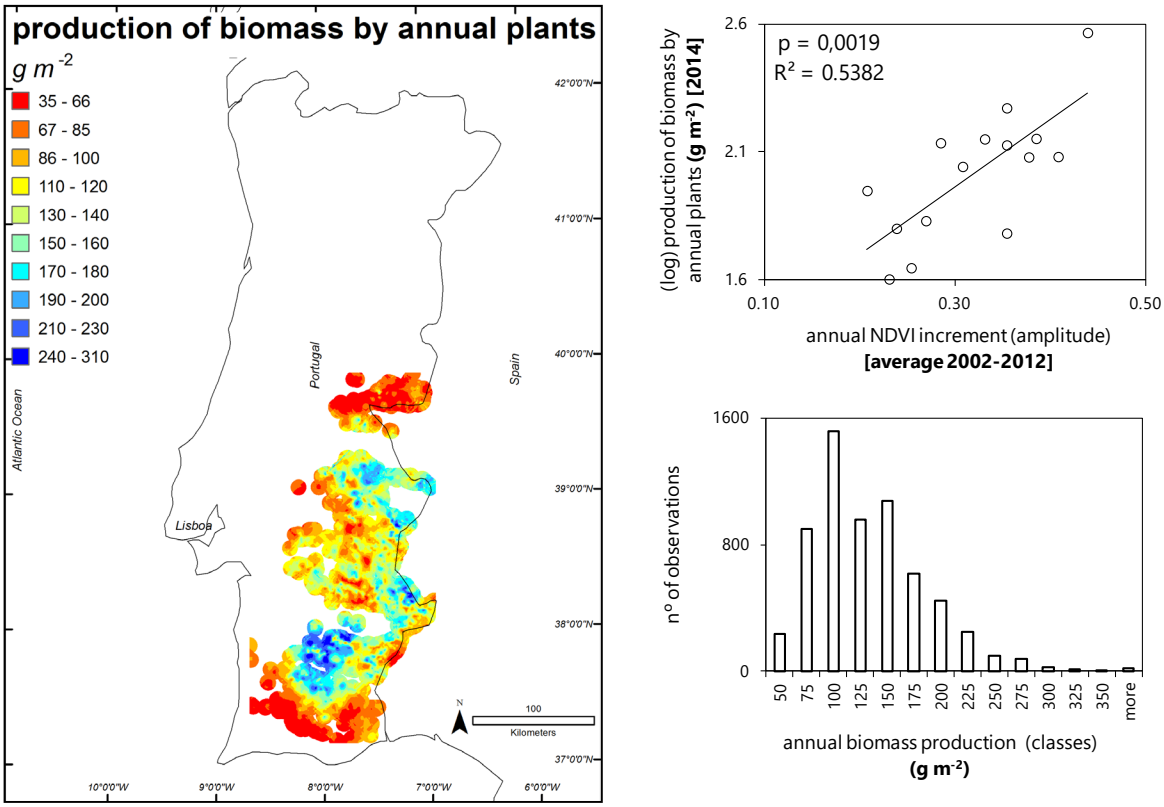

Figure 4.3. Biomass production by annual plants in Mediterranean evergreen woodlands (Portugal). Top: example of the woodlands, by the end of the growing season. Right: model used to relate NDVI increment (from satellite data) with annual plants biomass (from field measures); and histogram of the modelled annual biomass production, after applying the model to all woodlands. Left: map of the modelled biomass production by annual plants within the national distribution area of the studied Mediterranean evergreen woodlands.

4.3. On the importance of integrating expert knowledge into mapping ecosystem services: Swiss Alps forests

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Abstract

Providing spatially explicit information about different forest ecosystem services, their values and possible future changes supports adaptive forest management and a more balanced decision making in terms of sustainability. Mountain forests are highly valuable providing timber, carbon sequestration, habitat for endangered species, recreation, and particularly protection from natural hazards - mainly avalanches but also rock fall and

landslides. Sustainable forest management should aim at ensuring the provision of the various services under global change calling thus for more information about hotspots of ecosystem services provision, synergies and trade-offs to prioritize management options.

This contribution based on Grêt-Regamey et al. (2013) shows how spatially explicit information on current and future ecosystem services provision under two different scenarios supports targeting forest management. We particularly show how important it is to consider local expert knowledge in ecosystem services mapping in an iterative process in order to (1) reduce uncertainties in future ES estimates and (2) to foster a mutual learning process between local stakeholders and scientists. In a local case study in the region of Davos, Switzerland, we first map five ecosystem services including carbon sequestration, timber production, avalanche protection, habitat provision and recreation under current conditions (year 2000) as well as under two future scenarios considering land use change (trend scenario) and climate change (climate change scenario) until 2050 using a spatially explicit Bayesian Network (BN) approach. The BN allows to combine quantitative and qualitative information to quantify uncertainties due to the probabilistic framework and to update information iteratively. In a second step, we update the model parameters with local knowledge to improve the resulting ES maps and quantify uncertainties in the maps.

Results indicate that all ES values except timber production are expected to increase under the considered future scenarios related to the expansion of forest at altitude and changes in the forest structure. Highest ecosystem services values were found for avalanche protection followed by recreation, carbon sequestration, habitat provision and timber production. Analysing hotspots of ES provision and trade-offs under future scenarios with and without considering expert knowledge revealed a similar trade-off pattern for both scenarios where carbon sequestration and habitat services increased while avalanche protection and recreation remained similar and timber production decreased. However, there are considerable uncertainties attributed with these estimated future ecosystem services values, particularly under the climate change scenario. Integrating expert knowledge reduced this uncertainty substantially as local foresters have a deep understanding of the system they are managing. The presented study highlights the benefits of considering stakeholder knowledge to improve ES estimates and the added value of a spatially explicit quantification of uncertainty for a decision making process such as forest management.

Methods and Results

In order to evaluate forest management options on ecosystem services provision, we implemented an iterative approach linking ecosystem services quantification and valuation methods with expert knowledge in a BN as shown in Figure 4.4. Scenario-specific forest maps as well as other spatially explicit information provided input into a GIS-based BN linking in causal relationships the relevant variables for mapping the selected ecosystem services. Table 4.2 lists the indicators used for ES quantification and valuation. The "trend scenario" is a land-use change scenario assuming continuous development of the landscape where forest management focuses on small-scale interventions to maintain protection against natural hazards; forest growth exceeds harvest, and the abandonment of alpine pastures leads to a regrowth of forest. The "climate change scenario" combines land-use change and climate scenarios characterised by an increase of 2.4°C together with a decrease in governmental subsidies leading to an accelerated abandonment of alpine pastures. Under this scenario, forest cover is expected to increase by 21% with denser structures near the tree line.

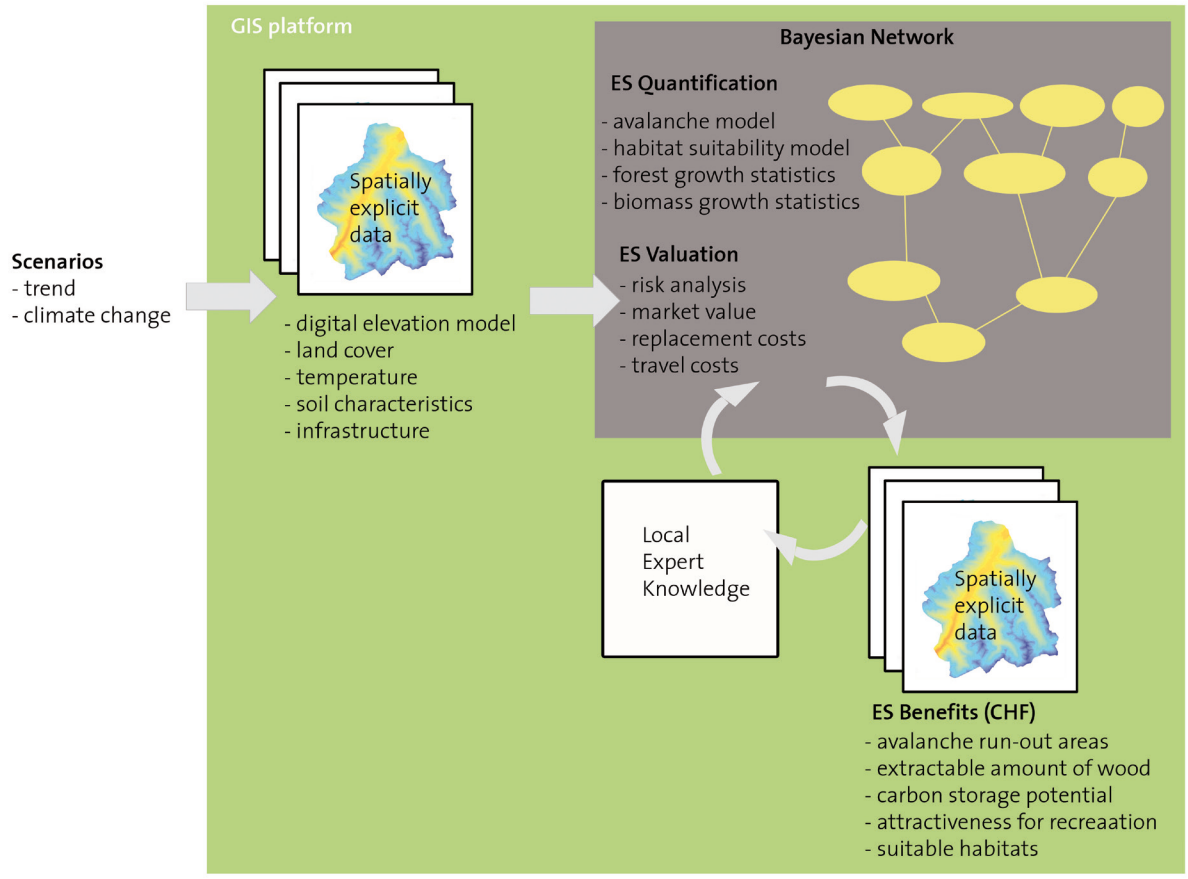

Figure 4.4. Mapping ecosystem services considering qualitative and quantitative information integrated in a spatially explicit Bayesian Network in an iterative process.

For each service, a map for the current state (year 2000), the trend scenario 2050 and the climate change scenario 2050 were produced as illustrated for avalanche protection in Figure 4.5. Avalanche protection is particularly valuable in densely populated areas where the demand is highest. Forest expansion on steep slopes increases avalanche protection under both future scenarios.

The generated ecosystem services value maps were then shown to local experts and the probability distribution of selected variables in the BN was updated according to their comments about the plausibility and parameter assumptions. For each service, at least five experts were considered. Results change considerably when taking local expert knowledge into account as illustrated in Figure 4.6. Ecosystem services values increase under future scenarios except for timber production and the increase is higher under the climate change scenario particularly when considering expert knowledge. The reduction in uncertainty, i.e. standard deviation, by including expert knowledge is particularly accentuated for avalanche protection (>90%), recreation and carbon sequestration (about 80%) and more than 30% for timber production and habitat provision.

The ecosystem services maps for the different scenarios allow analysing trade-offs in ecosystem services and thus a prioritisation of forest management strategies as shown in Figure 4.7. Overall, these trade-offs are similar in both future scenarios. Avalanche protection is the most important service of the forest in Davos at all locations where stands protect settlements from natural hazard events. On protective forest areas (red) main trade-offs arise with the recreation service, since relatively dense forests are required to maintain the protection, while visitors favour open stands. By contrast, the carbon sequestration service will be supported by silvicultural measures establishing stable dense forest patches. To ensure continuous regeneration and increase the

disturbance resilience of the forests protection, forests require controlled clearance measures also generating a win-win situation with timber production. Green and blue locations are characterized by conflicts between the provision of recreational services and carbon sequestration. In most of these regions the benefits from recreation are higher (green), thus, management strategies should target more open forest stands. The trade-off maps of the land-use and climate scenarios show two main differences: (i) on certain hillsides the extension of the protective forest areas varies due to slightly different predicted run-out areas in the two scenarios, (ii) the carbon sequestration service gains in importance in the climate scenario due to warmer temperatures and increased carbon storage potential.

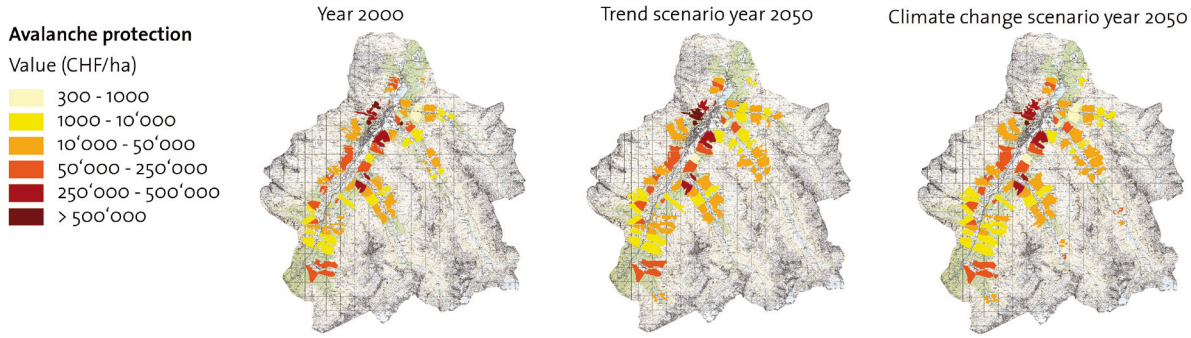

Figure 4.5. Avalanche protection maps under current state (year 2000), a land-use change scenario (trend scenario 2050) and a combined land-use change and climate-change scenario (climate change scenario 2050).

Ecosystem service	Quantification	Valuation
Avalanche protection	Avalanche run-out distances	Risk in CHF of endangered buildings within run-out distance
Timber Production	Amount of timber extracted per year (t/ha/year)	Price for timber in CHF and harvesting costs depending on harvesting methods
Habitat provision	Suitability for grouse	Price for reintroduction per species in CHF
Carbon Sequestration	Potential sequestration above- and belowground in biomass and soil	Social price for carbon sequestration in CHF
Recreation	Forest attractiveness according to forest stand structure and distance to road and settlement	Travel costs, subsistence costs of forests in CHF

Table 4.2. Indicators used to quantify and monetise ecosystem services values.

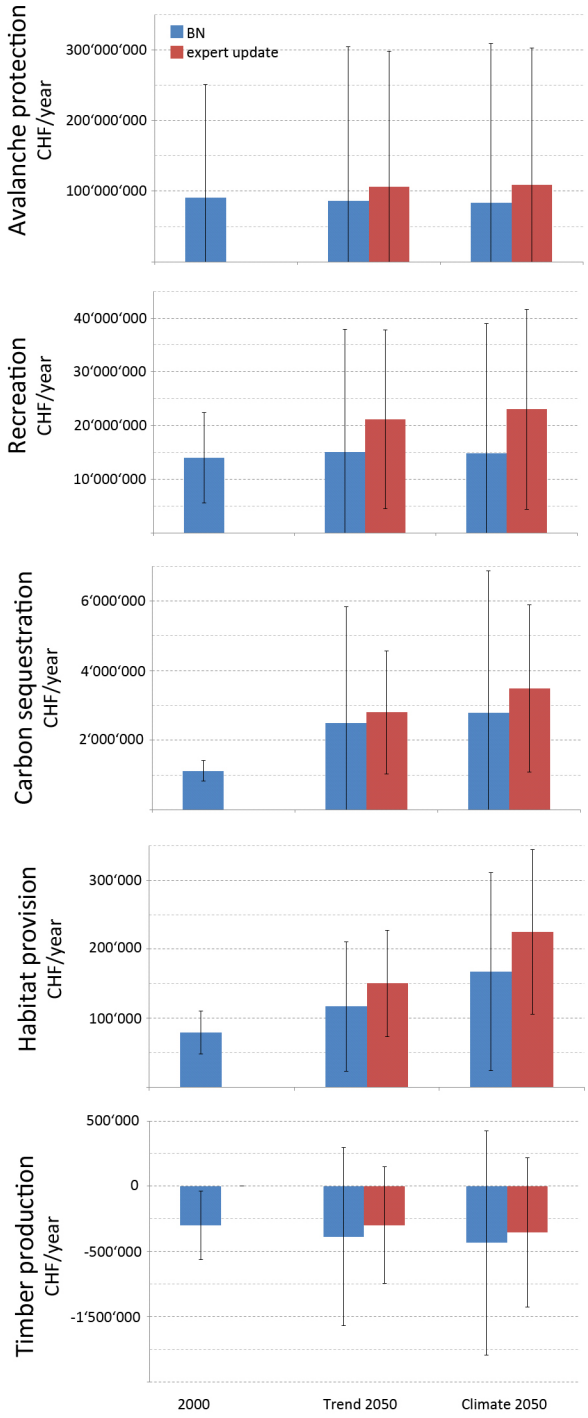

Figure 4.6. ES values estimated using a spatially explicit BN with and without considering expert knowledge. Standard deviations are given as percentage of the expected ES values.

Discussion

The presented study illustrates the benefit of considering local expert knowledge which considerably reduced uncertainty of estimated future ecosystem services values and refined ecosystem services maps according to local expert knowledge. The spatially explicit BN approach allows a combination of qualitative and quantitative information and an iterative updating of the parameters thus supporting a mutual learning process

between stakeholders and scientists. Despite the fact that the approach is resource demanding results provide clear recommendations to decision-makers, here foresters, regarding different management options, and the iterative stakeholder process is likely to increase confidence and trust in the mapping process.

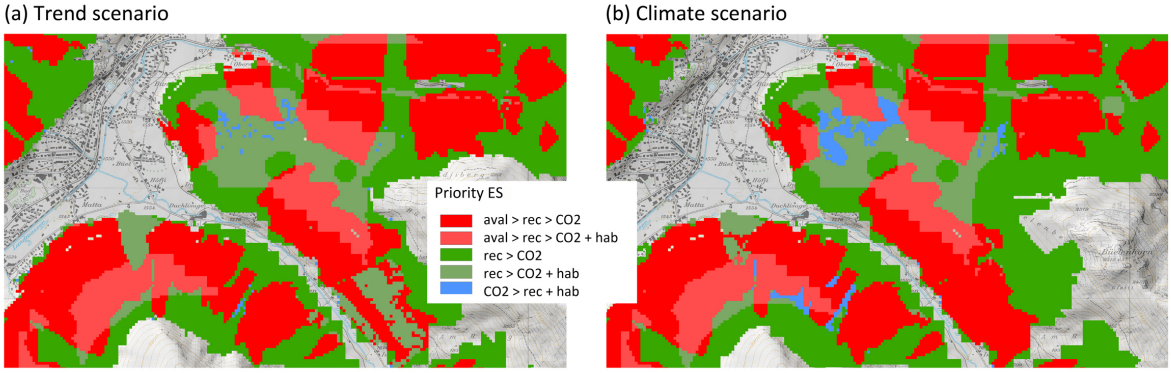

Figure 4.7. Future trade-offs between avalanche protection (aval), recreation (rec), carbon sequestration (CO2) and habitat provision (hab) (a) under a land-use change and (b) under a combined land-use and climate-change scenario.

Conclusion

Considering local expert knowledge in mapping five key forest ES in mountain areas refined the ecosystem services maps and reduced uncertainties for estimates of future ecosystem services provision. The analysis allows evaluating hotspots of ecosystem services provision and trade-offs under future scenarios providing clear recommendations to prioritize forest management.

4.4. Mapping green infrastructure based on ecosystem service supply and demand: Helsinki-Uusimaa Region, Finland

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Abstract

The Helsinki-Uusimaa Regional Council prepared Regional Plan 4, which complemented the previous regional land use plans. The goal of the plan was to ensure competitiveness of the region while not exceeding the limits of sustainable development. To support the green infrastructure theme of Regional Plan 4, Helsinki-Uusimaa Regional Council cooperated with the Finnish Environment Institute SYKE, which carried out a comprehensive analysis of regional green infrastructure based on ecosystem services. The results were utilised in making the new plan. Here we present a summary of the case study. A more detailed description of the methods can be found in Kopperoinen et al. (2015) and in Itkonen et al. (2015).

Helsinki-Uusimaa region consists of 26 municipalities with a total of 1.6 million inhabitants. The 1.1 million inhabitants of the capital region alone cover 20% of Finland's total population (Statistics Finland, 2014). In addition, Helsinki-Uusimaa Region is among the fastest growing regions in Europe. Thus, there is a constant urge to densify the urban structure and convert new areas for residential purposes. This takes often

place on the cost of forests. At the moment, forests cover about 64% of the Helsinki-Uusimaa Region's land area. Most of the new construction in the urban region of Helsinki has been located in forested areas during years 2000-2012. Even inside the borders of densely built areas, 2/3 of new construction has taken place at the expense of urban forests (Tiitu, 2014). As most of the un-built land is covered by forest in Helsinki-Uusimaa Region, mapping of ecosystem services actually relates in most of the cases to those provided by forests. Water and shoreline areas are also amongst the most important ecosystems providing services for the region. Although the applied analyses do not relate to forest ecosystems solely, all the methods are applicable in assessing forest ecosystem services.

Methods and discussion

Mapping the potential supply of ecosystem services

The potential supply of ecosystem services by the regional green infrastructure (GI) was assessed using GreenFrame methodology developed by SYKE (Kopperoinen et al., 2014). GreenFrame is an integrated approach to study the variation in the ecosystem services supply within a study region, making use of a wide variety of spatial data and expert knowledge. Instead of quantifying the actual stocks and flows of ecosystem services, the aim is to valuate areas based on their potential to support the supply of various ecosystem services. Spatial data is usually scarce on regulation and maintenance services and intangible services, such as cultural ecosystem services. GreenFrame provides an approach to infer this information from related thematic data based on assessments made by experts and local and regional actors. Qualitative assessments can be complemented, however, with existing quantitative spatial data about the study area when such exists. Quantitative data is more often available for tangible provisioning services, such as timber volume.

The potential supply of 23 ecosystem services was analysed (Table 7.1 in annex). Each ecosystem service was assessed individually using 22 data themes consisting of even more separate datasets (Table 7.2 in annex). The data themes were pre-processed into compatible format and overlaid in GIS. The weight of each theme in the assessment of each ecosystem service was determined by expert evaluation. The supply potential for provisioning services "Surface and ground water for drinking" and "Surface and ground water for non-drinking purposes" was complemented using quantitative data on groundwater formation (Source: Groundwater areas, © SYKE, Centre for Economic Development, Transport and the Environment). Provisioning services "Materials from plants, algae and animals and genetic materials from all biota" and "Biomass-based energy sources" were analysed using quantitative data on timber volumes and estimated biomass potential (Source: BalBic-data, © Forestry Development Centre TAPIO 2013 and © Finnish Forest Research Institute METLA 2013).

As outputs of the analyses, 23 raster layers of the supply potential of different ecosystem services groups were created (see examples in Figure 4.8 and Figure 4.9), as well as composite layers of each three ecosystem services sections (provisioning services, regulation and maintenance services, cultural ecosystem services) and the final synthesis layer including all ecosystem services (Figure 4.10).

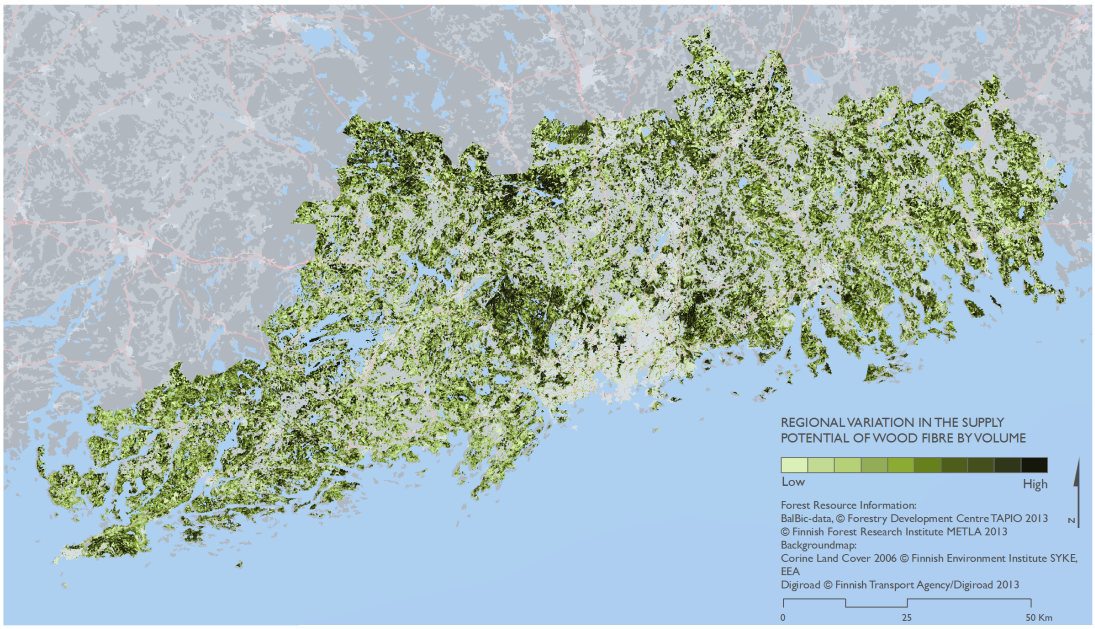

Figure 4.8. Regional variation in the supply potential of wood fibre by volume in Helsinki-Uusimaa Region.

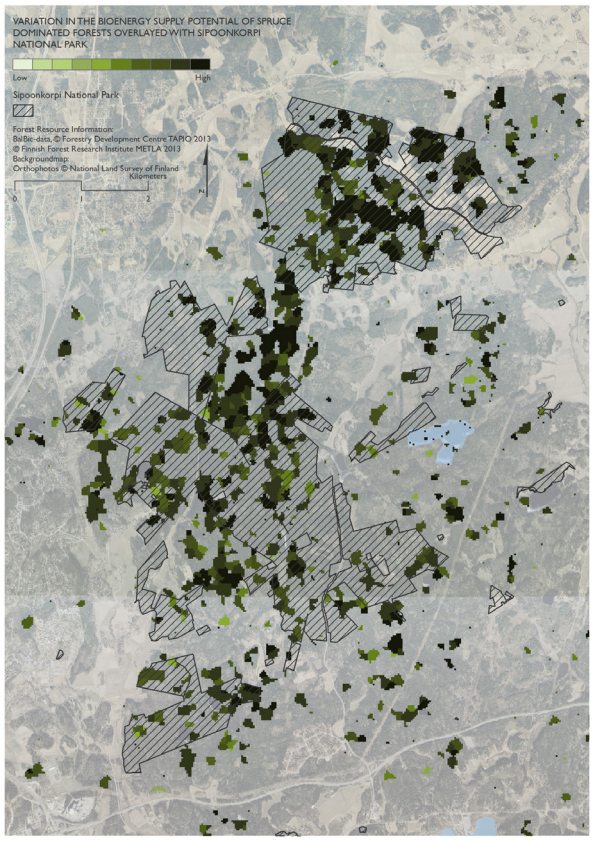

Figure 4.9. Variation in the bioenergy supply potential of spruce-dominated forests overlayed with Sipoonkorpi National Park in Helsinki-Uusimaa Region. Feasibility and restrictions of the used spatial data must be understood as indicated in this map with a simple example. The spruce-dominated forests inside the borders of National Park potentially provide bioenergy, but as a matter of fact are protected by the conservation law.

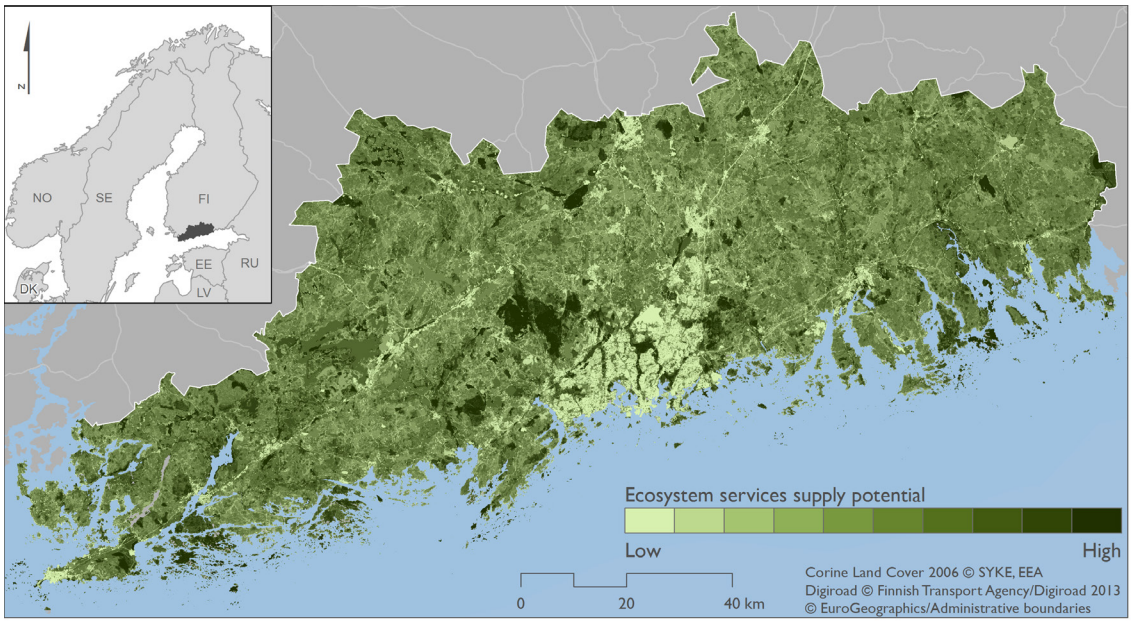

Figure 4.10. The regional variation in the overall ecosystem services supply potential in the Helsinki-Uusimaa region.

An approach to identify key areas of regional green infrastructure

The core of the regional GI consists of a network of protected areas and other areas with high nature values (EEA, 2014). Not only do these areas sustain biodiversity, but they also provide many important ecosystem services that have local, regional and national importance (e.g. water purification). However, there are large areas providing ecosystem services also outside the protected areas. These multifunctional areas need to be recognised and taken into account in decision making and land use planning. There is no way to unambiguously determine which areas belong to GI and which areas do not – the examination is always context and scale-dependent. In the case of Helsinki-Uusimaa Region, the process of identifying the most important areas of the regional green infrastructure involved interaction with a wide group of regional actors and experts in addition to regional planners.

The key areas of regional GI consisted of (Figure 7.1 in annex):

a) The core network of valuable nature areas.

b) 20% of the areas with highest ecosystem services supply potential of selected ecosystem services outside the network of protected areas and other valuable nature areas.

c) Core nature areas and connecting corridors not included in the first two steps. These were identified using Morphological Spatial Pattern Analysis (Soille and Vogt, 2009). Connectivity beyond the administrative borders of the region was taken into account to prevent arbitrary edge effects from affecting the results of the analysis.

For the sake of visual clarity and to focus on the most important targets having regional significance, separate patches of less than 10 hectares were removed, except those belonging to the core network of valuable nature areas.

Planners and stakeholders assessed and validated the outcome and noticed that the diverse mosaic of patches of forests and agricultural areas did not come up as clearly as it should have. These areas provide diverse habitats for many species and allow species movement between larger continuous habitats. Therefore, a complementary analysis on the ecological permeability of the landscape was carried out applying CORILIS spatial smoothing technique (Figure 7.2 in annex) (Páramo, 2006).

Mapping the demand for ecosystem services using Public Participatory GIS

Spatial analyses of the demand for ecosystem services within the region was not feasible for all ecosystem services, because the service flows from service providing units (e.g. a forest patch) to the actual beneficiaries may be very complicated and largely determined by other factors than the location of the population. Therefore, the spatial analyses focused solely on the demand for cultural ecosystem services that are important for the local residents.

An online Public Participatory GIS (PPGIS) survey titled "The meanings of nature for the people of Helsinki-Uusimaa" was carried out to examine the region's inhabitants' perceptions on cultural ecosystem services. The survey was targeted to all residents of Helsinki-Uusimaa Region, regardless of their background. The respondents were asked to pinpoint targets on a map from the following themes:

- Good places or routes for recreation
- Good places to learn from nature
- Very scenic places
- Good vantage points
- Places, where history and cultural heritage combine in a way that adds to the value of the place
- Regionally symbolic places
- Places having unique identity that people attach meanings to and where they can feel attached to their environment (sense of place)
- Relaxing / revivifying places
- Places where people can experience holiness
- Places having intrinsic value, to be preserved for future generations.

The respondents were allowed to mark places that are not necessarily pristine nature, but nature did have to be present in these places and affect their experience. In fact, in addition to the actual demand, these markings also represent the actual supply of cultural ecosystem services – the respondents mark locations where they already have consumed these ecosystem services. Altogether 5,043 point markers were marked by a total of 555 respondents (Figure 7.3 in annex).

Although the sample of the respondents was not fully representative of the demography of the region, the survey results can be used as a source of supplementary information in collaborative land use planning. The clusters of point markers constitute hot spots – locations to which many respondents attach several different meanings (Figure 7.4 in annex). Regional plan is a relevant planning instrument for cultural ecosystem services, as e.g. many recreation areas, cultural heritage landscapes and aesthetically valuable sites have regional importance and these themes are already covered separately in valid regional plans.

Mapping potential demand for ES using accessibility analysis

In order to analyse the potential demand for cultural ecosystem services, the amount of population that can access each location of the region in a given time via the transport network was calculated (Figure 7.5 in annex). A 250 meter gridded map containing the population of each grid cell was used (© SYKE/YKR). The estimates of the travel time between pairs of population grid cells were calculated using road network data (STK 2013 / © ESRI Finland, Finnish Transport Agency / Digiroad 2013). The estimates of travel time for each road segment takes into account different road types and the slowing effect caused by traffic in city centres.

Relating the supply of and the demand for ecosystem services

Although different areas may be equally good in terms of accessibility, their attractiveness and capability to supply different ecosystem services may vary. Therefore, it is useful to compare the estimates of the potential demand together with the supply potential of cultural ecosystem services in each grid cell of the region (Figure 7.6 in

annex). This allows inter alia the recognition of locations where high demand for ecosystem services meets high supply, or on the other hand, low supply of ecosystem services. In the context of land use planning, it is valuable to identify both types of areas.

The accessibility estimates represent the potential demand for the cultural ecosystem services based on the population density and accessibility to different areas – not the actual visits. Some locations, such as national parks, draw visitors from much larger areas than just their surroundings. When available, data on the admission of national parks and the use of other recreational areas are useful in assessing their actual demand.

Impacts of expected population growth on GI in the Helsinki-Uusimaa Region

Constantly increasing population and land use change could be named as the top drivers of change in the Helsinki-Uusimaa Region. To prevent further urban sprawl and to mitigate climate change by increasing eco-efficiency of cities, densification of urban structure is encouraged. This has twofold impact on the GI: both ES providing areas diminish and the number of potential users of them grows.

To visualize impacts of population growth on GI and therewith on the ecosystem services supply potential we carried out spatial analyses. The current situation and the anticipated future change in the population pressure were assessed by calculating the amount of population residing in the immediate surroundings of the key areas of the regional GI. In addition to the current distribution of population, also a scenario of the situation in 2035 was examined, based on the 2035 population scenario data by the Helsinki-Uusimaa Regional Council which predicts a growth by 300,000 new inhabitants and 132,000 new jobs compared to 2006 (Uudenmaan liitto, 2008). Figure 4.11 shows the current and future state of the potential population pressure and the predicted change in it.

Discussion

To get a comprehensive place-specific view on the status of ecosystems and services provided by or demanded from them, involves mapping ecosystem services from different points of view: supply potential, actual supply, potential demand, actual demand and flow of ecosystem services from the place of provision to beneficiaries. There are a variety of methods available for mapping these. Depending on the context and scale, different methods may be most appropriate. The specific case determines a lot as well, because availability of spatial datasets is not the same everywhere.

The methods we applied are very flexible in terms of place, scale and availability of data. The most time-consuming part can be to get hold of the spatial datasets. These are usually scattered in different institutes, authorities and even individuals. Many times negotiations, and sometimes also money, are needed to get the best datasets for the analysis. The quality of datasets can vary a lot and this has to be bore in mind while carrying out analysis. Sometimes the type of the data is difficult, e.g. point vector data depicting areas. In addition, questions of privacy or protection of vulnerable sites may lead to a need to generalize data so that the actual exact location of the feature data is presenting is blurred. Because of all these, enough time must be allocated for pre-processing of data.

In addition, establishing a temporary group of case-specific stakeholders, actors and experts for the scoring, validation of results and other support for the analysis demands networking and interaction skills. Stakeholder groups are very important for co-creation of knowledge. Engagement of knowledgeable people representing a variety of expertise in the case study area makes it possible to combine qualitative assessments with quantitative data to get a comprehensive view.

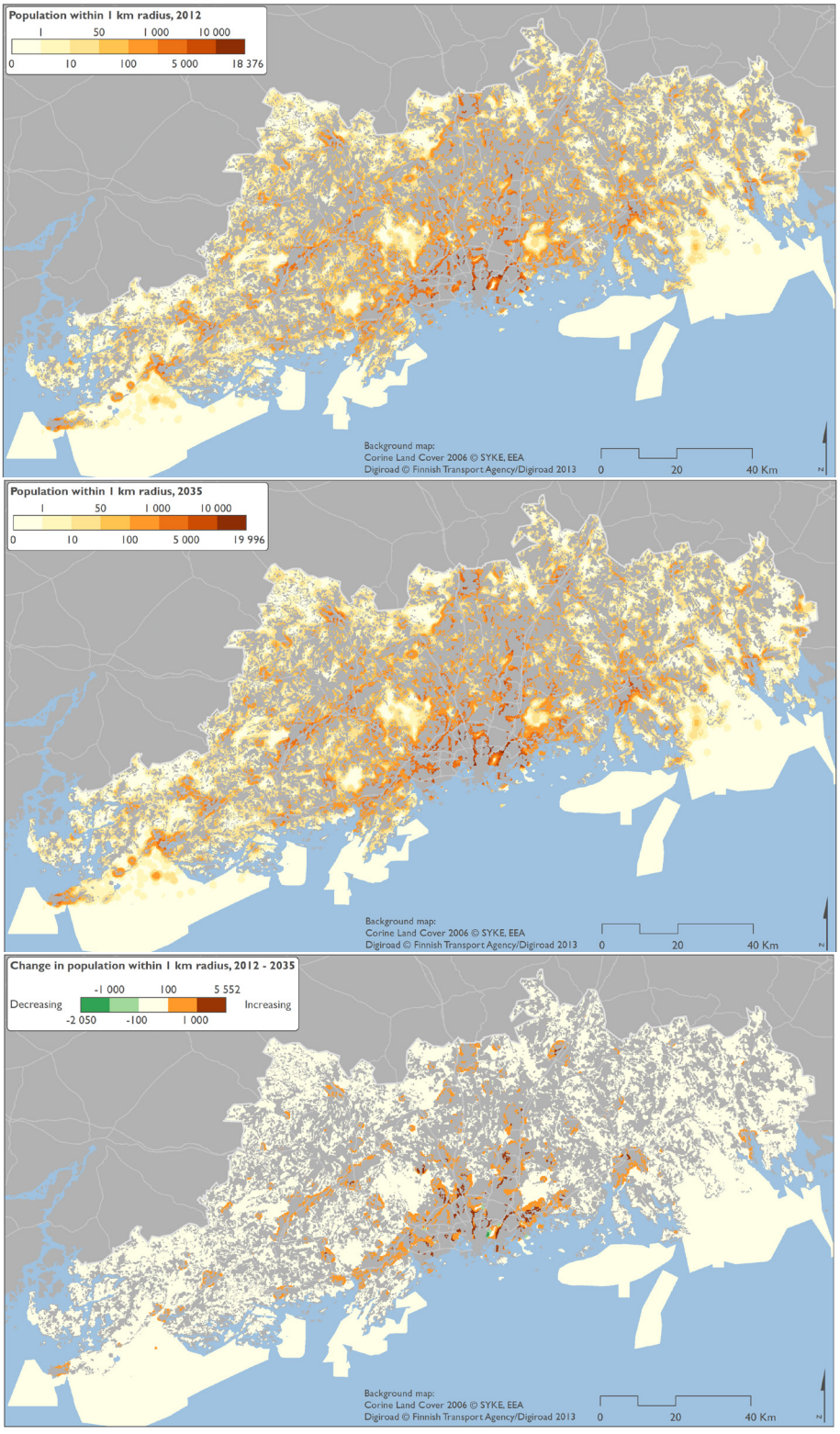

Figure 4.11. Current situation (2012, top), future scenario (2035, centre), and the anticipated change (2012 – 2035, bottom) in the immediate population pressure on the key areas of regional green infrastructure (Population data source: Helsinki-Uusimaa Regional Council).

Ecosystem services maps have to be understood to be able to use them in an appropriate way. Understanding includes knowledge of components of GI in the area, spatial datasets and their quality, of stakeholders and actors in the area, of the quality of expert scorings, of analysis methods applied, of drivers of change in the area, etc. The interpretation of ecosystem services mapping results together with local / regional / national stakeholders is very important, too. Also citizen knowledge is valuable because ecosystem services are for people and for communities.

Our case study was a regional one. In local cases the components of GI can be captured in much finer scale and a typology of the GI elements can be created for mapping both the supply of and demand for ecosystem services. In regional scale small areas were removed from e.g. the map of key elements of GI to make a clearer view of the most important areas. Small areas and features can be very significant in local level and therefore should not be neglected when downscaling the ecosystem services maps. On the other hand, when upscaling to national level, much regional detail will be lost but better picture of coarser variance between regions can be gained.

Conclusions

Ecosystem services maps can always be made better when better data becomes available. However, depending on the need for the ecosystem services maps, even a more general picture can be sufficient. The context defines what is enough. However, best available data in appropriate scale should always be used and possible distortions due to missing data should be kept in mind when presenting the resulting ecosystem services maps. Visualisations are powerful tools and therefore, producers of them have a responsibility to ensure the results of underlying analyses are reliable.

In order to ensure the goals of sustainable development, safeguarding biodiversity and sustaining vital ecosystem services, ecosystem services maps are valuable for spatial planning and decision making at all levels.

4.5. Mapping timber production and carbon storage forest ecosystem services from a case study in the Mediterranean region (Molise Region, Italy)

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Abstract

This case study shows the first results obtained using the MiMoSe (Multiscale Mapping of ecoSystem services) approach for the spatially explicit and multi-scale assessment of current and future potential Ecosystem Services provisioning of forest ecosystems. We implemented the MiMoSe method for the economic evaluation and scenario modelling of

two ecosystem services (timber production and carbon sequestration) and their trade-offs in a study area coincident with the forest area in the administrative region of Molise in Central Italy (approx. 157,609 ha). The impact of three different alternative forest management scenarios (business as usual, nature protection, and wood production) was assessed on the investigated services over a 20-year time period. In the study area, the Total Ecosystem Services Value increases by 85% in the "nature protection" scenario and decreases by 82% in the "wood production" scenario when compared to the business as usual. The MiMoSe approach has demonstrated flexibility and performance in providing a useful basis for the projection of benefits from different forest ecosystems over future scenarios.

Introduction

Mapping and quantifying the supply and demand of ecosystem services is a key step to support decision making in forest and environmental management and planning (Daily and Matson, 2008; Swetnam et al., 2011; Kroll et al., 2012; Marchetti et al., 2012). From global to landscape scale, the InVEST model has been recently used to explore the potential impacts of land use change under alternative policy scenarios (Lawler et al., 2014), to evaluate environmental and financial implications for ecosystem services provision among different planning scenarios (Goldstein et al., 2012), to assess the impact of conservation policies on biodiversity and habitat quality (Wu et al., 2014), to assess watershed regulating services (Harmáčková and Vačkář, 2015), to map pollination services at the landscape scale (Zulian et al., 2013), or to evaluate hydrological services (Bangash et al., 2013; Marquès et al., 2013; Terrado et al., 2014). In the context of global climate change, understanding how different forest management practices affect the provision of forest ecosystem services at different scales still remains a key challenge for decision-makers (Scarascia-Mugnozza et al., 2000; Kolström et al., 2011; Wang et al., 2012; Wang et al., 2013).

In the forestry sector, timber (or biomass) production and carbon storage and sequestration are the most studied ecosystem services. Timber and carbon, which are considered indicators for the provisioning and regulating services delivered by forests (MAES, 2014), are competing services as an increase in timber production generally determines a reduction in carbon sequestration.

In this study we present a spatially explicit method based on a multi-scale approach that we called MiMoSe (Multiscale Mapping of ecoSystem services) to assess the current and future potential of a given forest area to provide ecosystem services. We integrated a GIS-based model, scenario model, and economic valuation to investigate two ecosystem services (timber production and carbon sequestration) and their trade-offs in a test area in Central Italy. Spatial information and trade-off analyses were used to assess the influence of alternative forest management scenarios on the investigated services.

Materials and methods

The Molise region in Central Italy covering 443,758 ha was chosen as the study area, the forest area is 157,609 ha. Turkey oak (*Quercus cerris L.*) (40% of the total forest area), downy oak (*Q. pubescens Willd.*) (22% of the total forest area), and European beech (*Fagus sylvatica L.*) (9.5% of the total forest area) are the most widespread species in the area. Coppice systems account for 76% of the total forest area, while high forests represent the remaining 24% (Garfì and Marchetti, 2011).

A Forest Management Unit (FMU) map was created by segmentation of a satellite image and other ancillary information subdividing the forest area in polygons homogenous in terms of forest categories, and forest management systems (Chirici et al., 2014). The map contains 54,049 polygons having a size between 0.5 and 15 ha (with an average size of 2.7 ha, SD=2.8). For each polygon the overall growing stock volume derived from a previous work based on the application of the k-Nearest Neighbours system was also available together with information on slope and altitude from a digital terrain model (DTM).

Three alternative forest management scenarios were considered: Business as Usual (BaU) based on the continuation of the current forest management approach according to the local forest regulations, nature protection with a forest management focused on biodiversity and nature conservation, and finally wood production based on the increase of the coppice area and the reduction of the rotation age. Harvesting intensity was based on national literature (Hermanin, 1988; Piussi, 1994; Ciancio, 2009; Ciancio, 2011) and on expert judgment.

The forest management scenarios were simulated at the scale of FMUs over a period of 20 years (2015-2035) by using the model based on the area control method and the current annual increment (CAI, m^3 ha^{-1} $year^{-1}$), as reported by the Italian NFI (Gasparini and Tabacchi, 2011) for the different FCs and forest management systems. To simulate the amount of timber harvested from 2015 to 2035, the InVEST Managed Timber Production model was used. This model quantified the volume of harvested timber according to harvest intensity and frequency, rotation periods, and the associated monetary values based on market prices. The model was partially modified by adopting different harvest intensity and frequency thresholds based on alternative management scenarios, as implemented in each FMU.

To assess forest carbon sequestration from 2015 to 2035, the InVEST Carbon Storage and Sequestration model (Daily et al., 2009; Tallis et al., 2013) was used. This model estimates the net amount of carbon stored in a forest compartment over a given period, the total biomass removed from a harvested area of the FMU, and the social values of the carbon sequestered in the remaining stock. For each class, the model requires an estimate of the amount of carbon stored by each of the fundamental carbon pools according to the Good Practices Guidance for Land Use, Land Use Change and Forestry (GPG-LULUCF) classification and definition: living biomass, both above ground and below ground, dead organic matter, including dead wood and litter, and soil organic matter (IPCC, 2003).

We assessed trade-offs between timber and carbon using the BaU scenario (scenario A) as baseline. We considered that the best scenario should be that one that provides more economic benefits and increased timber removal without affecting the balance or equilibrium (E) among the examined ecosystem services. Although the concept of equilibrium is dynamic, we used E as a means to understand the interdependence of ecosystem services (Costanza et al., 1997; Tschirhart 2000; Finnoff and Tschirhart, 2008). To evaluate the threshold value of timber removed (m^3 ha^{-1}), we calculated the Total Ecosystem Services Value (TESV) as the sum of Total Net Present Value (TNPV), and Total Social Cost of Carbon (TSCC). TESV represents the capacity of a given area to provide multiple services (Maes et al., 2012b). With a TESV of zero there are no added benefits to society, only additional costs.

Results

Adopting the BaU scenario over a horizon of 20 years (2015-2035) a total wood production of about 8.5 million m^3 and a total residuals production of about 1.9 million m^3 can be obtained. When the nature protection scenario was considered, wood and residuals production decreased by 28% and 81%, respectively. In the wood production scenario, wood and removals production increased by 45% and 74%, respectively.

In all the considered scenarios, the trade-offs as a function of timber removed (m^3 ha^{-1}) corresponded to an increasing TNPV, while the TSCC decreased. Thus, the increase of an additional unit of wood removed increased the private benefits of the TNPV, while the social benefits of carbon sequestration (TSCC) decreased. In general, our results reveal that a forest management approach mainly directed at nature conservation and climate change mitigation (scenario B) at the regional scale increases the TESV by approximately 85% in comparison with the BaU approach (scenario A). A forest management approach mainly geared towards maximizing economic incomes from timber production (scenario C) reduces the TESV by approximately 82% compared to

scenario A (Figure 4.12). A spatial distribution of TESV for BaU scenario is reported in (Figure 4.13).

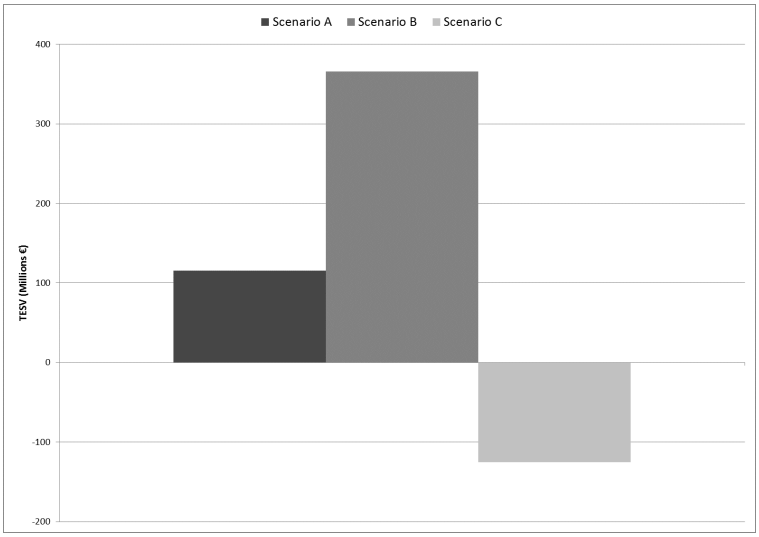

Figure 4.12. Total Ecosystem Services Value (TESV, in millions of €) using a discount rate of 1%. Scenario A for BaU, B for nature protection and C for wood production.

The trade-offs analysis showed that by adding units of removable timber the TNPV increases while the TSCC decreases and the E values change, indicating that removing quantities of timber that are higher or lower compared to E values produces an increase of one ecosystem service and a decrease of the other.

Results from our simulations mainly indicate that forest management, in terms of harvesting intensity and frequency, strongly influences ecosystem services provision and associated benefits. In particular, the results demonstrate that establishing management restrictions, prolonging rotation periods, reducing the harvesting intensity (amount of removals), and adopting close-to-nature forestry interventions increase carbon sequestration (and associated TSCC) and reduce timber production (and associated TNPV) (scenario B in comparison with scenario A), despite similar trends for the TESV (scenarios B and C in comparison with scenario A).

Conclusions

This study contributes to the ongoing debate on trade-offs and synergies between carbon sequestration and wood production benefits associated with socio-ecological systems. It provides a powerful approach for investigating general relationships between pairs of benefits and between different approaches for integrating services in conservation planning. Through the multi-scale approach for assessing forest ecosystem services and related benefits, the study enables decision-makers, stakeholders and landscape planners to better guide management strategies and decisions in the future.

The spatially-explicit estimation of ecosystem services across the regional area is useful to identify priority areas for maximizing ecosystem services provision and benefits for local communities (i.e. win-win and lose-lose area of intervention). This may assist in differentiating interventions so as to maximize economic incomes over a shorter time period (for coppice forests), or contribute to nature conservation and climate change mitigation (mainly for high forests and infra-opened stands). Moreover, the ecosystem services trade-off analysis could provide important information on how to balance economic incomes from alternative services according to management strategies and landscape characteristics. This is particularly useful for forest management (related objectives and purposes), which can be optimized by balancing the TNPV with the TSCC for each forest category, individually (i.e. higher and less productive forest categories in

terms of revenue). To this end, the outcome of this study stresses the critical role of detailed definition and mapping of both forest types and silvicultural systems; moreover, as distinctively concerns the forest types, the value of shared and integrated typological frameworks (e.g. Barbati et al., 2007; Barbati et al., 2014) should be more readily acknowledged.

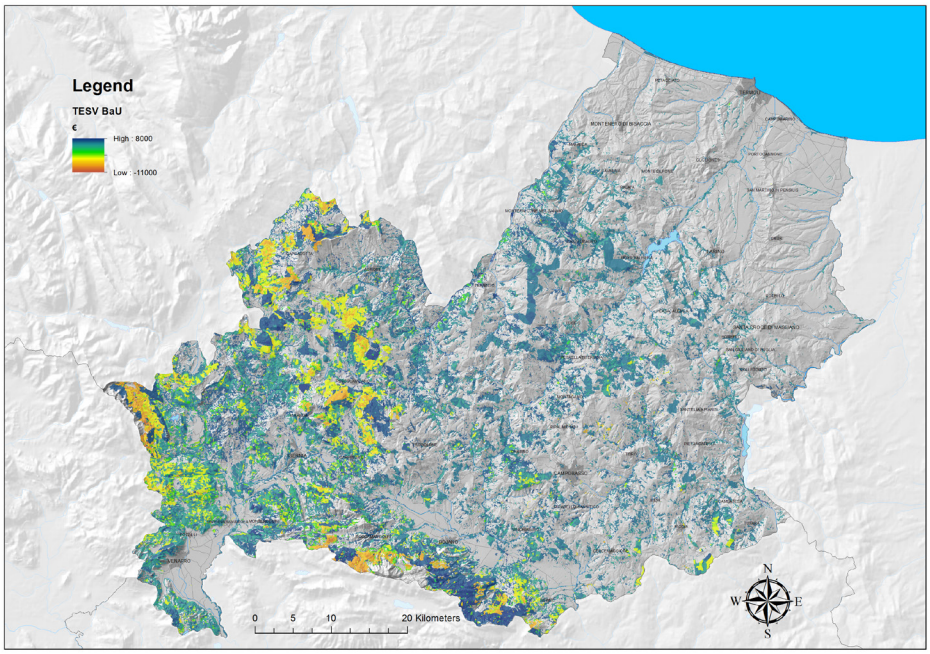

Figure 4.13. The geographical outlook of the Total Ecosystem Services Value (TESV) for the BaU, values are expressed in €/FMU.

The approach presented herein (including the implementation of the InVEST model) needs to be further developed by: (i) diversifying timber assortments; (ii) considering the Harvested Wood Products as an additional carbon pool to guide forestry practices towards better mitigation strategies; (iii) including the prediction of land use change; and (iv) considering more ecosystem services.

Acknowledgements

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4.6. Site-based ecosystem services mapping and assessment in Portuguese montado agro-forests – comparing the InVEST and TESSA tools

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Abstract

The montado is one of twelve exemplar case studies in the EU project OPERAs, where management tools are tested to help bridge the gap between ecosystem science and practice. The montado is a unique agro-forestry ecosystem with high ecological and socio-economic relevance, generating a range of provisioning (e.g. cork, wood, charcoal, honey, wild mushrooms, livestock fodder), regulation and maintenance (e.g. climate regulation) and cultural (e.g. nature-based recreation) ecosystem services. Its preservation is highly dependent on management done at the farmstead level, which in turn is dependent on economic objectives, and to effectively quantify ecosystem services in different management scenarios is key for the systems long-term sustainability.

To assess the impacts of management options on ecosystem services provided at a site-based scale, we defined three different land use scenarios (forest improvement, cattle intensification and urbanization) and compared them with the current land use baseline in one of the largest farmsteads in Portugal – Companhia das Lezírias. We used the scenarios to measure and map ecosystem services using two free supporting tools: InVEST and TESSA. Both tools were useful to estimate and map carbon stock and sequestration, and cork production under the different scenarios. The highest carbon stock was registered with TESSA (875,677 Mg) for the forest improvement scenario (2% more than with InVEST) and the lowest value was estimated by InVEST (679,369 Mg) for the cattle intensification scenario (0.2% less than with TESSA). The highest value for cork production was estimated by InVEST (€ 3.35 million) also for the forest improvement scenario (10% more than with TESSA) and the lowest value was estimated by InVEST (€ 0.77 million) for the cattle intensification scenario (38% less than with TESSA).

While the predictions obtained by both tools were similar for cork and carbon stock, for carbon sequestration InVEST produced estimates that were 413% lower than TESSA estimates in the cattle intensification scenario. This was mainly due to the different approach of these tools to estimate this service and highlights the need for a better harmonisation and/or refinement of available tools.

Methods and discussion

Study area – current land use at Companhia das Lezírias, Portugal

The study area covers about 11,500 ha (mainly cork oak forest) of which 55% are within the Natura 2000 Network (Figure 7.7 in annex). Currently a sustainable development approach is followed, managing the land according to traditional farming methods. Forest management is certified according to the Forest Stewardship Council standards and a large part of the forest area was classified as a "Model Forest" by the Regional Forestry Planning of Ribatejo, and is now an example of good management. Forests in Companhia das Lezírias include maritime and stone pines, eucalyptus and cork oaks. In spite of this diversity, the cork oak prevails (55%), providing cultivated goods such as cork and wood, wild goods such as game or mushrooms, and promoting cultural services such as leisure hunting and fishing, bird watching, walking or biking. The montado is also used for biological cattle grazing which rotate in herds of 50-300 animals (0.32 heads/ha). These free ranging cows feed on natural or permanent biodiverse pastures cultivated in the montado understory (Gonçalves et al., 2012).

Future land-use scenarios at Companhia das Lezírias

To achieve our objectives, and in agreement with the land manager, we defined three land use scenarios to compare with the current land use: Forest improvement, Cattle intensification and Urbanisation. The Forest improvement scenario is a scenario with an increase of the density of cork trees from 80 trees/ha today to 140 trees/ha. In spite of the good management practiced in the farm, there is still space to increase the density of trees and increase the incomes from forest products. In this scenario the number of

cows would be reduced from 0.32 to 0.1 heads/ha just to eliminate shrubs and to prevent wildfires.

In the Cattle intensification scenario the number of heads per hectare is quadrupled (from 0.32 to 1.4 heads/ha the maximum value of an extensive livestock farming) (DGADR). It is assumed that the area of natural and permanent pastures would increase to fulfil the needs of fodder. As a direct consequence of grazing intensification, areas with dense shrubs would change to areas with sparse shrubs. Urbanization corresponds to a scenario where residential housing is allowed in two parcels outside the protected areas. It was assumed that, as a consequence of this change, tree density in these areas will decrease, similarly to shrub density which is also reduced in this scenario since people usually prefer lawns. No annual cultures for fodder or permanent pastures will be produced, since there will be no cattle. Other land uses are kept with the current management.

Estimated Ecosystem Services and input data

We modelled three ecosystem services under each scenario: one concerning provisioning (cork production) and two other concerning regulation and maintenance (carbon stock and carbon sequestration). To estimate carbon stock we used values of above-ground live biomass (Pastor-López et al., 1997; Faias et al., 2007; Correia et al., 2008; Castro and Freitas, 2009), below-ground biomass (Martínez et al., 1998; Faias et al., 2007; Correia et al., 2008; Boutton et al., 2009; Ruiz-Peinado et al., 2012), dead organic matter carbon stock (Faias et al., 2007; Gasparini and Di Cosmo, 2015) and soil organic carbon (Bickel et al., 2006; Freyerová and Sefrna, 2014), according to each land use. To estimate cork production, real values of cork harvesting and related costs, we obtained values directly from the forest manager at Companhia das Lezírias.

To estimate carbon sequestration TESSA follows the procedures recommended by IPCC (Intergovernmental Panel on Climate Changes) (Bickel et al., 2006). Thus, we used values from Companhia's internal sustainability report (Moura Amado Pereira, 2010) determined according to these procedures, using Tier 3 approaches (requires the most complex and specific data) for Maritime pines and Tier 2 (requires an intermediate level of complexity and locally specific data) for the remaining land uses. The result is the carbon sequestered in a year interval. Additionally to estimate carbon sequestration InVEST calculates the differences in carbon stocks between the actual land use and the scenarios.

Modelling tools

The TESSA toolkit (Peh et al., 2013) was designed to provide practical guidance on ecosystem services assessment and monitoring at the site scale without substantial resources and technical expertise. Ecosystem services were estimated for each land use by multiplying the input values (carbon Mg/ha) by the area of each land use. These values were then summed up to obtain the total value of each ecosystem service. Although TESSA is not directly used to map ecosystem services, values estimated can be easily transposed to maps according to the land use with the assistance of a GIS. Ecosystem services for the three land use scenarios were estimated in the same way, although with different areas of land uses.

InVEST is a spatially explicit toolkit developed by the Stanford-based Natural Capital Project (http://www.naturalcapitalproject.org) with the overall aim to map and quantify ecosystem services. InVEST allows comparing different land use scenarios to project how changes in ecosystems will affect the provision of ecosystem services and to assess ecosystem trade-offs. Thereby, InVEST enables users to identify areas which are suitable for investment in ecosystem preservation while providing services for humans (Sharp et al., 2014).

Results and discussion

Both tools showed that the forest improvement scenario produced the highest values of cork and carbon stock and the cattle intensification scenario the lowest (Figure 4.14 and Figure 4.15). Cork production profit ranged from € 0.77 million in the cattle intensification scenario to € 3.35 million in the forest scenario, using InVEST, and from € 1.24 million in the cattle scenario to € 3.03 million in the forest scenario, using TESSA.

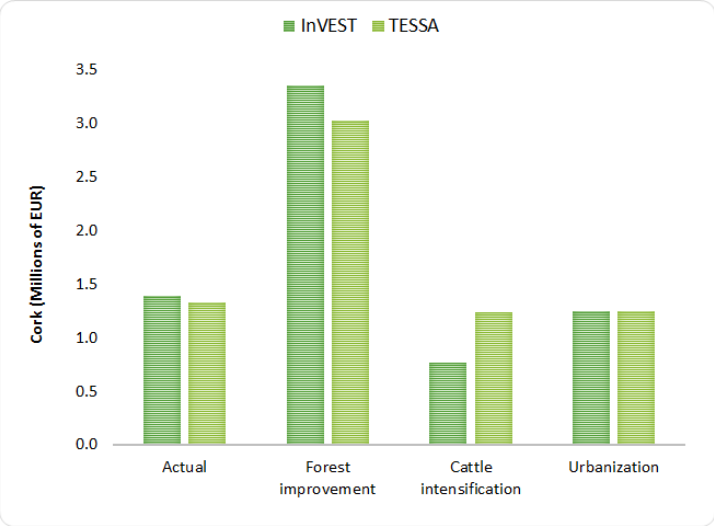

Figure 4.14. Cork profit (€ millions) for the four land use scenarios, estimated by the tools InVEST and TESSA. Profit is calculated as income from cork selling deducting the price of maintaining cork oaks and harvesting the cork. Both models agree that value would be close to tripled under the forest scenario.

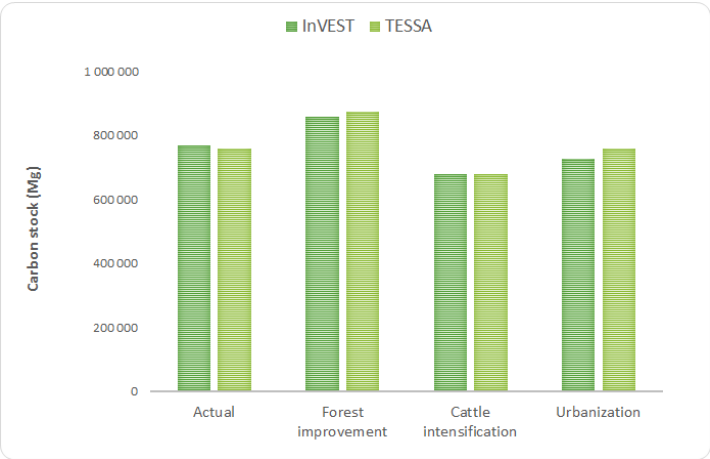

Figure 4.15. Carbon stock (Mg) for the four land use scenarios, estimated by the two ecosystem services models InVEST and TESSA. Results are similar (within 4% for all scenarios). Both models agree that the highest is for the forest scenario. This is 12% higher than the current (actual) scenario as estimated by InVEST and 15% higher as estimated by TESSA.

Carbon stock values ranged from 0.68 million Mg in the cattle intensification scenario (using both InVEST and TESSA) to 0.86 million Mg in the forest improvement scenario (using InVEST) and 0.88 million Mg (using TESSA). The corresponding maps were also very similar (Figure 4.16). Although the montado is not the land use with the highest carbon stock per hectare it is quite relevant for the company, since it occupies the largest area. Additionally, it has a high profit value for the cork production.

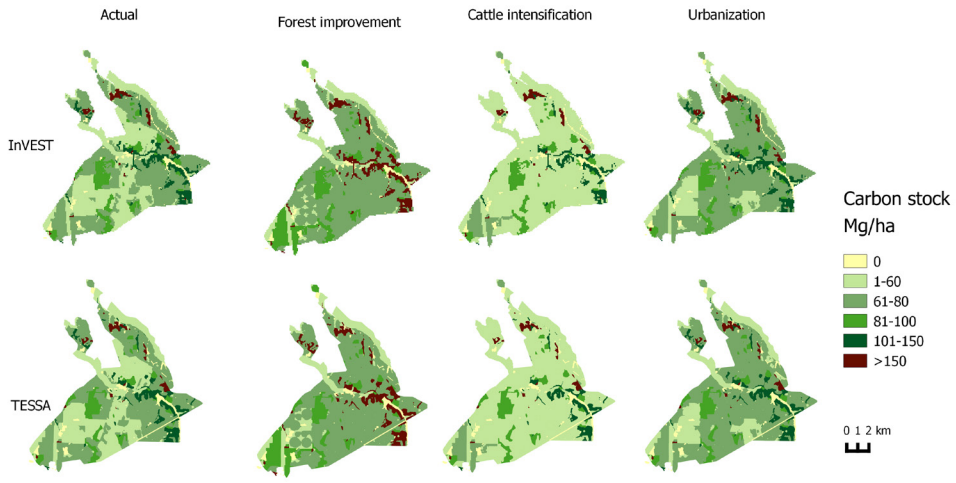

Figure 4.16. Maps of carbon stock (Mg/ha) in Companhia das Lezírias in four scenarios, estimated by InVEST and TESSA, revealing the similarity between methods. The maps show the highest carbon stock for the forest improvement scenario and the lowest carbon stock for the cattle intensification scenario, for both tools. It is also evident that the land uses with the higher carbon stock/ha are forests (pines, eucalyptus, mixed or riparian), although they have smaller parcels, as compared to the montado which has a lowest carbon stock, but a highest area.

Inversely, values of carbon sequestration were quite different among both tools (Figure 4.17). TESSA predicted a higher sequestration amount with the cattle intensification scenario (an uptake of 29,912 Mg) while for InVEST this was the scenario with the lowest value, 93,716 Mg (413% lower than TESSA estimate). For InVEST, the scenario with the highest carbon sequestration was forest improvement with 87,283 Mg of carbon sequestered. These differences are the result of the different methodologies applied with these two tools. While estimates of TESSA correspond to the carbon sequestered in a year for each scenario, estimated according to the IPCC guidelines, carbon sequestered using InVEST corresponds to the differences in the carbon stocks of the actual scenario and the plausible future scenarios (see methods). When we considered differences between scenarios for TESSA, the results became comparable, revealing again a clear advantage of the forest scenario for both tools: 87,283 Mg of carbon using InVEST and 117,346 Mg using TESSA. Once more, the cattle scenario revealed the lowest estimates. InVEST estimates that with this scenario there is a decrease in carbon sequestration of 93,716 Mg and TESSA estimates a decrease of 77,653 Mg (Figure 4.18).

The estimation and mapping of ecosystem services is largely dependent on the quality of primary data, the methodology applied and on the services considered (Eigenbrod et al., 2010a; Schulp et al., 2014). Although we used detailed data from the managers (particularly for cork production), for some parameters, particularly those related to carbon stock, bibliography was consulted, which is less accurate. Nevertheless, the estimation of carbon stock is the more consistent between both tools. To estimate carbon sequestration in its strict sense InVEST is not suitable since it estimates only the difference in carbon to a future scenario. However, TESSA also revealed poor estimates of carbon sequestration, since a better carbon sequestration with the cattle intensification scenario is not very plausible. InVEST seems more difficult to use by lay persons since it demands GIS knowledge. On the other hand, if the main goal is to map ecosystem services, and there is GIS expertise, it is more immediate, since it produces the maps automatically.

Figure 4.17. Carbon sequestration (Mg) accordingly to TESSA and InVEST estimations.

Figure 4.18. Differences in carbon stocks (Mg) between the actual baseline scenario and the alternative scenarios, estimated by InVEST and TESSA.

Conclusions

We compared three ecosystem services under three land use scenarios with two different tools: TESSA and InVEST. Both tools allowed the estimation and mapping of ecosystem services. The forest improvement scenario was the best for the delivery of the three ecosystem services, while the cattle intensification scenario was usually the worst. We found that carbon stock is the more stable estimate in both tools (differences below 4%). On the other hand, carbon sequestration shows differences of more than 400% in estimates made by these tools. We believe this difference is due to the way in which estimates are done, since InVEST considers carbon sequestration as a difference between the carbon stock of the actual land use and that of the scenarios and not the carbon sequestered from the atmosphere in a given time interval. Estimates of TESSA for carbon sequestration are also not reliable. Thus carbon sequestration estimations are poorly reliable in both models.

The model comparison shows that different models can produce different conclusions, and therefore should be carefully used, particularly for carbon sequestration. Moreover, these tools have some limitations, namely the difficulty of being used by non-qualified persons due to technical requirements, in spite this being the main aim. The specificity of some data input is also demanding for non-specialists. To these facts we need to add the complexity of the montado system which increases the complexity of estimates.

Results obtained therefore highlight the need for a better harmonisation and/or refinement of available tools.

Acknowledgment

This research was financed by Projects OPERA (FP/ENV/2012/308393/2) and Lter Montado (LTER/BIA-BEC/0048/2009). Authors are also in debt to Companhia das Lezírias, S. A.

National case studies

4.7. How is biodiversity changing in Spanish forest ecosystems?

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State and trends of biodiversity in Spain

The Spanish National Ecosystem Assessment (Spanish National Ecosystem Assessment, 2014) evaluated the state and trends of biodiversity and its relationship with ecosystem and their services. Systematic national assessments of biodiversity have been carried out using threatened species for a few taxonomic groups, such as vertebrates and vegetation, and the proportion of species evaluated in each taxonomic group differs greatly from their representation in Spanish specific diversity. Vertebrates are the taxonomic group in which the highest proportion of species has been assessed based on the criteria of the Red Lists. Assuming that it is impossible to assess extinction risks for all taxa, the Spanish Ministry of Agriculture, Food and the Environment has recently expanded its assessments of endangered status to more taxonomic groups, such as bryophytes.

Despite the fact that vertebrates are the taxonomic group receiving the most political and scientific attention, their extinction rates in Spain are slightly higher than global trends (Martín-López et al., 2011; Santos-Martín et al., 2013). While the proportion of vertebrates threatened at a global scale in 2010 was approximately 20% (Hoffmann et al., 2010), in Spain, 23.6% of vertebrate species are categorized as critically endangered, endangered or vulnerable based on national assessments (Figure 4.19) (Spanish National Ecosystem Assessment, 2014).

The Red List status of species provides a snapshot of what is happening to the assessed taxa at a given time, but it cannot provide information about trends. However, the Red List Index can be used to compare the proportion of species in different categories over time. Calculation of the Red List Index for vertebrates shows an increase in the proportion of threatened species since 1986 (Santos-Martín et al., 2013) (Figure 4.20). While much less is known about other taxonomic groups as well as marine organisms, on the basis of the National Catalogue of Threatened Species and the National Red List Assessment, we found that of the species assessed in Spain, between 40% and 68% are threatened, respectively.

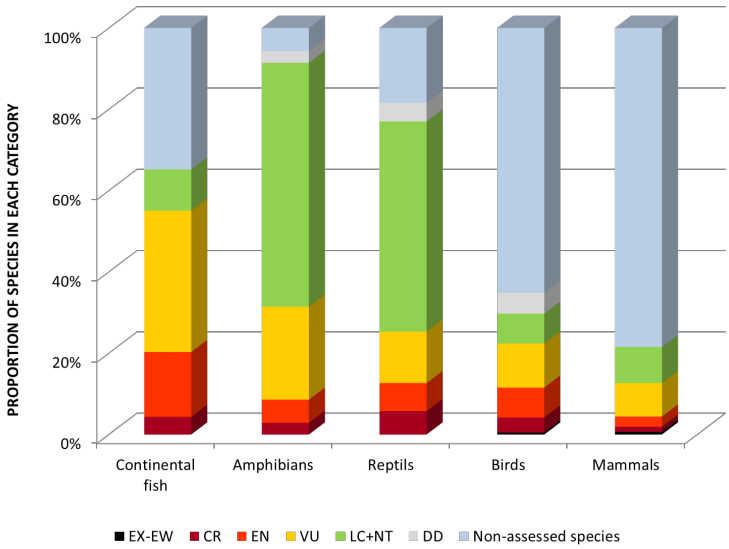

Figure 4.19. Proportion of endangered vertebrates in Spain according to national assessments. (EX: extinct; EW: extinct in the wild; CR: critically endangered; EN: endangered; VU: vulnerable; LC: least concern; NT: near threatened; DD: data deficient). (sources: Doadrio, 2001; Martí and del Moral, 2003; Pleguezuelos et al., 2004; Palomo et al., 2007).

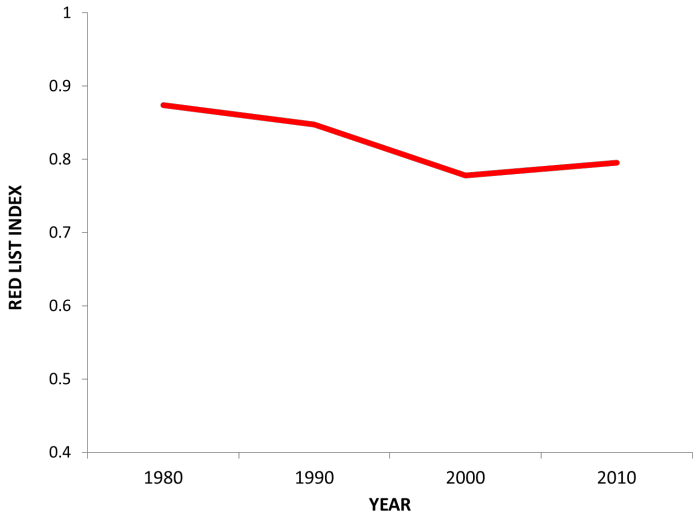

Figure 4.20. Trend of the Red List Index for Spanish vertebrates (N=233) (Santos-Martín et al., 2013).

In addition, the genetic diversity of domesticated animal species has suffered considerable erosion. According to the UN Food and Agriculture Organization's Global Databank for Spain, of the approximately 215 autochthonous animal breeds for which sufficient data are available, 48% are considered at risk, and a further 8% have become extinct (Figure 4.21). Most of this deterioration of genetic diversity has occurred because of the intensification of forest and farmland systems, in addition to the abandonment of traditional farming practices. In fact, we found that land-use change is the most important direct driver of change affecting the state of biodiversity in Spain. Thus, in line with global assessments (MA, 2005; Pereira et al., 2012), the driver of land-use change has a much greater effect than the impacts of the other four drivers of change (i.e. pollution, overexploitation, invasive alien species, or climate change) (Figure 4.22).

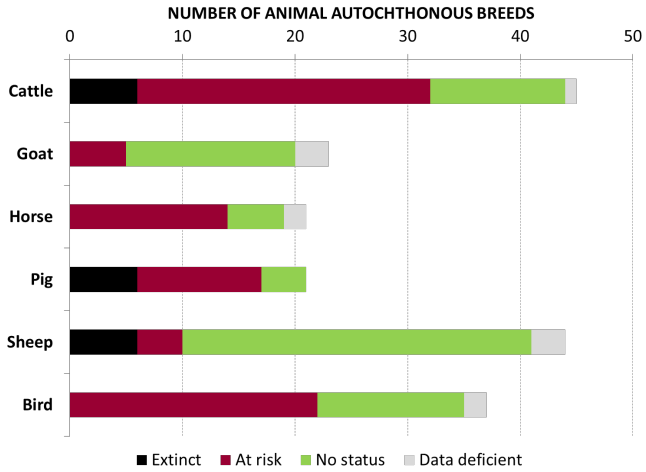

Figure 4.21. Proportion of threatened animal autochthonous breeds in Spain according to the UN Food and Agriculture Organization's Global Databank (http://dad.fao.org).

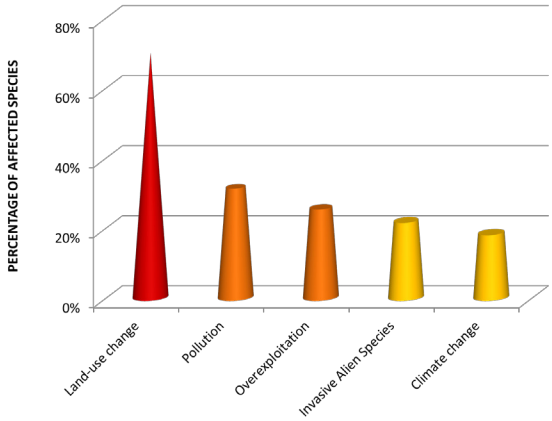

Figure 4.22. Proportion of species affected in Spain by different direct drivers of change. Source: Spanish National Ecosystem Assessment (2014).

Spatial distribution of terrestrial Spanish biodiversity in forest ecosystems

Based from data of the National Inventory of Biodiversity (Palomo et al., 2007) in Spanish National Ecosystem Assessment (2014) it was represented the spatial distribution of biodiversity by taxonomic groups. Figure 4.23 shows the number of species richness and threatened of terrestrial vertebrates that are shown in each grid of 5 x 5 km covering Spain and the Balearic and Canary Islands.

Based on GIS analysis it was found that most of these threatened terrestrial vertebrates occur in Mediterranean forests and mountain ecosystems (Figure 4.24). Instead, coastal and arid ecosystems have the lower levels of vertebrate's richness and threatened species. In addition, it is well known that in Mediterranean ecosystems, intermediate conditions of disturbance (i.e. multifunctional landscapes) are related to high levels of species diversity (García-Llorente et al., 2012). However, the multi-functionality of Mediterranean agro-silvo-pastoral systems is declining due to landscape homogenization as a result of landscape intensification, rural abandonment, and strict conservation policies, which, in turn, can result in decreases in biodiversity and ecosystem services. Consequently, biodiversity management policies should stimulate the revitalization of traditional rural practices and value the role of local communities as "sculptors" of landscapes that promote high levels of species diversity, maintenance of genetic diversity, and the preservation of a diverse set of ecosystem services.

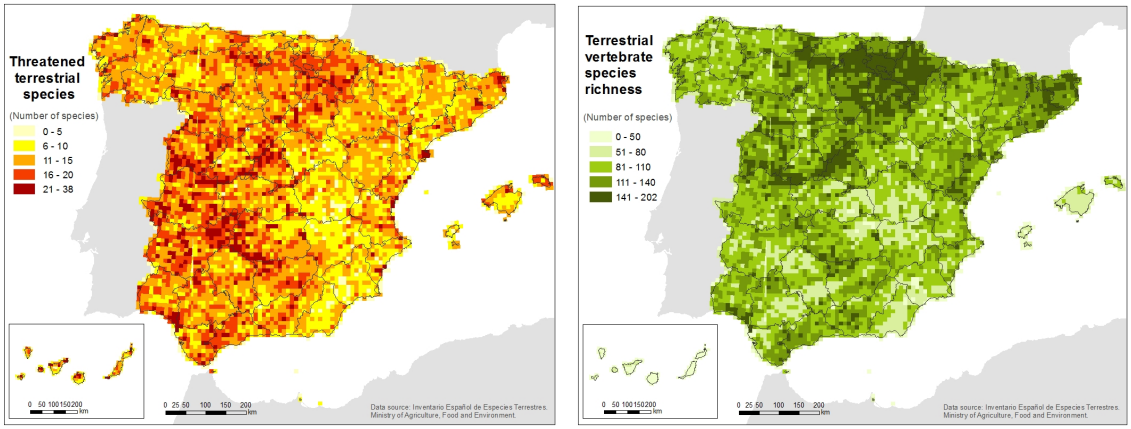

Figure 4.23. Spatial distribution of threatened terrestrial species (left) and terrestrial vertebrates (right) in Spain. Source: Spanish inventory of terrestrial species. Ministry of Agriculture, Food and Environment (2007).

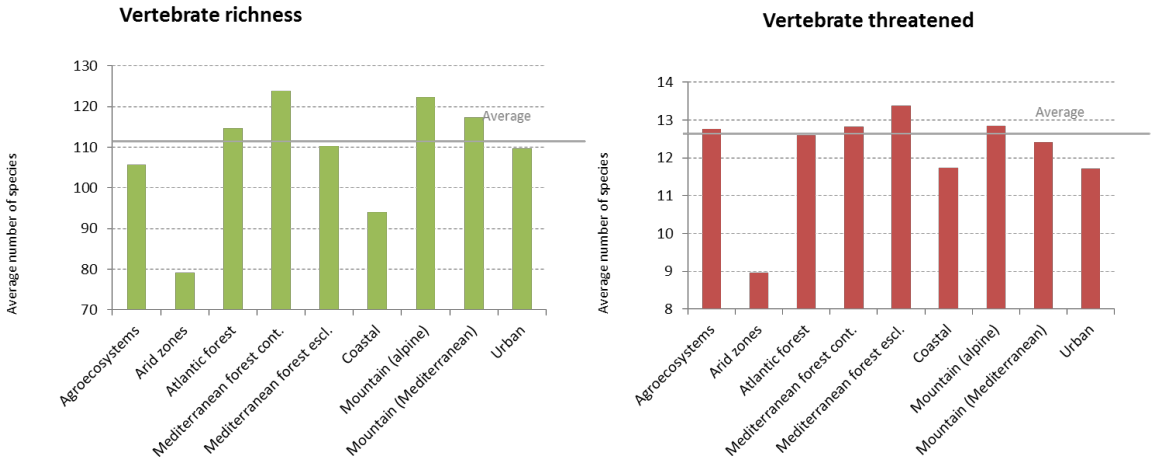

Figure 4.24. Number of vertrebrates species richness and threatened per ecosystem type in Spain. Source: Spanish National Ecosystem Assessment (2014).

Relationships between biodiversity and ecosystem services

The loss of specific and genetic diversity is inextricably linked to the deterioration of ecosystem services because of the important functional role that biodiversity plays in the processes that underpin ecosystem services. A review of the evidence of links between biodiversity and the delivery of ecosystem services shows that the functional role of microorganisms, fungi, vegetation and invertebrates is the main component of biodiversity that influences the delivery of ecosystem services (Table 7.3 in annex). However, this is the component of biodiversity receiving the least social, scientific and political attention in Spain (Martín-López et al., 2011). Consequently, there is a need to improve Spanish monitoring, scientific, and conservation programs to incorporate the components of biodiversity with a high capability to supply ecosystem services.

Depicting a future of biodiversity conservation in Spain

Justifying conservation exclusively based on ethical considerations about the right of species to exist (i.e. intrinsic value) ignores an important motivation for preserving species: the importance of biodiversity as a source of human wellbeing through the delivery of ecosystem services (i.e. instrumental value). Consequently, the two

approaches should co-exist in Spanish policies aimed at biodiversity conservation (Santos-Martín et al., 2013). Despite the large body of evidence indicating strong links between biodiversity and ecosystem services, the taxonomic bias in the available scientific information prevents us from assessing the specific role of the different components of biodiversity in the delivery of ecosystem services. Therefore, there is a need to extend the research objectives of scientific programs to less studied taxonomic groups as well as to emphasize the functional role of biodiversity (i.e. functional diversity). In addition, conservation programs should focus on preventing the continued effects of drivers of change, particularly those related to land-use change. Thus, conservation programs should be embedded within landscape management policies to preserve multifunctional Mediterranean landscapes that promote not only high levels of biodiversity but also a diverse flow of ecosystem services.

Acknowledgements

This case study is based on the chapter entitled 'How is biodiversity changing in Spain?' of the Spanish National Ecosystem Assessment (2014). Ecosystems and biodiversity for human wellbeing. Synthesis and key findings. Madrid: Ministerio de Agricultura, Alimentación y Medio Ambiente.

4.8. Mapping multiple ecosystem services (Sweden)

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Abstract

The Swedish Forest pilot project contributed to the general objectives of the MAES initiative for forests. However, it also tested an approach for mapping multiple forest ecosystem services in forests at a national level. The aim was to investigate the potential to map ecosystem services based on prediction with models that have been fitted to field data on the ecosystem services measured by the Swedish National Forest Inventory. Specifically, we first test whether significant relationships between field measurements on ecosystem services and mapped environmental variables that that have been obtained by modelling or remote sensing. If significant relationships to the mapped variables are found, then regression modelling and prediction should be a superior approach for ecosystem service mapping compared to spatial interpolation of the field measurements on the services. We also briefly discussed the limitations to identify synergies and trade-offs from maps of ecosystem services.

Materials and Methods

Data on ecosystem services from two nation-wide inventories

We used a nation-wide forest data set from the National Forest Inventory and the Survey of Forest Soils and Vegetation, covering an area of 400,000 km^2 of production forests. Hereafter the inventories are referred to as the NFI. The inventory uses a randomly planned regular sampling grid covering the whole country (Axelsson et al., 2010), and includes around 4,500 permanent tracts with each tract being surveyed once every 5 years. We used only plots on "productive forest", which had not been harvested, cleared, or thinned during the previous five years before the survey.

The three ecosystem services

Tree biomass production was estimated as the yearly change in tree biomass, calculated over a period of 5 years, and for all tree individuals higher than 1.3 m.

Soil carbon storage was measured as the amount of carbon in the topsoil, which consisted of either purely organic horizons, i.e. mor or peat layers, or less frequently of minerogenic A-horizons. This is the part of the soil most affected by the current above-ground biota.

Bilberry production was measured as the percentage of each plot covered by bilberry, *Vaccinium myrtillus*. The cover of *V. myrtillus* is strongly correlated to annual production. Bilberry is one of the economically most important wild berry species in Northern Europe (Miina et al., 2009).

Explanatory predictor variables and statistical modelling

Since the overall aim of the modelling was to map the ecosystem services by making model predictions, we used only explanatory variables for which we had nation-wide mapped data. The set of variables chosen was based on Gamfeldt et al. (2013).

The explanatory variables were length of the vegetation period, summed precipitation during April-October, the volume per hectare of spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), birch (*Betula spp.*), other broad leaved tree species collectively, forest stand age and tree species richness. The maximum tree species richness in the present models was set to four, specifically when the volume was >0 of each of spruce, pine, birch and other broad-leaved tree species. Finally, we used altitude and a soil moisture index as explanatory variables.

The climate variables were calculated based on the gridded dataset "PTHBV" produced by the Swedish Meteorological and Hydrological Institute (SMHI). The values of the forest stand variables were based on estimates combining satellite images and field data from the NFI from 2000, and has a resolution of 25 m, 'kNN-Sweden 2000' (http://skogskarta.slu.se/, (Reese et al., 2002)). The altitude was obtained from a digital topographic map with a cell size of 50 m (Geografiska Sverigedata, 2010). The soil moisture index was calculated according to Stein (1994) using the digital topographic map.

We modelled the three ecosystem services by linear mixed-effects modelling (Bates et al., 2013). We built the final models based on Akaike's Information Criterion (AIC; Akaike (1974)), on the estimates of the effect-size parameters, on knowledge of the biological system studied, and on Gamfeldt et al. (2013).

Results and Discussion

The national-scale mapping of the ecosystem services are biologically reasonable (Figure 4.25), the mapping is similar to preceding national mappings of these services (Lind, 2001; Sveriges Nationalatlas, 2011; Nilsson et al., 2014), and the final models are similar to the models that resulted from using NFI field measurements on also the explanatory variables (Gamfeldt et al., 2013). The preceding mappings were based on interpolating the NFI plot-level measurements on the ecosystem services. That is, in the mapping they do not utilize information on the environmental conditions between the NFI plots that affect the ecosystem service levels. In the Swedish pilot study, we utilized such information, specifically the mapped explanatory variables. This means that the Swedish pilot study should provide more accurate mapping of the ecosystem services than the preceding mappings.

Although our regression modelling and prediction approach is advocated for ecosystem service mapping (Martínez-Harms and Balvanera, 2012), the predicted magnitude of the ecosystem services at the smallest spatial scale, 25 x 25 m, is imprecise (not high R^2). However, the models are biologically reasonable and are similar to models that have utilized field measurements on the explanatory variables (Gamfeldt et al., 2013).

There are many ways to improve the predictive ability of these models, or in other words, to increase the variance explained by the models. First, additional explanatory variables can be included in the model building. The models in Gamfeldt et al. (2013) include about twice the number of explanatory variables that we utilized. Second, more

accurate data on the explanatory variables can be used. For example, the Swedish Meteorological and Hydrological Institute is currently producing maps on climate variables with higher spatial resolution and accuracy than the maps that we have used. Third, the algorithm used for the soil moisture index can be improved. Fourth, the mapped kNN forest variables that we have used are known to have low accuracy at the level of pixels and that accuracy improves as the area for which mean values are calculated increases (Reese et al., 2002). Thus, it may be better to use mean values for polygons that correspond approximately to forest stands. Finally, we are only using a small proportion of the NFI observations available on the ecosystem services; we have only used data on biomass from two inventories for calculating wood production, and data from one inventory on bilberry and soil carbon storage. We suggest using data from 2000 to today, representing the whole period for which kNN-data on the forest variables are available (every fifth year since 2000).

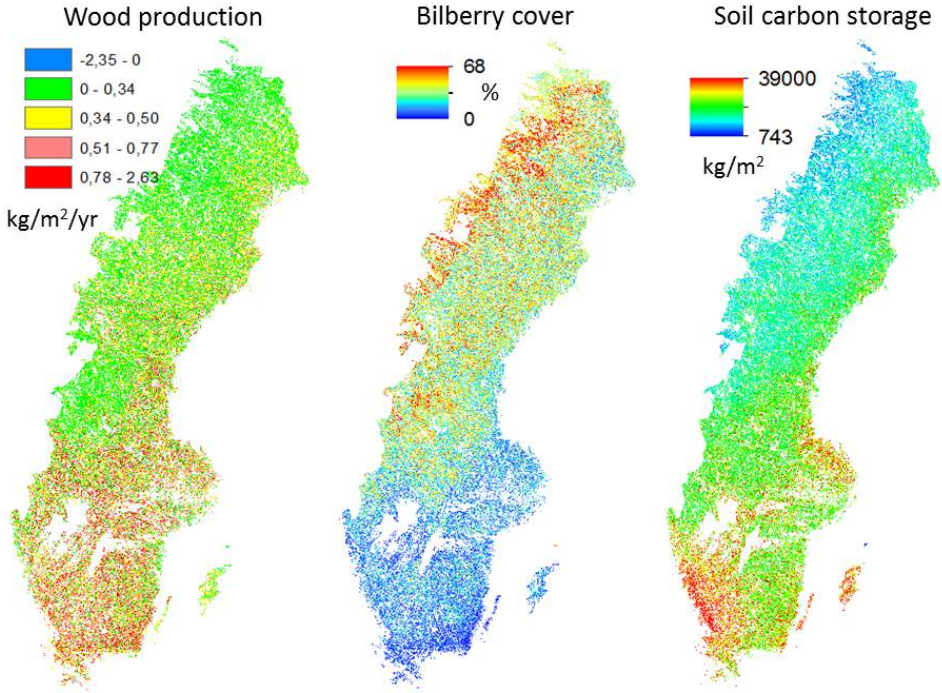

Figure 4.25. Mapped ecosystem services based on regression modelling of field measurements on ecosystem services on productive forest land and mapped environmental variables that that have been obtained by modelling or remote sensing.

Identifying synergies, and trade-offs from ecosystem service maps

Maps of ecosystem services can be used to identify sites with high or low levels of focal services (hotspots and coldspots, respectively), sites with high levels of a specific service or sites with intermediate levels of the services. However, the maps have limitations concerning identifying synergies, trade-offs or conflicts.

A hotspot site may indicate a synergy if the extraction of one service does not decrease the level of the other service, i.e. if they are independent. In contrast, it may indicate a possible conflict if the management for one service (including extraction) decreases the level of the other one. The underlying mechanisms may be direct in the form of changed interactions between the services, or indirect resulting from changed environmental

conditions. Here, a dialogue on trade-offs between the groups representing the services is necessary for appropriate management.

Also the mechanisms explaining a site with low (coldspot) or intermediate levels of the ecosystem services are difficult to identify. At a coldspot the natural environmental conditions may be poor for both services. These natural environmental conditions may or may not be possible to change with management. Another mechanism explaining a coldspot site of focal services may be interactions with another unmeasured service or driver. This interaction may be natural or result from management for the unknown service. It is also possible, but less likely, that low levels of both services result from negative interactions between them.

High levels of one service but not of another on a particular site may also be explained by natural environmental conditions, negative interactions or management benefitting only one of the services. However, at these sites we observe the result of these processes or conditions having had their effect, and further analyses are necessary to elucidate the reasons behind the observations.

Conclusions

The work undertaken by all the MAES Pilots in 2013 shows that there is a big potential for using data that already exists and combining these data into a coherent and integrated ecosystem assessment. The pilots have assembled an extensive list of indicators, which can be used, together with a typology and map of ecosystems to make a first assessment of ecosystem condition and ecosystem services. However, there are also several issues that remain to be resolved in the future. This includes more research on the links between biodiversity and ecosystem services, in particular for cultural services, the relations between forests and water services, and how to understand and manage synergies, trade-offs among services. It is also clear that whereas data may already exist, for instance as NFI data, additional modelling and analyses are needed before mapping can be done.

As for the pilot mapping, this study highlights some of the possibilities, but also some of the difficulties in using NFI data for nation-wide mapping of ecosystem services. Models for the prediction of ecosystem services need to be built. These models are constrained by the availability and resolution of potential predictor variables that also have to be available in mapped format. There are also limitations concerning identifying sites of synergy or trade-off. Nevertheless, ecosystem services maps for different habitats and for biodiversity have the potential to increase the potential for the management of ecosystems and their services across sectors, and thus to form a basis for a dialogue for actors that have an interest in forest and ecosystem services in general. This could be especially important in landscape management, for instance in building a green infrastructure (Snäll et al., 2015).

European-wide case studies

4.9. Developing a spatially-explicit pan-European map of forest biomass provision

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Abstract

Biomass is among the most important services provided by forest. Nevertheless, spatially-explicit information on forest biomass provision is often not available. The aim

of this study was to develop a methodology for mapping forest biomass increment at the pan-European level. The study used remotely sensed data of Gross Primary Productivity (GPP) from MODIS (NASA Product MOD17A3) adjusted with GPP data derived from upscaling FLUXNET observations using the Model Tree Ensemble (MTE) technique implemented by Jung et al. (2011) to derive a 1-km resolution woody biomass increment map. The resulting map serves as baseline for applications dealing with the potential supply of woody biomass e.g. for energy or timber production.

Methods and discussion

Data on forest biomass increment is usually only available at administrative units such as NUTS regions and for specific regions or countries. Information on forest biomass increment is important because it could be used for assessing the sustainable use of this service. Furthermore this information is useful for assessing trade-offs between this service and other forest services such as habitat provision, soil protection, etc. The aim of this study was to develop a pan-European wall-to-wall map of above ground woody forest biomass increment (AGBiW) (i.e., the yearly increase of the biomass stored in forests in their woody above-ground tissues) using GPP estimates derived from MODIS satellite imagery and other ancillary spatial datasets, and exploiting regional National Forest Inventory (NFI) data for validation. In this section we show a brief summary of the methodology, a detailed description is available in Busetto et al. (2014). Input data used in this study was:

1) MODIS GPP Data: yearly maps of GPP for the period 2000-2010 at 1-km spatial resolution (MODIS Product MOD17A3–v0.55) derived by the Numerical Terradynamic Simulation Group (NTSG)/University of Montana (UMT) from MODIS imagery. In this study, only grid cells having the following UMD classes were considered for the computation of AGBiW: Evergreen Needleleaf Forests (ENF), Deciduous Needleleaf Forests (DNF), Evergreen Broadleaf Forests (EBF), Deciduous Broadleaf Forests (DNF) and Mixed Forests (MF).

2) Model Tree Ensemble (MTE) GPP Data: The second source of GPP data was the GPP map derived by Jung et al. (2011) from upscaling of FLUXNET observations of carbon dioxide, water and energy fluxes observations using the MTE machine learning technique (Jung et al., 2011). These data were used to compute maps of the average yearly MTE GPP for the 2000-2010 period for different land cover classes, for each 0.5° grid cell. This data was used for adjusting the raw MODIS GPP data which exhibits some overestimation in Subtropical (Mediterranean) areas.

3) NFI Data: Regional AGBiW estimates were derived from NFI data of net annual increment (NAI) of growing stock volume. These AGBiW estimates were used for validation and accuracy assessment of the AGBiW map derived from MODIS GPP.

The adjusted GPP map was used to compute the average annual above ground woody net primary productivity (NPPW), for each 1-km forest grid cell. The computation was conducted following the carbon partitioning scheme of Ise et al. (2010) where NPPW can be computed from GPPW (primary production allocated to woody tissues). Finally, AGBiW was computed as the ratio between NPPW and the biome (and forest-type) specific carbon fraction of dry matter in above ground biomass factors, derived from IPCC (2006).

The AGBiW map implemented is shown in Figure 4.26. The map illustrates a large variability in the estimated yearly increment of above ground biomass across latitudinal and altitudinal gradients. Higher values are observed in temperate forest, while lower values are evidenced in boreal areas and arid and Mediterranean regions.

Results of the validation using NFI data (NUTS 1-2) suggests a reasonably good agreement between estimated and NFI biomass increment cumulated at regional level, as shown by the high R^2 value (0.92) and by the slope coefficient close to 1. The mean absolute error of the estimates is 0.75 million tonnes of dry matter per year, and the

relative MAE (rMAE) 37%. At country level R^2 value is 0.98, MAE 2.64 million tonnes of dry matter per year, and rMAE 18.4%. The discrepancies between the MODIS and NFI NUTS values are due to several reasons, i.e. inaccuracies in the input GPP map, uncertainties in the coefficients used for the GPP to AGBiW conversion, and in the coefficients used for converting the NFI growing stock increment estimates to biomass increment estimates. The combination of the mentioned uncertainties leads us to suggest that the relative errors observed in the different regions indicate a reasonable accuracy of the produced map. Nevertheless, caution is deemed in analysing biomass increment variability at local scale.

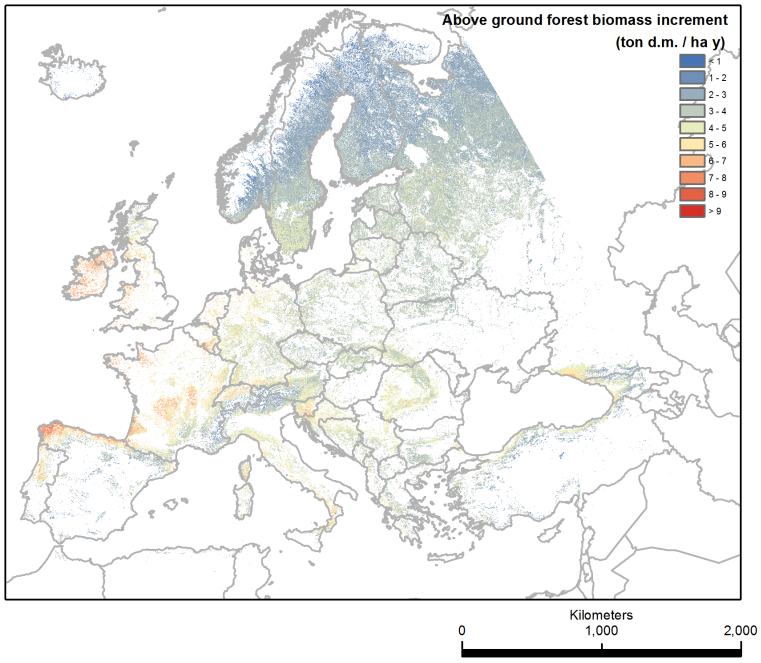

Figure 4.26. Pan-European map of above ground forest biomass increment (ton d.m./ha yr). Source: Busetto et al. (2014).

The main achievement of the study is a seamless wall-to-wall map of AGBiW for Europe. The method provides a measure of woody biomass increment by excluding tree roots and leaves validated using NFI data. This dataset closes a gap regarding large-scale mapping of the potential provision of biomass from forests. The method described is a contribution towards a more comprehensive understanding of the services provided by forest ecosystems. The map offers the possibility of assessing geographically the distribution of biomass that could be sustainably felled and removed. Moreover, the map is a useful instrument for supporting discussions on forest ecosystem services and assessing trade-offs between different forest services.

Conclusions

The method described in the study case provides a map of woody biomass increment by excluding tree roots and leaves that is validated using NFI data. The map measures the amount of woody biomass increment per year, which is the potential forest ecosystem service of biomass provision.

The map presented is considered an instrument for supporting discussions on forest ecosystem services and assessing trade-offs between different forest marketed and non-market services such as habitat provision, carbon sequestration, erosion protection, etc. The use of NFI data in the validation is an important step for decision makers, because it provides a quantitative measure of uncertainty of the map. Further work regarding this study case would be to validate the map using plot level measures of forest biomass increment. This will deliver a more robust measure of uncertainty and a more informed

decision-making process, for instance for analysing trade-offs between different forest services and options for biomass use.

4.10. Mapping forest carbon stock distribution in European forest

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Abstract

The aim of this case study is to illustrate a methodology used for implementing a map of forest carbon stock, describe the main features of the map and discuss advantages and limitations of the approach. The method was implemented by Thurner et al. (2014) to infer a forest carbon density map at 0.01° (~1 km) resolution from remotely sensed radar imagery in Northern Hemisphere boreal and temperate forests covering the whole European territory.

The resulting map was tested using inventory based biomass data from Russia, Europe and the USA. In addition, the map includes a spatially-explicit estimation of uncertainty at the same spatial resolution of the carbon map. This is a novel aspect that increases applicability of the product in decision making processes easing to account for uncertainties at different sites. The forest carbon map was implemented in the framework of the European Space Agency (ESA) Support to Science Element (STSE) project BIOMASAR.

Methods and discussion

The implementation of the carbon stock map was based on a forest growing stock volume (GSV) product (Santoro et al., 2011; Santoro et al., 2015) retrieved from synthetic aperture radar (SAR) data. Forest carbon stock and spatially explicit uncertainty estimates were derived from the GSV and related uncertainty estimates using databases of wood density and allometric relationships between forests biomass compartments (stem, branches, roots, foliage).

Forest GSV data describes the volume of tree stems per unit area and is measured in m^3 ha^{-1}. GSV was estimated from multi-temporal observations of the SAR backscattered intensity acquired by Envisat Advanced SAR (ASAR) acquired between October 2009 and February 2011, thus the GSV dataset contains information of the year 2010. The GSV data product was masked using the GLC2000 global land-cover map (JRC, 2003) to exclude non- forested areas. In addition, the Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009) and the JRC GHG-AFOLU Biomass Compartment Database (JRC, 2009) were used. Information from these databases was aggregated to the level of three leaf types, i.e. broadleaf, needleleaf deciduous and needleleaf evergreen forest.

The method was implemented in three steps. First, stem biomass was computed from GSV using information on wood density from the Global Wood Density Database. Second, allometric functions at leaf type level between stem biomass and the other biomass compartments (branches, foliage and roots) were computed by fitting root functions to the Biomass Compartment Database. Finally, total biomass was computed by summing the biomass compartments (stem, branches, root and foliage biomass) and

converted into carbon units considering carbon content in broadleaf and needleleaf tree species (from Thomas and Martin, 2012).

The input factors (GSV dataset, wood density, allometric relationships) used for the computation of the map contribute to the uncertainty of the product. An uncertainty estimate of the total carbon map was implemented for each grid cell. Similarly compartment-specific uncertainty maps were computed. The uncertainty of the total carbon map was computed as the sum of the compartment-specific uncertainty maps. The resulting map was evaluated at a regional scale using inventory based data from Russia, USA and Europe (at country level using EFI (2005)). At country scale there was high agreement with EFI (2005) national statistics in Europe (r^2 = 0.7, RMSE = 0.87 kg C m^{-2}). This evaluation could be further refined by applying reference data with higher spatial resolution.

The highest content of carbon in Europe is evident in mountain ranges, European Russia and other remaining forested areas in Europe's temperate forests like for instance Southern Sweden (Figure 4.27). In the boreal regions there is a proportional decline along a latitudinal gradient. Relative uncertainty is mostly between 20 and 40%, especially in high forest carbon areas. In Europe, total forest carbon stocks of 19.9 ± 7.3 Pg C and a mean carbon density of 6.08 ± 2.24 kg C per square meter forest have been quantified based on this dataset. Although Europe's contribution to total Northern Hemisphere boreal and temperate forest carbon stocks (79.8 ± 29.9 Pg C) is smaller compared to North America and Asia, Europe's forests have the highest carbon density (mean carbon density in Northern Hemisphere boreal and temperate forests: 4.76 ± 1.78 kg C per square meter forest area). More detailed estimates of carbon stock and density are derived for different forest biomes and can be calculated at finer spatial or species scales in more detailed analyses.

The carbon stock map has many potentialities and a few constraints. The bakscattered intensity of SAR images acquired at longer wavelength compared to Envisat ASAR present stronger sensitivity to GSV, which would reduce uncertainties and errors primarily in high GSV forest. Repeated observations are of benefit to reduce the noise compared to estimates obtained from a single backscatter value. Yet, there is no such dataset available from any spaceborne SAR mission.

The approach used in this study makes use of leaf type information only instead of more detailed tree species spatial distributions. The applied algorithm could be improved by the availability of a consistent global tree species map. For Europe such a detailed tree species map is already available in Köble and Seufert (2001). In addition, more comprehensive and standardised measurements of biomass compartments covering the most important tree species across all climate zones could further improve the modelling of allometric relationships and hence the carbon map.

Results of the evaluation indicate that the accuracy of the map is comparable with other products derived from upscaled forest inventory data at a regional scale. This demonstrates the potentiality of remote sensing data to complement forest biomass inventories. In the future, a higher GSV mapping resolution together with fine-scale land cover information may improve forest carbon stock estimates in Europe's typically patchy forest ecosystems. Synergy of data from SAR, optical and LiDAR sensors is suggested to overcome limitations posed by each single data source (temporal and spatial resolution, policy of access and use, correlation with biomass and biomass component).

Conclusions

This case study presented a carbon stock map from a consistent remote sensing and modelling approach. The map has the advantage of having a spatially-explicit account of uncertainty of the same spatial resolution. This provides an important instrument for supporting informed decision-making regarding trade-offs between forest ecosystem services and the potential effects of territorial actions having an impact in forest areas

and specifically in forests carbon stocks. The map is considered to be a new benchmark of spatially explicit and consistent carbon stock estimates with a moderate spatial resolution. In the future, a regular repetition of consistent biomass estimation from remote sensing data may also help to improve our knowledge on disturbance, deforestation, degradation and regrowth processes in addition to the current state.

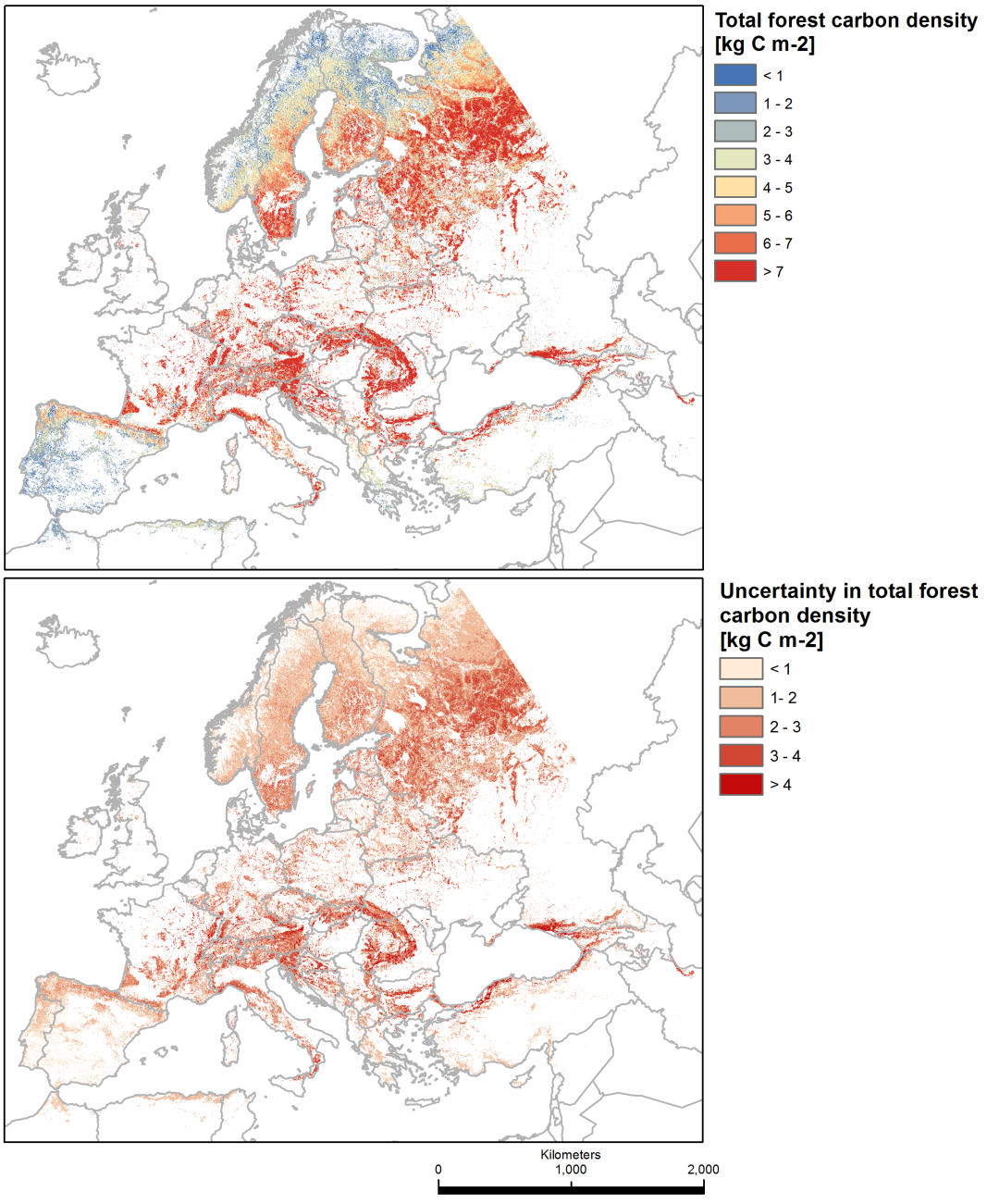

Figure 4.27. Upper panel: map of total forest carbon density (tree stems, branches, roots and foliage) in Europe. Lower panel: Absolute uncertainty of the total forest carbon density map. Non-forested areas are masked according to the JRC (2003) GLC2000 land-use/land-cover map [source: Thurner et al. (2014), version 3, available from https://www.bgc-jena.mpg.de/geodb/projects/Home.php].

5. Summary and guidance for decision making

A series of approaches has been proposed in recent years for mapping and assessment of ecosystem services, including forest ecosystem services. Summaries of these approaches are presented in Eigenbrod et al. (2010a); Ayanu et al. (2012); Crossman et al. (2012); Egoh et al. (2012); Maes et al. (2012a); Martínez-Harms and Balvanera (2012); Crossman et al. (2013); Schägner et al. (2013); and Willemen et al. (2015). The multiplicity of approaches resulting from the combination of data sources, type of data sources, scales and methods poses difficulties to decision makers for having a complete understanding of the strengths and weaknesses of each approach. A simple search in Scopus using the words "mapping ecosystem services" produces a list of more than 700 articles, each using a specific method, data and approach for assessment. Maps of ecosystem services have become a popular tool for policy making and territorial decision making; they are useful for trade-off analysis among ecosystem services, as well as to support prioritising green infrastructure investments and regional policy. Taking into consideration the current popularity of ecosystem services maps in the policy arena, an overview of the main approaches using the ten case studies as examples will provide a more robust basis for informed decisions, including options for model and data validation, and uncertainty measures which are inherent to each method and dataset used for mapping and assessment.

This chapter presents a summary of the ten case studies. For analysing the case studies we adopted a framework using as a basis the work of Martínez-Harms and Balvanera (2012), Eigenbrod et al. (2010a) and Schägner et al. (2013). Hence the case studies were classified on the basis of five criteria; i.e. type of ecosystem services, availability of data sources, type of data sources, scale, and methods used to map ecosystem services. In addition, we included information regarding validation and uncertainty. The following paragraphs describe the five criteria.

First, according to the CICES classification (Haines-Young and Potschin, 2013) adopted in MAES, the type of forest ecosystem services is classified in three main categories: provisioning, regulating and cultural services. A detailed description of the typologies and sub-categories of forest ecosystem services and potential indicators for mapping is available in the 2nd MAES report (MAES, 2014) resulting from the MAES Forest Pilot Study. Second, the availability of data sources is grouped in two categories: primary and secondary. Primary data sources are maps derived from field sampling. In our case the most relevant information is provided by NFI (Tomppo et al., 2010); other sources are surveys, field data, interviews and census data. Secondary data are maps derived from readily available information usually not verified in the field: e.g. remote sensing imagery, cartographic data, socio-economic data, and mixed sources like databases and statistics. Third, three types of data sources have been defined: a) biophysical data such as land-cover, remote sensing imagery, topographical, hydrological, and climate data; b) socioeconomic data such as road maps, population maps, photos, and census data; and c) mixed data such as databases, statistics, bibliography, interviews, surveys and field data.

Fourth, formally the scale of a map defines the ratio of a given distance in the map to the corresponding distance on the ground. In plain language scale can be understood as the grain of the map. The higher the grain, the more detailed is the resulting representation of the phenomena described in the map. In this report we have classified scale in three main categories; i.e. regional, national and European-wide, likewise addressing the extent of the area covered by the case studies.

Fifth, the method for mapping (or modelling) is the way (and tools) used to quantify and map ecosystem services. A series of methods has been implemented in the socio-ecological domain and in many cases they are not mutually exclusive, on the contrary, they are often integrated in studies for mapping forest ecosystem services. A typology of

methods built upon the studies of Martínez-Harms and Balvanera (2012), Eigenbrod et al. (2010a) and Schägner et al. (2013) is presented:

1) Look-up tables (LUT): This approach makes use of existing ecosystem services values from the literature and applies to land-cover classes in other spatial domains. This is the Tier 1 approach according to MAES (2014).
2) Expert knowledge: Experts rank land-cover types based on their potential to provide specific ecosystem services. This method is based on the knowledge that the experts may have about the potential of the land cover categories in a specific location to supply given ecosystem services. Often this approach is integrated with the LUT approach.
3) Causal relationships: This approach incorporates existing knowledge about how different layers of information (usually secondary data) relate to ecosystem processes and services to create a new proxy layer of the ecosystem services. This includes methods using spatial variables such as distance relationships (e.g. to roads), amount of a type of land (e.g. protected areas or forest areas), land cover data, population density, climate data, soil data, elevation. Causal relationships are usually taken from the literature, expert knowledge or are derived empirically on the basis of available observational data; then spatially-explicit variables are integrated using GIS modelling tools for producing a new proxy layer (map) of ecosystem services. This is the Tier 2 approach according to MAES (2014).
4) Statistical and machine learning models: This approach employs field data (primary data) of ecosystem services for modelling the relationship with explanatory variables and proxies, e.g. biophysical data and other sources of information obtained from GIS. One of the strengths of this approach is the ability to provide measures of error/accuracy, in some cases in a spatially-explicit way (see case study 4.10). This is the Tier 3 approach according to MAES (2014).
5) Implicit modelling: This approach uses value functions relating variation in ecosystem services values to variation in the characteristics of the ecosystem, context and beneficiaries of the services. Local-level parameter values are input into the value function to extrapolate the value to other sites of the study area with unknown value information. This approach is common in studies from the environmental economics domain (e.g. for mapping cultural services, but not only) (Schägner et al., 2013).
6) Representative sampling: This approach offers the best estimate of observed levels of ecosystem services. However, ecosystem services mapping studies based on this approach are limited due to the high costs and difficulty to collect the large amount of data required (Eigenbrod et al., 2010a).

Figure 5.1 shows a schematic representation of the five criteria used for classifying ecosystem services mapping approaches and the many potential combinations that configure multiple methodological options. The grey circle represents the criteria to be assessed in ecosystem services mapping exercises. The external boxes represent possibilities or choices that mappers should address. The choices are often a consequence of data availability, hence leading to a data-driven mapping exercise where the method is not a choice but the consequence of the type of available data; e.g. primary or secondary, and then whether it is biophysical, socio-economic or a combination (i.e. mixed).

The case studies of chapter 4 have been classified on the basis of the five criteria of Figure 5.1 (see Table 5.1). The assessment of the case studies reveals that in many cases the availability of data, type of data sources and method is not mutually exclusive; on the contrary, often mapping studies integrate different types in the methodology implemented. Regarding availability of data, there is no predominance of one category over the other and in most cases both primary and secondary data are used. Biophysical data is the preferred option of data sources; all case studies make use of this typology even if in some cases it was integrated with socio-economic and mixed data. Finally, causal relationships is the method used more frequently, followed by statistical and machine learning models. In a few cases different types of methods are integrated, such

as in case study 4.3 which uses casual relationships integrated with expert knowledge for fine-tuning of the model, and case study 4.1 using causal relationships integrated with LUT. Finally case study 4.7 uses representative sampling.

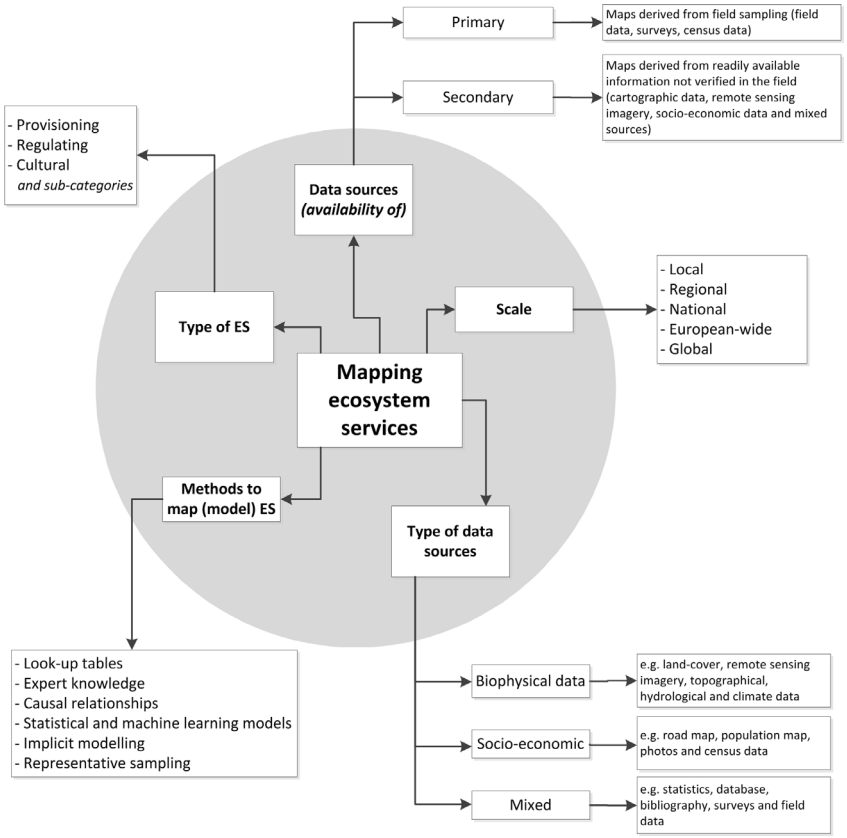

Figure 5.1. Criteria used for classifying ecosystem services mapping approaches. The grey circle includes the criteria, the information outside the circle represents the many options that can be adopted for each criterion (modified from Martinez-Harm and Balvanera, 2012).

In summary, results from Table 5.1 and literature reviews (Eigenbrod et al., 2010a; Maes et al., 2012a; Martínez-Harms and Balvanera, 2012; Schägner et al., 2013) suggest that there is no univocal way for selecting and using data and methods, and that each mapping methodology has specific features. A practical consequence of this diversity of approaches, methods and data is that decision makers, the users of this information, could easily get submerged by the complexity of the methodologies and the difficulty in disentangling the capability of the studies to convey useful information for territorial decision making and assessments, such as trade-offs between different ecosystem services, or regional prioritisation of ecosystem services (e.g. case study 4.3) and green infrastructure (e.g. case study 4.4).

A contribution to facilitate the understanding of the potentials and limitations of the mapping approaches is presented in Figure 5.2. The figure integrates data sources typologies and methods and its capacity to convey useful information to policy makers. This figure was built upon literature review and uses the case studies as illustrative examples. Primary data is considered more robust and close to field measurements; an example is the information included in NFI. However, collecting this information is costly and requires a high level of expertise and highly qualified modellers to deal with it. Primary data is well suited for statistical and machine learning models and in some cases for causal relationships assessments and implicit modelling. Examples of their use are case study 4.8 in Sweden, and case study 4.7 in Spain that is based purely on primary

data collected in sampling campaigns. Secondary data is more accessible and in many cases maps are readily available at no cost. For example, land cover or remote sensing datasets (e.g. NPP, GPP, NDVI, etc.) are widely available. This explains to some extent the popularity of causal relationships studies using secondary data and, often, primary data for model validation or accuracy assessment. As described in Figure 5.2 studies using primary data are considered more able to provide guidance to decision making. Nevertheless this also depends on the type of method implemented and on the validation approach followed. Regarding methods, Martínez-Harms and Balvanera (2012) recommend statistical and machine learning models as the preferred option followed by causal relationships using primary or secondary data. Implicit modelling using primary data is also among the most robust methods. Statistical and machine learning models reveal the relationship between primary field data of ecosystem services and environmental spatial (GIS) variables (Crossman et al., 2013). A limitation of these models is the time and human resources needed for its implementation, this is because they are more complex and require highly skilled modellers in comparison to other methods (e.g. causal relationships or LUT). Causal relationships methods were the preferred option within the case studies. This typology is based on the understanding (evidence-based) of ecosystem services supply and environmental spatial variables. This is the preferred option when primary data are not available or are available in a limited way but still useful as validation dataset.

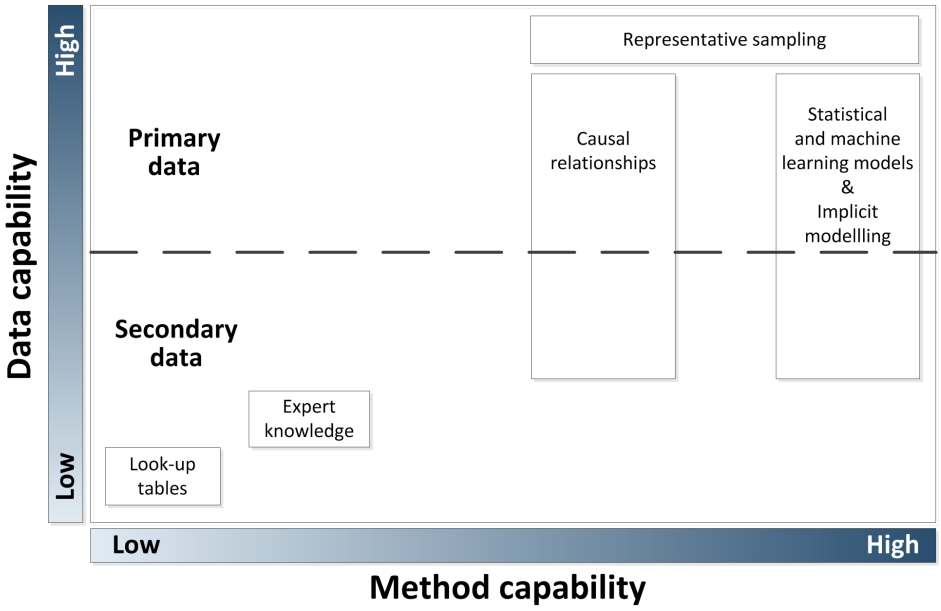

Figure 5.2. Capability of methods and data for ecosystem services mapping to convey information to decision makers.

On the other side, methods based on simple look-up tables are easy to implement but their reliability, mostly at local level, is usually poor because of over-simplification of the distribution of the ecosystem services supply over large areas. Therefore their reliability at the local level, for example for assessing trade-offs, is low. Also, expert knowledge methods are in the lower side of the horizontal axis of Figure 5.2. These types of methods may contain high levels of subjectivity on the basis of the selection of the experts and their background and pre-defined criteria towards the assessed ecosystem services. Different groups of experts could provide different resulting values for the same subject. A review of the limitations of these methods is in Eigenbrod et al. (2010a) and Eigenbrod et al. (2010b).

Case study	Type of forest ES	Availability of data sources (Primary, secondary)	Types of data sources	Scale	Methods used to map ES	Validation
CS 4.1 Basque Country (Spain)	Habitat provision; carbon storage; water flow regulation	Primary and secondary	Biophysical and mixed	Regional	Causal relationships, Look-up tables	–
CS 4.2 Portuguese woodlands	Biomass supply	Primary and secondary	Biophysical	Regional	Statistical and machine learning models	–
CS 4.3 Swiss Alps forests	Carbon sequestration; timber production; avalanche protection; habitat provision; recreation	Primary and secondary	Biophysical and mixed	Regional	Statistical and machine learning models (Bayesian Networks) and expert knowledge for fine tuning	Spatially-explicit measure of uncertainty
CS 4.4 Helsinki-Uusimaa Region	23 ecosystem services	Primary and secondary	Biophysical and socio-economic	Regional	Causal relationships and expert knowledge	–
CS 4.5 Molise Region	Timber production; carbon storage	Primary and secondary	Biophysical and socio-economic	Regional	Causal relationships (model)	–
CS 4.6 Portuguese *montado*	Carbon storage; carbon sequestration; cork production	Secondary and primary	Biophysical and mixed	Regional	Causal relationships (model)	–
CS 4.7 Spain	Habitat provision	Primary	Biophysical, mixed	National	Representative sampling	–
CS 4.8 Sweden	Tree biomass production; soil carbon storage; bilberry production	Primary and secondary	Biophysical and mixed data	National	Statistical and machine learning models	Validation using global measures and survey data
CS 4.9 European	Forest biomass supply	Secondary (primary for validation)	Biophysical	European-wide	Causal relationships	Validation using global measures and survey data
CS 4.10 European	Forest carbon storage	Secondary (primary for validation)	Biophysical	European-wide	Causal relationships	Spatially-explicit measure of uncertainty

Table 5.1. Case studies from chapter 4 and criteria for mapping ecosystem services. ES: ecosystem services. Global measures are those addressing the whole extent of the study area.

A fundamental piece of information in ecosystem services mapping studies is map validation and uncertainty assessment. As pointed out by Egoh et al. (2012) often ecosystem services mapping studies do not validate their results or test the method for sensitivity. Therefore, in these cases the reliability of the maps produced is difficult to evaluate by users. Martínez-Harms and Balvanera (2012) explains an urgent need for validation techniques to assess the errors associated with ecosystem services mapping studies. In summary, as suggested by Schulp et al. (2014) there is little attention for the accuracy of ecosystem services maps. The validation can be implemented following two main approaches. First, using general measures, such as in case studies 4.8 and 4.9 where different measures of error/agreement with survey data are presented. And second, spatially-explicit measures of error (maps) such as in case studies 4.3 and 4.10 (Table 5.1). This last option is preferred when the maps are input into local or regional level decision processes, e.g. prioritisation of ecosystem services, hotspot or coldspot analysis or green infrastructure investments. Spatially-explicit information on uncertainty could be useful for excluding those areas where the models perform poorly or where the input data are less reliable. This option also facilitates assessing the resulting uncertainty of integrating the maps with other datasets having explicit uncertainty measures as is often the case in trade-off analyses.

A recent study implemented a systematic intercomparison of four European-scale maps of different ecosystem services (Schulp et al., 2014). They indicate five main sources of uncertainty in ecosystem services mapping studies. First, the definition of the ecosystem services typology. In some cases it was not consistent between the studies assessed, leading to discrepancies for the intercomparison. In the case of the MAES initiative this issue was avoided by the adoption of CICES as reference classification. Second, the level of process understanding and the ability to replicate in a data process model. Not all the processes within ecosystems are completely understood or quantified. Third, the aim (e.g. mapping supply, demand or stock) of the mapping exercise may influence the selection of the proxies for mapping ecosystem services and the parameterisation of the models. Fourth, the input data contains a degree of uncertainty that is increased in the mapping results when integrating different datasets in the method or model used for mapping. Finally, the method (model) used for mapping is a source of uncertainty as mentioned previously and described in Figure 5.2.

Finally, as summary we present three main blocks of best practices for ecosystem services mapping according to Willemen et al. (2015). They have suggested three properties necessary for mapping studies: robust, transparent and stakeholder-relevant. Robust ecosystem services mapping regards the technical aspects of implementation of the studies. It is related to data and method considerations and choices and the best way to communicate accuracy and uncertainty of the ecosystem services maps to decision makers and users of the maps. Willemen et al. (2015) indicate an urgent need for validation and accuracy assessment of ecosystem services maps. This piece of information is fundamental for robust mapping approaches regarding supply, demand or stock of ecosystem services in the spatio-temporal domain.

Transparent practices are oriented to contribute to clear information sharing and the creation of linkages with decision support processes. Mapping practices need to be explicit in describing model assumptions and approach, and underlying data and its limitations. The aim here is to reduce inadequate use or misinterpretation of the maps. Stakeholder-relevant ecosystem services mapping needs to meet the expectations and needs of map users and engage with stakeholders and decision makers at different stages of the mapping process in order to contribute to a better reciprocal understanding of the potentialities, limitations and options for using the maps, and moreover, to understand decision-makers' needs. The choices to be addressed in mapping exercises is an aspect requiring transparency, but also stakeholder involvement when the maps are to be used in territorial decision making.

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Abbreviations

BaU: Business as usual
CAI: Current annual increment
DTM: Digital terrain model
FISE: Forest Information System for Europe
GI: Green Infrastructure
GIS: Geographic Information System
GPP: Gross Primary Productivity
GSV: Growing stock volume
LUT: Look-up tables
MAES: Mapping and Assessment of Ecosystems and their Services
MTE: Model Tree Ensemble
NAI: Net annual increment
NDVI: Normalized difference vegetation index
NFI: National Forest Inventory
NPP: Net Primary Productivity
SAR: Synthetic aperture radar
TESV: Total Ecosystem Services Value
TNPV: Total Net Present Value
TSCC: Total Social Cost of Carbon

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ES Section	ES Group
Provisioning	Agricultural and aquacultural products
	Wild plants, animals and their outputs
	Surface and ground water for drinking
	Surface and ground water for non-drinking purposes
	Materials from plants, algae and animals and genetic materials from all biota
	Biomass-based energy sources
Regulation and maintenance	Mediation of waste and toxics
	Mediation of smell/noise/visual impacts
	Mass stabilisation and control of erosion rates, buffering and attenuation of mass flows
	Hydrological cycle and flood protection
	Mediation of air flows
	Pollination and seed dispersal
	Maintenance of nursery populations and habitats, gene pool protection
	Pest and disease control
	Soil formation and composition
	Maintenance of chemical condition of waters
	Global climate regulation
	Micro and regional climate regulation
Cultural	Recreational use of nature
	Nature as a site and subject matter for research and of education
	Aesthetics and cultural heritage
	Spiritual, sacred, symbolic or emblematic meanings of nature
	Existence and bequest values of nature

Table 7.1. Ecosystem service groups analysed in the regional assessment. The classification is adapted from the Common International Classification of Ecosystem Services, CICES v. 4.3 (Haines-Young and Potschin, 2013).

Data theme	Datasets	Source
1. Conservation areas	1.1 Natura 2000 areas	© SYKE
	1.2 Nature reserves on public and private land, founded based on Nature Conservation Act	© SYKE
	1.3 Nature conservation program areas	© SYKE
	1.4 Forest Service's property reserved for conservation purposes	© Metsähallitus
	1.5 Conservation areas of regional plans	© SYKE
2. Valuable landscapes	2.1 Nationally significant landscapes	© SYKE
	2.2 Regionally significant landscapes: national database on regional plans	© SYKE
3. Valuable cultural heritage environments	3.1 Cultural environments of Helsinki-Uusimaa	© Helsinki-Uusimaa Regional Council
	3.2 Nationally significant built heritage	© Finland's National Board of Antiquities
	3.3 Relics	© Finland's National Board of Antiquities
	3.4 Protected built heritage	© Finland's National Board of Antiquities
4. Traditional agricultural biotopes	4.1 Traditional agricultural biotopes	© SYKE
5. Important forest habitats	5.1 Habitats of special importance according to Forest Act	© Finnish Forest Centre
6. Undrained peatlands	6.1 Undrained peatlands	© SYKE
7. Important bird areas (IBA)	7.1 Important bird areas (IBA)	© SYKE
8. Valuable geological features	8.1 Nationally significant bedrock outcrops	© SYKE
	8.2 Nationally significant moraine landforms	© SYKE, Geological Survey of Finland GTK
	8.3 Nationally significant windblown and shore deposits	© SYKE, Geological Survey of Finland GTK
9. Groundwater areas	9.1 Groundwater areas	© SYKE, Centres for Economic Development, Transport and the Environment
10. High Nature Value farmlands	10.1 High Nature Value farmlands	© SYKE

(Continued)

11. Good and continuous agricultural areas	11.1 Good and continuous agricultural areas	© Helsinki-Uusimaa Regional Council
12. Surface waters of high or good ecological status	12.1 Surface water formations of the Water Framework Directive, second planning term	© SYKE, Centres for Economic Development, Transport and the Environment
13. Surface waters with low or very low level of human-induced alterations	13.1 Hydrologic-morphological status of surface waters	© SYKE, Centres for Economic Development, Transport and the Environment
14. Regional recreation areas	14.1) National database on regional plans	© SYKE
	14.2) Recreation areas managed by the Association of Uusimaa recreation areas	© Uudenmaan virkistysalueyhdistys
15. Groundwater areas at risk	15.1 Groundwater areas	© SYKE, Centres for Economic Development, Transport and the Environment
16. Sealed surfaces	16.1 Urban Layer	© SYKE
17. Land extraction sites	17.1 Finnish National CORINE Land Cover raster 25 m	© SYKE (partly ©METLA,MMM,MML,VRK)
18. Peat extraction sites	18.1 Draining status of peatlands	© SYKE
19. Surface waters of moderate, poor or bad ecological status	19.1 Surface water formations of the Water Framework Directive, second planning term	© SYKE, Centres for Economic Development, Transport and the Environment
20. Sites of frequent algae bloom observations	20.1 National algal bloom monitoring database	© SYKE
21. Surface waters with moderate or high level of human-induced alterations	21.1 Hydrologic-morphological status of surface waters	© SYKE, Centres for Economic Development, Transport and the Environment
22. Land cover	22.1 Finnish National CORINE Land Cover raster 25 m	© SYKE (partly ©METLA,MMM,MML,VRK)

Table 7.2. The data themes used in GreenFrame analyses on ecosystem services supply potential, scored by experts.

Ecosystem services	Organizational level at which biodiversity is involved	Main taxonomic groups involved
Provisioning		
Food	Genes, species populations, communities	Mainly vegetation (plant crops, wild fruits, etc.), fish, birds, mammals. In specific cases, fungi, invertebrates, and other vertebrates
Medicine	Genes, species populations	Microorganisms, fungi, vegetation, and animals
Regulating		
Micro-climate regulation	Communities, functional groups	Vegetation
Air purification	Species populations, functional groups	Microorganisms, vegetation
Water depuration	Communities, functional groups	Microorganisms, vegetation, and aquatic invertebrates
Hydrological regulation, erosion control and flood mitigation	Species populations, communities, functional groups	Vegetation
Soil fertility	Communities, functional groups	Soil microorganisms, nitrogen-fixing plants, soil invertebrates, and waste products of animals
Pollination	Species populations, functional groups	Insects, birds and mammals
Cultural		
Recreation activities and nature tourism	Species populations, communities.	Vegetation, Fish, Birds, Mammals.

Table 7.3. Links between ecosystem services delivery and biodiversity, considering both the organisational level of biodiversity and main taxonomic groups involved (modified from: Kremen, 2005; Cardinale et al., 2012; Martín-López and García-Llorente, 2013).

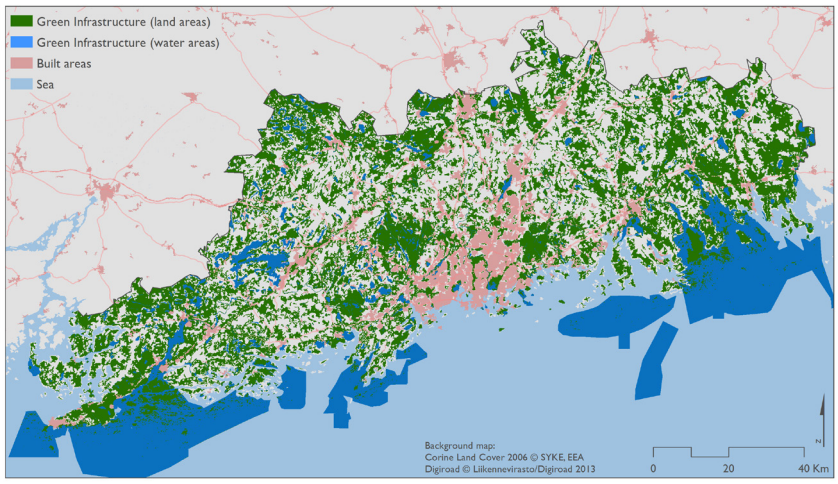

Figure 7.1. Key areas of the regional green infrastructure in Helsinki-Uusimaa Region.

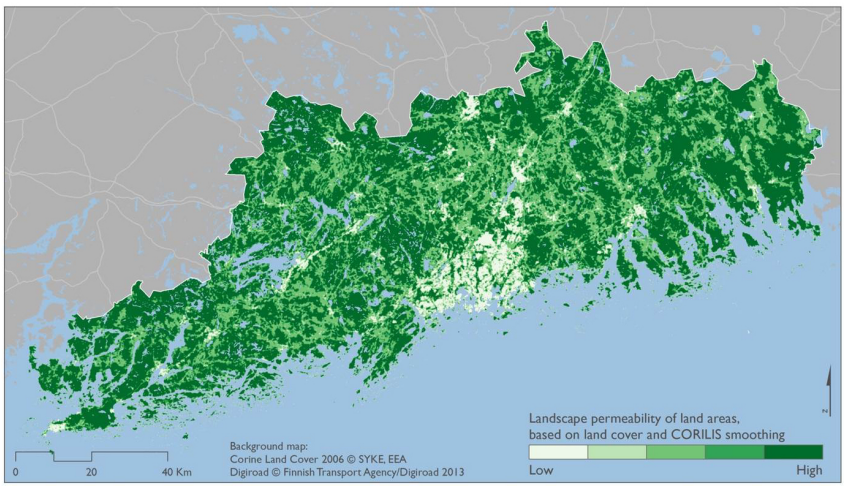

Figure 7.2. Landscape permeability of land areas in Helsinki-Uusimaa Region. The analysis is based on given impedance values for the land cover within a radius of 250 meters. Permeability of especially forest and field mosaic is depicted in this kind of a map.

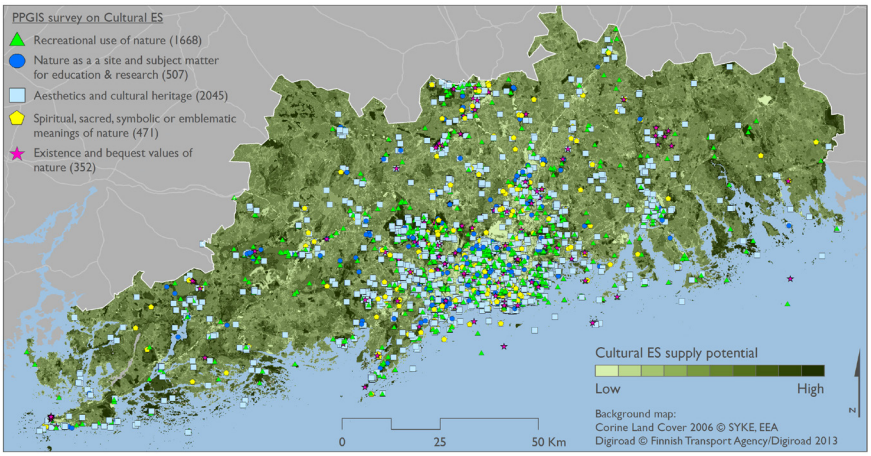

Figure 7.3. Places marked by the respondents of the PPGIS survey "The meanings of nature for the people of Helsinki-Uusimaa", displayed on top of GreenFrame analysis on cultural ES supply potential. 5,043 point markers were placed, covering all cultural ecosystem services. Most of them are placed in forests or in or close to water areas.

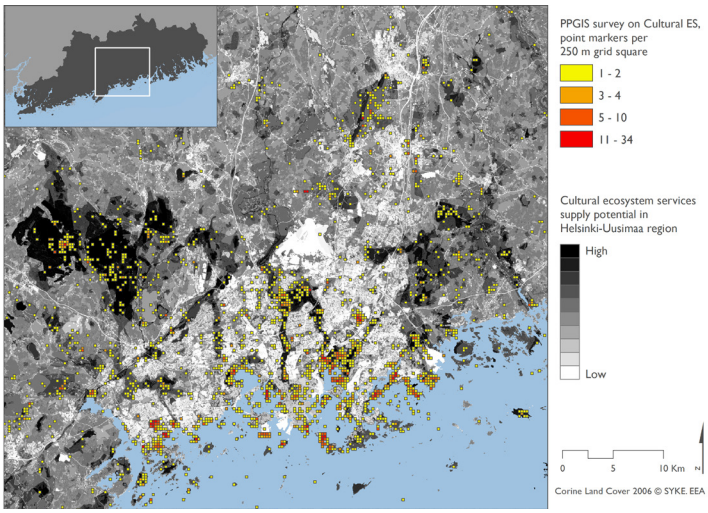

Figure 7.4. Point markers of the PPGIS survey aggregated in 250 m grid cells. Red cells indicate hot spots of cultural ES based on clusters of markers placed by the respondents. The variation of cultural ES supply potential is displayed in the background (Helsinki-Uusimaa region).

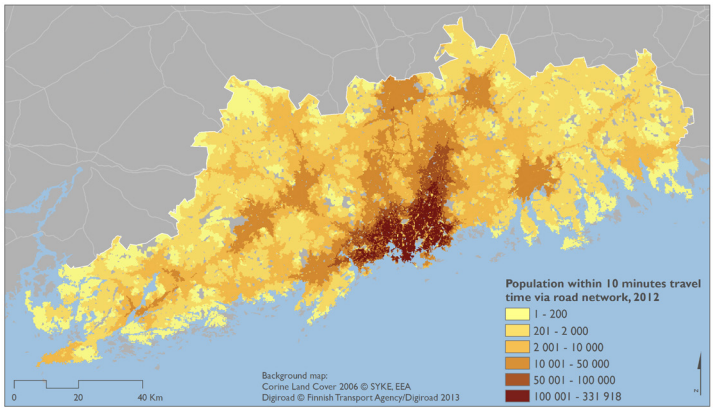

Figure 7.5. Population within 10 minutes' travel time via road network in Helsinki-Uusimaa region. The estimate is based on population data (SYKE/YKR) and road network data (STK 2013 / © ESRI Finland, Finnish Transport Agency / Digiroad 2013).

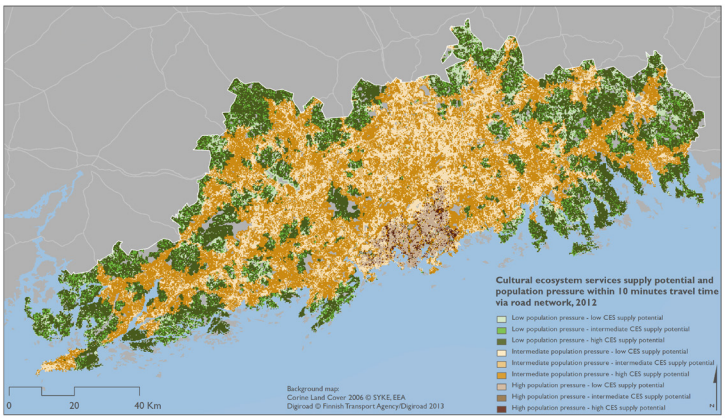

Figure 7.6. Cultural ES supply potential in relation to the potential demand for cultural ecosystem services in Helsinki-Uusimaa region.

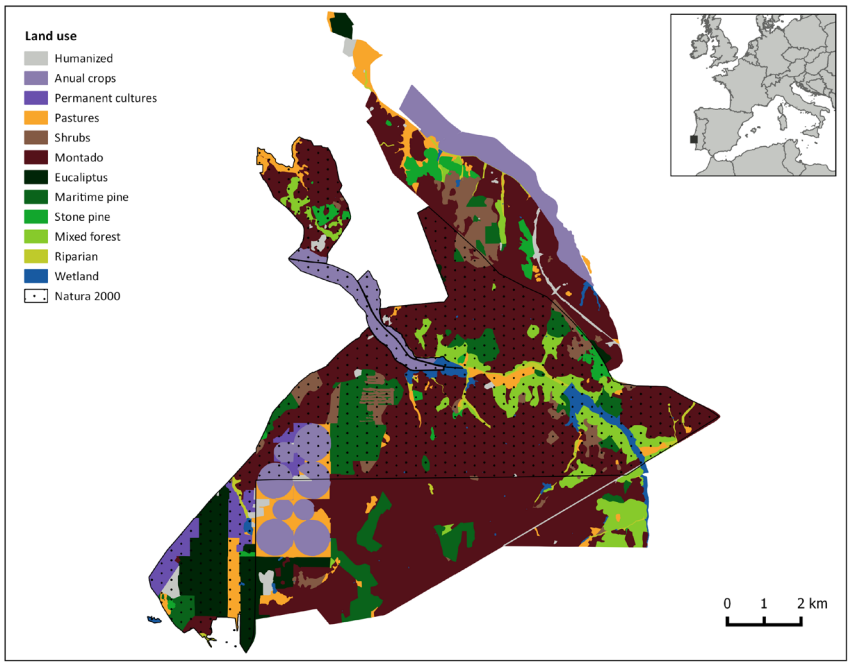

Figure 7.7. Land use at the study area (Companhia das Lezírias) and Natura 2000 network.

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