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Strategic Green Infrastructure and Ecosystem Restoration

Geospatial methods, data and tools

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ABSTRACT

Strategic Green Infrastructure and Ecosystem Restoration
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This report draws on a range of European-wide datasets, geospatial methods, and tools available for green infrastructure (GI) mapping. It shows how two complementary mapping approaches (physical and ecosystem based) and the three key GI principles of connectivity, multifunctionality and spatial planning are used in case studies selected in urban and rural landscapes; it provides guidance for the strategic design of a well-connected, multi-functional, and cross-border GI, and identifies knowledge gaps. GI mapping has been demonstrated to enhance nature protection and biodiversity beyond protected areas, to deliver ecosystem services such as climate change mitigation and recreation, to prioritise measures for defragmentation and restoration in the agri-environment and regional development context, and to find land allocation trade-offs and possible scenarios involving all sectors.

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Executive summary

This report provides methodological guidance to support strategic policy- and decision-making on Green Infrastructure (GI). It draws on a range of European-wide datasets, geospatial methods, and tools available for GI mapping. It shows how two complementary mapping approaches (physical and ecosystem based) and the three key GI principles of connectivity, multifunctionality and spatial planning are used in case studies selected in urban and rural landscapes. It focuses on: (1) the physical mapping of recommended GI landscape components; (2) the strengthening of the connectivity of ecosystems to enhance biodiversity and nature protection, and to prioritise measures for defragmentation and restoration; and (3) the multi-functionality of ecosystems for the long-term delivery of multiple ecosystem services such as climate change mitigation, air cleaning and recreation.

Policy context and green infrastructure definition

Green infrastructure (GI) is defined as a strategically planned network of natural and semi-natural areas with other environmental features that are designed or managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue ones in aquatic ecosystems) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings[1]. This report is intended to improve and strengthen information about GI, and contributes to "*reviewing the extent and quality of the technical and spatial data available for decision-makers in relation to GI deployment*" identified in the EU Strategy on Green Infrastructure. It also contributes to the EU Biodiversity Strategy to 2020, which calls for the strategic deployment of GI supported by a robust evidence base developed through the Mapping and Assessment of Ecosystems and their Services (MAES) process[2].

GI incorporates green and blue natural and semi-natural areas in urban and rural areas as well as terrestrial, freshwater, coastal and marine areas. However, not all green and blue areas qualify as GI. Only areas that are rich in biodiversity and lead to the delivery of ecosystem services or, for semi-natural components, those which directly enhance biodiversity and ecosystem services such as green bridges and ecoducts qualify as green and blue infrastructure. In contrast, intensive land uses such as monoculture are not considered as green infrastructure.

Data and tools: knowledge base and gaps

Europe-wide data, and some regional data for demonstration purposes, are listed (with a web link to facilitate downloading) and specify the GI element in question. GI includes ecosystem-based natural and semi-natural components, natural connectivity features, artificial connectivity features, protected areas, sustainable and multifunctional areas, and GI urban components.

Physical mapping is undertaken at large to medium scales (25 ha down to one hectare Minimum

[1] EU green infrastructure (GI) Strategy (COM(2013)249)

[2] For more information please see: https://biodiversity.europa.eu/maes

Mapping Unit) at the European level from land-cover and land-use maps such as Corine Land Cover, the more recent European Copernicus High Resolution Layers and the OpenStreetMap layers. The qualitative assessment in terms of the environmental condition of land cover classes is limited. The availability of fine-grained data on the environmental condition of all ‘green’ spaces varies depending on ecosystems, protected/unprotected spaces, and country- or region-based surveys. This gap in qualitative knowledge is expected to be filled in the near future through the MAES process. In addition, data on land-use intensity and management of agricultural and forest lands (e.g. to support the incorporation of grassland, some permanent crops, agro-forest holdings, and plantations into GI) are only partially available and accessible, mainly through High Nature Value Farmlands and High Value Forest European maps.

European spatial data available for mapping GI properties at large or medium scale include terrestrial ecosystems, areas to be restored or under restoration, connectivity level per geographical unit, connectivity pathways, ecosystem landscape fragmentation level, places for defragmentation, and landscape permeability. Some regional data is provided to show the current feasibility of obtaining products at high resolution. Available data and portals are also listed owing to their relevance in assessing threats to GI, such as natural hazards, invasive species and pests, soil sealing, and external input in agricultural lands such as fertilisers and pesticides.

The available tools (mainly open source software packages and a few commercial software packages) are listed with a web link so that they can be downloaded. They can be used to map and assess connectivity and ecosystem multi-functionality, identify places to prioritise actions, explore trade-offs and synergies of policy options or interventions by management, and assess the potential impact of land-use policy scenarios.

They enable assessment at multiple scales within reasonable timeframes (from a few seconds to a few weeks) as computing capacity grows. There is, however, no standalone user-friendly tool currently available that does not require a basic knowledge of geospatial analysis. Many practitioners have limited knowledge and experience in using standard geographic information system (GIS) including environmental system analysis tools, and have inadequate programming skills. This is a clear limitation for incorporating GI into the work of practitioners, and it underlines the need for specific additional resources, building capacity and expertise.

There is a need for more public open data and more interoperability of data and information systems to support the deployment of GI. Deploying and assessing the performance of GI implies setting a comprehensive and integrative indicator-based framework across all types of GI and ecosystem services, and understanding the level of contribution and degree of importance of each indicator within the GI context and set targets. The assessment is easier to implement when tools are customised and integrated, as bespoke integrated models developed at the Joint Research Centre and the European Environment Agency have demonstrated in this report. Integrated information systems would allow stakeholders to interact, interconnect and work together, thus rendering participatory approaches more efficient and effective in the future.

Demonstration case studies: knowledge base and lessons learnt

The data and tools are illustrated by concrete examples of mapping and assessing GI components and ecosystem services at both rural and urban levels. The knowledge base on mapping a well-connected and multi-functional GI has been reported by providing methodological guidance through best-practice cases at European, national, regional, and local levels.

Case studies illustrate how datasets and tools are used covering areas such as:

- **Mapping GI** to support and enhance nature protection beyond protected areas and across country borders, and looking at how well connected protected areas are, and whether connectivity enhances biodiversity (cf. action 6 of the Biodiversity Strategy) and the delivery of ecosystem services. Spatially explicit mapping methods can help identify key corridors between protected areas, and can help determine the best conservation strategies between designing new protected areas, enhancing conservation corridors or implementing restoration measures (and improving landscape permeability) in the unprotected land.
- **Planning GI** as a cross-border but also as a dynamic and resilient network to mitigate climate change. The network of protected areas, acting as the backbone for GI, can be assessed and designed to respond to the species range shifts in the context of climate change. GI mapping is usually addressed as a static map, but there is a need for a dynamic approach.
- **Deploying** well-connected, multi-functional **GI in the rural landscape**, prioritising actions for conservation and restoration, enhancing landscape permeability, and prioritising defragmentation measures to mitigate the impacts of agricultural intensification and road infrastructure on species movement. Datasets and methods are now available and of interest for application in different European countries and regions as well as in a EU-wide assessment.
- **Deploying GI in large urban areas** and regions, planning green and multi-functional urban spaces as well as human development infrastructure in an urbanised context. Tools for urban mapping include connectivity measures and can assess the territorial and ecological coherence between urban and peri-urban areas.
- **Exploring GI for enhanced biodiversity and ecosystem service delivery** by spatial modelling land-use scenarios of ongoing demographic, economic, and agricultural developments in the next few decades in Europe, finding trade-offs and resolving conflicts in land allocation in decision-making involving all sectors.
- **Monetary cost assessment** of prioritisation measures and GI benefits for society so that GI projects could be encouraged as cost-efficient alternative solutions to grey infrastructure or as cost-benefit solutions for prioritising natural/semi-natural land reallocations in the agri-environment and forestry context (greening measures).
- **Multi-scale integration** of GI maps. Maps can be made available at multiple scales to show fragmentation patterns and the connectivity of recommended GI landscape components. They can be jointly assessed with the provision of ecosystem services. Local and regional scales of assessment represent the scale of action and implementation of measures; they require fine-grained, accurate and detailed data. The large-scale (and less detailed) mapping of GI is

appropriate over large regions on matters of national or transborder relevance like defragmentation measures, the planning of highways, territorial cross-border coherence for the connectivity of protected areas or targeted ecosystems (woodlands, riparian vegetation along rivers, etc...).

This knowledge base can benefit Member States and other stakeholders by facilitating the use of spatial information and tools to support the strategic deployment of GI. It contributes to more consistent data collection, data use, and the coordination of decision-making across regions and countries, and the prioritisation of conservation and restoration efforts.

Gaps in knowledge and challenges in assessment and methodologies were identified, such as:

- Places qualifying for restoration opportunities can be identified but more knowledge is needed on the conditions of degraded ecosystems in order to better define restoration measures.
- Assessing the connectivity of green urban spaces to enhance biodiversity is challenging and knowledge is still lacking on species response to city disturbances such as noise.
- Ecosystem service mapping could be improved by a more systematic development of cross-case comparisons and methods. Ecosystem models outputs are highly variable due to the differences in indicator definition, level of process understanding, mapping aim, data sources, spatial resolution, and methodology. Regulating services on climate regulation and provisioning services related to food, water and timber are most frequently mapped. Local and regional expert knowledge are very valuable in informing cultural ecosystem services.
- Most results in the report focused on the terrestrial environment. There is a significant gap in knowledge regarding the deployment of GI in the marine environment and regarding the nexus between blue-green infrastructure. The provision of a conceptual framework, data and tools for the mapping and assessment of marine ecosystems and their services (a marine MAES) would certainly help deploy a marine GI, particularly at the sea-land interface.
- The lack of coordinated management between sectorial departments is one obstacle to the deployment of GI. Clear methodological guidelines, training and participatory approaches may help solve this problem in the future. The EU GI strategy aims to ensure that the creation and enhancement of GI become an integral part of spatial planning and territorial development.

Conclusions and way forward

By sharing available knowledge, data, and tools, and addressing the linkages between regional, national, and EU scales, this report helps build a common understanding of the usability and interoperability of existing tools; it promotes consistent and reproducible approaches across scales and regions and also demonstrates the benefit of integrated information systems to support the deployment of GI. As such, these tools can be used to support the integration of ecosystems and their services in wider policy and planning decisions, beyond ecosystem restoration and GI, e.g. in order to identify, prevent, or mitigate damage to ecosystems and their services. Furthermore, by demonstrating case studies selected in the urban and rural landscapes, this report provides guidance for the strategic design of a well-connected, multi-functional, and cross-border GI, and identifies knowledge gaps.

A large new body of evidence on GI is expected from a group of European research projects that are listed in the report. These projects promote a participatory approach by involving stakeholders, will contribute to the currently scattered evidence on costs and benefits of GI, and foster a European territorial dimension in development and cooperation. They should be closely monitored to improve knowledge and stimulate innovation at EU level, that can feed into relevant EU and national policy processes in a timely matter. They support deploying an EU level GI that responds to the three key GI principles of connectivity, multifunctionality, and spatial planning and management, as addressed in this report.

1 AIM AND STRUCTURE OF THIS REPORT

Improving data availability and knowledge sharing on ecosystem connectivity, ecological coherence and ecosystem services are a priority for research and monitoring to support Green Infrastructure (GI) deployment and implementation.

The purpose of this report is to respond to these priorities (as reflected in the EU GI strategy), by presenting tools developed by the European Union as examples that can support strategic policy and decision-making on GI and ecosystem restoration; in particular in the context of the implementation of the EU Action Plan for nature, people and the economy (EC, 2017). The tools can potentially be applicable throughout Europe at multiple scales, and can be improved by using data locally available, or to address specific needs.

The use of selected data and tools is demonstrated through examples of mapping and assessing GI components and ecosystems services, particularly with respect to their physical mapping and ecosystem based mapping components to support the implementation of action 1 (ecosystem services) and action 12 (EU-level green and blue infrastructure projects) in the EU Action Plan for nature, people and the economy (European Commission, 2017). By sharing available knowledge, data and tools, and addressing the linkages between regional, national and EU scales, this report contributes towards building a common understanding of the usability of existing tools, and promote harmonized and reproducible approaches across scales and regions.

Tools developed and applied in EU Member States are based on the availability of national collected data and tailored to their planning systems. National, regional and local stakeholders could usefully run their data with the tools presented in this report to address cross-border issues for example. Research and developments of tools taking place at European level would also benefit from applying national and local data in order to obtain a more consistent spatial representation of GI across scales.

The application of the tools demonstrated in the selected case studies do not intend to address the financial benefits and costs of nature-based solutions and their comparison to grey solutions.

This report may inform and contribute to several policy processes. It is developed and organised around interconnected key dimensions:

- *Chapter 2* describes the EU policy context for GI and restoration and how these can contribute to the implementation of several EU policies and sectors.
- *Chapter 3* provides an overview of the conceptual framework of GI and the knowledge base for measuring ecosystem services from GI.
- *Chapter 4* provides a presentation of the data and tools available within the demonstration case studies related to mapping of GI components and ecosystems services for GI. It presents the classification and description of the various approaches that are available to measure GI and restoration viewed from a physical mapping and ecosystem service based mapping dimension.

- *Chapter 5* focuses on the application of approaches through case studies. These are split up into two streams of methods: a) physical mapping of GI and b) ecosystem service-based mapping applied in both rural and urban landscapes.
- *Chapter 6* discusses gaps in knowledge, data and tools, and the feedback needed for improvement from stakeholders and practitioners including an outlook for future requirements.
- *Chapter 7* presents the conclusions.

2 POLICY CONTEXT

2.1 THE EU BIODIVERSITY STRATEGY TO 2020

The EU Biodiversity Strategy to 2020 aims through Target 2 to "*maintain and enhance ecosystems and their services by establishing green infrastructure and restoring at least 15% of degraded ecosystems*".

The achievement of Target 2 is underpinned by important actions:

i) the EU initiative on Mapping and Assessment of Ecosystems and their Services (MAES) implemented by Member States with the assistance of the EU, which aims to reinforce the knowledge base - including the assessment and valuation of the benefits that nature provides to human society - and to set a baseline against which progress related to GI and restoration can be measured; and

ii) the set-up of Restoration Prioritization Frameworks (RPF), which should support strategic restoration activities.

In 2013, the EU adopted a *Green Infrastructure (GI) Strategy* (COM(2013)249), which seeks to set up a physical and functional, ecosystem service-based transboundary network of natural and semi-natural areas that is able to ensure the long-term delivery of ecosystem services throughout Europe (see Box 2.1). This includes "regulation services" like the removal of air pollutants, water provision, pollination, flood protection and water regulation, which benefit people but can be compromised, with potentially significant unforeseen costs to society and our economy.

The GI Strategy calls for assessing the opportunities of developing EU-level GI projects, which could act as an important catalyst for further promoting GI at European, national, regional and local levels and boosting the integration of GI in policy.

The GI Strategy also calls for a review of the *"extent and quality of spatial and technical data available for decision-makers in relation to GI deployment*". Comprehensive, usable and high quality spatial data as well as tools are required to support the objectives of restoring 15% of degraded ecosystems and of strategic deployment of GI at regional, national and European levels.

The Action Plan for nature, people and economy (European Commission, 2017), adopted as follow-up of the fitness check of nature legislation, reinforces the need for actions both within and outside the Natura 2000 network of protected sites and includes dedicated actions related to GI. It calls, in particular for the development of guidance for further supporting the deployment of EU-level GI projects that contribute to the goals of the Nature Directives, including through improving connectivity of Natura 2000 sites (see Box 2.2) in unprotected landscapes and cross border contexts, so as to enhance the delivery of essential ecosystem services throughout the EU territory (Action 12). Equally important is the development of guidance to support the integration of ecosystems and their services into decision-making (Action1), which should help prioritising for GI and restoration actions.

Box 2.1 What is GI?

Source: European Commission, 2013. Building a Green Infrastructure for Europe

GI is defined as "*a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings.*"

Source: EU Strategy on Green Infrastructure, 2013.

Box 2.2 Natura 2000 network and GI

The Natura 2000 network is a central part of the European GI as it harbours many of Europe's remaining healthy natural and semi-natural ecosystems and biodiversity, and provides a legal and organisational framework, which can contribute to long-term efficiency and cost-effectiveness of investments in GI. GI can support achieving the objectives of the Birds and Habitats Directives, by contributing to the ecological coherence both within and outside of the Natura 2000 network and by improving the status of species and habitats covered by the Directives.

GI-related projects have until recently been carried out on ad hoc basis, responding to independent initiatives, which now need to be up scaled to deliver their full potential to restore natural capital and help accommodate future infrastructure demands in a more cost-effective way. It is increasingly recognised that biodiversity and well-functioning natural or semi-natural ecosystems play an important role in supporting the delivery of multiple ecosystem services, (e.g. open storm water drainage, greening of cities, semi-natural habitat restoration, etc.) with environmental, social and economic benefits, which can be cost-effective alternative to conventional grey infrastructure solutions (e.g. manufactured dikes, sewage systems, etc.).

Green and blue infrastructure and nature-based solutions can be considered as alternatives to conventional solutions, and useful tools for planners and managers to use when comparing different potential solutions to a specific problem. GI solutions are in many cases less expensive than grey alternatives and provide a wide array of co-benefits for local economies, the social fabric and the environment at large (EEA, 2015). However, GI takes time to reach its ultimate objectives – in the realm of 10-15 years – and since it is a relatively new concept, there are limited thorough long-term evaluations as yet (Naumann et al 2011 and Naumann et al. 2011a).

2.2 GREEN INFRASTRUCTURE AND RESTORATION IN THE CONTEXT OF EU POLICIES

GI offers a frame to integrate and strengthen the coherence between policy objectives of different sectors. GI is associated with a variety of environmental, economic and social benefits, many of which go hand-in-hand, and thus addressing the three crucial aspects of sustainable development.

Investment in GI usually promotes the sustainable protection of natural capital, which in turn ensures healthy and well-functioning ecosystems which can provide long-term services that benefit the development of the society. For example, connectivity and GI are gaining a prominent role also when implementing the Habitats and Bird Directives (European Commission, 1992 and 2009). Legal tools are adopted, which mainly focus on the adequate management and enhancement of the physical continuity and ecosystem services of linear landscape elements that may act as connectors i.e. livestock trails, rivers, riparian forest, hedgerows, and as support to an improved delivery of ecosystem services i.e. habitat provision, pollination, natural pest control (see section 3.1 for details on GI concept).

By maintaining healthy ecosystems, contributing to improve the conservation status of habitats, reconnecting fragmented natural areas and restoring damaged habitats, GI networks can offer a socio-economically viable and sustainable infrastructure that provides multiple goods and services to human populations. Indeed, the underlying principle of GI is its ability to offer many environmental, social, cultural and economic benefits in the same area, provided ecosystems are in a healthy condition (please refer to section 3.1 for more details on GI and ecosystem services).

Mapping and assessment of ecosystems and their services[3] is an essential pre-requisite to understand ecosystems' condition, coherence and connectivity, as well as to support policies that have an impact on natural resources and human wellbeing. This is particularly relevant for policies that impact natural resources, such as agriculture, forestry, fisheries and regional developments (business activities, livelihood and recreation).

For instance, the current EU Common Agricultural Policy (CAP) includes options for GI enhancement:

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

(i) The Greening package under Pillar 1 of the CAP, besides payments for crop diversification, includes payments aiming at maintaining grasslands and at reaching the minimum target of 5% of arable and permanent crop be Ecological Focus Areas (although in the selection of elements for these areas, non-permanent crops such as nitrogen-fixing crops are accounted for and are beneficial to climate change mitigation rather than to biodiversity and connectivity). The package also includes preventing land abandonment and fragmentation through direct support for farmers;

(ii) under CAP pillar 2, priorities include 'restoring, preserving and enhancing ecosystems related to agriculture and forestry' and appropriate measures are defined under the rural development programmes. They include non-productive investments, agro-environmental measures (e.g. farmed landscape conservation measures, maintaining and enhancing biodiversity and connectivity through hedgerows, buffer strips, terraces, dry walls, silvo-pastoral measures etc.), payments fostering the coherence of Natura 2000, cooperation on maintaining valuable field boundaries, and conserving and restoring rural heritage features. Rural development plans may thus include measures for farmland and forests supporting Green infrastructure.

2.3 PARTICIPATION OF STAKEHOLDERS AT APPROPRIATE SCALES

GI being multi-functional by definition, it spans many policy sectors. These sectors may have different priorities, opposing views and conflicts of interest, which affect how to plan, implement and evaluate GI. This makes the involvement of stakeholders from different sectors (e.g. forestry, agriculture, industry, etc.) at the appropriate scale (e.g. local, regional, national and European) very important, for measures to optimised (see example if Box 2.3). The EU level is well suited to encourage consistency and promote synergies across countries and among policies. Still, stakeholders involved in GI projects have often emphasized the importance of key local individuals, multi-disciplinary and multi-scale knowledge as drivers for successful GI projects. It has been highlighted as well that knowledge in the GI field has been too compartmentalised so far.

An important challenge is that the deployment of innovative nature-based solutions in response to critical problems requires more integrated approaches between policy departments, expertise and national legislation. There is a need to unlock the barriers that have often weakened connections between different communities of practice.

Sharing trans-national expertise through GI projects is expected to facilitate the simplification, integration and mutual supportiveness of policies. The integration of national datasets and implementation of already available technical solutions should be promoted to facilitate the creation of the necessary impetus for investment in GI and nature-based solutions that preserve and generate ecosystem services across borders. A value added of EU level GI is to enable and promote networking with implementers of GI projects within and across countries.

Box 2.3 Stakeholder engagement - example within the forestry sector

The deployment of GI is a key policy response to encourage and help stakeholders, planners and managers from different sectors to prioritize actions to maintain, protect and restore ecosystems. For example, within the forestry sector, the successful integration of GI depends strongly on the understanding and motivation of forest holders. Knowledge transfer and implementation of sustainable forest management (SFM) principles is easier for large publicly owned forests where forest management plans are used and when the management scale ensures the economic sustainability of forest management.

In addition, private forest owners with small holdings (less than 10 ha and rarely exceeding 100 ha), which represent more than 60% of Europe's forests (EEA, 2016), are key players in enhancing GI at the local scale. Currently, they is no compensation of forest holders in monetary terms for measures such as small-scale forest planting for climate regulation, repository of biodiversity, habitat protection and/or natural pest control. The application of landscape perspectives and ecological connectivity concepts faces some difficulties, namely:

(i) coordinating multiple sectors and public bodies with diverse management competences (agriculture, urban, transport);

(ii) different planning instruments, taking decisions over multiple scales (e.g. local, regional and national) that usually comprise multiple ownerships, municipalities or even provinces or regions; and

(iii) the lack of tools and methodological guidance (Saura et al., 2015).

In the last decade, new practices like payments for ecosystem services (PES)(for example, Matzdorf et al, 2014) are being advocated to motivate small-scale forest farming[4] and GI, from the European Agricultural Fund for Rural Development (Council Regulation 1698/2005, particularly under axis 2 for agri-environmental payments, for Natura 2000 payments), the Life+ programme, the European Regional Development Fund (ERDF) and Cohesion Fund (CF).

Yet, most of expenditure still goes to 'first afforestation' measures, with a focus on exotic species. There is an under-spending and thus an under-implementation of forestry measures like fostering sustainable forest management, tree planting at the edge of agricultural fields or agroforestry. The development of tools and methodological guidance providing direction to where the most cost-effective places are to allocate resources and where to prioritize small-scale ecosystem management improvement actions may help to promote and optimize the use of measures among decision makers, forest holders and practitioners.

The establishment and development of stakeholder platforms to facilitate trans-national cooperation on different topics, as well as the exchange of experience and application of lessons learnt across stakeholders in the countries involved are important tools to support GI projects. There are already inspiring examples such as the supra-national corridor in the Alpine and Carpathian mountain ranges, the creation of a GI continuum along the Danube river basin and the urban greening policy in urban and peri-urban areas.

Such projects include the promotion of best practices among practitioners in both governmental and non-governmental institutions in various countries and help raising awareness and gaining support for developing additional GI projects.

One of the biggest threats to biodiversity is the fragmentation of habitats, both within and outside protected areas. To support sustainable land use planning, critical areas for defragmentation can be

[4] Forest farming is the cultivation of high-value specialty crops under a forest canopy that is intentionally modified or maintained to provide shade levels and habitat that favour growth and enhance production levels. Forest farming encompasses a range of cultivated systems from introducing plants into the understory of a timber stand to modifying forest stands to enhance the marketability and sustainable production of existing plants (Chamberlain et. al., 2009).

identified on the basis of connectivity analysis and can contribute to the mapping of GI. Therefore, it is important to ensure participation and involvement of stakeholders from all sectors, to understand and acknowledge the values and logic behind different points of view in successful planning, implementation and evaluation of GI.

The spatial representations of GI should aim to enable stakeholders to visualise the biodiversity, ecosystem and human pressure elements involved, and how to prioritise actions. Involving stakeholders in planning, implementation and evaluation can be instrumental in successful participatory approaches by collecting the views of those involved and constantly feeding them into the development of GI (cf. EnRoute project on urban GI and urban ecosystems[5]). Participation from stakeholders to assess whether GI is performing its functions, e.g. providing cost-effective solutions, multiple ecosystem services, co-benefits for local economies, contributing to community cohesion and social inclusion, is very important (EU, 2012).

A multi-stakeholder approach can help find the right balance between different land-based policy objectives by rendering them spatially explicit. There is a need to develop and apply an analytical framework for spatial prioritisation, which might include the following elements:

(i) restoration, maintenance or enhancement of biodiversity (priorities for conserving species/genetic diversity/habitats/ecosystems);

(ii) spatially explicit information on pressures, and on ecosystem services (or the underlying natural capital from which they are derived); and

(iii) system properties (e.g. through measures of connectivity, naturalness, and vulnerability).

The availability of technical and spatial data for the analysis of the impacts of GI on ecosystems and their services would allow determining, for example, the impact of increasing natural or semi-natural forest area on carbon storage and water regulation and how an increase in wetland area would improve flood protection. This would allow to correlate the mapping of the quality of GI to the functions that it performs insofar knowledge becomes available of the ecosystem service-based relationship between ecosystem properties, such as habitat area and quality, and ecosystem functions and services.

With more stakeholder consultation, future research could involve a strong component of citizen science, which would serve the dual goals of stakeholder participation whilst conducting localised research cost-effectively. Involvement on a voluntary basis is expected to raise awareness and acceptance of GI solutions.

2.4 THE VALUE ADDED OF AN EU LEVEL PLANNING FOR GI AND RESTORATION

A coherent EU-level approach would have many advantages. It could scale up biodiversity enhancement and ecosystem restoration, enhance the delivery of ecosystems services, contribute to the goals of the nature legislation by ensuring that Natura 2000 network, habitats and species of Community interest

[5] For more information see: https://oppla.eu/enroute.

both within and outside the network and cross-border ecosystems such as major river basins, mountain chains and forests are managed in a way which takes into account physical and ecosystem service based approaches (including connectivity, and transboundary processes) in order to deliver an optimum level of ecosystem services to citizens. It would also contribute to other policy goals in areas such as climate change, sustainable development, sustainable agriculture, and disaster risk reduction.

Developing a coherent and coordinated approach across different spatial scales (local, regional, national, and European) to map and assess ecosystems and their services, including the development of natural capital accounts (cf. action 5 of the EU Biodiversity Strategy to 2020), would help the creation of an EU-level strategically planned network. A better understanding of the links between biodiversity, ecosystems, their condition and functioning, and the delivery of ecosystem services, potentially complemented by the value of the ecosystem services and ecosystem accounts, would also better inform the prioritisation of ecosystem enhancement and restoration and GI intervention/investments and enhance its effectiveness by accounting for their trans-border dimension.

The promotion of EU GI could include the improvement of the connectivity of Natura 2000 sites within and across national borders, linking up through biodiversity-rich areas where investments for ecosystem protection and restoration are prioritized, so as to enhance the delivery of essential ecosystem services throughout the EU territory. Doing so could stimulate innovation through encouraging complementary or alternative cost-efficient solutions to grey infrastructure, and providing nature-based solutions such as restoring natural or semi-natural forests and enhancing forest management for flood control and water purification, restoring wetlands, enhancing green spaces in cities to reduce the impact of heat waves, and increasing recreation opportunities.

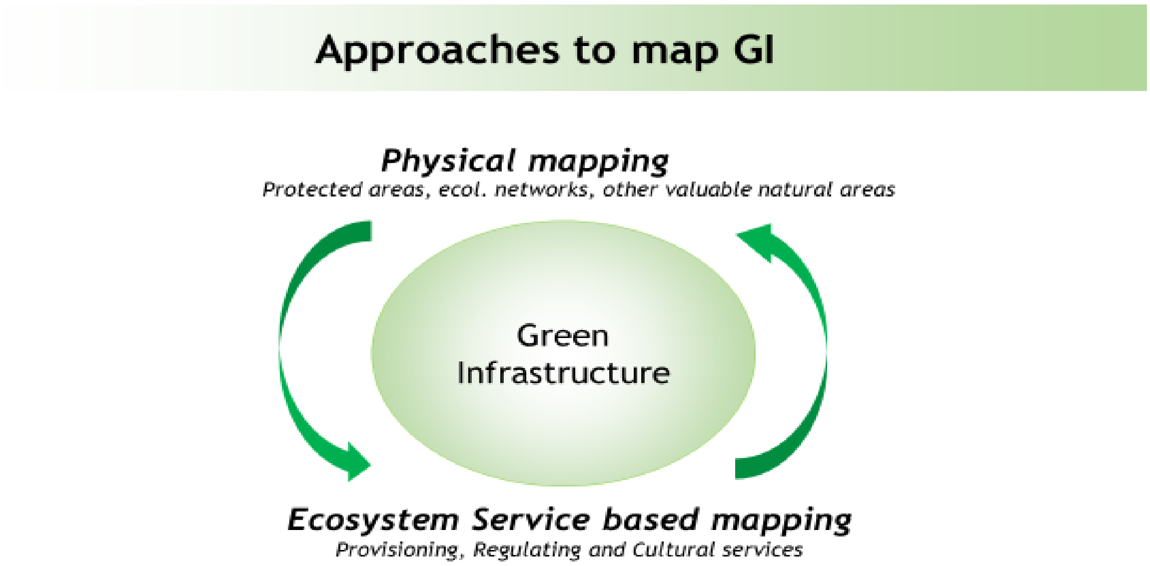
3 CONCEPTUAL FRAMEWORK

3.1 CONCEPTS OF GREEN INFRASTRUCTURE

This report highlights two complementary planning approaches. One starting from a *physical mapping* of existing GI components identifying and delineating landscape elements such as protected areas, ecological networks, other protected areas, etc. To ensure that those elements lead to the delivery of multiple ecosystem services, the second functional approach also takes into consideration *ecosystem service-based mapping* targeting connectivity and delivery of multiple ecosystem services such as provisioning, regulating and cultural services.

Figure 3.1 illustrates the two approaches, indicating that they are interconnected and should be considered as two complementary perspectives since GI is made of biodiversity-rich habitats, which also provide multiple ecosystem services.

Figure 3.1: Approaches to map GI: Physical mapping and ecosystem service based mapping.



Source: Own development, 2018.

The combination of the two approaches embraces two underlying key principles of the GI concept, i.e. *connectivity* and *multi-functionality* (Mell, 2017).

Connectivity directly relates to the enhancement of biodiversity and the ecosystem service of habitat provision. Connectivity refers to the enhancement of species' ability to move between areas and can be of a structural nature (i.e. habitat continuity) or functional nature (i.e. how landscapes allow various species to move and expand to new areas without necessarily being physically connected) (Baro et al. 2015). The lack or loss of connectivity reduces the capability of organisms to move and interfere with pollination, seed dispersal, wildlife migration and breeding, thus also impacts ecosystem services.

Multi-functionality represents the ability of GI to provide not only habitat (ecological) services but many other ecosystem services (e.g. ecological/regulating, social/cultural, and/or economic/provisioning) simultaneously on the same spatial area (Mell, 2017). Ensuring healthy ecosystems and maintaining long-term delivery of multiple ecosystem services within a well-connected GI network is supporting the objectives of numerous EU policy sectors, such as cohesion, water, energy, transport, agriculture, climate and biodiversity. This is part of a real "resilience strategy" able to cope with potentially changing conditions to human populations in the future, and thereby contributing to the European Union's 2050 vision[6] of living well within the limits of the planet (European Commission, 2013).

The *physical mapping approach* (Figure 3.1) focuses on the identification and physical delineation of landscape features (GI network) consisting of green and blue elements (e.g. *Trame verte et bleue* in France) in order to support and enhance nature, natural processes and natural capital within a region. This approach has a physical and mapping connotation of landscape elements that qualify for the GI network regardless of their functions.

The concept is scale-dependent and extensively employed in urban and rural areas, for example when looking into the share and connectivity of green urban areas in a city, or when using pre-existing landscape elements like protected sites or small woody features in rural areas to define the core elements of the GI network.

The *ecosystem service-based mapping approach* (Figure 3.1.) of GI is to be understood as assessing the capacity of the land to provide ecosystem services. In contrast to the physical mapping approach, which refers to the delineation of physical landscape elements, the ecosystem service-based mapping approach further adds a function to the physical element. Benefits of well-functioning GI elements are expressed in terms of ecosystem services they deliver.

Biodiversity-related services, and their values (ecologic, social and economic) are accounted for and approaches serve to strengthen the recognition of the human dependency on nature (Benedict and McMahon, 2006; Mell, 2008). The ecosystem services concept can thus offer a valuable approach for linking human and nature, i.e. the human-well-being and the current and potential environmental conditions (European Commission, 2018) as well as arguments for the conservation and restoration of natural ecosystems (Benedict and McMahon, 2002).

It is important to recognise that ecosystems provide services that may contribute to other, possibly conflicting policy requirements. In these cases, the ecosystem service based mapping dimension of a GI network may be complex, imprecise or biased due to the generalisation of data or missing data that are essential to depict the bundle of sometimes hidden but important services for different policy sectors and objectives. To overcome these difficulties, measuring approaches and mapping systems should be versatile enough to accommodate the requirements of different policy sectors and maximize the number of ecosystem services that can be assembled together within the same GI.

[6] For more information see: https://ec.europa.eu/research/social-sciences/pdf/policy_reviews/global-europe-2050-report_en.pdf.

3.2 THE KNOWLEDGE BASE FOR MEASURING ECOSYSTEM SERVICES FROM GREEN INFRASTRUCTURE

Several approaches and tools are available to map, model and assess service capacity and demand for ecosystem services (for a recent overview see Burkhard and Maes, 2017). The selection of an appropriate tool depends on the questions to be addressed by GI, the spatial scale of its application, data availability and so on. If primary data[7] are available, ecosystem services can be measured directly. Typically, these data are only relevant for studies at the local scale. In most cases, approaches to measure ecosystem services are based on indirect observations or models (see European Commission, 2014).

Earth Observation (EO) data can be used as input to map ecosystem services, and are examples of indirect data for assessing their spatial distribution. For example, land surface temperature, NDVI (Normalised Difference Vegetation Index), land cover, maps of surface water distribution, leaf area index (LAI) and primary production are EO products which can be used for mapping ecosystem services (see section 4.1).

The standard method to map and assess ecosystem services is the use of modelling tools (see section 4.2 and 4.3). Ecosystem services modelling, is understood as the simulation of supply, use and demand based on ecological and socio-economic input data and knowledge. Models can vary from simple expert-based scoring systems to complex ecological models, which simulate the planetary cycles of carbon, nitrogen and water. The following steps are foreseen in a GI ecosystem services assessment:

1. Ecosystem service-based mapping in terms of current or potential supply of ecosystem services.
2. Ecosystem service-based mapping in terms of current or potential demand of ecosystem services.
3. Ecosystem service-based mapping in terms of prioritisation among ecosystem services.

In 2013 the working group on Mapping and Assessment on Ecosystems and their Services (MAES) proposed a coherent analytical framework (European Commission, 2013 - 1st MAES Report) and promoted a first set of consistent biophysical indicators that can be used at European and Member State level to map and assess ecosystems, their condition and the services they provide (EC, 2014 - 2nd MAES Report) for the ecosystems (agro-ecosystems, forest, freshwater and marine).

An analytical framework for mapping and assessing the condition of ecosystems in relation to the services these ecosystems provide has been developed by DG Environment based on key indicators with the feedback of some Member States. The major results published in the 5th MAES Report of 2018 also include nature, urban and soils. The 4th MAES report focuses specifically on urban ecosystems and includes case studies on mapping ecosystems and GI.

The MAES framework will be used for measuring progress in reaching the EU biodiversity targets and for analysing the effectiveness, efficiency, relevance and coherence of the actions under the EU Biodiversity Strategy 2011-2020 in accordance with the Better Regulation Guidelines[8].

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[7] Examples of primary data are the number of visitors entering a national park (nature based recreation), the total volume of timber in a forest stand (timber production) or records of the crop yield of a farm (crops).

[8] For more information please refer to: http://ec.europa.eu/smart-regulation/guidelines/toc_guide_en.htm.

4 EXPLORING DATA AND TOOLS FOR MAPPING AND MEASURING GREEN INFRASTRUCTURE

This chapter provides an overview of the range of datasets and methods that are applied within the case studies presented in chapter 5 from the local to pan-European scales. Spatially explicit datasets and methods are available to support the assessment and mapping of GI and its components as a "*strategically planned network of natural and semi-natural areas*" (European Commission, 2013).

Datasets and methods are used to identify key GI components, assessing their physical delineation, connectivity and provision of ecosystem services. To further develop and improve GI, datasets and methods are also available to identify priority areas for conservation and restoration efforts. In certain cases, and depending on the availability of monetary data, methods exist to assess the cost-effectiveness of actions like ecosystem restoration. Furthermore, decision support tools exist to develop scenarios using different land use policy drivers to test their impact on GI in the next decades, including assessing their synergies and conflicts for building a multi-purpose GI network "providing ecological, economic and social benefits" (European Commission, 2013).

Models for GI development and assessment require the input of spatial datasets at multiple scales, i.e. from the local to pan-European scale. Data are needed on species, habitats, land cover and land use, land ownership, monetary costs for GI implementation and enhancement, and ecosystem services. Such data are nowadays still only partially available and hamper the application of available tools, particularly over large regions (Zulian et al. 2014).

The consistency of data across regions is also of concern when used for comparison and to inform trans-boundary decisions. Data inputs and outcomes from models can be organized as: a) aggregated metrics and b) spatially explicit indicators (Maes et al. 2015). Aggregated metrics may be sufficient for a policy request like reporting, since they provide a single value indicator translating a GI related issue, and to support decision making for an entire region or country. Aggregated metrics are however not able to capture the spatial distribution of a process occurring at local scale or locate hotspots to prioritize actions for GI development to be implemented at more local scales. In this case, spatially and thematically detailed land use and land cover data form the base layers for prioritization and accounting for GI in landscape planning, conservation, and restoration policies.

4.1 DATASETS AVAILABLE FOR EUROPEAN GREEN INFRASTRUCTURE ASSESSMENT

To strategically support the planning and management process of GI at EU level, datasets on existing ecosystem services, core GI elements and the elements connecting them are indispensable. On the landscape level, the core elements of a European GI network, i.e. the "network nodes", are the Natura

2000 sites that are defined in the framework of the Birds (Directive 2009/147/EC)[9] and Habitat (Directive 92/43/EEC)[10] Directives. The Natura 2000 sites include core breeding and resting sites for rare and threatened bird species, as well as natural habitat types and species of Community interest. Human activities are not excluded from Natura 2000 sites, but the management of the sites focus on conservation objectives. Around 26 % of the total land surface of the EU is covered between European (Natura 2000 and Emerald networks) and nationally designated protected areas.

Part of the added value of GI is to build on the designated protected areas and complement the network with other key features in order to allow, for instance species to migrate across the wider countryside and urban environment. Connecting features can be part of the existing landscapes that need to be conserved or of landscapes, which are restored to a more natural state to close gaps in the network.

Those landscapes are composed of natural and semi-natural land cover or land use classes. The European CORINE Land Cover (CLC) data set is one of the only harmonised and regularly updated available information that can be used (see e.g. Larondelle and Haase, 2013) for mapping land use and land cover across the EU territory, covering the urban-rural interface. However, the spatial resolution, i.e. the Minimum Mapping Unit (MMU) of CLC (i.e. 25 ha) is too coarse for a reliable mapping and subsequent analysis of GI in cities, as all patches smaller than MMU (e.g. small parks or cemeteries) are merged with their surroundings and, by consequence, disappear from the map (see findings from the ESPON FOCI project[11]).

The more recent European Copernicus Programme provides new opportunities such as, amongst other data, the local component product Urban Atlas[12], which is a high-resolution land cover and land use map covering all European cities and functional urban[13] areas above 100.000 inhabitants (2006) and 50.000 inhabitants (2012), respectively. The Urban Atlas is produced with a MMU of 0.25 ha for the urban areas and 1 ha for the non-urban classes. It is not a full wall-to-wall map product like CLC, but it provides a zoom into 697 urban areas and their direct surroundings. In addition, this information can be complemented by some of the Copernicus High Resolution Layers[14], such as Degree of Imperviousness, Forests, Grasslands or Water.

The relevance and value of land cover and land use maps has to be accounted for to comply with the third key principle of GI, i.e. the concept of providing multiple ecosystem services on the same piece of land. Maps and data with that kind of information have recently been produced by the EEA[15] and JRC (Maes et al., 2011 and 2015), which can be used to identify connectors and assess their importance for providing multiple ecosystem services.

Table 4.1 presents an extensive, but not exhaustive, list of datasets and respective sources, which are

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[9] http://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm

[10] http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm

[11]https://www.espon.eu/export/sites/default/Documents/Projects/AppliedResearch/FOCI/FOCI_FinalReport_ScientificReport-r.pdf, p.37

[12] http://land.copernicus.eu/local/urban-atlas/view

[13] The functional urban area consists of a city plus its commuting zone.

[14] https://land.copernicus.eu/pan-european/high-resolution-layers.

[15] http://biodiversity.europa.eu/maes/mapping-ecosystems/map-of-european-ecosystem-types.

available for mapping GI and its components from the local to the regional scales in the EU. This list comprises datasets that can be used in the framework of both physical mapping and ecosystem service based mapping of GI. Whereas land cover information is generally available at a low resolution, which is not sufficient to depict detailed GI elements that are essential to assess qualitative traits of landscapes (Estreguil et al., 2016), some of the datasets presented in Table 4.1 can provide a starting point towards targeted analysis of these structures.

Still, additional GI elements may be added because of their availability in the future, including scattered information not standardized at large scales, but that could be useful for specific applications. Most of these datasets have origin in the sources used by the EU or other public institutions. Some have been published in peer-reviewed literature, whereas other datasets have not yet undergone a completed validation.

Table 4.1: Overview of GI mapping and assessment datasets that could potentially be considered to depict specific GI components for different GI applications.

Descriptor	GI element (0r GI related issue)	Potential Datasets	Data Origin	Coverage	Access/ Link to dataset
GI components	Semi-natural grassland	Corine Land Cover HRL grassland	Primary	Pan-European	http://land.copernicus.eu/pan-european/corine-land-cover/view https://land.copernicus.eu/pan-european/high-resolution-layers
	Forests and other wooded lands	Corine Land Cover HRL Forest Density HRL Forest type European Atlas of Forest Tree species	Primary	Pan-European	http://land.copernicus.eu/pan-european/corine-land-cover/view https://land.copernicus.eu/pan-european/high-resolution-layers/forests/view http://fise.jrc.ec.europa.eu/data/ http://data.jrc.ec.europa.eu/ (select FISE) http://forest.jrc.ec.europa.eu/european-atlas-of-forest-tree-species/
	Large marsh and bog areas	Corine Land Cover HRL Water and Wetness	Primary	Pan-European	http://land.copernicus.eu/pan-european/corine-land-cover/view https://land.copernicus.eu/pan-european/high-

Descriptor	GI element (0r GI related issue)	Potential Datasets	Data Origin	Coverage	Access/ Link to dataset
					resolution-layers
	Freshwater systems	Corine Land Cover HRL Permanent Water Bodies HRL Water and Wetness Water quality, quantity, use and demand Permanent/seasonal surface water layer and changes	Primary Derived Derived	European European Global	http://land.copernicus.eu/pan-european/corine-land-cover/view https://land.copernicus.eu/pan-european/high-resolution-layers Water portal at http://water.jrc.ec.europa.eu/waterportal Global Surface Water Explorer at https://global-surface-water.appspot.com/
	Riparian vegetation	Local Component - Riparian zones	Primary	European	https://land.copernicus.eu/local/riparian-zones/view Data RZ2000[16] Case study 5.1.3
	Natural/semi-natural lands GI (exclude agriculture and artificial land use)	European land cover/use 1 ha resolution layer [17] (CLC-OpenStreet) Regional land cover map (HR forest-OpenStreet-HNV share of natural land per ha)	Derived	European Region Region Local	Estreguil et al, 2014. doi: 10.6084/m9.figshare.1063300. ArXiv: 1406.1501 Estreguil et al 2016. doi:10.2788/170924 Case study 5.1.4[18] (Spain) Case study 5.1.6[19] (Italy)
	Share of GI per region	Share of GI and total ecosystem services	Derived	European Region	Maes et al, 2014. doi: 10.1007/s10980-014-0083-2

[16] Database 'RZ2000' for information on European stream riparian zones distribution (Clerici et al., 2011).

[17] EU-wide map land layer of GI elements (100m spatial resolution, year 2012) based on Corine Land Cover that was upgraded with the road layer OpenStreetMap at finer spatial resolution (25m, and including tunnels, bridges, wildlife passages structures). GI elements include Natura 2000 protected areas and all natural and semi-natural lands e.g. forest and other wooded lands, non-wooded vegetated lands that include 'trees outside forest' in agricultural lands, grasslands, extensive agricultural lands. Land use elements that do not qualify for GI are intensive agriculture, human settlements and transport infrastructure (e.g. roads). (Estreguil et al, 2014, Forest Europe, 2015 (indicator 4.7) and EEA/SEBI 2015 for indicator 13).

[18] Regional map layer of landscape elements that qualify for GI in Castilla-Leon in Spain.

[19] Regional map layer of landscape elements that qualify for GI in Lombardy, Italy. Each hectare pixel provides the share of forest (25 m resolution), of semi-natural non-forest vegetation, of agricultural areas and of artificial areas (25m resolution) (Estreguil et al, 2016).

Descriptor	GI element (0r GI related issue)	Potential Datasets	Data Origin	Coverage	Access/ Link to dataset
	(exclude artificial land use and agriculture except when HNV)	per NUTS 2 region			
GI Backbone, core components	Protected sites	Natura 2000	Primary	Pan-European	N2000 data viewer at http://Natura 2000.eea.europa.eu/
		Common Database of Designated Areas	Primary	Global	WDPA protected planet: http://www.protectedplanet.net/ DOPA explorer[20] http://dopa-explorer.jrc.ec.europa.eu
	Biodiversity rich areas	Article 12 & 17	Primary	Pan-European	http://Natura 2000.eea.europa.eu/
	Biodiversity rich areas and degree of multi-functionality	EEA Ecosystem map	Derived	Pan-European	http://biodiversity.europa.eu/maes/mapping-ecosystems/map-of-european-ecosystem-types
		MAES –Ecosystems condition and Services	Derived	Pan-European	http://data.jrc.ec.europa.eu/collection/maes
Connectivity and multi-functionality of protected sites	Connectivity of protected areas	Well-connected protected sites per geographical unit, Distance from the 17% Aichi Target 11	Derived	Global European Country Eco-region	JRC data catalogue http://data.jrc.ec.europa.eu/ [select protected sites]
	Connectivity of	Map layers [21]	Derived	European	http://fise.jrc.ec.europa.eu

[20] The Digital Observatory for Protected Areas (DOPA) is a set of web services and applications that can be used primarily to assess, monitor, report and possibly forecast the state of and the pressure on protected areas at multiple scales.

[21] EU-wide map layer of Natura 2000 forest sites, as GI landscape elements, and their connectivity based on broad patterns of movement of generalist species between protected sites through the unprotected lands. The map (100 m land cover spatial resolution, year 2012) shows structural and functional protected corridors, as well as potential paths of dispersal and barriers for dispersal in the unprotected landscape barriers. Land use elements that do not qualify for GI are intensively used e.g. agriculture,

Descriptor	GI element (0r GI related issue)	Potential Datasets	Data Origin	Coverage	Access/ Link to dataset
	Natura 2000 forest sites	Continuity of protected sites Functionally connected sites Isolated sites		Country	/topics/ecosystem-services/forest-biodiversity/protected-areas-and-green-infrastructure/ Case study 5.1.4; Case study 5.1.6
	Connected and multifunctional GI	Map layers of connected protected sites and delivery of ecosystem services	Derived	Country	Case study 5.1.11 Estreguil et al, 2014. doi: 10.6084/m9.figshare.1063300. ArXiv: 1406.1501
GI, artificial connectivity features	Wildlife overpass	OpenStreetMap (OSM)	Primary	Global (partially available)	https://www.openstreetmap.org
	Fish ladders, passes	OpenStreetMap (OSM)	Primary	Global (partially available)	https://www.openstreetmap.org
GI, natural connectivity features	Riparian zones Riparian vegetation	Riparian Zones	Derived	Local/ European	https://land.copernicus.eu/local/riparian-zones/view
		Connected riparian vegetation (and connectivity gaps)	Derived	Local/regional /European	Clerici et al, 2013 Doi:10.1016/j.jag.2012.07.001
	Small woody features	Islets, Linear and Corridor woodlands	Derived	Local/regional /European	Forest Europe, 2015[22] (ind. 4.7)

human settlements and transport infrastructure (e.g. roads). Country based estimates on the connectivity of N2000 forest sites are also available. (Estreguil et al, 2013 and 2014).

Regional map layer of potential GI elements and their connectivity. The map show accounts for the species movement patterns between potential habitats in the landscape (map of structural and functional corridors, bottlenecks for dispersal and barriers), (demonstrated in Castilla-Leon in Spain, and in Lombardy in Italy, see respectively case study 5.1.4 and 5.1.6).

[22] EU-wide map of forest landscape elements, their fragmentation and their connectivity (Corine land cover based, 100m spatial resolution, year 2012) and trends in the time period 2000-2012. Data are available per pixel (one hectare), per landscape unit (grid cell 25kmx 25 km), per province (NUTS2/3), per country and at European level. For further information, christine.estreguil@ec.europa.eu, Forest Europe, 2015 (indicator 4.7) and SEBI, 2015. The layers are relevant to the deployment of GI with a forest focus.

Descriptor	GI element (0r GI related issue)	Potential Datasets	Data Origin	Coverage	Access/ Link to dataset
		(1 ha grid)			SEBI 2015 (ind. 013)[23]
		Green Linear Elements within riparian zones	Primary	Pan-European	https://land.copernicus.eu/local/riparian-zones/view
		HRL on Small Woody Features	Primary	Pan-European	https://land.copernicus.eu/pan-european/high-resolution-layers/view
	Hedgerows	Green Linear Elements within riparian zones	Primary	Local	https://land.copernicus.eu/local/riparian-zones/view
		Street Tree layer	Primary	Local	http://land.copernicus.eu/local/urban-atlas/view
	Natural and semi-natural connectivity features	Linear, islets, corridors (1 ha grid)	Derived	Pan-European Country Region	EEA SEBI 2015 (ind. 013 [23])
GI in urban and peri-urban areas	Parks and Recreational Areas	Urban Atlas	Primary	Local	http://land.copernicus.eu/local/urban-atlas
		Riparian zones	Primary	Local	https://land.copernicus.eu/local/riparian-zones/view
		Street Tree layer	Primary	Local	http://land.copernicus.eu/local/urban-atlas/view
	Share of green areas in cities		Derived	European cities	EEA Technical report No 2/2012[24]

[23] SEBI indicator 013 on fragmentation and connectivity of natural and semi-natural lands is available at https://www.eea.europa.eu/data-and-maps/indicators/fragmentation-of-natural-and-semi-1/assessment-1. JRC has provided the updated assessment with data from year 2000-2012 and extended European coverage including Greece. The update on the EEA web page is under preparation.

[24] EEA, 2012, Urban adaptation to climate change in Europe - Challenges and opportunities for cities together with supportive national and European policies, EEA Report No. 2/2012, http://www.eea.europa.eu/publications/urban-adaptation-to-climate-change.

Descriptor	GI element (0r GI related issue)	Potential Datasets	Data Origin	Coverage	Access/ Link to dataset
	Access to green areas			Local	Map from DG Regio and urban policy[25]
GI related issue for urban and regional development	Air quality	Air Quality Atlas	Primary	European cities	Urban PM2.5 Air Quality Atlas[26]
	Urban pattern and sprawl Impact of land use change policy scenarios on GI for the next decades	Built-up layer (core compact, connectors, isolated clusters) Urban expansion patterns (cluster, ribbon development, leapfrogging) Potential loss/gain of GI under land use change scenarios (energy and climate, water retention measures)	Derived	European large urban zones European urban zones Pan-European Region	Case study 5.1.8 Case study 5.1.8 Mubareka et al 2013 Doi:10.1080/13658816.2013.782408 Maes et al, 2014. doi: 10.1007/s10980-014-0083-2
	Urban sprawl / Weighted Urban Proliferation	Urban sprawl indicators	Derived	32 European countries	Urban sprawl in Europe, EEA Report 11/2016, https://www.eea.europa.eu/publications/urban-sprawl-in-europe

25 Maps from DG Regional and Urban Policy on access to green spaces (Working paper: A walk to the park? Assessing access to green areas in European cities, 2016).

26 Air Quality Atlas: In this Atlas, both the spatial (urban, country...) and sectoral (transport, residential, agriculture...) contributions are quantified for 150 European urban areas in Europe.

https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/urban-pm25-atlas-air-quality-european-cities.

Descriptor	GI element (0r GI related issue)	Potential Datasets	Data Origin	Coverage	Access/ Link to dataset
	Human Settlement in regions and cities	Settlement layer and degree of urbanisation	Derived	Global European Regional	http://ghsl.jrc.ec.europa.eu/data.php http://ghsl.jrc.ec.europa.eu/ghs_smod.php http://ec.europa.eu/eurostat/web/degree-of-urbanisation/overview https://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006-1
	Imperviousness and imperviousness change	Degree of imperviousness and changes 2006-2009-2012-2015	Primary	Pan-European	https://land.copernicus.eu/pan-european/high-resolution-layers/view
GI, sustainable used and multifunctional zones	Multifunctional sustainable farmland	HNV Farmland	Derived	Pan-European	https://www.eea.europa.eu/data-and-maps/data/high-nature-value-farmland
		Agri-environment indicators	Derived	Pan-European	http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicators
		MAES -ESS datasets[27]	Derived	Pan-European	http://data.jrc.ec.europa.eu/collection/maes
	Multifunctional sustainable	HNV Forests[28]	Derived	Pan-European	http://land.copernicus.eu/pan-european/high-

[27] For full list of indicators please refer to: http://biodiversity.europa.eu/maes/mapping-ecosystems/indicators-for-ecosystem-services-across-ecosystems.

[28] HNV forest is defined as all forests, managed or non-managed, having the principle characteristics and key elements of native forest ecosystems, in terms of composition, structure, and ecological functions that support a high diversity of native species and habitats including the presence of species of European, and /or national, and/or regional conservation concern.

Source: ETC ULS (2018): Task 1.8.4.3 Milestone 5 - Consolidation of the methodology for identifying the HNV forest areas in Europe. and EEA (2014)

Descriptor	GI element (0r GI related issue)	Potential Datasets	Data Origin	Coverage	Access/ Link to dataset
	forestry				resolution-layers/forests/view
		MAES -ESS datasets	Derived	Pan-European	http://data.jrc.ec.europa.eu/collection/maes
	Multifunctional natural/semi-natural lands	Total ecosystem services index	Derived	Pan-European Region	Maes et al, 2014. doi: 10.1007/s10980-014-0083-2
Restoration zones	Mine dump restoration area	CLC - changes	Primary	Pan-European	http://land.copernicus.eu/pan-european/corine-land-cover/view
	"Active" restored area after targeted action (e.g. agri-environment, forestry)	CLC - changes	Primary	Pan-European	http://land.copernicus.eu/pan-european/corine-land-cover/view
	Remediated sites and brownfields	CLC - changes	Primary	Pan-European	http://land.copernicus.eu/pan-european/corine-land-cover/view
Connectivity of GI , defragmentation and prioritisation	Fragmentation of natural/semi-natural lands, Connectivity of GI status and trends (2000-2012) Connectivity enhancement Defragmentation	Landscape mosaic patterns (core natural, mixed, highly fragmented) Connectivity level per landscape unit Connectivity pathways and gaps Best places Best cost-benefit places for new GI habitats for a minimized loss of agricultural revenue.	Derived	Pan-European Country Region 25km grid 1ha	Forest Europe (2015)22 indicator 4.7 SEBI 2015 (ind. 013) Estreguil et al 2016. doi:10.2788/170924 Case study 5.1.4 (Spain) Case study 5.1.6 (Italy)

Descriptor	GI element (0r GI related issue)	Potential Datasets	Data Origin	Coverage	Access/ Link to dataset
	measures				
	Landscape fragmentation pressure from urban and transport infrastructure expansion	Fragmentation pressure of urban and transport infrastructure expansion Fragmentation pressure within and outside Natura 2000 sites per biogeographical region	Derived	Pan-European	https://www.eea.europa.eu/data-and-maps/indicators/mobility-and-urbanisation-pressure-on-ecosystems/assessment/view
	Connectivity of a forest GI -status and trends (2000-2012) Connectivity enhancement Defragmentation measures (road, fire, settlements)	Connectivity level of forest areas Connectivity pathways and gaps for forest species	Derived	Pan-European Country Region 25km grid 1 ha grid	Forest Europe (2015)[29] indicator 4.7 SEBI 2015 (ind. 013)23 http://fise.jrc.ec.europa.eu/topics/ecosystem-services/forest-biodiversity/ Estreguil et al 2016. doi:10.2788/170924 Case study 5.1.4 (Spain) Case study 5.1.6 (Italy)
	Forest fragmentation, Forest landscape mosaic status and trends (2000-2012)	Landscape mosaic patterns of forest: Core natural, mixed, highly fragmented. Interior forest areas Forest edge interface	Derived	Pan-European, Country Region 25 km grid 1ha grid	Forest Europe, 2015[29] (ind. 4.7) EEA SEBI 2015[23] (ind. 013) http://fise.jrc.ec.europa.eu/topics/ecosystem-services/forest-

[29] EU-wide map of forest landscape elements, their fragmentation and their connectivity (Corine land cover based, 100m spatial resolution, year 2012) and trends in the time period 2000-2012. Data are available per pixel (one hectare), per landscape unit (grid cell 25kmx 25 km), per province (NUTS2/3), per country and at European level. For further information, christine.estreguil@ec.europa.eu, Forest Europe, 2015 (indicator 4.7) and SEBI, 2015. The layers are relevant to the deployment of GI with a forest focus.

Descriptor	GI element (0r GI related issue)	Potential Datasets	Data Origin	Coverage	Access/ Link to dataset
		Linear forest			biodiversity/
	Key areas to be defragmented (road fragmentation)	Landscape fragmentation of natural-semi-natural lands	Derived	Pan-European	EEA/FOEN (2011)
	Landscape permeability	Landscape resistance (favorable to hostile for species dispersal)[30]	Derived	Pan-European Regional (forest species) Local (pollinators and flying insects)	Estreguil et al, 2014 doi: 10.6084/m9.figshare.1063300. ArXiv: 1406.1501 Estreguil et al, 2016 doi:10.2788/170924 Case study 5.1.4 (Spain) Case study 5.1.6 (Italy)
	Landscape permeability for large mammals Areas for conservation and restoration	GI network based on multi-functional areas	Derived	Pan-European	EEA Technical report 02/2014 https://www.eea.europa.eu/publications/spatial-analysis-of-green-infrastructure

[30] The landscape resistance is defined as favorable to hostile landscape for species dispersal with increasing resistance values (ranging from 1 to 100) from natural, to agricultural and artificial lands. The maps (European and regional layers at spatial resolution depending on land cover land use data availability) enable identifying barriers for the dispersal of species, and delineate pathways of dispersal between habitats.

Descriptor	GI element (0r GI related issue)	Potential Datasets	Data Origin	Coverage	Access/ Link to dataset
Threats to GI, towards a dynamic and resilient GI	GI to mitigate impacts of weather- and climate change- natural hazards GI dynamic and resilient network to adapt to climate change Natural Hazards Occurrence, risk, and impact (fires, drought, floods)		Derived	European Regional Pan-European	EEA Technical report 12/2015 Case study 5.1.5 (Spain) European Forest Fires[31] http://effis.jrc.ec.europa.eu/ European Flood Awareness system(EFAS)[32] https://www.efas.eu/ Flood risk foresight tool European drought observatory [33] http://edo.jrc.ec.europa.eu
	Biotic factors Invasive species Pests				European Alien Species Information Network https://easin.jrc.ec.europa.eu/ European Tree Pest Portal http://fise.jrc.ec.europa.eu/topics/disturbances/pests/

[31] The European Forest Fire Information System (EFFIS) provides updated and reliable information on wildland fires in Europe and in the Mediterranean area. This includes today meteorological fire danger maps and forecast up to 6 days, daily updated maps of hot spots and fire perimeters.

[32] Data : river likely to be affected, the likely magnitude of flooding in different areas , flood hazard maps and exposure data such as land use, building types, road networks and information on how vulnerable the exposed assets are, to assess the impact on people, infrastructure and the economy.

[33] Data and indicators to describe meteorological drought, soil moisture or agricultural drought, hydrological drought, socioeconomic drought. Also Combined Drought Indicator (CDI), for agricultural and ecosystem drought.

Descriptor	GI element (0r GI related issue)	Potential Datasets	Data Origin	Coverage	Access/ Link to dataset
	Soil Agro-ecosystems	Soil erosion, sealing Soil biodiversity, protection Data [34]on Natural pest control Total external input in agricultural land			European Soil portal[35] http://eusoils.jrc.ec.europa.eu/ http://publications.jrc.ec.europa.eu/repository/handle/JRC97764 http://www.quessa.eu/deliverables deliverable 4.4

Source: Own compilation.

4.2 TOOLS AVAILABLE TO MEASURE PHYSICAL MAPPING OF GREEN INFRASTRUCTURE

GI projects are mainly planned and implemented at regional and local levels, and their geographic mapping is reliant on classical geographic information system (GIS) techniques (e.g. overlay or buffering operations). Currently, there are no dedicated standalone tools that can be used to map, model and assess the spatial distribution of GI. Applied GI projects are based on a compilation of spatial and analytical tools that have been developed for different objectives, namely for quantifying and analysing habitat aspects of interest to GI deployment. This implies that practitioners must be able to manipulate standard GIS and environmental systems analysis tools, and have some ordinary computer programming skills.

For example, a plethora of methods implemented via standalone software packages are now available to assess the connectivity and continuity of habitats[36], and/or any other geographic feature relevant to GI, such as protected areas in the landscape. These methods are implemented through several spatial patterns and connectivity tools that exist as standalone software (e.g. GuidosToolbox, Conefor, Linkage Mapper, Circuitscape, etc.), and their use can be customised and integrated as demonstrated with the integrated modelling framework in Estreguil et al. (2013).

Although some specific methods are only implemented in commercial software, such as QuickScan, most GIS functionalities are already present in many free software packages, such as GuidosToolbox, Linkage Mapper, or Conefor. Free tools now available enable assessment at multiple scales, i.e. from local to regional, but also at European and global scales, due to increased computational capacities. The

[34] Distribution upon request: Map of natural pest control (QUESSA project), Map of semi-natural vegetation in agricultural areas (CAPRI disaggregated data (1 sq km) on crops, livestock density, nitrogen input. Agricultural biomass (yields in MJ/ha), Total external input in agricultural land (fertilisers, pesticides, labour, seeds, energy, machinery, irrigation)

[35] EU-wide data on soil biodiversity, soil protection (organic carbon/matter content, compaction, salinization, erosion, soil sealing)

[36] See http://conservationcorridor.org/corridor-toolbox/programs-and-tools/ for specific methods on landscape connectivity.

assessment of some landscape characteristic may be more or less demanding in terms of computational time, ranging from few seconds to few weeks depending on the model used, the spatial and thematic resolution of the data and the scale of application.

A comprehensive list of tools and methods relevant to the measurement of GI and planning of ecosystem restoration tasks is presented in Table 4.2.

Table 4.2: Tools and methods relevant to the development of GI.

Tool	Main purpose	Data input needs	Overview of outcome products	Case studies (Chapter 5)	Link to tool
Guidos Toolbox (Free license)	Spatial pattern analysis	Raster data layer (land cover or binary maps)	• Morphological Spatial Pattern Analysis • Landscape mosaic patterns (LPTs) • Fragmentation, contagion, entropy • Elasticity • Spatial resistance	5.1.3; 5.1.4; 5.1.6; 5.1.8	http://forest.jrc.ec.europa.eu/download/software/guidos/
Conefor software package (Free license)	Connectivity analysis	Vector or raster data layers to create node and distance files	• Connectivity metrics (Integral Index of Connectivity, Probability of Connectivity) at the node (patch), link and landscape levels. • Identification of stepping stone patches, well-connected patches and isolated patches. • Key sites (patches) and links for conserving or restoring connectivity.	5.1.1; 5.1.4; 5.1.5; 5.1.6; 5.2.3	http://www.conefor.org/
Linkage Mapper[37] (Free license)	Connectivity analysis	Raster data layers (core habitat areas and maps of resistance to movement)	• Map with least-cost linkages between core areas	5.2.3; 5.2.6	http://www.circuitscape.org/linkagemapper
QUICKSCAN (Can only be used in cooperation with developer)	Explore the impacts and trade-offs of policy questions in a stakeholder process	Base maps, expert rules	• Interactive maps • Summary charts • Trade-off diagrams	5.2.1; 5.2.2	http://www.quickscan.pro/
Marxan (Free license)	Geospatial conservation decision support software to select a network of priority conservation	(1) Planning unit file; (2) Conservation feature file (species and habitat list); (3) Planning unit versus conservation feature file; (4)	Maps with priority areas for conservation	5.2.4	http://marxan.net/

[37] It should be noted that Linkage Mapper (which if free) is a toolkit of a commercial software, but which cannot be used without Arc GIS (which is not free).

	areas.	boundary length file; (5) input parameter file.			
LARCH (Can only be used in cooperation with developer)	Habitat Network Assessment Tool	Vegetation map or land use map that has enough detail to distinguish the habitat and non-habitat areas for the modelled species.	On a regional scale: Spatially explicit maps of the functional connectivity of the GI in the landscape; On a European scale: generalized connectivity contour maps	5.1.2	http://www.delta-alliance.org/toolboxoverview/LARCH
Method	**Main purpose**	**Data input needs**	**Overview of outcome products**	**Case studies (Chapter 5)**	**Access to method**
Integrated JRC model for GI	Customised analysis of GI based on pattern and connectivity analysis (*GuidosToolbox*, Conefor, GIS corridor mapping, and self-coded Python)	Vector or raster data layers	• morphological habitat shapes (interior, edge, islet, linear) • habitat edge interface types (natural, artificial) • habitat functional connectivity (poor, medium, high) • immediate landscape surroundings (core natural, mixed, some natural) • network physical continuity (simple, complex) • network functional connectivity • corridor maps cost-benefit spatial analysis	5.1.4; 5.1.6; 5.1.8;	Customized method that can only be used by trained practitioners. See application description here: http://forest.jrc.ec.europa.eu/activities/forest-pattern-fragmentation/connectivity-protected-areas/
Integrated EEA model for GI	Customised analysis of GI based on ES and ecological connectivity	Vector or raster data layers	Map of GI network at the landscape level	5.2.6	Customized method that can only be used by trained practitioners. See application description here: https://www.eea.europa.eu/publications/spatial-analysis-of-green-infrastructure/at_download/file
ESTIMAP	GIS model-based approach to quantify and model ecosystem services	Raster data layers	Quantification of pollination, recreation, coastal protection, air quality and other ES at continental scale; Scenario assessments can be realized by coupling ESTIMAP to a dynamic land use model (such as LUMP, Land Use Modelling Platform).	5.2.3; 5.2.4; 5.2.5	Customized method that can only be used by trained practitioners. See application description here: https://ec.europa.eu/jrc/en/p

					ublication/eur-scientific-and-technical-research-reports/estimap-ecosystem-services-mapping-european-scale
LUISA	Modelling platform for Land Use-based Integrated Sustainability Assessment for cross-section integration and ex-ante evaluation of the territorial impact of EC policies	Macro-economic models e.g. energy, regional economy, agriculture. Geo-spatial models e.g. transport, climate, natural hazards, Data on demographic and economic growth.	Spatially explicit indicators grouped according to land function (societal, economic or environmental) and sector (transport, forestry, etc...), projected in space at various geographical levels (country, region, local) and in time (e.g. now up to 2050).		Customized method that can only be used by trained practitioners See description and applications: https://ec.europa.eu/jrc/en/luisa http://data.jrc.ec.europa.eu/collection/luisa

4.3 TOOLS AVAILABLE FOR ECOSYSTEM SERVICE-BASED MAPPING OF GREEN INFRASTRUCTURE

The deployment of ecosystem service-based mapping of GI includes identifying potential GI landscape elements based on their conditions, their pattern and connectivity, and their capacity as providers of ecosystem services. Software of “systematic multi-objective planning” (SMP), such as Marxan (Table 4.2), can be used to identify priority areas for GI implementation, based on the ecosystem services provided by different ecosystem types. An application of SMP tools at EU level based on the ecosystem services supply modelled with ESTIMAP (Table 4.2) can be found in Vallecillo et al. (2016) and Vallecillo et al. (under review). Different alternatives for the spatial planning of GI and ecosystem restoration across the EU were assessed by comparing three scenarios in which the supply of ecosystem services, beneficiaries (i.e. people) and ecosystem condition play different roles:

1. ‘Services in nature’ (SIN): the objective of this scenario is to identify priority areas for GI implementation where the only inputs are the prioritization features (i.e. ecosystem services and suitable land uses for threatened species), without including any spatial constraint.
2. ‘Services for people’ (S4P): while meeting the objective stated in the previous scenario, areas closer to populated places are preferentially selected. In these areas, demand of ecosystem services is typically higher and would reinforce the link between ecosystem and socio-economic systems.
3. ‘Services under concern’ (SUC): where prioritization was favoured in areas with poorer ecosystem condition. Poor ecosystem condition in these areas may hinder the long-term provision of multiple ecosystem services.

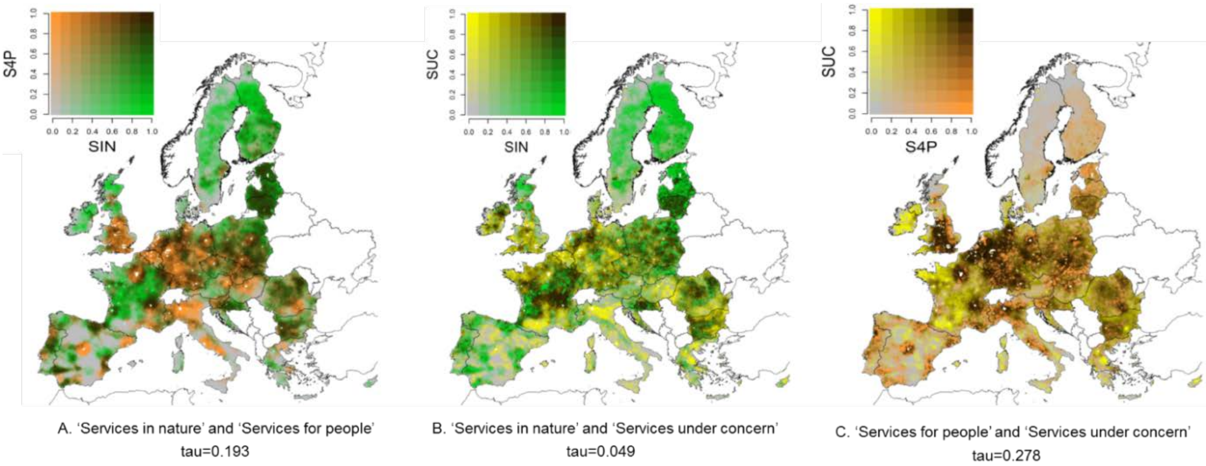
For the current study, 11 ecosystem services were used as prioritization features for each scenario. MARXAN was run 100 times for each scenario using the simulated annealing algorithm, delivering each time a network of prioritization areas. The selection frequency is the number of times that each geographic area was selected from the 100 runs. Selection frequency is a MARXAN output frequently used as a proxy of the level of importance of an area, and helps identifying areas gathering ecosystem services not available elsewhere, following always the spatial constraint set for each scenario.

Spatial comparison of the selection frequency may also help identifying win-win situations where GI development can deliver to several policy objectives simultaneously. Figure 4.1 illustrates the pairwise comparisons of the selection frequencies (i.e. how irreplaceable a geographic area was to accomplish the required level of the prioritization features) for the different scenarios: ‘Services in nature’ (SIN), ‘Services for people’ (S4P) and ‘Services under concern’’ (SUC).

The axes steps represent 10% quantiles of the selection frequency. For instance, the selection frequency of the SIN plotted against the selection frequency of the S4P scenario (Figure 4.1 A) depicts priority GI areas where not many people benefit from them (in green); while other areas are prioritized for GI implementation because they are closer to many beneficiaries (in orange). In dark brown appear those areas that are important under both scenarios. By comparing all three maps (Figure 4.1), it is possible to identify some regions with high selection frequency in all three scenarios, for instance Lithuania, North of Croatia and Bulgaria.

The scenarios comparison results suggest that in general terms, peri-urban areas are important for supply and particularly for demand of ecosystem services, where GI could be implemented to guarantee the delivery of multiple ecosystem services. However, restoration costs in these areas would be higher than in rural landscapes because ecosystem condition is often poorer due to the proximity to cities.

Figure 4.1: Pairwise comparisons of the selection frequencies for the different scenarios: ‘Services in nature’ (SIN), ‘Services for people’ (S4P) and ‘Services under concern’ (SUC). Kendall rank correlation coefficient (tau) between scenarios is also given.



Source: EU FP7 OpenNESS Project Deliverable D3.3: Sara Vallecillo, Chiara Polce, Ana Barbosa, Carolina Perpiña Castillo, Grazia Zulian, Ine Vandecasteele, Graciela M. Rusch and Joachim Maes. Synergies and conflicts between the delivery of different ES and biodiversity conservation: Spatial planning for investment in green infrastructure and ecosystem restoration across the EU. European Commission FP7, 2016. pp. 17.

Implementation and restoration of GI in areas with very poor ecosystem condition, as those prioritized under the SUCN2R scenario, would not only be more expensive, but would also require a larger effort to guarantee the same level of delivery of ecosystem services compared to areas with better condition.

In another application of ESTIMAP in relation to GI, Maes et al. (2015) compared ecosystem services delivered under present and future land use. Eight ecosystem services were mapped and linked to different land cover classes that represent potential elements of a European GI network. Under a baseline scenario (Lavalle et al. 2013), the total supply of ecosystem services was expected to decrease between 0 and 5 % by 2020 and between 10 and 15 % by 2050 relative to the base year 2010. Maes et al. (2015) concluded that urbanisation is a major driver of the loss of ecosystem services. Converting this negative trend requires investing in GI. Based on regression analysis, it was estimated that every additional percent increase of the proportion of artificial land needs to be compensated with an increase of 2.2 % of land that qualifies as GI in order to maintain ecosystem services at 2010 levels.

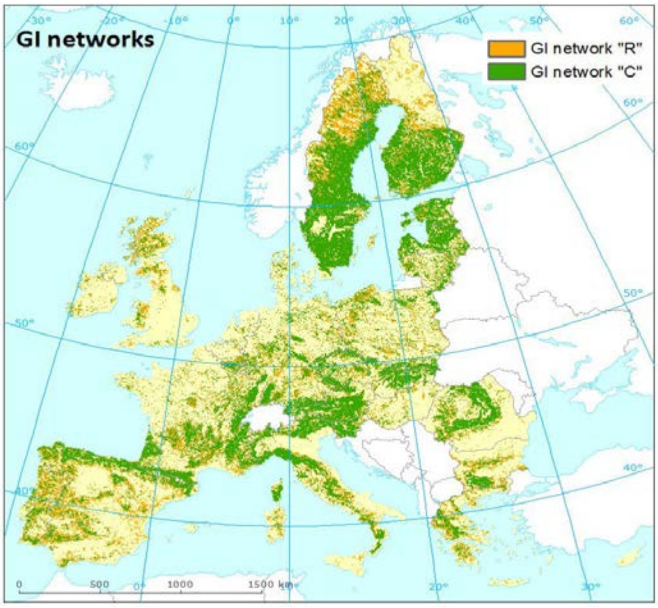
Another study at EU level (EEA 2014, Liquete et al. 2015), has proposed a methodology that integrates the natural capacity of areas to deliver ecosystem services with the core habitats and wildlife corridors for large mammals within the EU territory. This methodology was used to identify and map a European GI network (Figure 4.2) based on multi-functional ecosystem services and a coherent ecological network of connected habitat zones that facilitates dispersal, migration and genetic exchange of those animals.

This example highlights the relevance of ecological networks for GI, which aims at strengthening the link between core wildlife habitats in combination with sustainable forms of land use outside protected areas and the delivery of a wide range of ecosystem services. This experimental methodology, applicable at different scales, indicates that healthy areas of GI cover approximately a quarter of Europe's land. Although this study focuses on core habitats for large mammals and wildlife corridors for their displacement, and is applied in a continental scale analysis, it can be tailored to different objectives and spatial scales for use in research, planning or policy implementation.

At national scale for example, Scolozzi et al. (2012) estimated the value of ecosystem services corresponding to each land use class integrating a GI (urban green spaces, agricultural areas, pastures, forest, wetlands and rivers) throughout the Italian territory. The values of the ecosystem services of each land use class were measured in EUR/ha/year, by considering “local conditions” such as elevation and distance from urban areas, assuming that these spatial characteristics affect ecosystem services supply.

Although this knowledge framework was tailored for the Italian conditions, the authors suggest that their results may foster strategies for sustainable landscape planning and management in other regions. Indeed, Llausas and Roe (2012) evaluated the technical possibility of transferring GI planning between different regions in Europe, namely from North East of England (UK) to Catalonia (Spain). While recognizing that there are key differences between these regions, particularly in relation to climate, societal characteristics, institutional organisations and frameworks for landscape planning, the authors concluded that, overall, the implementation of GI planning from UK would be relatively easy to achieve and mostly beneficial under a Mediterranean environment.

Figure 4.2: Mapping of the potential European GI networks. “C” (for Conservation) and “R” (for Restoration).



Source: EEA (2014).

In recent years, the Urban Atlas has been used in a number of activities in relation to urban adaptation to climate change, urban sustainability typologies and urban GI. Map details for urban GI in Europe can be found on the Climate-Adapt web portal[38] and in the two EEA Reports on urban adaptation (EEA, 2012[39] and EEA, 2016[40]).

Moreover, the EEA also hosts a dedicated web site including a map viewer on urban GI[41]. Urban GI data derived from Urban Atlas were presented in the 2015 State of the Environment Report Synthesis[42] and the thematic briefing on the urban system[43]. Recently, the EnRoute project has been focusing on urban ecosystems in the EU, applying the MAES framework.

The urban pilot concentrates on urban ecosystems and how these can be mapped and their conditions be assessed; i.e. the focus is put on urban GI mapping and the question how urban ecosystem services and their benefit to people can be quantified[44]. A number of indicators were identified to represent the different relevant urban ecosystem services and the application of ecosystem service concepts in ten case study cities were analysed. EnRoute also makes use of the findings of a number of European

[38] http://climate-adapt.eea.europa.eu/knowledge/tools/urban-adaptation/introduction.

[39] EEA, 2012, Urban adaptation to climate change in Europe - Challenges and opportunities for cities together with supportive national and European policies, EEA Report No. 2/2012, http://www.eea.europa.eu/publications/urban-adaptation-to-climate-change.

[40] EEA, 2016, Urban adaptation to climate change in Europe 2016 — Transforming cities in a changing climate, EEA Report No. 12/2016, http://www.eea.europa.eu/publications/urban-adaptation-2016.

[41] http://www.eea.europa.eu/themes/sustainability-transitions/urban-environment/urban-green-infrastructure/urban-green-infrastructure-1.

[42] http://www.eea.europa.eu/soer-2015/synthesis/report/5-riskstohealth.

[43] http://www.eea.europa.eu/soer-2015/europe/urban-systems.

[44] http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/102.pdf.

research projects, such as Green Surge[45], ESMERALDA[46], and OpenNESS[47].

[45] http://greensurge.eu/.

[46] http://www.esmeralda-project.eu/.

[47] http://www.openness-project.eu/.

5 APPLICATION OF APPROACHES THROUGH CASE DEMONSTRATIONS

This chapter is a compilation of case studies demonstrating the development and application of GI and restoration measures in Europe, using the datasets, GIS analysis techniques and as other mapping and assessment methods and tools outlined in Chapter 4. The case studies aim at answering some GI questions, namely:

- What and where are the GI components in the protected landscape, wider countryside and urban environment?
- How well connected is the network of protected areas? Does it provide ecosystem services?
- Which European regions are most resilient in relation to anthropogenic environmental pressure and degree of protection of riparian corridors?
- Where should actions be prioritised to enhance GI? What is the monetary cost and what are the benefits for connectivity, species and ecosystem services?
- Are we able to measure the impact of pressures like agricultural intensification, urbanisation, building up of roads and occurrence of large fires on the connectivity of GI? Where would road defragmentation and permeability measures be beneficial for enhancing the functional connectivity of the network? Where should be prioritised restoration and other improvement actions in the context of sustainable ecosystem (like forest and agri-environment) management?
- How can GI be factored into landscape planning, conservation and restoration actions?
- Where in Europe and in its sub-regions does GI cross state boundaries? How could policy scenarios of land use conversion impact these GI networks in the next decades?
- How will pressures such as climate change impact particular species? Could the GI network compensate for the loss of climatically suitable areas over time? Is there the need, and if so where, to identify features between protected sites to prioritise restoration in the future and allow climate change adaptation and range shift in such a dynamic network?
- How can GI also support the long-term delivery of multiple ecosystem services?
- How does GI serve multiple sectors?
- How can GI-related spatial layers support and facilitate the discussion process among stakeholders to resolve conflicts and make decisions? How can nature conservation, habitat defragmentation and connectivity as well as provision of multiple ecosystem services be considered in an integrated way with landscape and urban planning?

Table 5.1 summarizes the topics and scales of application of the case studies included in this report. Case studies focus on GI mapping, prioritisation and planning at landscape level, GI mapping and planning at urban level, and ecosystem services mapping to build an improved GI. Case studies covering different regions and established at different spatial scales, are implemented with the data and tools described in Chapter 4.

Table 5.1 Demonstration case studies for GI and ecosystem restoration

Topic/ Case study	Landscape/ rural	Urban/ Peri-urban	Regional	EU-wide Cross-border
Physical mapping				
5.1.1 Connectivity of European terrestrial protected areas	x		x	x
5.1.2 European overview of GI network connectivity	x		x	x
5.1.3 European riparian corridors	x			x
5.1.4 GI for forest protection	x		x	x
5.1.5 Climate change impact on GI: Prioritisation for more resilience	x		x	x
5.1.6 Cost-benefit solutions for GI well connected GI for forest and agri-env.: restoration priorities	x		x	x
5.1.7 Harmonization of regional green spaces: towards a national GI network	x		x	
5.1.8 EU large urban zones: Compactness and expansion patterns according to land use policy scenarios		x		
Ecosystem service based mapping				
5.2.1 Green Infrastructure for healthier environment in the city		x		
5.2.2 Green Infrastructure for climate proofing in the city		x		
5.2.3 Providing ecosystem services through Natura 2000 linkages			x	x
5.2.4 Conservation tools to identify restoration priorities				x
5.2.5 Cultural ecosystem services to inform the implementation of GI	x		x	
5.2.6 EU level GI network for conservation and restoration of habitats	x		x	x
5.2.7 Contribution of the European Green Belt to the implementation of EU-level GI	x		x	x

5.1 PHYSICAL MAPPING

5.1.1 ARE PROTECTED AREA SYSTEMS DESIGNED TO SUPPORT CONNECTIVITY?

Keywords

Europe, GI, protected area (PA) connectivity, Natura 2000, transboundary connectivity, Aichi Target 11, evaluating and improving PA systems.

General objective and policy relevance of method

- To assess the connectivity of the terrestrial protected areas (PAs) in a country or ecoregion.
  The connectivity of PAs, and notably of Natura 2000 sites, is a key part of the EU GI Strategy, of the EU Biodiversity Strategy to 2020, and of the Habitats Directive. It is specifically addressed in action 12 of the Action Plan for nature, people and the economy adopted in 2017[48].
- To assess the progress towards international targets for the connectivity of PAs in the EU and globally.

[48] Available at http://ec.europa.eu/environment/nature/legislation/fitness_check/action_plan/index_en.htm

In Aichi Target 11 of the Convention on Biological Diversity the international community, including all EU countries, agreed to increase by 2020 the terrestrial area under protection to at least 17% in well-connected systems of protected areas.

- To evaluate how much PA connectivity depends on unprotected lands and transboundary linkages.

The EU GI Strategy promotes the deployment of a "strategically planned network of natural and semi-natural areas" and the consideration of all lands and management measures, including those outside PAs, as well as a cross-border/transnational perspective.

What does the method provide answers to?

The Protected Connected (ProtConn) indicator (Saura et al. 2017, 2018) quantifies the percentage of a country or ecoregion covered by protected connected lands, and can be used to assess:

- The degree to which the design of PA systems, which involves the number, coverage and spatial arrangement of PAs in a country or ecoregion, is successful in promoting connectivity of protected lands.
- The contribution of different categories of land (protected, unprotected, transboundary) to the connectivity of PAs.
- How far countries or ecoregions are from the Aichi Target 11 connectivity element of having 17% of the land covered by well-connected systems of PAs.
- Where, in the EU or elsewhere, additional efforts are most needed in expanding or reinforcing the connectivity of PA systems, and which are the main priority actions to that end in each country or ecoregion.
- Whether new PAs (designated or under evaluation) provide effective connectivity gains in the PA system by acting as corridors or stepping stones between other PAs, i.e. how to improve PA systems for connectivity.

Which stakeholders and practitioners does the method target?

Decision-makers at national and regional levels, DGs of the European Commission, Convention on Biological Diversity, conservation planners.

Data sources used

The Protected Connected (ProtConn) indicator has been calculated at the country and ecoregion level globally using the following datasets:

World Database on Protected Areas (WDPA). The WDPA is compiled and managed by IUCN and UNEP-WCMC, and is available at www.protectedplanet.net. The June 2016 version of the WDPA was used for all the ProtConn results shown below. For the EU, the WDPA includes both Natura 2000 sites and nationally designated sites.

Terrestrial Ecoregions of the World by Olson et al. (2001)[49].

Global Administrative Unit Layers (GAUL) 2015 by FAO[50].

Description of method/tool

ProtConn is an indicator that measures the degree to which the design of a PA system supports the connectivity of protected lands. ProtConn quantifies the percentage of a country (or ecoregion) that is covered by protected connected lands (Figure 1), differentiates several categories of land (unprotected, protected or transboundary) through which species movement between protected locations may occur, and is easy to communicate and to compare with PA coverage (Figure 2).

ProtConn considers the spatial arrangement, size and coverage of terrestrial PAs, and accounts for both the land area that can be reached within PAs and that which is reachable through the connections between different PAs, considering both direct and indirect (stepping stone) movements. ProtConn is obtained through network analysis, using the Conefor software (see Section 4.2) to calculate the Probability of Connectivity and the Equivalent Connected Area, which are the metrics underlying ProtConn. ProtConn has been obtained for a range of median dispersal distances (1-100 km) covering the dispersal abilities of the large majority of terrestrial vertebrates, but 10 km is used as the reference median dispersal distance that is most representative of the PA connectivity (all results shown below correspond to 10 km of median dispersal distance). The probability of dispersal (strength of the connection) between two PAs decreases with inter-PA distance, as given by a negative exponential function of the inter-PA distance in which the probability of dispersal is 0.5 for two PAs separated by a distance equal to the considered median dispersal distance (here 10 km). See Saura et al. (2018b) for further details.

All the ProtConn values shown below do not penalize the country scores by the PA isolation due to the sea or to foreign lands, i.e. they only consider the PA isolation that is due to limitations or deficiencies in the design of the PA system of the country, which is referred to as $\text{ProtConn}_{\text{Bound}}$ in Saura et al. (2018).

Application of method and main results

1. Protected area systems in the EU are well designed for connectivity as compared to the global average

The EU already meets the Aichi Target 11 of having 17% of the land covered by well-connected PA systems, as given by an average ProtConn=18.9% in the EU (Figures 1 and 2). The EU scores considerably better than the global average, which is ProtConn=7.5% (Figures 1 and 2).

The spatial arrangement of PAs is, however, not fully successful in ensuring the connectivity of protected lands in the EU, given that ProtConn (18.9%) is clearly lower than the 25.7% of PA coverage in the EU (Figure 2b), and there is a considerable variability in the ProtConn values across EU countries (Figure 1).

49 Available at www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world

50 Available at www.fao.org/geonetwork/srv/en/metadata.show?id=12691

2. Different country-level priorities for PA connectivity in the EU

In 15 of the 28 EU countries, ProtConn is below the 17% target, as show in Figure 1 (but note that Romania is already very close to the target, with ProtConn = 16.98%). In these countries, a targeted designation of new PAs in strategic locations for connectivity is needed, focusing on their role as corridors or stepping stones between other PAs (Figure 3).

In the EU countries with ProtConn equal to or above the 17% target (Figure 1), the designation of more terrestrial PAs is not a priority regarding the connectivity of their PA systems and the Aichi Target 11 for 2020. These countries should concentrate efforts on other important priorities for the connectivity of their PA systems, particularly on ensuring the permeability of the unprotected landscapes between PAs and the coordinated management of transboundary PAs and of neighbouring PAs within the country (Figure 3), as further described in the next two points.

3. Ensuring permeability of the unprotected landscapes: a top priority for the EU

The results of the ProtConn indicator show that the connectivity of PAs in the EU is strongly dependent on the possibility of movement through unprotected landscapes (Figure 2b), much more than in any continent (Figure 4). This is because, in the EU, PAs are generally small, as compared to other regions or continents, and are embedded in unprotected landscapes. The differences in PAs' sizes among countries and in PAs' connectivity when accounting for the unprotected landscape are documented for the European Natura 2000 protected sites network in the assessment by Estreguil et al. (2014), which accounted for the barrier effects of less permeable land uses (roads, settlements and intensive agriculture) for forest generalist species dispersing in average 500 meters.

Because PAs in the EU are generally small, it is unlikely that they are sufficient to ensure, individually, some of the conservation goals for which they were declared. Meeting these goals will only be possible if PAs are part of an ecosystem service based network of linked sites, which necessarily involves the conservation or restoration of GI elements in the unprotected landscapes. This would need to involve multiple sectors and actions, from the agro-environmental measures in the CAP to the defragmentation of transport infrastructure in key locations for connectivity (as shown in case studies 5.1.4 and 5.1.6 in this report).

4. Transnational planning of protected area connectivity: a specific need for the EU

In the EU, the connectivity of PAs depends on transnational connectivity to a similar degree as in the American continent, but much more than in any other continent (Figure 5). This is the result of several reasons, of which two are here highlighted.

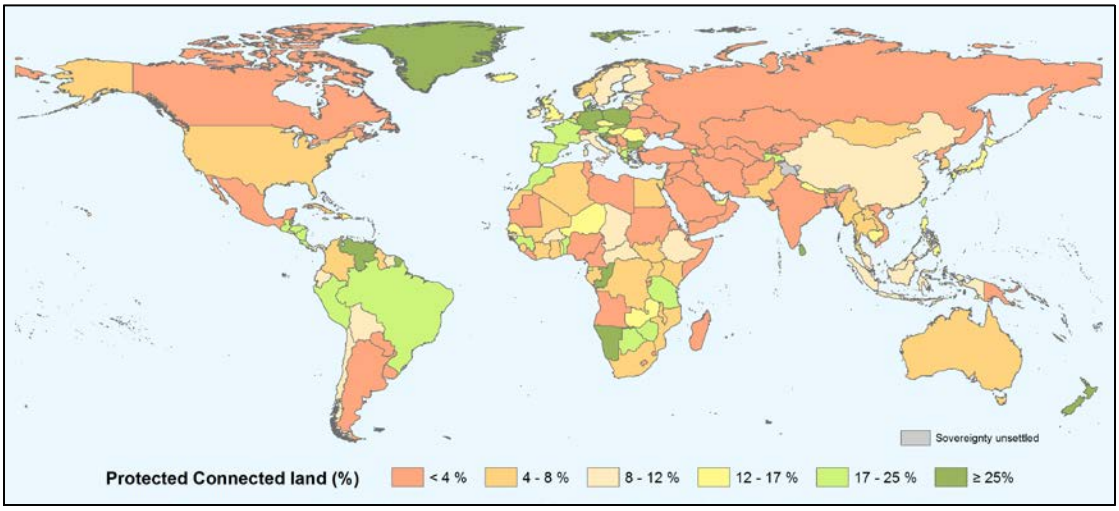
First, a significant number of PAs are located in or near the boundaries of EU countries (e.g. in some mountain ranges like the Pyrenees, the Alps or the Carpathians, or along some main rivers), which increases the dependency of the PAs in one country on the PAs across borders.

Second, several EU countries are too small to ensure by themselves the connectivity of PAs at the scale at which species movements and other ecological flows need to happen, even more so when compared with the size of countries in other continents.

These results highlight the need for a transnational coordinated effort across the EU for building and reinforcing the linkages between the Natura 2000 sites, as well as between other protected and non-protected elements that constitute the EU GI.

Outcome products

The detailed results of the ProtConn indicator, in the form of datasets and maps with the values for all countries and ecoregions, can be downloaded or interactively explored at the Digital Observatory of Protected Areas of the JRC of the European Commission, which can be accessed at http://dopa.jrc.ec.europa.eu.



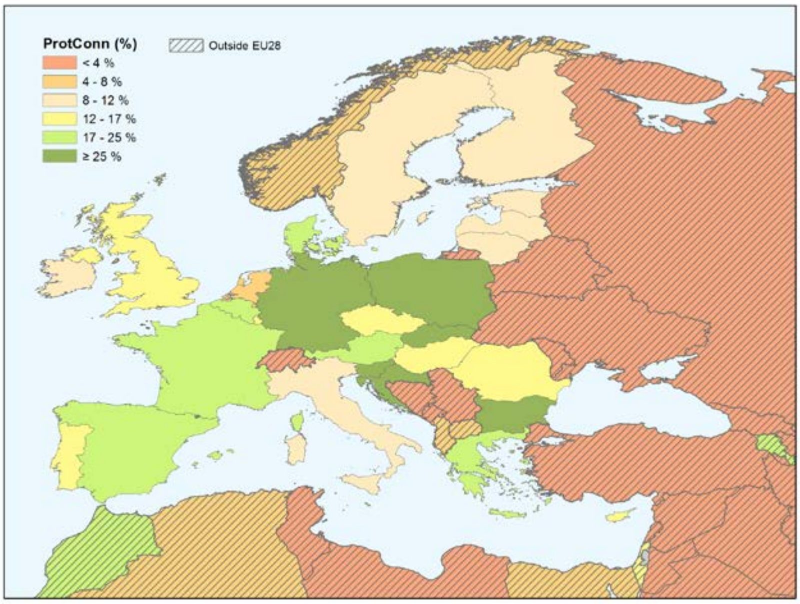


Figure 1. Protected Connected land (ProtConn, % of country area) for the world's countries (top) and in a more detailed view for the EU (bottom) (Saura et al. 2018). The two green classes include the countries that already meet the Aichi Target 11 element on connectivity, as given by ProtConn $\geq$ 17%. Disputed territories (sovereignty unsettled) in the top global map are as in GAUL 2015. See Saura et al. (2017) for the ProtConn results at the ecoregion level.

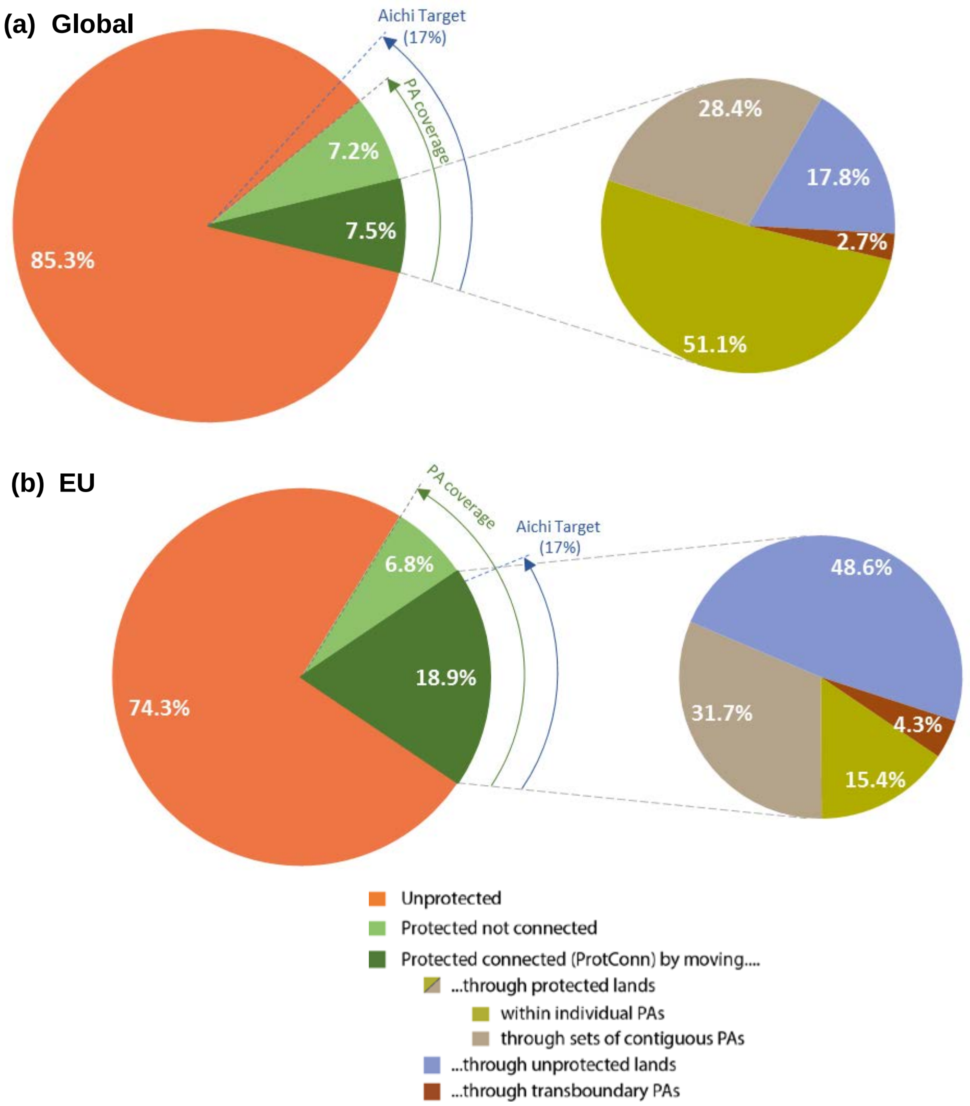


Figure 2. Global (a) and EU-28 (b) values of ProtConn and related indicators, obtained as a weighted average of the country-level indicator values. Globally, ProtConn is 7.5% and PA coverage is 14.7% (7.2% + 7.5%), both below the 17% level of Aichi Target 11. In the EU, ProtConn is 18.9% and PA coverage is 25.7% (6.8% + 18.9%), both above the 17% level of Aichi Target 11. The four ProtConn fractions (pie charts to the right) assess the percentage of the protected connected land that can be reached within individual PAs, that can be reached by moving through adjacent PAs, that depends on movement through unprotected lands, and that depends on transnational linkages (i.e. on using PAs outside a country when moving between two PAs of the country). See Saura et al. (2018) for further details.

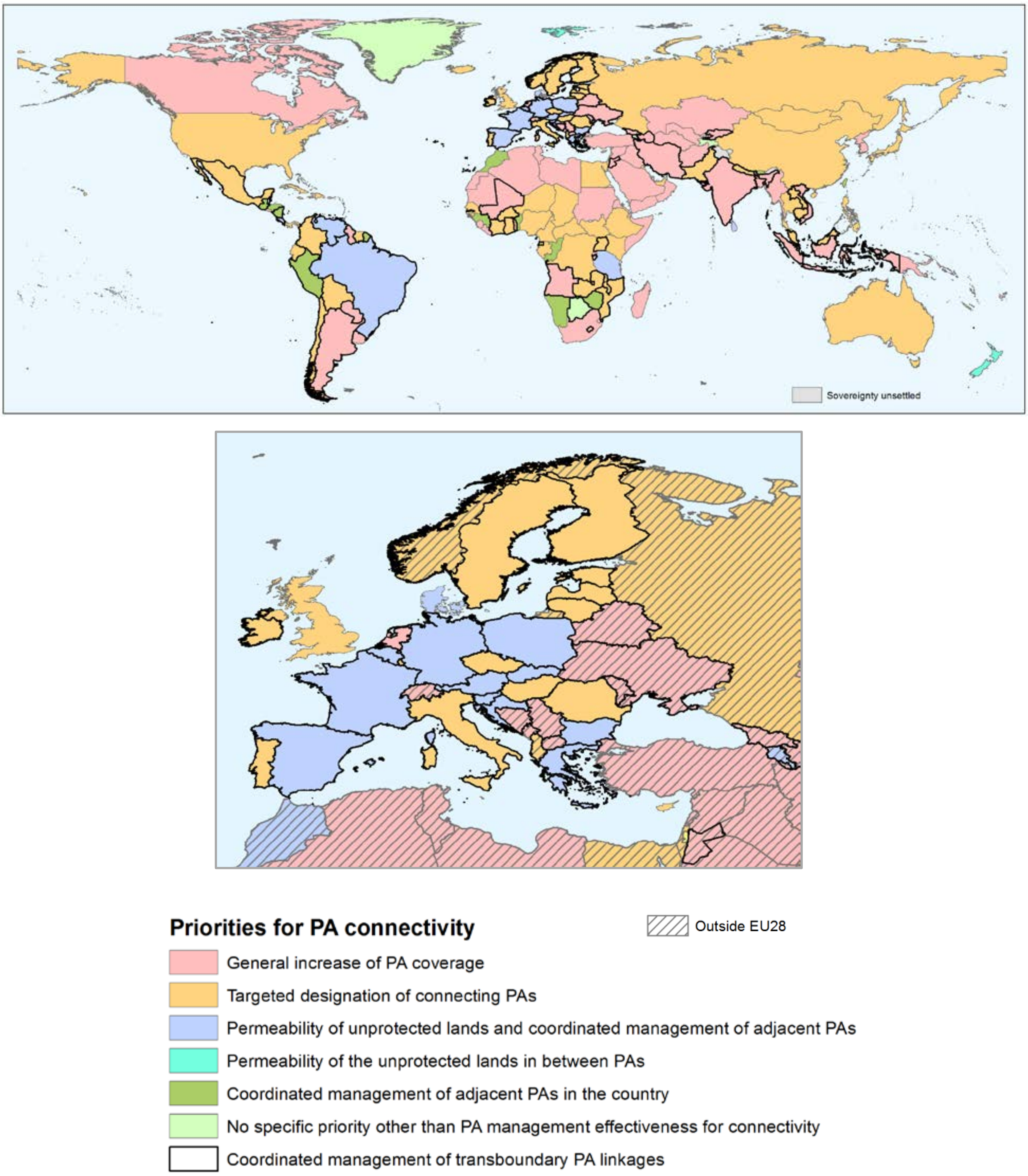


Figure 3. Priorities for improving or sustaining PA connectivity in each country of the world and in a more detailed view for the EU, as identified through the ProtConn indicator and its fractions (Saura et al. 2018). PA management effectiveness for connectivity is an assumption of the ProtConn indicator, and is therefore a priority for all countries (and not just for those in B3). See Saura et al. (2018) for further details and insights on the interpretation of this classification of country-level priorities.

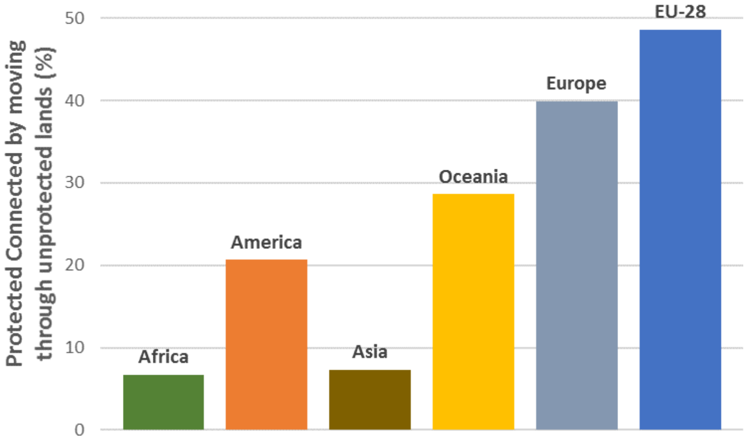


Figure 4. Percentage of PA connectivity (ProtConn) that depends on movement through unprotected lands. Country values were aggregated at the continental and EU-28 levels. See Saura et al. (2018) for further details. The value for EU-28 (48.6%) is also shown in the blue slice of the pie chart to the right in Figure 2b.

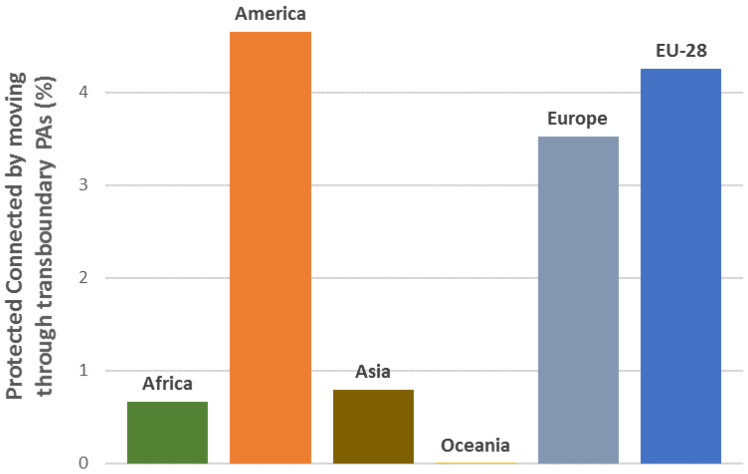


Figure 5. Percentage of PA connectivity (PrtoConn) that depends on transnational linkages, i.e. on using PAs outside a country when moving between two PAs of the country. Country values were aggregated at the continental and EU-28 levels. The value for EU-28 (4.3%) is also shown in the right pie chart in Figure 2b.

References

- Saura, S., Bastin, L., Battistella, L., Mandrici, A., Dubois, G. 2017. Protected areas in the world's ecoregions: how well connected are they? Ecological Indicators 76: 144-158. Available at http://dx.doi.org/10.1016/j.ecolind.2016.12.047

- Saura, S., Bertzky, B., Bastin, L., Battistella, L., Mandrici, A., Dubois, G. 2018. Protected area connectivity: shortfalls in global targets and country-level priorities. Biological Conservation 219: 53-67. Available at https://doi.org/10.1016/j.biocon.2017.12.020

- Estreguil, C., Caudullo, G., de Rigo, D. 2014. Connectivity of Natura 2000 forest sites in Europe. F1000Posters 2014, 5: 485. http://dx.doi.org/10.6084/m9.figshare.1063300 . ArXiv: 1406.1501. And in EUR 26087EN. Luxemburg: Publications Office of the European Union. JRC 83104. http://dx.doi.org/10.2788/95065

- Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V., Underwood, E.C. et al. 2001. Terrestrial ecoregions of the world: a new map of life on Earth. BioScience 51: 933-938. Available at https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2

Comments

The currently available version of the ProtConn indicator:

- Assumes that PAs are effectively conserved and managed as to ensure sufficient connectivity levels that allow the successful movement of species through protected lands. If this is not the case, the actual connectivity levels will be below those given by the indicator.
- Does not consider the heterogeneity of the landscape matrix in between PAs, due to high variability in species responses (e.g. a corridor for a bear or a capercaillie may be a barrier for an open-habitat butterfly or a steppe bird). Instead, it aims at a more general overarching assessment on how well PA systems are designed for connectivity considering the range of median dispersal distances observed for most terrestrial vertebrates (1 to 100 km). Future versions of the indicator may however be adapted to account for matrix heterogeneity.

5.1.2 EUROPE-WIDE OVERVIEW OF THE GI NETWORK'S FUNCTIONAL CONNECTIVITY

Keywords

Regional, prioritisation, functional connectivity, sustainability, species, habitat, GI map.

General objective and policy relevance of the method

- Provide Europe-wide overview of the functional connectivity of the GI network.
- Analyse the sustainability of the GI network on local and regional scales and identify priority corridor zones to increase connectivity.
- Identify changes in connectivity and sustainability of the GI network over time.

What does the method provide answers to?

- Where the creation of additional GI would be most effective to increase connectivity and link habitats.
- Where areas are needed for additional GI to create sustainable habitat networks.

Which stakeholders and practitioners does the method target?

Decision-makers at national and regional levels, DGs of the European Commission, conservation planners.

Data source used

Multiple datasets may be required though data inputs are user-defined and not prescriptive. Depending on the aims of the user and the level of detail of the available input data, both regional species-specific network analysis as well as Europe-wide generalized assessments of connectivity are possible. For this case study, the following datasets were used:

Corine Land Cover (EEA)

- Use in tool analysis: to analyse Europe-wide overview of the functional connectivity of the GI network

The datasets below are an example of input data used in a regional analysis. The actual choice of national or regional maps is flexible and depends on the available data for the study area and the required output.

Dutch habitat map (Bal et al., 2001)

- Use in tool analysis: to analyse the regional habitat networks in the transboundary region between Netherlands and Germany.

Habitat maps of North Rhine-Westphalia, Lower Saxony, and Schleswig-Holstein in Germany (Riecken et al. 2003).

- Use in tool analysis: to analyse the regional habitat networks in the transboundary region between Netherlands and Germany.

Description of method/tool

The connectivity of habitats is calculated with the habitat network assessment tool LARCH developed by Wageningen Environmental Research (Alterra) (Verboom & Pouwels 2004). The method is based on metapopulation theory.

The LARCH tool indicates the connectivity of the GI for every point on a map by calculating the amount of suitable habitat that is available within the dispersal range of a species or species group, taking landscape resistance and barriers into account. The tool can be used with the characteristics of real species, but also with more generalized species group characteristics called 'ecoprofiles'. The model produces connectivity contour maps, where depending on the amount of connected habitat, regions with high, medium or low connectivity are identified, for instance for forests at the European level (Groot Bruinderink et al. 2003). It can be replicated on regional, national or European level across EU-28 and all countries involved in CLC (CLC2006 38 countries in, CLC2012 39 countries).

Application of method and main results

On a regional scale the method provides spatially explicit maps of the functional connectivity of the GI in the landscape. Species-specific maps of spatial cohesion are produced at 100 × 100 m resolution, which show whether the available habitat is connected or consists of a separated network (Figure 1). Furthermore, each habitat network can be categorised as potentially sufficient to maintain (1) a key population, (2) a sustainable network or (3) a highly sustainable network (Figure 2). A key population is defined as a relatively stable and large local population in a network (Verboom et al 2001). A habitat network is sustainable if it is large enough to support a minimum viable metapopulation with an extinction probability of less than 5% in a period of 100 years (Opdam et al. 2003). A habitat network is highly sustainable when the size is at least five times larger than a sustainable network.

On a European scale (Figure 1) the output is more generalized, e.g. modelling for 'forest' habitat or 'wetlands'. General parameters are used, for example for a 'medium range' forest bird, or 'large mammal'. Based on species group characteristics, providing connectivity contour maps, where depending on the amount of connected forest or wetland habitat, regions with high, medium or low connectivity can be identified (Figure 2).

Outcome products

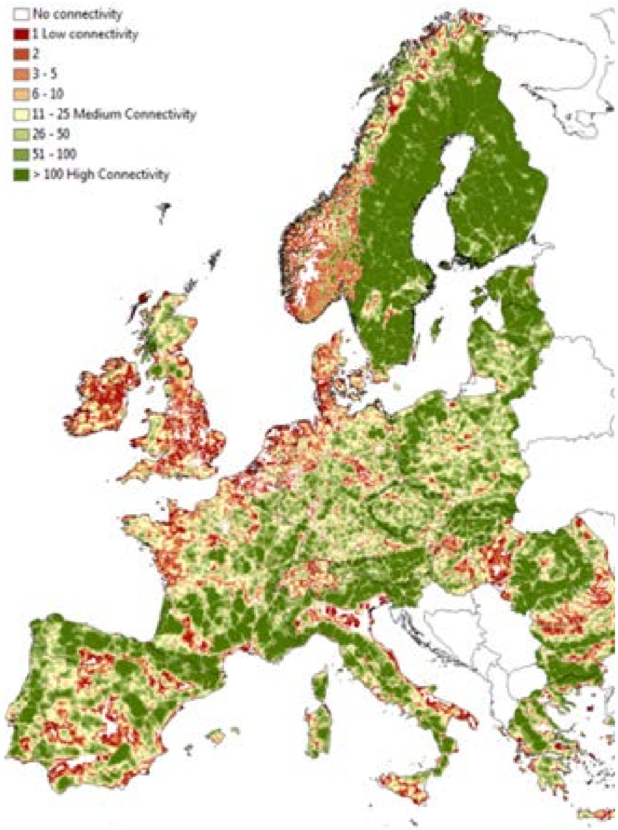
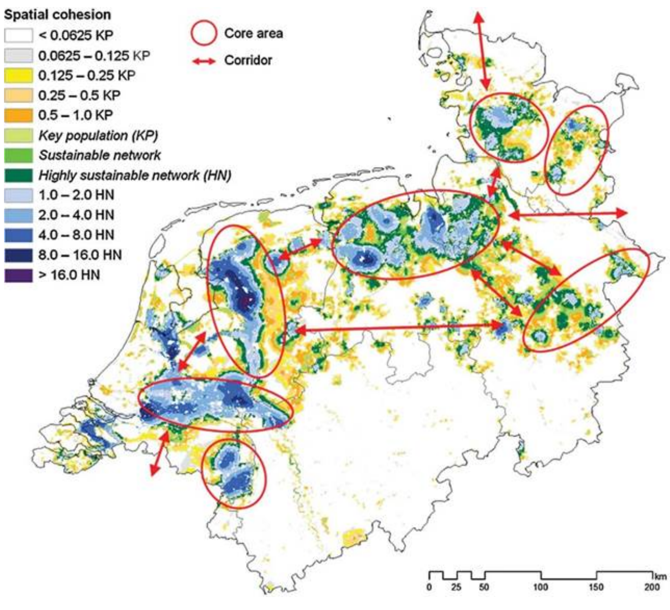


Figure 1. Example output of the LARCH tool: Landscape connectivity for forests on a European scale, based on the ecoprofile characteristics of a barrier sensitive large mammal (Source: IEEP & Alterra, 2010).

Figure 2. In the example of the otter in the Dutch-German study (see figure right), the identified core areas and corridors are illustrated as circles and straight-line arrows in habitat network maps. Thus, regions are identified where GI networks could best be improved to increase functional connectivity (Source: Rüter et al. 2014).



References

Bal, D., Beije, H., Fellinger, M., Haveman, R., Van Opstal, A. and Van Zadelhoff, F. (2001) Handboek natuurdoeltypen, Expertisecentrum LNV (in Dutch).

Groot Bruinderink, G., Van der Sluis, T., Lammertsma, D., Opdam,P., & Pouwels, R. (2003). Designing a coherent ecological network for large mammals in northwestern Europe. Conservation Biology, 17, 549–557.

IEEP & Alterra (2010) Reflecting environmental land use needs into EU policy: preserving and enhancing the environmental benefits of “land services”: soil sealing, biodiversity corridors, intensification / marginalisation of land use and permanent grassland. Final report to the European Commission, DG Environment on Contract ENVB1/ETU/2008/0030. Institute for European Environmental Policy / Alterra Wageningen UR.

Opdam, P., Verboom, J. and Pouwels, R. (2003) 'Landscape cohesion: An index for the conservation potential of landscapes for biodiversity', Landscape Ecology, 18(2), 113-126.

Riecken, U., Finck, P. Raths, U., Schröder, E. and Ssymank, A. (2003). Standard Biotopenliste für Deutschland. 2. Fassung. Landschafspflege und Naturschutz 75: 1-66.

Rüter, S., Vos, C.C., Van Eupen, M., Rühmkorf, R. (2014). Transboundary ecological networks as an adaptation strategy to climate change: The example of the Dutch – German border. Basic and Applied Ecology (15) 639-650.

Verboom, J., Foppen, R., Chardon, P., Opdam, P. and Luttikhuizen, P. (2001) 'Introducing the key patch approach for habitat networks with persistent populations: an example for marshland birds', Biological Conservation, 100(1), 89-101.

Verboom, J., & Pouwels, R. (2004). Ecological functioning of eco-logical networks: a species perspective. In R. H. G. Jongman, &G. Pungetti (Eds.), Ecological networks and greenways: concept, design, implementation (pp. 65–72). Cambridge: Cambridge University Press.

Comments

It can be replicated on regional, national or European level across EU-28 and all countries involved in CLC (CLC2006 38 countries in, CLC2012 39 countries).

The LARCH analysis on European level would gain from higher resolution GIS information on small natural elements, as these elements are important for connectivity in multi-functional landscapes. It is expected that detailed information on woody elements (New HRL Small Woody Features -with 2.5 m spatial resolution, based on SPOT imagery 2015) will become available for entire Europe in 2018.

5.1.3 RIPARIAN CORRIDORS IN EUROPEAN GI

Keywords

European, riparian zones, structural riparian corridors, environmental pressure, priority region.

General objective and policy relevance of method

- To support the harmonised spatially explicit development of riparian zones that have a key role in maintaining landscape connectivity through ecological corridors for animals and plants.
- To map the riparian structural corridors in Europe.
- To identify and rank European regions as providers of riparian structural corridors and rank them based on the degree of environmental pressure and presence of protection schemes.
- To provide a backbone that Member States and regional planners could use to coordinate their GI projects.

What does the method provide answers to?

The development of a riparian vegetation pattern map can be used to answer:

- Where the regions are in Europe, acting as best providers of structural connectivity for stream riparian environments.
- Where to prioritise conservation efforts.
- Where structural corridors are more at risk due to high environmental pressure and low protection.

Which stakeholders and practitioners does the method target?

Decision-makers at European and national levels, regional planners.

Data source used

Database ‘RZ2000’ available at JRC for information on European stream riparian zones distribution (Clerici et al., 2011). The data at spatial resolution of 50m have continental Europe extension and include both ‘river-floodplain’ systems as well as ‘stream-riparian’ networks of minor and ephemeral watercourses.

Protected areas as Common Database on Designated Areas (CDDA) and Natura 2000 network.

Description of method/tool

GUIDOS *Toolbox* is used for the Morphological Spatial Pattern Analysis (bridge class, edge distances of 50m, 100m, 200m). Three indices are calculated per 1km grid cell:

- Proportion of structural corridor presence.
- Structural corridor under pressure (depending on presence of artificial and agricultural land cover).
- Priority regions for conservation and management with large presence of structural corridor, under high pressure and with low protection scheme.

Critical situations towards riparian conservation and management perspective are identified by high proportions of urban and agricultural land-cover in the 1km grid cell. This is considered as a reasonable proxy for anthropogenic pressures on the riparian structural corridors that in this case, are more prone to fragmentation, particularly when in addition, those corridors are not under a protection scheme.

Application of method and main results

Riparian zones are small and narrow. Structural riparian connectors (structural riparian corridors) among core habitat patches are identified and mapped over Europe according to three edge distance parameters: 50m, 100m and 200m. This is ecologically meaningful, considering that some riparian species need smaller extensions of interior core habitat, associated to low edge distance, to perform all necessary ecological functions. Other species that need extended core areas and edge distance can only exploit small riparian patches as corridors to reach larger core regions.

European regions are identified as providers of structural riparian corridors and ranked with reference to conservation priority. The ranking is performed using a simple set of indices that take into account the degree of environmental pressure and the presence of land protection schemes. An example for environmental reporting is carried out using European administrative regions and major rivers to summarize indices value.

Outcome products

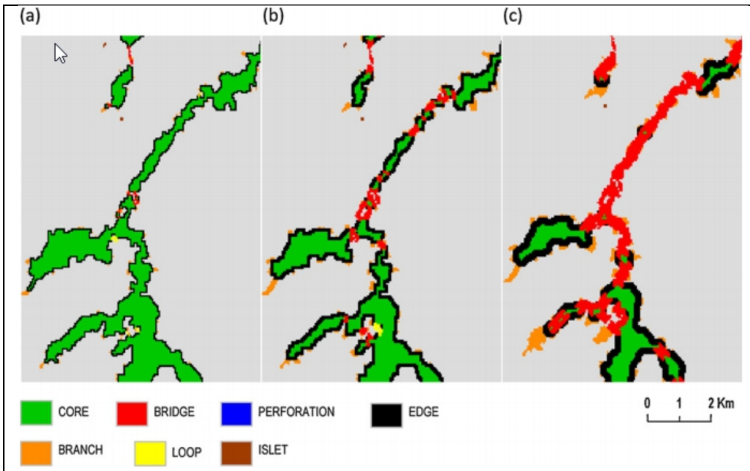


Figure 1. Characterisation of the riparian vegetation pattern, using three different edge distances: 50 m (a), 100 m (b) and 200 m (c).

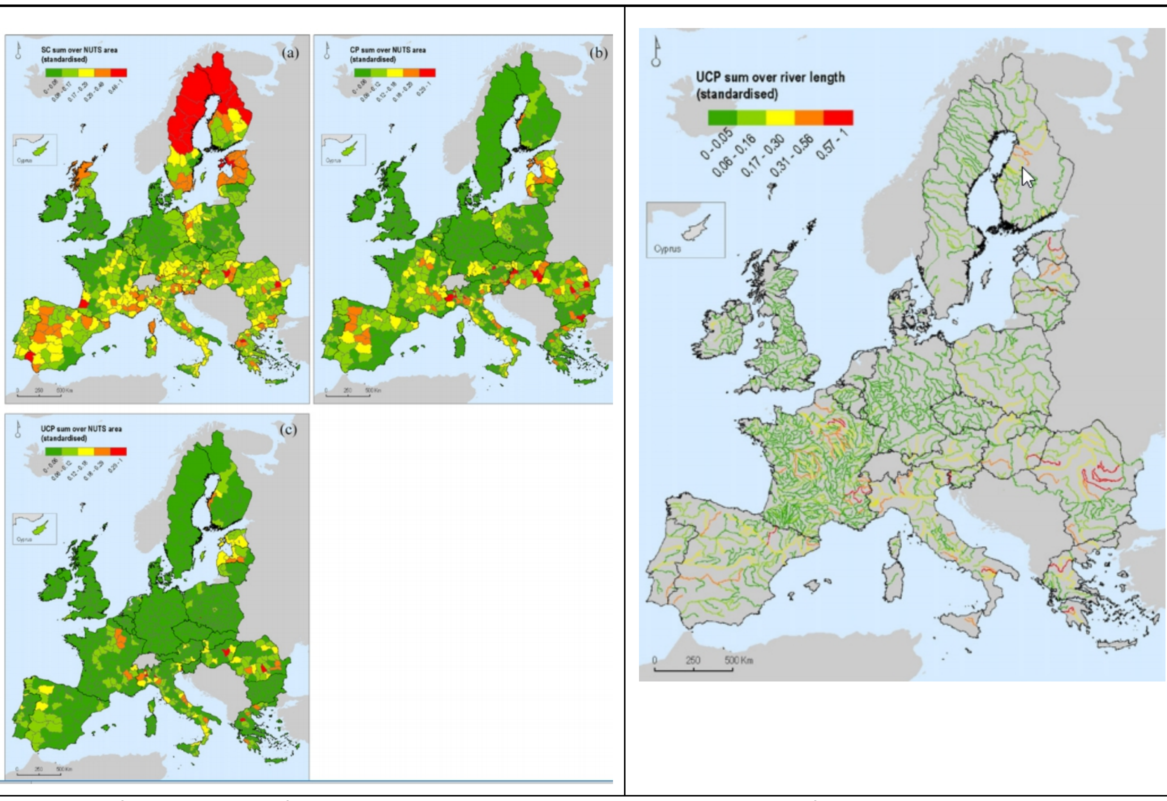


Figure 2. (left) Distribution of indices SC (a), CP (b) and UCP (c). SC: proportion of structural corridor presence. CP: structural corridor under pressure (depending on presence of artificial and agricultural land cover). UCP: priority regions for conservation and management with large presence of structural corridor, under high pressure and with low protection scheme. Values refer to standardized sum over NUTS 2-3 administrative area. (right) UCP summation over river length for the major European rivers (min–max standardized).

References

Clerici, N., Vogt, P., 2013. Ranking European regions as providers of structural riparian corridors for conservation and management purposes. International Journal of Applied Earth Observation and Geoinformation 21, 477–483. http://dx.doi.org/10.1016/j.jag.2012.07.001

Comments

- The results obtained cannot provide a comprehensive multi-scale assessment of riparian connectivity in Europe, but rather illustrate valuable analysis tools and information with regard to the physical component of riparian vegetation.
- The method is rapid and robust, easily reproducible due to software availability (free distribution of *GuidosToolbox),* and the simplicity of the indices proposed which exploit the bridge class from the Morphological Spatial Pattern Analysis (*GuidosToolbox/ MSPA tool*)
- Land use and land cover information derived from the new European Copernicus Sentinel-2 satellites are expected to support environmental monitoring and habitat mapping at large scale and will likely improve the analysis of natural and semi-natural habitat structural connectivity and anthropogenic pressures in Europe.

5.1.4 ENHANCING FOREST PROTECTION THROUGH A REGIONAL GI: KEY LANDSCAPE COMPONENTS AND WHERE TO PRIORITISE DEFRAGMENTATION MEASURES

Keywords

Regional, prioritisation, connectivity, Natura 2000, forest species, GI key components, pressures, defragmentation measures.

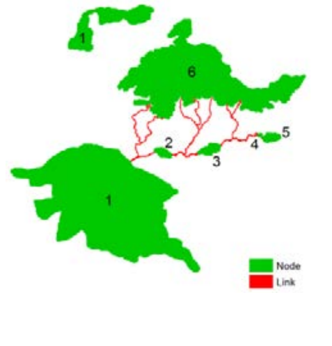
General objective and policy relevance of method

- Natura 2000 forest sites are considered as a recommended backbone component of GI
- Map GI as a "*strategically planned network of natural and semi-natural areas*" (European Commission, 2013) at regional level, and incorporate the connectivity criteria to define key GI wooded and non-wooded components.
- Identify key unprotected landscape elements where to concentrate conservation and restoration management efforts.
- Identify species dispersal paths most affected by transport infrastructure, and guide and prioritise defragmentation measures.

What does the method provide answers to? • What is the level of structural connectivity of the Natura 2000 network in the region and how does it compare to the European country level average? • Where are the preferential least cost paths to be established or maintained that contribute to the connectivity of the Natura 2000 network and benefit most forest species ecoprofiles? • What differences are there in path trajectories and density between different forest species ecoprofiles and dispersal distance capabilities? • What is the contribution to connectivity of key landscape components like forests of "Public Utility" (as defined by the Spanish forest law), private forest, riversides, and livestock trails along unprotected pathways? • Where are Natura 2000 sites that are isolated due to roads, and where would road defragmentation measures be needed?
Which stakeholders and practitioners does the method target? • Advisory and service organisations of the agricultural and forestry sectors. • Farmers and forest owners. • Forest managers • Regional planners.
Data source used Four ecoprofiles are used: • Generalist forest species (forest canopy cover above 30%). • Generalist open forest species (forest canopy cover above 10%). • Broadleaved forest species (canopy cover above 30%). • Specialist forest species of mature forests and closed canopies above 70%. For each ecoprofile, four average dispersal distances in a landscape of intermediate resistance are considered: 200 m, 500 m, 1 km and 5 km. The input data to the model is a regional land cover map (scale 1:25,000, minimum mapped unit 2 ha) prepared from the Spanish Information System on Land Cover (SIOSE) and the Spanish forest types map (MFE) available for the Castile and Leon Spanish region. Forests of public utility are documented from the regional datasets. The road network is mapped from the road layer OpenStreetMap (25 m). This layer is translated into a landscape resistance layer for each ecoprofile. The resistance of land cover and land use classes is a priori defined based on expert knowledge as favourable to hostile for the dispersal of species and is used as one possible criteria for the land cover/land use to act as a GI component. Dispersal of species in forest lands are always considered the highest (in other terms, resistance values are the lowest), but with differences according to forest type, development stage and closeness of canopy depending on the ecoprofile. The resistance values for open land cover classes increase, in this order, for areas with shrub lands, wetlands, grasslands and pastures, unvegetated natural or semi-natural areas, permanent (woody) crops, non-woody crops, water bodies and artificial areas. Post-fire (burned areas) resistance values are considered equivalent to the ones of unvegetated areas. Artificial lands including roads are always considered as acting as main barriers for dispersal and have the highest resistance values in all ecoprofiles.
Description of method/tool Integrated modelling framework available at JRC based on *GuidosToolbox* for the physical continuity and landscape mosaic pattern analysis, on Conefor software for the functional connectivity analysis, on GIS least-cost paths and on Python programming language. (Estreguil et al. 2013)
Application of method and main results The spatial pattern of the Natura 2000 network in a region is made of structurally connected (continuous) sites and of isolated sites. The proportion of structurally connected sites within the network can be compared across regions (or countries) and can also be compared to the average European country level. Functional connectivity account for the size of Natura 2000 sites and the landscape resistance between them, to delineate least cost paths (corridors) most favourable to species dispersal in the unprotected space between sites. Their differences across ecoprofiles and dispersal capabilities are highlighted. The impact of transport infrastructures on the functional connectivity of the Natura 2000 sites network is assessed by removing the road network of OpenStreet Map layer from the landscape resistance layer. Priority places for road defragmentation are then identified. This method is demonstrated over the region of Castilla Leon in Spain. Outcome products are a summary table for the structural connectivity analysis of the Natura 2000 sites network, spatially explicit maps of corridors of dispersal between Natura 2000 sites, preferential paths and GI components that best contribute to connectivity and guidelines to prioritise forest conservation and restoration management efforts. The use of four forest ecoprofiles (generalist to specialist species) and four dispersal capabilities (short to large distance) enable to conclude that a generic approach can be applied. Particularly, the large dispersal distance of 5000 m provide a very high or close to

maximum connectivity between the Natura 2000 sites, and larger distances may not be necessary in future similar analyses. Short to intermediate distances of 200 and 500 m seem valid as representative or indicative distances of the main connectivity patterns and trends, for example: (i) major contribution of key elements in least cost paths like forest of “Public Utility”, riversides, Natura 2000 sites, (ii) no isolated sites for distances larger than 500 m, (iii) highest sensitivity to the impacts of transport infrastructure and forest fires for these distances.

Outcome products



	Castile and León	Average of European countries
Number of Natura 2000 sites	177	746
% of land protected as Natura 2000 sites	27.2%	16.8%
Number of sub-networks (simple nodes and group of Natura 2000 sites structurally connected)	272	1025
Mean subnetwork area (ha)	9,420	5,764
Median subnetwork area (ha)	60	367
% of subnetworks with sites structurally connected	18.4%	16.8%

Table 1. The Natura 2000 network in Castile and León has a good structural connectivity thanks to the relatively high proportion of subnetworks made of connected sites (18.4%) with respect to the European country-level average. This is mainly due to the designation of many riparian Natura 2000 sites (link in figure on the left) in continuity with other forest sites. The low median value size of subnetwork (60 ha) is explained by the large number of very small simple nodes (isolated node 1 in figure), often wetland sites resulting from one single Natura 2000 site identifier. This is however compensated by several other large or very large subnetworks, which results in the mean subnetwork area being higher (9,420 ha) for Castile and León than for the European country-level average.

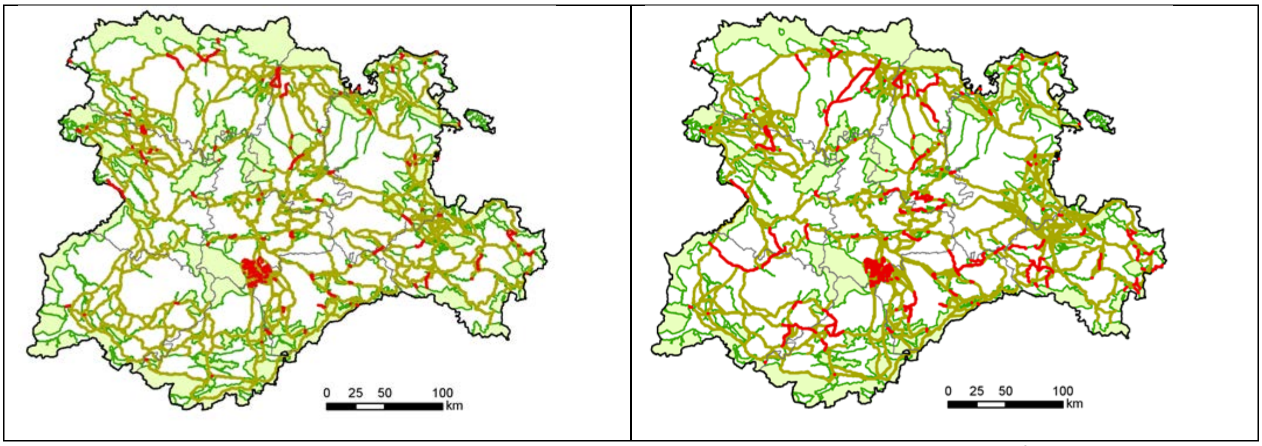


Figure 1. Species dispersal between Natura 2000 sites occur along least cost paths acting as corridors of species dispersal in the unprotected land. The Natura 2000 sites are shown as polygon in green shades; forest species with the largest dispersal capabilities (5000 m) dispersed along the paths shown as olive green lines. Preferential least cost paths for species with low dispersal capability of 200 m are overlaid as red lines. The map on the right is for generalist species which acknowledge the densest paths network when compared to the network for specialist species of mature forest with closed canopy (map on the left). Also the paths trajectories and density show differences for species with limited dispersal capacities (red lines) due to their higher sensitivity to the matrix resistance. GI landscape components should ideally be located along these least cost paths in order to improve the connectivity of the Natura 2000 network in the region.

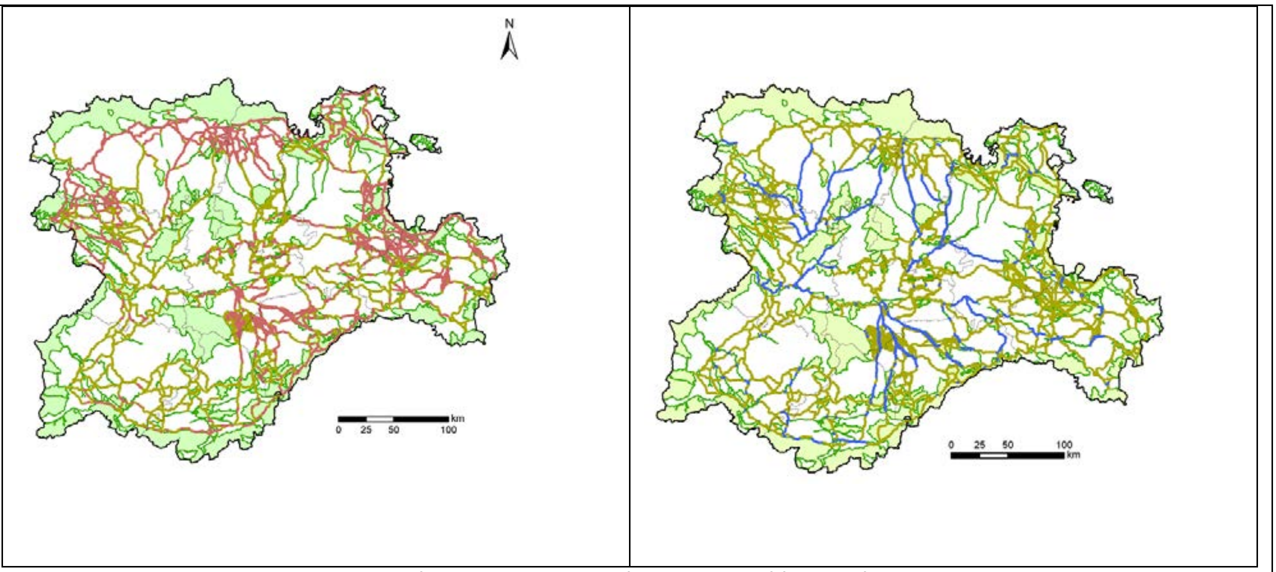
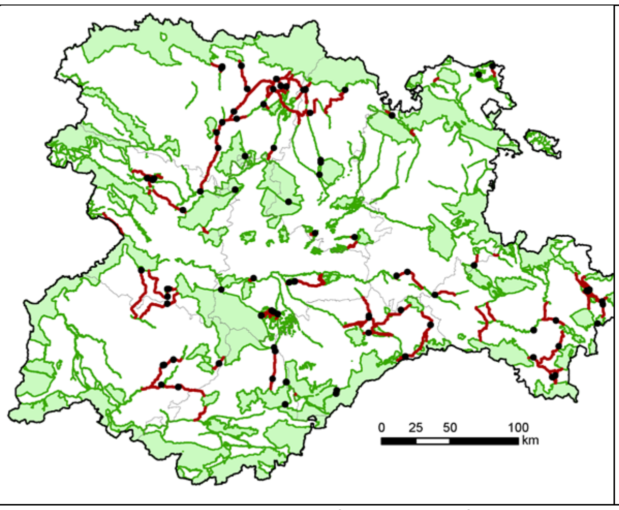


Figure 2. Functional paths (corridors) are found to include significant sectors of forests of public utility (overlaid as red lines in the map on the left), and of riversides (overlaid as blue lines in the map on the right) that would be worth considering as potential GI components. The maps show all least cost paths up to a dispersal capability of 5000m for generalist forest species.



Dispersal distance (m)	*Relative change in connectivity due to road impact*
200	20.9%
500	14,7%
1000	9,4%
5000	2,6%

Figure 3. Among all least cost paths for generalist forest species delineated in figure2, the least cost paths that are negatively impacted by transport infrastructure are shown as red lines in the map; intersections of the paths with major roads (motorways, trunks and primary roads) are identified with black dots. The effects of roads on the connectivity of the Natura 2000 network are strongly dependent on species dispersal abilities, with the more mobile species being less affected by these impacts. Due to their a-priori defined high barrier effect, roads have an important negative impact on connectivity and the map provide the places where prioritising road defragmentation measures (e.g. tunnel, bridges).

References

Estreguil, C., Caudullo, G., Saura, S., Mateo-Sánchez, M.C., Gastón, A., García-Viñas, J.I. and López-Leiva, C. 2015. Pilot analysis of the connectivity of the Natura 2000 forest sites to guide forest conservation and restoration. Final report of SC16 contract in the framework contract reference N° 388432 with the Universidad Politécnica de Madrid (UPM) for the 'provision of forest data and services in support to the European Forest Data Centre' Available for download at http://fise.jrc.ec.europa.eu/topics/ecosystem-services/

Estreguil, C., de Rigo, D., Caudullo, G., 2013. A proposal for an integrated modelling framework to characterise habitat pattern. Environmental Modelling & Software, Vol. 52 (February 2014), pp. 176-191, ISSN 1364-8152, doi: 10.1016/j.envsoft.2013.10.011.

Estreguil, C., Caudullo, G., San-Miguel-Ayanz, J. 2013. Connectivity of Natura 2000 Forest Sites. JRC scientific and policy report EUR 26087EN. Luxemburg: Publications Office of the European Union. doi: 10.2788/95065.

Comments

Practitioners highlighted the relevance of the method and tools for management, particularly to support decision making and environmental impact assessments in the unprotected landscape. Most interesting results and of more direct applicability in planning and conservation are (1) the identification and prioritization of the corridors (least cost paths) where to concentrate conservation management efforts, (2) the comparison of connectivity for different ecoprofiles and habitats, and (3) the identification of Natura 2000 sites that are isolated or poorly connected.

The methodology was also applied to analyse the impact of other environmental pressures like fire on the connectivity of the protected sites network. The most impacted least cost paths were identified and guidance was provided where to prioritise vegetation restoration measures after fire occurrences.

Forest of public utility and riversides cover a significant proportion of the identified potential corridors in the unprotected landscape and this finding is important because their effective management as well as the implementation of corridors are certainly more feasible for those landscape elements. Livestock trails (cattle way) were also considered, they provided a minor contribution to the functional connectivity of the protected network, which suggest that some of them may be degraded and in need of restoration measures.

The impact of the spatial and thematic resolution of the input datasets on the results were also analysed. Functional connectivity was about 20% underestimated from the European Corine Land Cover compared to the finer-scale regional land cover maps. The largest differences in least cost paths were found for the dispersal distance of 500 m, and the lowest differences for the largest distance of 5000 m. The more restrictive forest habitat preferences of certain ecoprofiles (e.g. broadleaves and specialist species) also translated into higher sensitivity to scale of the connectivity outcome.

5.1.5 A PROTECTED NETWORK SUITED TO ADAPTING TO CLIMATE CHANGE: THE NEED FOR A DYNAMIC NETWORK RESILIENT TO CHANGE FOR GI AND WHERE TO PRIORITISE CONSERVATION MEASURES.

Keywords

Regional, climate change adaptation, connectivity, Natura 2000, forest species, GI key components

General objective and policy relevance of method

- Natura 2000 sites are considered as a recommended backbone component of GI
- Map GI as a "*strategically planned network of natural and semi-natural areas*" (European Commission, 2013) at regional level, that can adapt to climate change and incorporate the connectivity criteria to render GI more resilient to change.
- Select species most sensitive to climate change and assess their migration possibilities within the Natura 2000 network
- Guide protection, restoration and conservation measures to maintain and enhance the connectivity of the protected network over time under climate change.

What does the method provide answers to?

How could climate change impact the migration of climatic sensitive species in the three future 30 years time periods (2010-2039, 2040-2069, 2070-2099)?

Where are the climatically suitable Natura 2000 sites for these species in the current time period? Which ones will remain suitable, which ones will become climatically unsuitable and suitable?

Is the Natura 2000 network connected enough to respond to these changes and still enable the dispersal of these species? Where to enhance connectivity to accommodate migration needs by creating new sites? Where to compensate negative impacts of climate change (sites becoming unsuitable)?

The species at focus is the *Juniperus Thurifera* forest, priority Habitat 9560, in the priority habitat Annex 1 Directive 92/32/EEC. *Juniperus thurifera* is a fleshy fruited relict tree endemic to the western Mediterranean Basin, it forms open forests in areas that in general have poor soils and a Mediterranean continental climate, with low winter temperatures and dry summers; it is a particularly sensitive species to climate change and in literature, there are predictions of considerable reductions of its range in the future.

Which stakeholders and practitioners does the method target?

- Advisory and service organisations of the agricultural and forestry sectors.
- Farmers and forest owners, forest holders and managers
- Regional planners.

Data source used

This case study is similar to the one 4.1.5; the ecoprofile is the forests of *Juniperus thurifera*, for four average dispersal distances in a landscape of intermediate resistance (200 m, 500 m, 1 km and 5 km). The resistance values for land cover classes are the lowest for forest areas including *Juniperus thurifera* (from low forest coverage, FCC≥10%) and increase, in this order, shrublands, wetlands, grasslands and pastures, unvegetated natural or seminatural areas, permanent (woody) crops, non-woody crops, water bodies. Artificial lands including roads are acting as main barriers for dispersal and have the highest resistance values.

The input data to the model is the regional land cover map (scale 1:25,000, minimum mapped unit 2 ha) which is prepared from the Spanish Information System on Land Cover (SIOSE) and the Spanish forest types map (MFE) available for the Castile and Leon Spanish region. The presence of the priority Spanish Juniper forest habitat in the Natura 2000 Sites of Community Importance (SCI) is derived from the regional Map of Natural and Semi-natural Habitats (scale 1:10,000, minimum mapped unit 0.5 ha) available from the Department of Environment of Castile and Léon.

The land cover layer is translated into a landscape resistance layer defining favourable to hostile landscape for the dispersal of the targeted climatic sensitive species, and thus define the likeliness to act as a GI component.

Description of method/tool

Climatic data are derived from the regional climatic model ENSEMBLES that is based on monthly temperature and precipitation (http://ensembles-eu.metoffice.com/) and applies the IPCC A1B scenario (a future world of rapid economic growth, global population that peaks mid-century and decline thereafter and a balanced energy system from fossil and non-fossil sources). Data are disaggregated to one km and bias corrected. The model is built with data for 1971-2000 and is used to predict suitability in one km cells in the three future 30 years-time periods. Occurrence probabilities are converted into binary suitability (prevalence method), only Natura 2000 Sites of Community Importance (SCIs) that either has some presence of *Juniperus Thurifera* forest or has at least 100 ha suitable for this forest type in at least one period of time, are retained for the connectivity analysis.

The spatio-temporal connectivity analysis is conducted with the integrated modelling framework available at JRC, particularly using the Conefor software for the functional connectivity analysis, GIS least-cost paths and Python programming language. The analysis accounts for the species suitability dynamics resulting from the climate change models. It focuses on the possibilities for migration in a directional network, from sites with current presence of the Spanish juniper to those sites that will be (or will remain) climatically suitable in the future.

Application of method and main results

Potential impacts of climate change on Spanish *Juniper woodlands* could be considerable with an increasing migration pressure (towards higher altitudes and the periphery of the region). The Natura 2000 network showed a limited connectivity that would not allow to fully compensate for the loss of climatically suitable areas over time, nor accommodate the migration needs of the species in the future.

Results highlighted a number of corridors (least cost paths) that would need to be prioritized to allow for Spanish juniper climate change adaptation and range shift; a dynamic approach is recommended to the network in order to render it more resilient to climate change.

The impacts of climate change on habitat connectivity (at least for the case study on *Juniperus thurifera*) for species with large dispersal distance (above 500 m) are similar to those reported for smaller dispersal of 200 or 500 m. An interesting fact is also that the connectivity decreased moderately (by 10-20%) in the first period 2010-2039, then sharply after in 2040-2099.

Outcome products

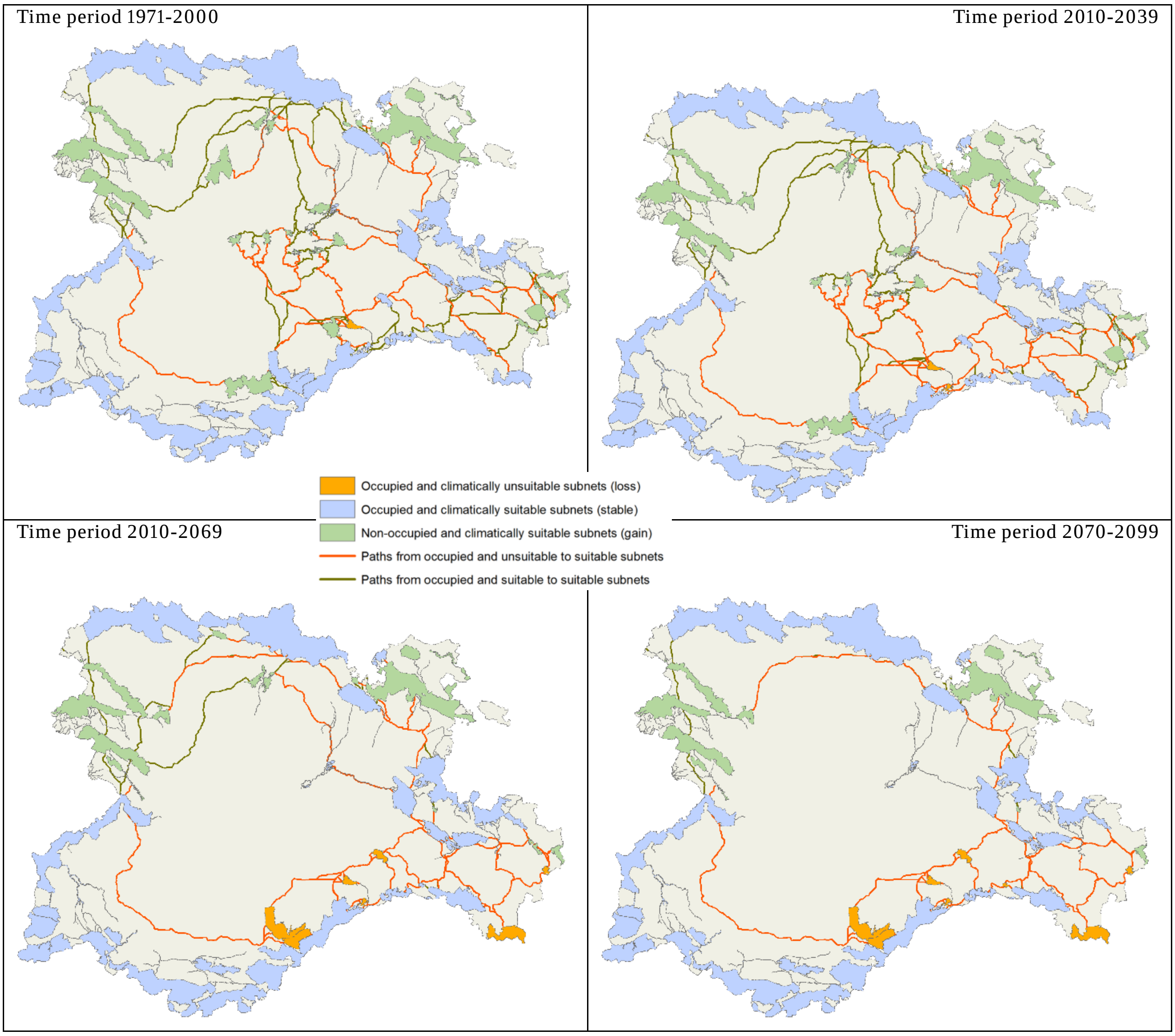


Figure 1. Directional least cost paths between Natura 2000 subnets (structural connected sites), that allow for climate change adaptation and range shift of *Juniperus thurifera* up to dispersal distance of 5000m in each time period considered. The subnets differ by the presence of species and their climatic suitability over time. Species' migration occur according to a directional path network, e.g. from a 'loss' subnet to a 'gain' subnet but not in the opposite direction. Two different types of least cost paths are highlighted. The paths shown in orange from occupied and climatically unsuitable subnets to suitable subnets are displayed on the top of the paths from occupied and suitable to suitable subnets (hence the figure only shows the first type of 'orange' paths in those sectors when both overlap).

We notice a strong decrease of *J. thurifera* connectivity under climate change, particularly an increased migration pressure with time and more 'loss' subnets (currently occupied but climatically unsuitable in the future). There is a limited connectivity between the 'loss' subnets and the suitable 'stable' or 'gain' subnets. The current network will not be able to fully accommodate migration needs, nor compensate negative impacts climate change (loss of suitable areas).

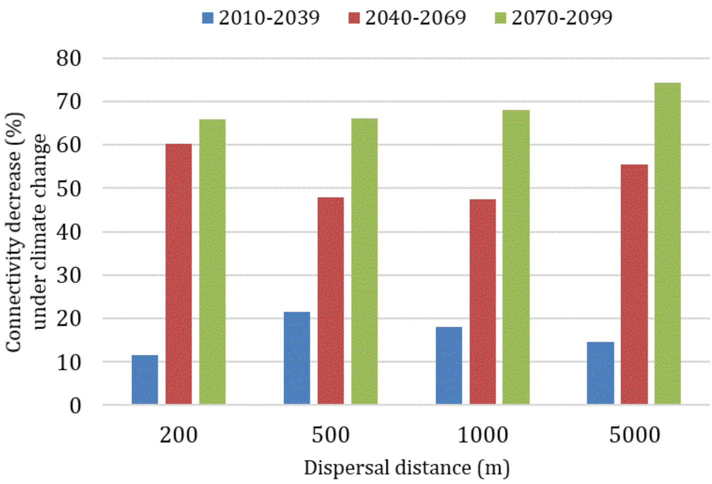


Figure 2. Decrease in connectivity for *Juniperus thurifera* habitat under climate change compared to the connectivity levels in the reference period 1971-2000. Results are given for the four considered species dispersal distances. Connectivity decreases moderately (11%-22%) in the first period (2010-2039) and sharply after (average ≈ 53% in 2040-2069 and ≈ 69% in 2070-2099).

References

Estreguil, C., Caudullo, G., Saura, S., Mateo-Sánchez, M.C., Gastón, A., García-Viñas, J.I. and López-Leiva, C. 2015. Pilot analysis of the connectivity of the Natura 2000 forest sites to guide forest conservation and restoration. Final report of SC16 contract in the framework contract reference N° 388432 with the Universidad Politécnica de Madrid (UPM) for the 'provision of forest data and services in support to the European Forest Data Centre' Available for download at http://fise.jrc.ec.europa.eu/topics/ecosystem-services/

Estreguil, C., de Rigo, D., Caudullo, G., 2013. A proposal for an integrated modelling framework to characterise habitat pattern. Environmental Modelling & Software, Vol. 52 (February 2014), pp. 176-191, ISSN 1364-8152, doi: 10.1016/j.envsoft.2013.10.011.

Estreguil, C., Caudullo, G., San-Miguel-Ayanz, J. 2013. Connectivity of Natura 2000 Forest Sites. JRC scientific and policy report EUR 26087EN. Luxemburg: Publications Office of the European Union. doi: 10.2788/95065.

Martensen, A.C., Saura, S. and Fortin, M.-J. (2017). Spatio-temporal connectivity: assessing the amount of reachable habitat in dynamic landscapes. Methods in Ecology and Evolution 8: 1253–1264.

Comments

Practitioners recommended more analyses, also including non-forest habitats (such as wetlands or steppe bird habitats), they felt that the climate change analyses give an interesting perspective for land management but may not be reliable enough as to determine their local management decisions because of the uncertainty of climate change predictions and the importance of non-climatic drivers at local scales.

Practitioners mention the need of specific training on the methods, tools and management options related to connectivity. They regret the lack of precise information on species traits and their responses to landscape features (species movement abilities, distribution, habitat suitability, land cover permeability, etc.) to accurately guide decision making on functional connectivity.

Finding ways to make these analyses less computationally intensive would be of interest for future applications of these methods.

5.1.6 *A STRATEGICALLY PLANNED REGIONAL GI FOR FOREST AND AGRICULTURE: BEST COST-EFFECTIVE AREAS TO PRIORITISE GREENING MEASURES AND ENHANCE CONNECTIVITY*

Keywords

Regional, GI network map, prioritisation, connectivity, forest, agri-environment, greening measures, cost-benefit.

General objective and policy relevance of method
• To map GI as a "*strategically planned network of natural and semi-natural areas*" *(European Commission, 2013)*, and to support harmonised spatially explicit developments of well-connected GI networks at regional level. • To propose spatially explicit cost-benefit solutions to enhance connectivity of GI components when needed, and strategically geo-locate greening measures based on economic and ecological criteria, as such supporting GI as "*providing ecological, economic and social benefits*". • To encourage the cooperation of the forest, agri-environment and regional development sectors and policies when developing GI, by providing a common spatially-explicit platform for the synergic consideration of all land cover and uses.
What does the method provide answers to?
The development of a regional GI connected network map can be used to answer: • Where potential GI networks are, and whether they are connected in a region. • Where the core and linear GI components are. • How natural the landscape is in their immediate surroundings. • The location of corridors that allow best the movement of most species in between GI networks. • Where gaps are in connectivity, thus potentially hampering the dispersal of most species due to land elements that do not qualify for GI because they are intensively used or human dominated lands like roads and intensive land uses. • Where to improve GI connectivity at the best cost-benefit ratio, *i.e.* implement more biodiversity-friendly agricultural practices, maximize connectivity and minimize the cost of the loss of agricultural land/production.
Which stakeholders and practitioners does the method target?
• Advisory and service organisations of the agricultural and forestry sectors. • Farmers and forest owners, forest holders and managers. • Decision-makers and regional planners.
Data source used
• The input data layer to the model has a 100 m resolution and is based on a refined version of Corine Land Cover (100 m resolution), road layer OpenStreetMap (25 m), Copernicus Forest High Resolution Layer (25 m), semi-natural grassland in agricultural land based on the Common Agricultural Policy Regionalised Impact (CAPRI) model and the High Nature Value farmland map (100 m). For data references, see Estreguil et al. (2016). • Each hectare pixel provides the share of forest, of semi-natural non-forest vegetation, of agricultural areas and of artificial areas (ranging from 0 to 100%). The layer is translated into a landscape resistance layer defining favourable to hostile landscape for species dispersal with increasing resistance values (ranging from 1 to 100) from natural, to agricultural and artificial lands. • Potential GI habitat (*e.g.* forest, 'trees outside forest', grasslands) are identified, as hectares from a given threshold (low or medium) to high share of semi-natural vegetation. The remaining elements are defined as land elements that do not qualify for GI because they are intensively used or human dominated lands with a given resistance value. • The CAPRI data on agricultural gross margin including premiums under CAP Pillar I (€/ha), available per Homogeneous Spatial Mapping Units (1 km^2) is used as proxy for the monetary conversion cost of agriculture to GI habitat areas.
Description of method/tool
The integrated modelling framework available at JRC that generates the maps is based on GUIDOS *Toolbox* for the spatial pattern and landscape mosaic pattern analysis, on the Conefor software for the functional connectivity analysis, on GIS based least-cost paths, and on Python programming language. The functional corridor mapping analysis is enriched with the assessment of the monetary cost of enhancing functional connectivity within the corridor. A monetary cost of conversion of non-habitat cell to habitat is defined as the loss of revenues from agricultural production a farmer would incur if he/she decided to have a certain share of uncultivated land covered by semi-natural vegetation. Simulated new habitat cells are obtained by applying shares within hectares, like for example, with at least 20% semi-natural vegetation to benefit wild bees and other pollinators, or hectares with at least 80% to benefit forest species. For more details, see Estreguil et al. (2013 and 2016).
Application of method and main results
This case study addresses the cost-effective spatial development of a well-connected GI relevant to the integration of forest, agri-environment and regional development policies. The approach is demonstrated over the region of Lombardy in Italy, at regional scale to benefit 'connectivity sensitive' terrestrial species (figures 1 and3) and at micro-scale to benefit pollinators and pest predators (figure 2). Hectares including at least 80% of semi-natural vegetation (SNV) are defined as recommended component of GI to analyse the connectivity of the landscape at regional level for 'connective sensitive terrestrial species' of medium dispersal capability (figure 1). The continuity (morphological shape) of SNV, as well as their surroundings described according to three landscape mosaic types based on natural share (above 60%, 40-60%, below 40%) are assessed over the whole region (subset of the region shown in figure 1 on the left). The functional connectivity of SNV is also assessed for the whole region to benefit 'connectivity sensitive' terrestrial species. Corridors most favourable to species dispersal (with high dispersal probability) are mapped and gaps in connectivity are identified (figure 1 on the right). The same analysis is then conducted at local level for hectares including at least 20% of semi-natural vegetation that are defined as recommended component of GI. The goal is to analyse the connectivity of the landscape at local level for pollinators and pest predators of low dispersal capability and address where to prioritise the allocation of greening subsidies (figure 2). Spatially explicit solutions are then proposed to prioritise improvement actions based on their monetary cost through payments of 'greening' subsidies and their benefit for connectivity (as an example, the new inter-cluster path delineated in figure 1 on the right, the blue areas in figure 2, and at regional scale in figure 3).

Outcome products are spatially explicit maps of GI components with presence/absence of corridors of dispersal, also proposing new paths on where to convert agricultural areas into vegetation to enhance connectivity and quantifying the monetary cost involved. In figure 3, a schematic synoptic view of GI based on existing regional components and including its cost effective potential improvement is proposed as a tool to support decision-makers, particularly to prioritize subsidies at the best cost/benefit places, and to motivate land owners to implement biodiversity friendly measures.

Outcome products

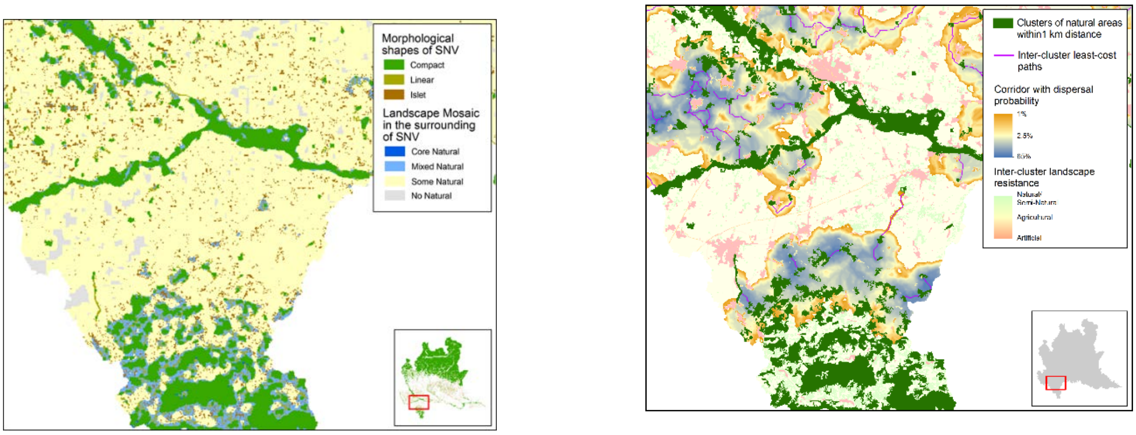


Figure 1. (left) Spatially-explicit map of potential GI networks based on hectares with high natural/semi-natural vegetation share. Their core, compact, linear and islets components are shown, as well as the landscape mosaic pattern in their immediate surroundings. (right) Connectivity of the networks showing their clusters and corridors of dispersal for terrestrial 'connective sensitive' species of medium average capability (500 m in agriculture up to 5,000 m in natural areas). Outside corridors' boundaries, agricultural landscapes are particularly to be considered for restoring vegetation and improving GI.

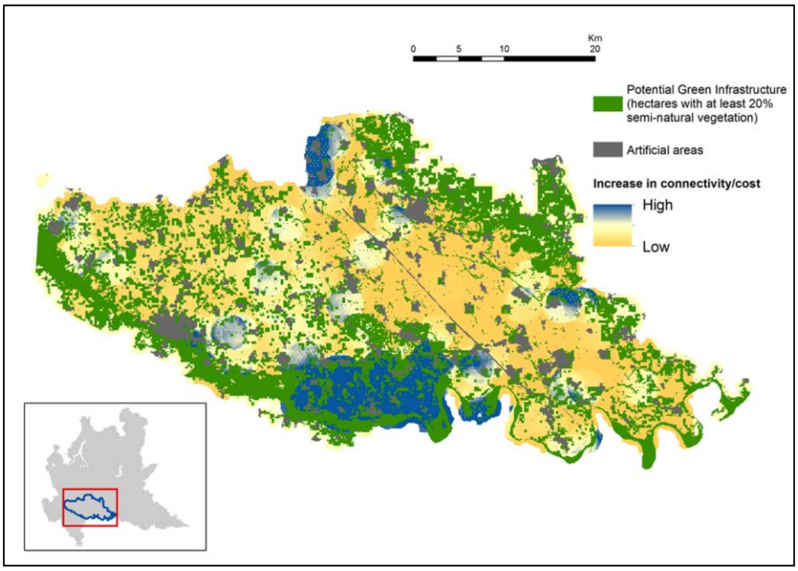


Figure 2. Location of best cost-benefit places for new GI habitats (shown in blue) where the GI network connectivity is most enhanced for a minimized loss of agricultural revenue. The connectivity of GI habitats was computed for pollinators and beneficial predators, *i.e.* flying insects with low dispersal capability (between 200 m and 500 m).

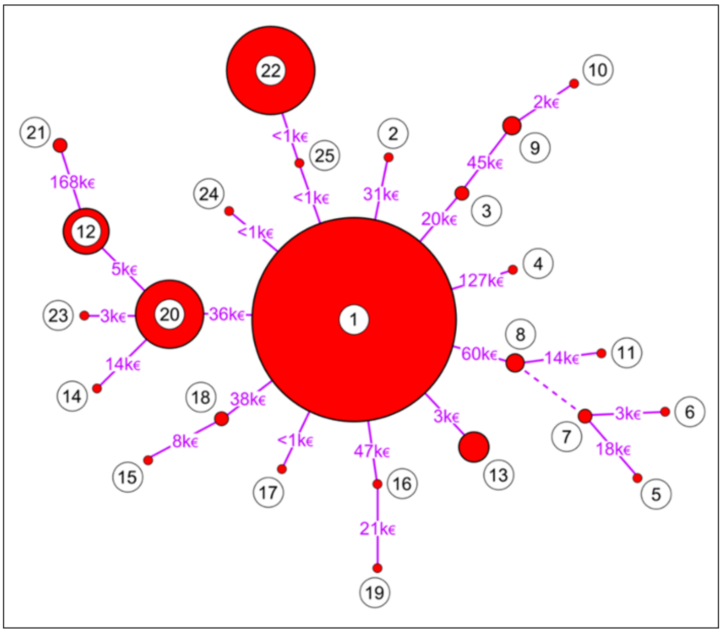


Figure 3. Schematic synoptic representation of GI networks and new cost-benefit paths for enhancing connectivity in Lombardy. GI is made of 25 clusters of habitat with their size proportional to the red circle area. A cluster is formed by one or more habitat patches closer than 1km. 11 clusters are 'functional' *i.e.* habitat patches internally connected by corridors, while 14 are isolated. To improve GI connectivity, 24 new paths (purple links) are identified with the minimum monetary cost involved (k€) by creating new vegetated areas. The average cost per unit area varies between 100€ and 2,500€. Four new paths from cluster 1 (1 to 20, 1 to 22 via 25, 1 to 13) have the best cost-benefit value.

References

Estreguil, C., Caudullo, G., Rega, C., Paracchini, M.L., 2016. Enhancing Connectivity, Improving Green Infrastructure; EUR 28142 EN; doi:10.2788/170924

Estreguil, C., de Rigo, D., Caudullo, G., 2013. A proposal for an integrated modelling framework to characterise habitat pattern. Environmental Modelling & Software, Vol. 52 (February 2014), pp. 176-191, ISSN 1364-8152, doi: 10.1016/j.envsoft.2013.10.011.

Britz, W., P. Witzke (2012): CAPRI model documentation 2012, http://www.caprimodel.org/docs/capri_documentation.pdf.

Comments

- Flexibility of the method to define potential GI components and landscape elements that do not qualify for GI.
- The method proposes spatially explicit solutions with cost-benefit analysis.
- The approach is not species specific and provides a generic approach for mapping functional corridors of dispersal favourable to most species; it is appropriate for territorial GI development and planning at regional level. The methodological concept is easily adaptable to urban.
- Computing time varies from seconds to a few weeks depending on the spatial resolution of data input and the number of potential GI components (thus the number of least-cost paths between them) in the region. For the region of Lombardy, data preparation was circa 2 days and computation was 2 weeks (36 seconds per path).

5.1.7 *MAPPING AND CONNECTIVITY ANALYSIS OF THE AUSTRIAN OPEN GREEN SPACE NETWORK*

Keywords

Prioritisation, connectivity, spatial planning, decision support, restoration, green open space, habitat connectivity, corridors, national, GI maps

General objective and policy relevance of method

- Mapping of the Austrian open green network to support political decision makers.

- Development of an Austria-wide homogenous database reflecting the actual situation of the Austrian open green space network. The developed maps are an essential basis for several responsible local government planning divisions according to the protection and restoration of the Austrian open green space network.
- Evaluation of the open green space network into three categories (intact, warning, disturbed) to target on critical sections with less/lost connectivity for the prioritisation of restoration activities.

What does the method provide answers to?

- Where the most important national and international migration routes in Austria are for all organism groups relying on the existence of a network/mosaic of meadows, pastures and forest.
- In-Situ data available for the identification of barriers within the open green space network.
- Type of barriers that could be identified using Sentinel II data and remote sensing technologies.
- Existing maps of the open green space network from different Austrian federal provinces that are based on different methodologies and varying in timeliness of data (see: www.lebensraumvernetzung.at). Because existing maps are included in some legislative spatial planning documents, these datasets must be considered for a homogenous Austria-wide dataset of open green space. Therefore, one key issue is the development of an Austria-wide standardised and comprehensible mapping approach which takes into account the existing mas from the different Austrian federal provinces in an unambiguous way.

Which stakeholders and practitioners does the method target?

- Spatial planning.
- Nature protection.
- Agriculture.
- Forest and hunting authorities of the federal provinces.
- Research.

Data source used

- For the calculation of the resistance model a dedicated land cover map is used (Figure 1), which is based on Sentinel II satellite images with a spatial resolution of 10 meter.
- Barrier effective landscape elements, like linear transport infrastructure (railroads, motor highways...), were considered using the Austrian wide available GIP dataset (Graph integration platform, further information: http://www.gip.gv.at/home-en.html).
- An unpublished dataset with spatial information about underpasses and bridges (also green bridges) for the linear high traffic infrastructure was taken into account.

Description of method/tool

The whole model is implemented within the ESRI ArcGIS 10.4 environment. The implementation of the algorithms is based on the programming language python using the ArcGIS API for Python. The calculation of the resistance model (Figure 2) is fully based on the basis functionality available in map algebra. This resistance model was used as input dataset for the calculation of the open green space axis. The calculation of the open green space axis is based on cost path algorithm.

The results are reviewed by different experts who take into account the existing maps of the Austrian federal provinces and determine the final spatial location of the open green space network axes.

The last process step is the calculation of a connectivity index for 2x2 km segments. This index represents the cumulative resistance value of the resistance model for the 2 x 2 segment. It is influenced by the spatial distribution of land cover classes within a segment and different topographic analysis according to intersections of the axes with linear high traffic infrastructure.

Application of method and main results

This case study addresses the harmonisation process of existing maps of the open green space networks from the different Austrian federal provinces, which are part of legislative spatial planning instruments and therefore must be considered for a harmonised Austrian wide map of the open green space network.

Outcome products are spatially explicit GIS maps which provide essential information about:

- the spatial location of the best remaining open green space axes (Figure 3).
- connectivity of the open green space network based on 2x2 axis segments (Figure 4).

The map in Figure 4 provides required information for the different planning authorities on federal, provincial and municipality level and enables these authorities to integrate this information in the different available legislative spatial planning instruments. This leads to a legal protection status for these last available permeable open green space connections in Austria.

Furthermore, the data are used e.g. by the Austrian motor- and highways authority (ASFINAG) for the prioritization and evaluation of green bright locations on existing motorways. To guarantee the functionality of these new build up green bridges, the protection and restoration of the open green network around the green bridge location is obligatory. For these and other protection and restoration activates the outcomes of the project represent an essential and solid database.

Outcome products

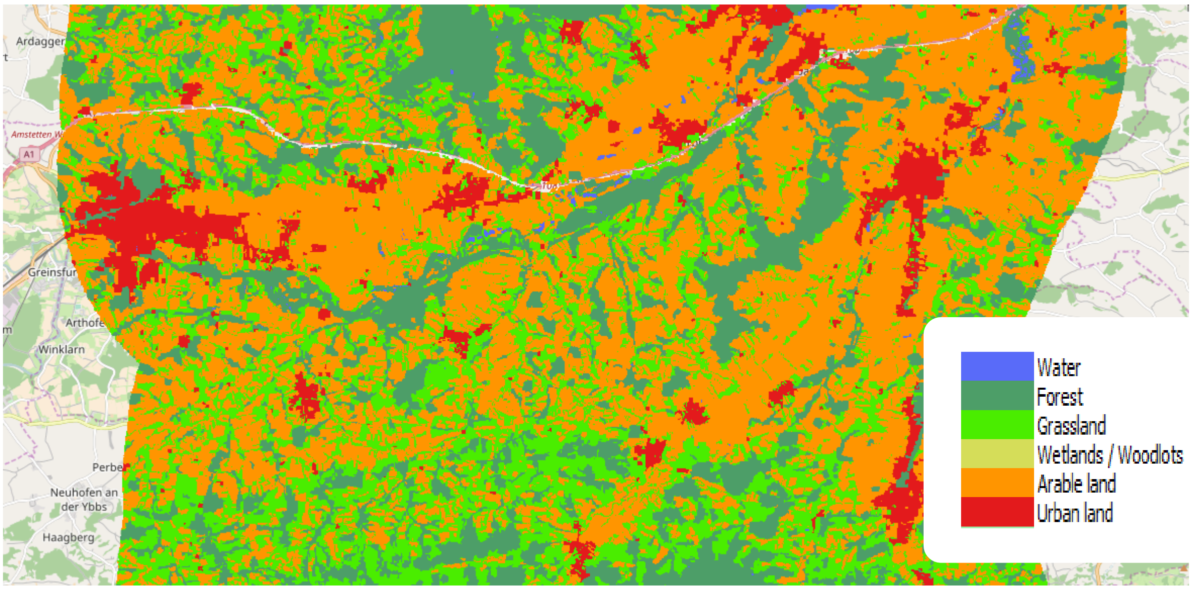


Figure 1. Dedicated Sentinel II data-based land cover map within the Austrian open green space network with a spatial resolution of 10 m. Database for the calculation of the resistance model (Figure 2).

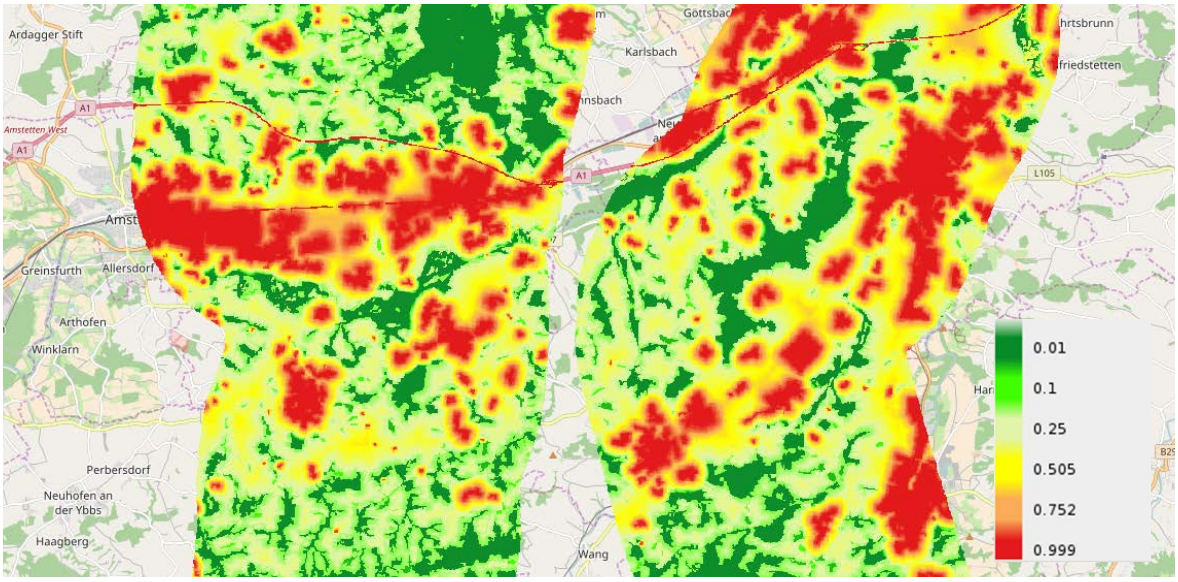


Figure 2. Resistance model reflecting spatial resistance when organisms are migrating though the open green space network. Database for the calculation of the concrete spatial location of the open green space network axes (Figure 3).

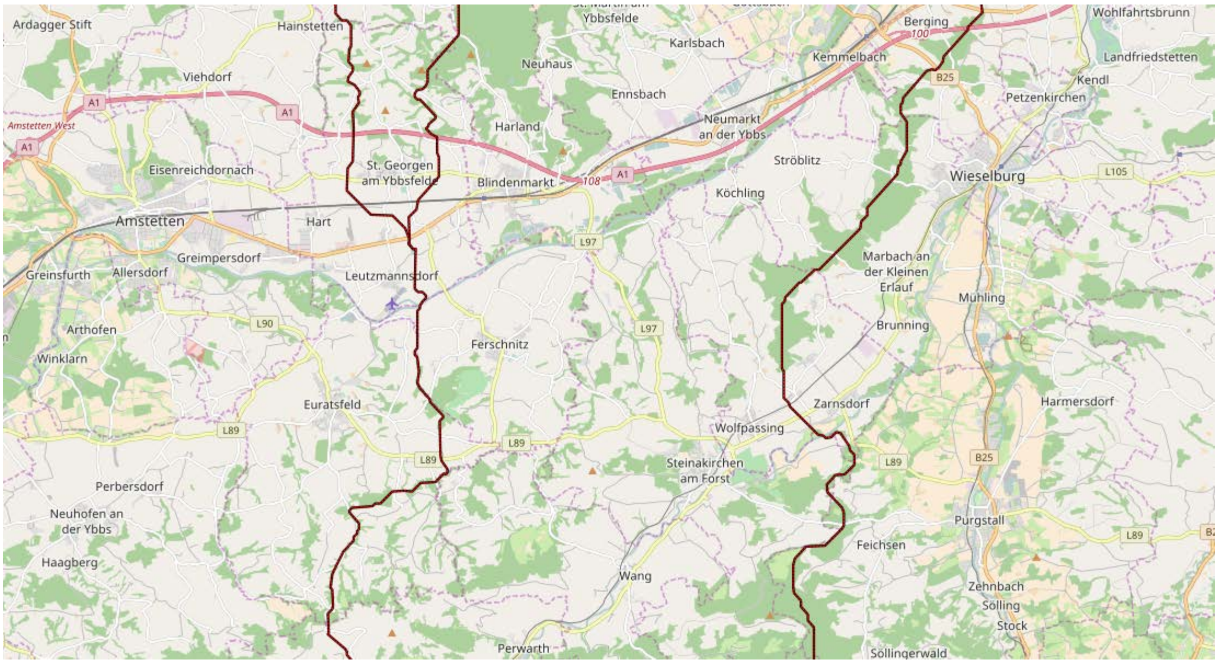


Figure 3. Modelling result of the shortest path analysis. The red lines represent the migration routes with the lowest resistance values. These axes are spit in 2x2 km segments, which represent the spatial frame for the connectivity evaluation of the network (Figure 4).

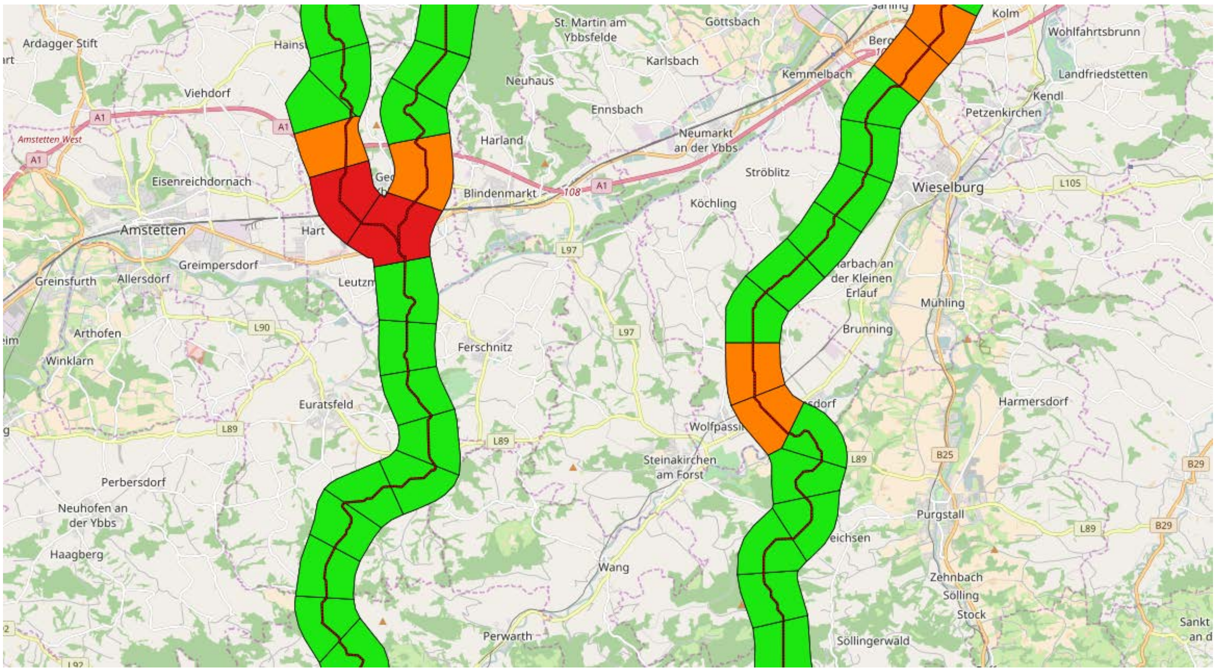


Figure 4. Final result. Spatial explicit location of the migration axes and their quantification according the connectivity based on 2x2 km segments. Red marked segments represent landscape unites with an absolute barrier (e.g motorway, railroad with noise barrier). Orange segments represent landscape units, which are influenced by human activities like mining areas or settlements. Green segments represent intact areas within the open green space network.

References

Grillmayer, R; Proschke, M; Köhler, C., 2007. GIS – Modellierung von wildökologischen Vernetzugspotentialen als Grundlage zur raumplanerischen Absicherung; REAL CORP 2007: To Plan Is Not Enough, At Tech Gate, Vienna, http://programm.corp.at/cdrom2007/archiv/papers2007/corp2007_GRILLMAYER.pdf

Comments

- Transparent and reproducible mapping of the Austrian wide-open green space network.
- Missing information about the actual situation of the open green space networks in most of the neighbour states, which directly influences the functionality of the Austrian open green space networks.

5.1.8 URBAN SPRAWL AND SUBSEQUENT LOSS OF GI BASED ON LAND USE AND CLIMATE CHANGE POLICY SCENARIOS FOR THE COMING DECADES

Keywords

European large urban zones, urban compactness, urban sprawl, landscape mosaic, green areas, land use and climate change policy scenarios.

General objective and policy relevance of method

- To map GI as a "*strategically planned network of natural and semi-natural areas" (European Commission, 2013)* within the urban context
- To characterise and map urban sprawl patterns and processes in European cities, thus enabling comparative analysis of urban growth at the expenses of 'green' and agricultural spaces. To consider large urban zones i.e. including the peri-urban and rural-urban fringe, and their landscape mosaics patterns made of natural, agricultural and urban areas.
- To forecast and map urban growth in the next decades, based on land use and climate change policy scenarios and their impact on land use/land cover dynamics. To identify scenarios promoting urban compactness and minor losses of semi-natural areas within and around cities in Europe.
- To support regional and urban planners from different countries to exchange on their GI urban projects and develop coherent approaches for integrating built up and green spaces in cities and surroundings.

What does the method provide answers to?

Urban patterns are relevant to understand and measure the following urbanisation processes:

- Urban 'nuclearity' which relates to the density (compactness) of built up areas and is linked to short commuting distances between home, services and work.
- Urban sprawl patterns that are described in terms of (1) leapfrogging, *i.e.* the isolated development of built-up clusters that are small in size with respect to the core compact urban areas, (2) "linear branching" from core built-up areas without going to another core areas, and (3) ribbon development, which indicates linear urban features such as along existing roads, whose role is essentially to connect core areas.
- Landscape mosaic patterns including built-up areas, to enable identifying and characterising the infringement of built-up areas onto open semi-natural 'green' areas and farmlands.

Urban patterns and sprawl of European cities are assessed not only over the urban core areas but include the peri-urban and urban-rural fringe, i.e. the so-called Large Urban Zones (also named Functional Urban Areas).

Land use and climate change policy scenarios with a time horizon of 2030 are assessed in terms of their potential to limit urban sprawl and encourage compactness, as well as their impact differences with respect to built-up encroachment and subsequent losses of landscape semi-natural components and more generally on landscape identity in the Large Urban Zones across Europe. This would support decision making on GI planning within cities but also in their surroundings.

Which stakeholders and practitioners does the method target?

- Advisory and service organisations in cities.
- Decision-makers at European and national levels, regional and city planners.

Data source used

- The input data reference layer is the 100-m resolution Corine Land Cover layer from year 2000. Forecast derived land use/cover maps are for year 2030.
- The morphological urban pattern maps are derived from the morphological spatial pattern analysis for the reference year and simulated years. The landscape mosaic pattern maps are derived from the landscape mosaic pattern analysis for the reference year and simulated years. (Estreguil et al, 2013; *GUIDOS Toolbox*)
- Simulated land use/cover maps for year 2030 are obtained from the EU-ClueScanner land use model (Verburg et al, 2011)
- The Large Urban Zones layer (recently renamed as Functional Urban Areas (FUA)) comes from the Urban Atlas datasets from the European Union (now available at https://land.copernicus.eu/local/urban-atlas) and includes cities with more than 100.000 inhabitants as defined by the Urban Audit.

Description of method/tool

The classes of Corine Land Cover layer are aggregated to produce a binary built-up/non-built up map at 1 ha spatial resolution that is used as input for the morphological pattern analysis (MSPA) from the GUIDOS *Toolbox*. Urban form only refers to the actual structural form and compactness of the built-up areas in Europe according to a predefined size or shape, and do not on their content and functionalities. Urban 'nuclearity' is measured by the number and average size of 'core' compact areas within a large urban zone, while 'leapfrogging', 'branching' and 'ribbon development' use respectively the MSPA classes 'islets', 'branches' and 'bridges'. A composite index is developed to characterise urban sprawl according to four morphological expansion patterns.

The landscape mosaic pattern analysis can be run either in GIS or using the GUIDOS *Toolbox*. The derived landscape mosaic pattern map has fifteen landscape pattern categories based on pre-defined thresholds for pre-defined 3 land cover/land use classes within a pre-defined radius. In this study, the landscape surroundings of all built-up land are characterised according to the proportion of natural, agricultural, built-up areas within a 7-km radius.

Land use model scenarios are run from 2000 to 2030 using the pan-European EuClueScanner land use model. They are two baseline scenarios from IPCC *i.e.* the B1 (IPCC-SRES B1 “Global cooperation”) and the biofuel BF (BF: IPCC-SRES A2 “Continental Markets” with assumption that 10% renewable energy target for transport sector will come from biofuels (BF), and three hypothetical policy alternatives (BFnf: policy promoting biofuel with for the EU, restricted land conversion of forests into agricultural land, B-Biodiversity' policy promoting conservation, and B- Soil and climate change alternative: policy aiming at mitigating and adapting to climate change, also includes soil preservation actions). From a natural resources point of view, there is an emphasis on ecosystem services with a reduction of 33% on agricultural income support with the exception of less favoured areas, which are maintained under the second pillar of the Common Agriculture Policy.

The EUClueScanner, based on the Land Use Scanner and Clue, is a framework for Land Use change modelling at a European scale and is available as part of the Land-Use-based Integrated Sustainability Assessment Modelling that is developed at JRC (LUISA). The Pan-European EU-ClueScanner in this study was based on a one km resolution grid for the land use model runs.

Based on the land use scenarios, seven land cover/land use maps are obtained for the year 2030. For each scenario changes between 2000 and 2030 are analysed within the Large Urban Zones across Europe and compared to answer:

- The degree to what the urban compactness is affected by each scenario and which scenario affects less natural and semi-natural areas, as a proxy for GI components.
- Whether or not landscape mosaic types influence the compactness of the urban expansion patterns.

Application of method and main results

The urban pattern and sprawl are characterised by the degree of compactness of urban land e.g. nuclearity, ribbon development, leapfrogging and branching processes (Figure 1).

The land use/cover map of the reference year is translated into a landscape mosaic pattern map (Figure 2). The fifteen landscape mosaic types describe the 7 km radius surroundings of each hectare of lands in terms of agricultural and/or natural and/or built up surfaces, as well as their predominance, within the large urban zones. This provides a spatially explicit indication of where potential GI components are and how they are surrounded by built-up and agricultural areas.

Two baseline scenarios and three hypothetical policy alternatives, are run and simulations of urban expansion patterns are analysed and compared with a time horizon 2030. Among the 305 large urban zones, the top 5% of cities showing the largest increase in urban areas are listed (Figure 3 left). For those cities, the landscape mosaic types that are present in the reference year are further documented for only the new built up surfaces in 2030.

The LUZs behaved differently in part because the unique landscape in each LUZ, from a morphological and compositional point of view. Land demand drove urban growth, but the constraints and incentives placed upon the actual allocation of the built-up areas for each policy alternative determined whether or not conversion occurred in the LUZ or elsewhere, for example in the hinterland. Mixed landscape mosaic with no particular dominant class are predominantly converted to built-up lands in all scenarios (Figure 3 right). Under the B1 scenario, the biodiversity policy alternative was well configured in terms of limiting urban sprawl, and more than half of the new urban land came from mixed landscape mosaic, followed by 20% with preferably built up and agriculture or natural land.

The landscape mosaic, and particularly mixed landscape with no dominant class, can thus be considered as one proxy to determine which urban areas are more likely to have less compact urban expansion patterns for scenarios with an increase in land claims for built-up areas.

Outcome products

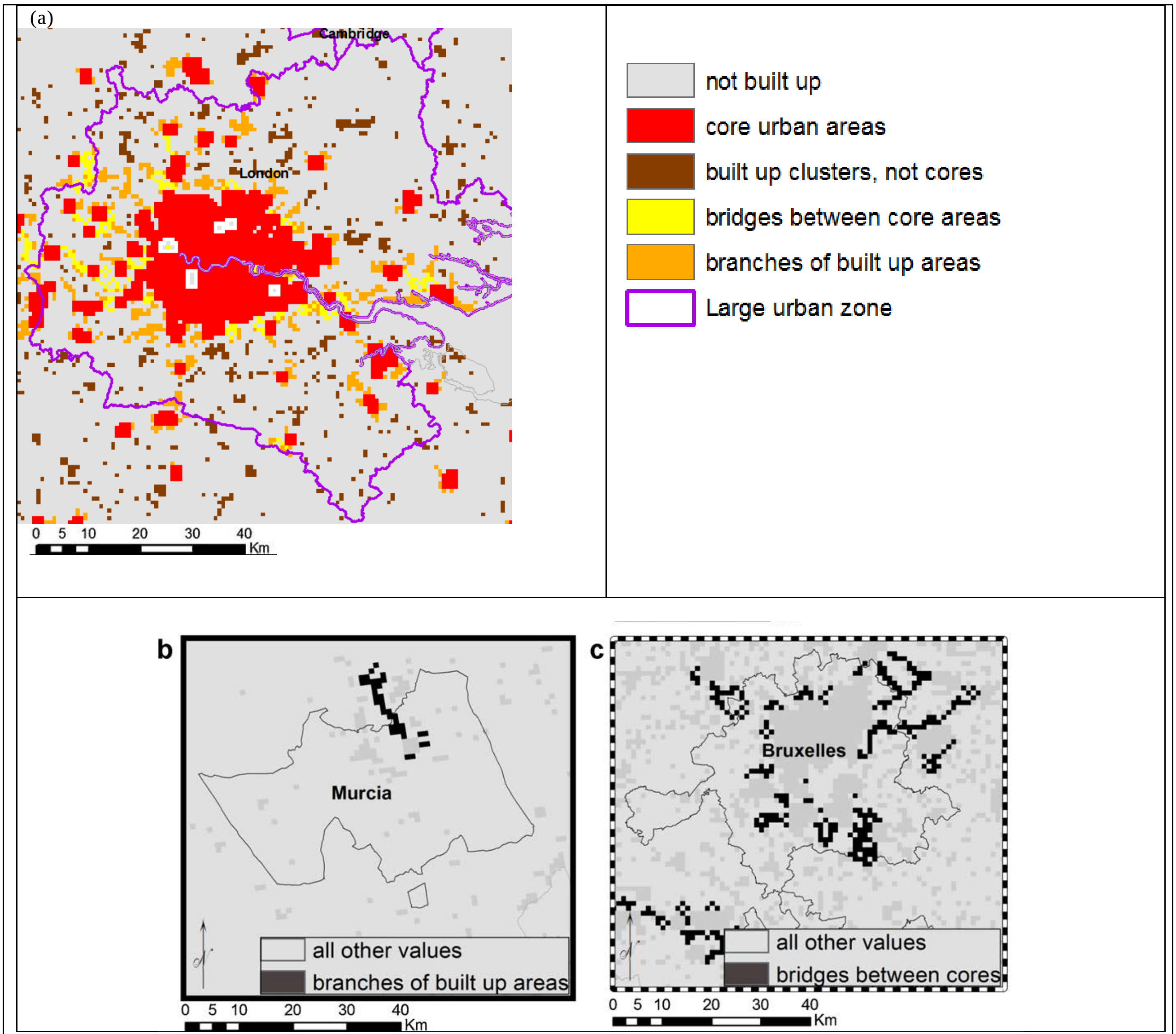


Figure 1. Characterisation of urban pattern at year 2000 : (a) urban components from the morphological analysis illustrated for London, nuclearity (only core in red shade) and the urban sprawl processes of (a) leapfrogging (only built up clusters, islets with no core), (b) branching in Murcia (only branches) and (c) ribbon development in Brussels (only bridges between core urban areas).

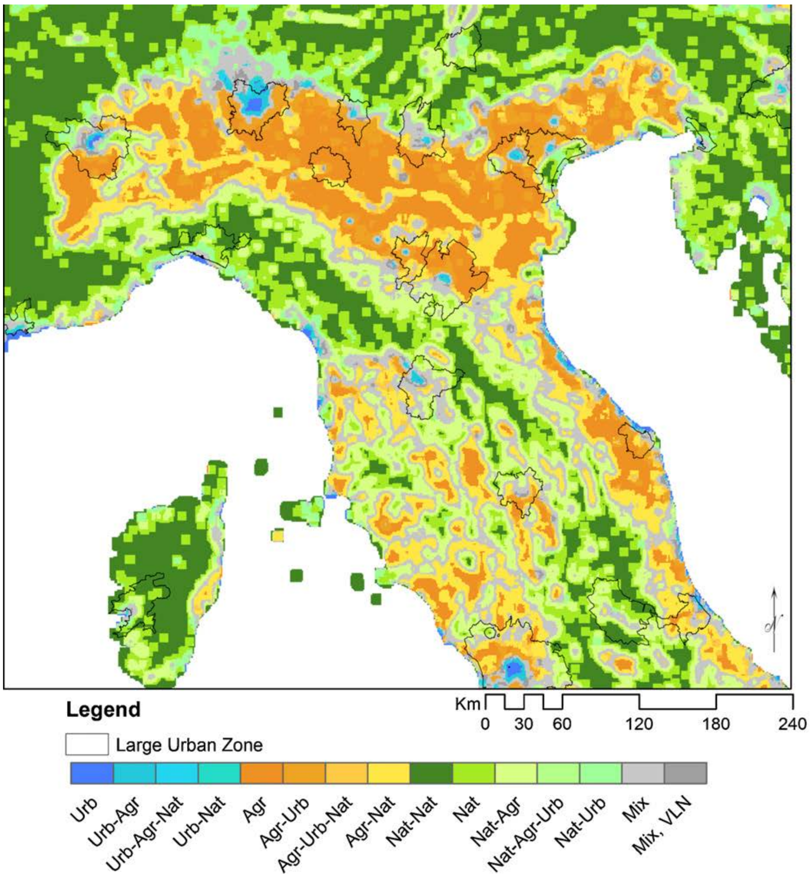


Figure 2. Landscape mosaic pattern map according to fifteen landscape mosaic types and Large Urban Zones (overlay in black) in Northern Italy. The (7 km radius) surroundings of each hectare of land is characterised according to the proportion of 3 classes and their pre-dominance (more than 60%): natural (Nat, when predominant in green shades), agricultural (Agr, when predominant in orange shades) and built-up (Urb, when predominant in blue shades), no dominant class (Mix, Mix with very low vegetation in grey shades).

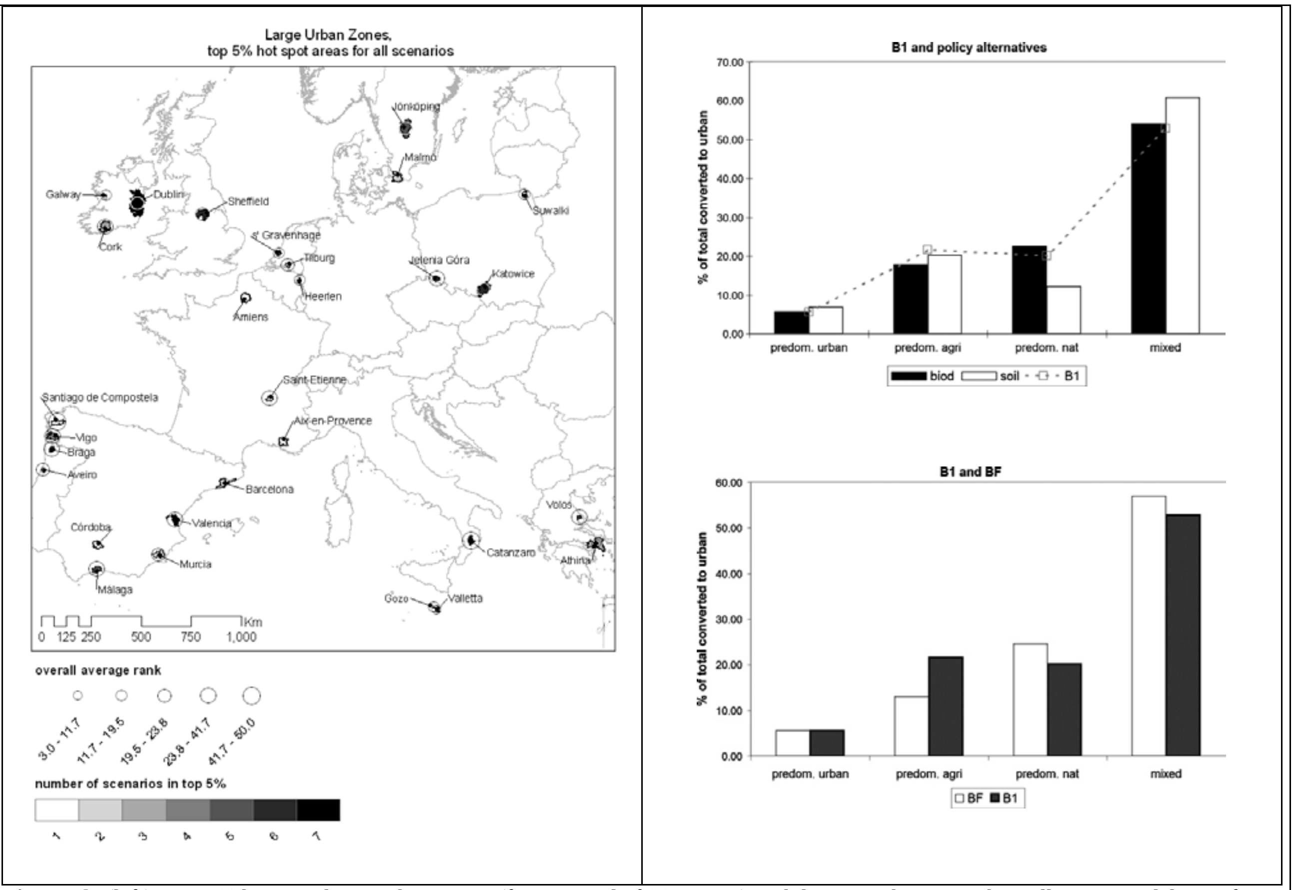


Figure 3. (left) Top 5 % hot spot large urban zones (from a total of 305 LUZs) with largest urban growth in all seven model runs from the land use scenarios and policy alternatives with a time horizon of 2030. (right) Landscape mosaic types at year 2000 converted to built-up areas by year 2030 according to the B1 baseline scenario ('global cooperation') and its three policy alternatives ('Biodiversity', 'Soil and Climate Change' and according to B1 and BF (biofuel) scenarios.

References

Mubareka, S., Koomen, E., Estreguil, C., & Lavalle, C. (2011). Development of a composite index of urban compactness for land use modelling applications. Landscape and Urban Planning, 103(3-4), 303-317. DOI: 10.1016/j.landurbplan.2011.08.012

Verburg, P. H., Lesschen, J. P., Koomen, E. & Perez-Soba, M. 2011 Simulating Land Use Policies Targeted to Protect Biodiversity with the CLUE-Scanner Model. In : Land Use, Climate Change and Biodiversity Modeling: Perspectives and Applications. Trisurat, Y., Shrestha, R. P. & Alkemade, R. (eds.). Hershey: IGI Global, p. 119-132. Doi: 10.4018/978-1-60960-619-0.ch006

Lavalle C, Baranzelli C, Batista e Silva F, Mubareka S, Rocha Gomes C, Koomen E, Hilferink M (2011) A high resolution land use/cover modelling framework for Europe. In: ICCSA 2011, Part I, LNCS 6782, pp 60–75

Comments

The analysis of urban pattern and sprawl could now be made at a finer resolution than the currently used CLC data input thanks to the newly available European-wide Copernicus land cover/land use data and Urban Atlas year 2012. This would enable mapping and analysing the pattern of urban GI components across European cities.

The resolution of land use modelling based on the LUISA platform could also be upgraded to one hectare.

The LUISA platform accommodates multiple policy scenarios in order to represent different facets of EU policy that would be of interest to assess in the urban development context.

5.2 ECOSYSTEM SERVICE BASED MAPPING

5.2.1 SOCIETAL FUNCTIONS OF URBAN GREEN TO ACHIEVE A HEALTHY CITY, THE CASE OF UTRECHT IN THE NETHERLANDS

Keywords

Regulating temperature, air quality, water storage and drainage, noise reduction, aesthetics and recreation, multi-functional GI.

General objective and policy relevance of method

To identify greening scenarios and design principles (including green roofs, green facades, tree borders, etc.) to plan for a healthier environment in the city.

What does the method provide answers to?

Utrecht is a medieval city in the centre of the Netherlands. Because of its geographic location, the city is a hub of highways, waterways and railroads. With its population of 350.000 inhabitants, Utrecht is one of the largest cities in the country. The municipality recognizes the increasing pressure on the living environment by a multitude of functions, resulting in air pollution, stress by noise, soil sealing, flooding and heat islands. The city wants to implement measures to counteract these effects by focusing on GI. These measures should also solve specific issues of the existing GI, like plague vulnerability for single-species tree lanes and bad air circulation at busy roads covered by trees. *What planning principles should be applied and where?*

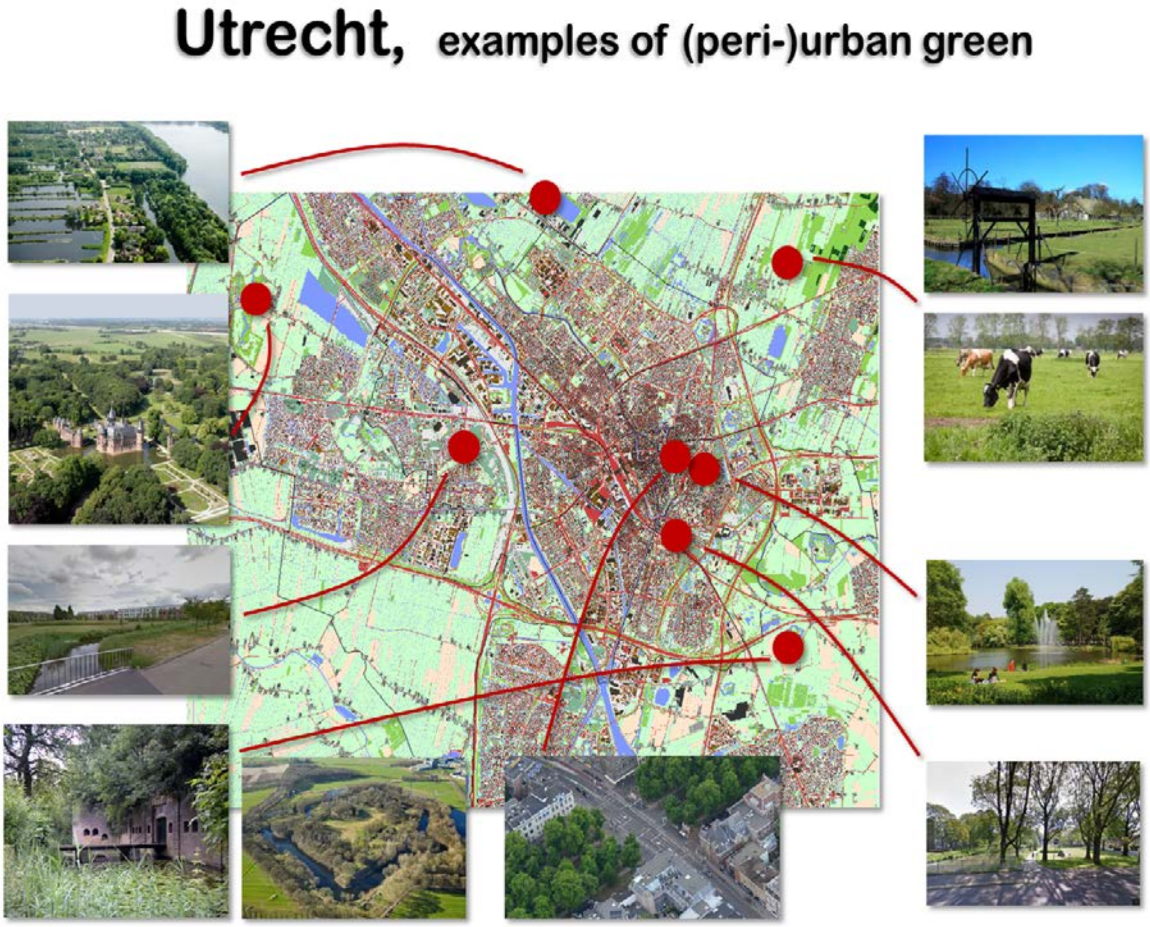


Figure 1: Typical (peri-)urban green in the city of Utrecht, the Netherlands.

What stakeholders and practitioners does the method target?

Municipal civil servants on green design, soil, energy, health, air quality and experts on nature-based solutions.

Data source used

Local high resolution (5x5m) spatial information provided by the municipal office, including: land use, exposure-, vulnerability-, adaptive capacity- and risk-maps on (coastal and river) floods and urban heat island effects (on biodiversity and health), and potential Nature Based Solutions (NBS).

Description of method/tool

QUICKScan is a participatory modelling method that links stakeholder and decision-maker knowledge and preferences to available spatial and spatio-statistical data. It is designed for group use. Workshops are undertaken where an iterative approach is followed, starting with simple (knowledge-based) rules and step-by-step adding complexity, using the participants' interpretation of model-results. Successive iterations are used to 1) improve the quality of the model, 2) try out alternative (spatial) plans and policy options and, 3) include different stakeholder values and perspectives (http://www.quickscan.pro).

Application of the method and main results

Identified scenarios, design principles and hotspots for GI implementations and dismissed non-effective options (e.g. GI for noise reduction). As a first step, storytelling by participants, supported by maps of the city, converged mental images of the areas under pressure by e.g. noise, air pollution, heat island, etc. This was followed by an inventory of options for counteractive measures, including green management regimes and changing accessibility. In a final step, the feasibility and effectiveness of solutions were mapped building on the consensus of all participants (i.e. academia, practitioners and policy makers), and future scenarios were created from those solutions (see Figure 2 for an example of participatory modelling outputs).

Outcome products

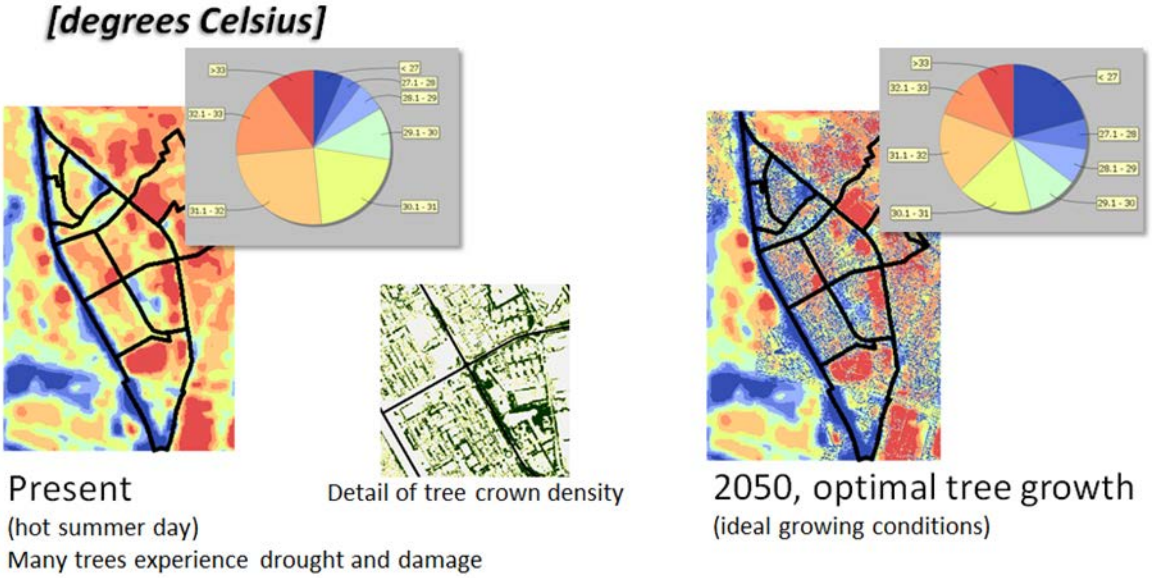


Figure 2: Cooling effect of tree presence in the city of Utrecht: present conditions and future scenario.

References

Verweij, P., Janssen, S., Braat, L., van Eupen, M., Perez-Soba, M., Winograd, M., de Winter, W., Cormont, A., 2016, *QUICKScan as a quick and participatory methodology for problem identification and scoping in policy processes*, Environmental Science & Policy, 66, 47-61

http://www.quickscan.pro/node/51

Comments

- The method speeds up the first stages of the policy cycle: gaining understanding, finding evidence, identifying data and knowledge gaps and the rapid evaluation of strategies when doing impact assessments.
- The method stimulates and works interdisciplinary. Each individual responds to the visualisations of modelled results, which is then discussed by the group. This proves that it is possible to do an assessment without complex, time consuming and expensive modelling.
- If the stakeholders don't bring in important information you might miss out the effects that make a difference.
- Workshop participants asked themselves how strong the evidence-base of the results of a workshop will be back in the political arena.
- The method relies heavily on the availability of spatial data. If the data is of poor quality results will subsequently be poor.

5.2.2 GREEN INFRASTRUCTURE FOR CLIMATE PROOFING, THE CASE OF DONOSTIA-SAN SEBASTIAN, SPAIN

Keywords

Health, biodiversity, river flooding, coastal flooding, heat waves, urban heat, nature-based solutions.

General objective and policy relevance of method

To identify the hotspots (high priority areas for action) with regards to flooding and heat stress, as input in the process of elaborating the city's climate change adaptation plan.

What does the method provide answers to?

San Sebastian is a coastal city of just below the 200.000 inhabitants in the Basque country (north of Spain, Figure 1). Its main economic activities are commerce and tourism. San Sebastian features an oceanic climate, but it experiences an increased amount of extreme climatic events such as severe storms, river flooding and heat waves. The city wants to implement measures to counteract the climate change effects. *Where are the high priority areas for action located?*

Figure 1. Image of the climate change-vulnerable area of Donostia-San Sebastian, Spain.

Which stakeholders and practitioners does the method target?

- Municipal civil servants on environment.
- Water management.
- Urban planning.
- GI.
- Population and experts on climate change adaptation and nature-based solutions.

Data source used

Local high resolution (5x5m) spatial information provided by the municipal office, including: land use, exposure-, vulnerability-, adaptive capacity- and risk-maps on (coastal and river) floods and urban heat island effects (on biodiversity and health), potential nature-based solutions.

Description of method/tool

QUICKScan is a participatory modelling method that links stakeholder and decision-maker knowledge and preferences to available spatial and spatio-statistical data. It is designed for group use. Workshops use an iterative approach, starting with simple (knowledge-based) rules and gradually adding complexity, using the participants' interpretation of model-results. Successive iterations are used to 1) improve the quality of the model, 2) try out alternative (spatial) plans and policy options and, 3) include different stakeholder values and perspectives (http://www.quickscan.pro).

Application of method and main results

Helping the demand articulation for defining GI and agreement on the hotspot areas. As a first step, storytelling by participants, supported by maps of the city, were converged into mental images of the climate change-vulnerable areas. Causes of natural disasters were listed. This was followed by an inventory of options for counteractive measures and their possibilities for application. Subsequently, these were mapped by linking solutions to topographical features. In a final step, the feasibility and effectiveness of solutions were mapped (Figure 2) building on the consensus of all participants, including academia, practitioners and policy makers.

Outcome products

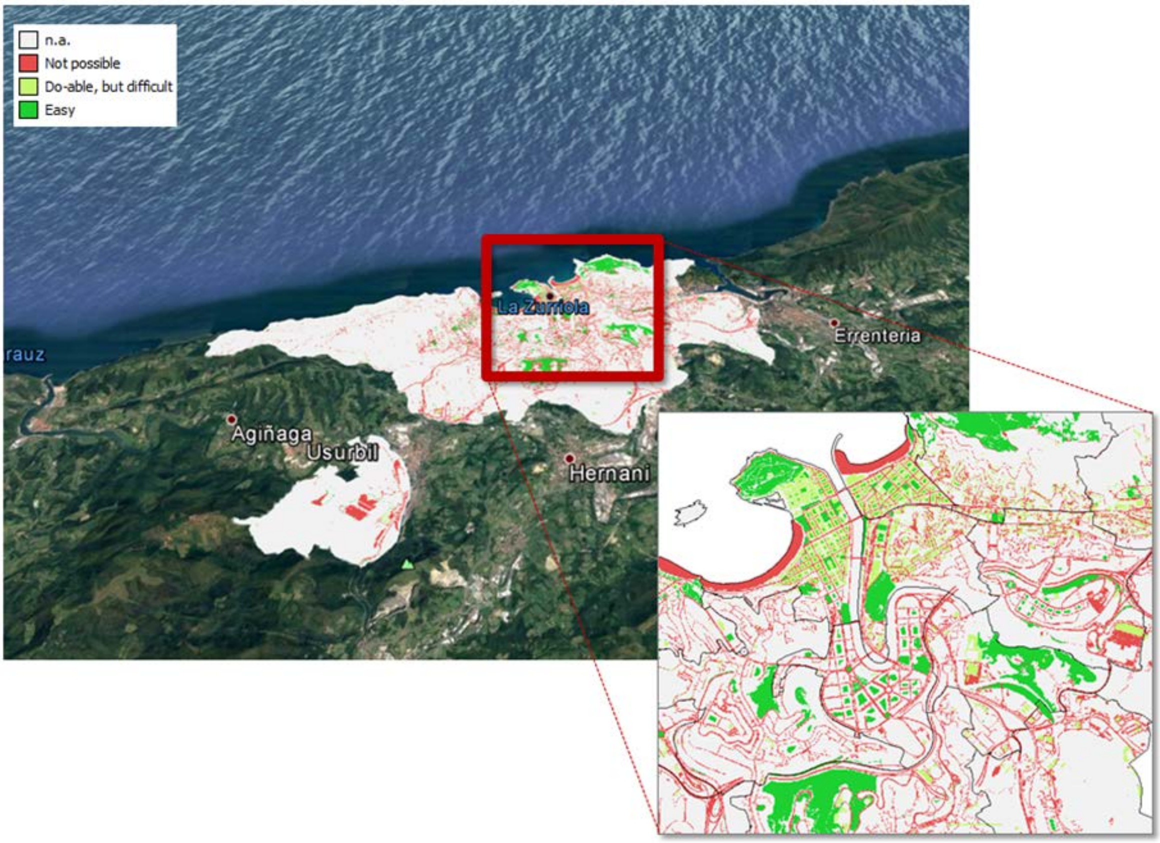


Figure 2. Possibilities for application of counteractive measures against impacts of climate change.

References

Verweij, P., Janssen, S., Braat, L., van Eupen, M., Perez-Soba, M., Winograd, M., de Winter, W., Cormont, A., 2016, *QUICKScan as a quick and participatory methodology for problem identification and scoping in policy processes*, Environmental Science & Policy, 66, 47-61.

http://www.quickscan.pro/node/51

Comments

- The method speeds up the first stages of the policy cycle: gaining understanding, finding evidence, identifying data and knowledge gaps and the rapid evaluation of strategies when doing impact assessments.
- The method stimulates to truly work interdisciplinary. Each individual response to the visualisations of modelled results, which is then discussed by the group
- This proves it is possible to do an assessment without complex, time consuming and expensive modelling.
- If the stakeholders don't bring in important information you might miss out the effects that make a difference.
- Workshop participants asked themselves how strong the evidence-base of the results of a workshop will be back in the political arena.
- The method heavily relies on the availability of spatial data. If the data is of poor quality you will also get poor results.

5.2.3 *PROVIDING ECOSYSTEM SERVICES THROUGH NATURA 2000 LINKAGES: TOWARDS A CONNECTED AND MULTI-FUNCTIONAL GI*

Keywords

GI, ecosystem services, protected areas, Natura 2000, functional connectivity, corridors, transboundary connectivity, multi-functional landscapes.

General objective and policy relevance of method

- To identify and prioritize a corridor network that sustains Natura 2000 connectivity.

  The connectivity of protected areas, and notably of Natura 2000 sites, is a key part of the EU GI Strategy, of the EU Biodiversity Strategy to 2020, and of the Habitats Directive. It is specifically addressed in action 12 of the Action Plan for nature, people and the economy adopted in 2017[51].

- To support the design and deployment of a multi-functional GI, illustrating how Natura 2000 connectivity and the provision of multiple ecosystem services can be jointly assessed and prioritized.

  The EU GI Strategy promotes the deployment of a "strategically planned network of natural and semi-natural areas designed and managed to deliver a wide range of ecosystem services". This strategy aims to ensure that the protection, restoration, creation and enhancement of green infrastructure become an integral part of spatial planning and territorial development. The Natura 2000 network constitutes the backbone of the EU green infrastructure.

- To integrate ecosystem services into decision-making.

  The maintenance and enhancement of ecosystem services by stablishing GI is the main goal of the Target 2 of the EU Biodiversity Strategy to 2020. The need to promote the integration of ecosystem services into decision-making is stated in action 1 of the Action Plan for nature, people and the economy adopted in 2017.

What does the method provide answers to?

- Where key corridors between Natura 2000 are located.
- Which corridors and landscapes should be prioritized for conservation and restoration actions.
- Whether key areas for connectivity are important in delivering ecosystem services.
- Whether it is possible to build a coordinated GI network that enhances multiple benefits for nature and humans.

Which stakeholders and practitioners does the method target?

- Decision-makers at national and regional levels.
- DGs of the European Commission.
- Land use planners.
- Conservation practitioners.
- NGOs.

Data sources used

The case study focuses on mainland Spain (≈ 500,000 km^2), combining the results of a connectivity assessment for the Natura 2000 woodland sites performed by Universidad Politécnica de Madrid and WWF-Spain (De la Fuente et al. 2018) with the EU-wide maps of ecosystem services developed in the JRC by Maes et al. (2015).

The connectivity analyses were separately conducted for three woodland habitats (closed mature forest, open forest and shrub), and determined the corridors between all Natura 2000 sites covered by any of these habitats, considering the landscape heterogeneity and resistance to species movements in all mainland Spain and in the transboundary areas in Portugal and France (De la Fuente et al. 2018). The Natura 2000 sites that were considered as focal sites to connect represented more than 90% of the total area covered by Natura 2000 sites in Spain. The data sources used for these connectivity analyses were the following:

Map of Natura 2000 sites in mainland Spain[52].

Forest Map of Spain at a scale 1:50,000 (minimum mapped unit of 2.5 ha for forests)[53], which gives information on forest canopy cover and development stage in each patch. It was used to characterize the distribution and abundance of the woodland habitats in the Natura 2000 sites.

SIOSE land cover map of Spain[54], with a scale 1:25,000 and a minimum mapped unit of 2 ha. This map was used to obtain a fine-scale mapping of landscape heterogeneity and land cover resistance to movement.

Corine Land Cover 2006 (with a spatial resolution of 100 m)[55] to consider potential patterns of transboundary connectivity by accounting for landscape resistance to movement in Portugal and France.

OpenStreetMap[56] to account for the resistance to movement from transport infrastructure in Spain, Portugal and France.

Four ecosystem services were considered in the analyses: soil erosion control, crop pollination, outdoor recreation and water retention. The data sources used to develop these ecosystem service maps were the following (Maes et al. 2015):

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[51] Available at http://ec.europa.eu/environment/nature/legislation/fitness_check/action_plan/index_en.htm

[52] Latest version for all the EU available at https://www.eea.europa.eu/data-and-maps/data/natura-8 and for Spain at http://www.mapama.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/red_natura_2000_inf_disp.aspx. The Natura 2000 sites that were considered as focal sites to connect represent

[53] Map developed in coordination with the Third Spanish National Forest Inventory by the Spanish Ministry of Agriculture and Fisheries, Food and Environment. Available at http://www.mapama.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/mfe50.aspx

[54] Available at http://www.siose.es/

[55] Latest version available at http://land.copernicus.eu/pan-european/corine-land-cover

[56] https://www.openstreetmap.org

Common for all ecosystem services: Land cover map of 2010 for the EU Reference Scenario simulated by the LUISA platform with a spatial resolution of 100 m (Baranzelli et al. 2014).

Specifically, for soil erosion control: MODIS NDVI product of 2009 with a 250 meter pixel resolution[57], observed precipitation from the European Climate Assessment and dataset (E-OBS) for 2010[58], topographic data, soil erodibility from the European Soil Database (ESDB)[59]

Specifically, for crop pollination: High Natural Value farmland 2006[60], AGRI4CAST for solar radiation and temperature[61].

Specifically, for outdoor recreation: TeleAtlas MultiNet dataset 2009, High Natural Value farmland 2006[9], Nationally designated areas[62].

Specifically, for water retention: slope derived from the Global Digital Elevation Model at 90 m resolution[63], Leaf Area Index[64], environmental zones[65], total available water capacity from the European Soil database (ESDB[8]), parent material (ESDB), hydrological class (ESDB), European Soil Sealing Map[66].

Description of method/tool

The identification and prioritization of corridors between Natura 2000 sites used a combination of methods for functional connectivity analysis across heterogeneous landscapes, which included least-cost based modelling, the Probability of Connectivity metric, and a resistance surface with a spatial resolution of 100 m that was parameterized to capture the difficulty for movement of forest/woodland mammals through different land covers. Corridors were determined between the central points of the Natura 2000 sites, so that the corridor trajectory, characteristics and potential bottlenecks could be evaluated both in the protected and unprotected landscapes. The variable width of the permeable land strips along the corridors (corridor width) was also considered (Figure 1). Corridors were prioritized for their importance for Natura 2000 connectivity. Two software tools were used in these connectivity analyses: Linkage Mapper and Conefor (see the description of these tools in Section 4.2). Further details are provided in De la Fuente et al. (2018).

The maps for the four considered ecosystem services were developed with the Ecosystem Service Mapping Tool (ESTIMAP)[67]. ESTIMAP is a GIS model-based approach to quantify and model ecosystem services. Models are developed at EU scale and the spatial resolution varies across ecosystem services depending on the available datasets at EU level.

The key corridors between Natura 2000 sites, defined as the 25% of the corridors that most contribute to maintain the connectivity of the Natura 2000 network for the three considered habitats, were assessed in their capacity to deliver ecosystem services considering only the part of these corridors located in the unprotected landscapes (outside Natura 2000). For each key corridor, we calculated the ratio between the average of each service along the corridor and the average of the service in the unprotected landscapes. We identified whether each corridor was above or below the average of the service in the unprotected landscapes, and counted the number of ecosystem services that were above the average in each corridor (Figure 2).

Application of method and main results

1. Most of the key corridors between Natura 2000 sites rank high as areas delivering multiple ecosystem services

65 % of the key corridors deliver ecosystem services above the average of the landscapes outside Natura 2000 (corridors in light and dark green, Figure 2). An additional 33 % of the corridors are above the average for half of the ecosystem services considered (in yellow, Figure 2). The results for individual ecosystem services are shown in Figure 3.

2. Key Natura 2000 corridors could be prioritized to become part of a European GI because of their multi-functionality

Corridors in green in Figure 2, and also but to a lower extent those in yellow, identify areas that are good to promote connectivity while delivering multiple ecosystem services. They could effectively contribute to the development of a multi-functional GI.

3. Transboundary corridors are important both for connectivity and ecosystem service delivery

The obtained results highlight the importance of the transboundary corridors, crossing mainly over Portugal (and to a lesser extent over the French side of the Pyrenees) to connect Natura 2000 sites of Spain. These corridors not only guarantee the connectivity of Natura 2000, but they also contribute to the delivery of multiple ecosystem services (Figures 2 and 3).

4. The need of coordinated restoration actions for connectivity and ecosystem services

57 https://modis.gsfc.nasa.gov/data/dataprod/mod13.php

58 http://www.ecad.eu/

59 https://esdac.jrc.ec.europa.eu/resource-type/datasets

60 https://www.eea.europa.eu/data-and-maps/data/high-nature-value-farmland

61 http://agri4cast.jrc.ec.europa.eu/DataPortal/Index.aspx

62 https://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-12

63 http://srtm.csi.cgiar.org/

64 http://data.jrc.ec.europa.eu/dataset/jrc-mappe-europe-setup-d-18-lai

65 http://inspire.ec.europa.eu/codelist/EnvironmentalStratificationClassificationValue

66 http://www.eea.europa.eu/data-and-maps/explore-interactive-maps/european-soil-sealing-v2

67 https://ec.europa.eu/jrc/en/publication/estimap

Corridors in red and orange (Figure 2), which represent only 2 % of the total number of corridors, increase the connectivity of the Natura 2000 sites but deliver a limited number of ecosystem services, at quantities lower than the average delivered by landscapes outside Natura 2000. Given the connectivity importance of these corridors, specific restoration measures might be considered to increase their multi-service delivery. However, the restoration measures to apply should be aligned with the local/regional demand of each specific ecosystem service.

5. Building a multi-functional European GI

This case study provides a useful example of integration of connectivity of the Natura 2000 network and ecosystem service delivery that could be further developed at EU level to improve decision support to the GI initiative. It tentatively shows that it is possible to build a multi-functional European GI, formed by the Natura 2000 sites and the corridors between them, which safeguards both connectivity and the provision of multiple ecosystem services in Europe. The case study illustrates the considerable added value of a set of available datasets and methods and its interest and potential of application in different European countries as well as in a EU-wide assessment.

Outcome products

Based on De la Fuente et al. (2018) and on Maes et al. (2015), a number of maps and spatially explicit products have been produced for mainland Spain, as shown in the next figures.

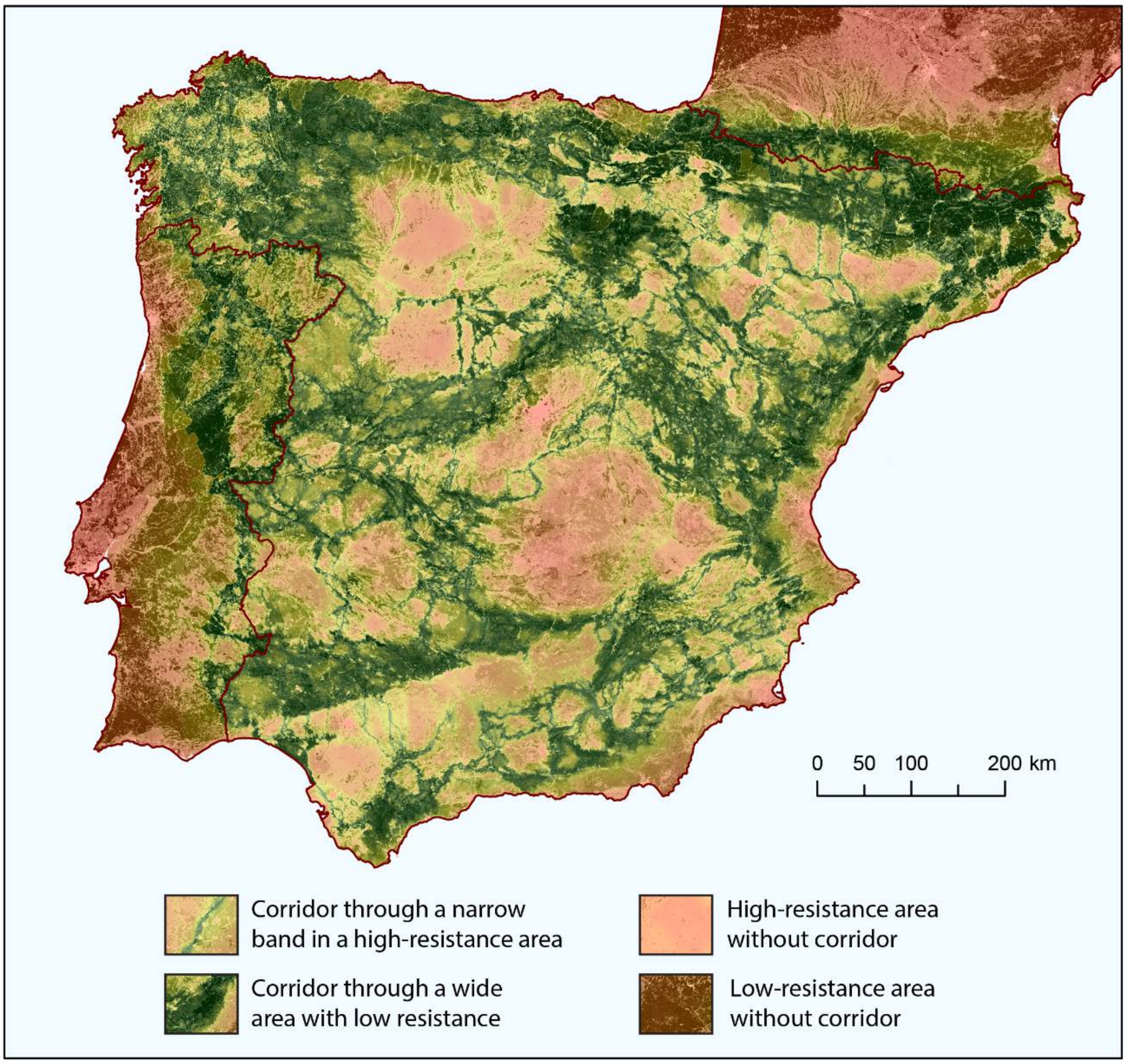


Figure 1. Map of the corridors of variable width between the Natura 2000 woodland sites in mainland Spain (De la Fuente et al. 2018). The corridor maps depict four categories of land regarding connectivity (as indicated in the graphical legend) and intermediate cases between them. A subset of these corridors corresponding to the key corridor sectors outside Natura 2000 that most contribute (top 25%) to maintain the connectivity of the Natura 2000 sites was considered to evaluate ecosystem service provision; these key corridors are shown in Figures 2 and 3, represented by the lines (central axis) along the corridors.

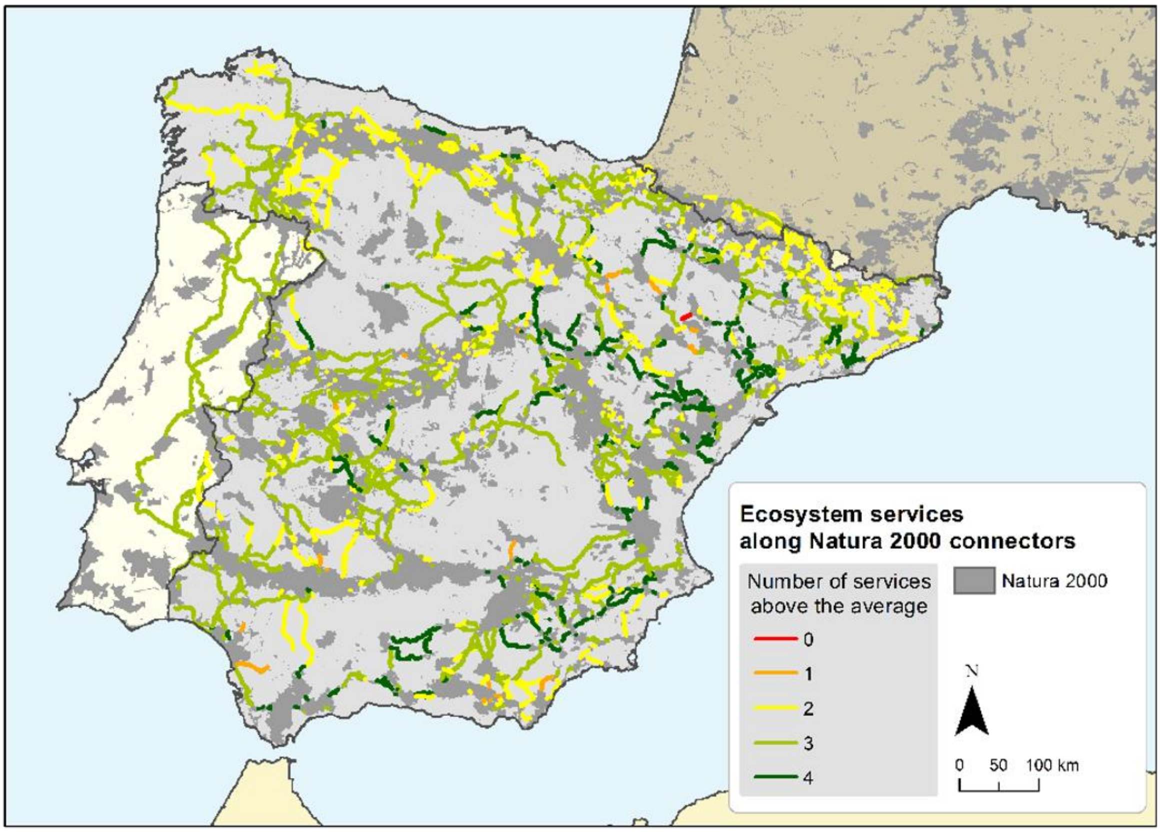


Figure 2. Assessment of the delivery of multiple ecosystem services in the corridors between Natura 2000 sites of Spain. The figure indicates, from red to dark green, corridors with an increasing number of ecosystem services above the average service delivery outside Natura 2000.

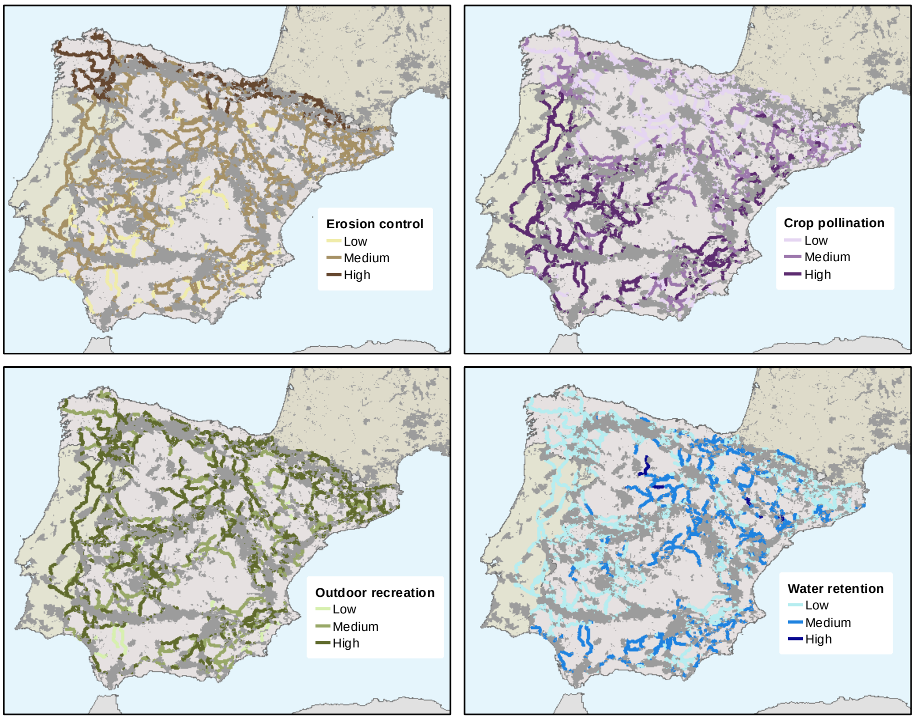


Figure 3. Assessment of the provision of each ecosystem service along Natura 2000 corridors. Low, medium and high refer to the potential delivery of the service in the corridors compared to the average value of the service in all Spanish lands outside Natura 2000: below the average (low), up to 50% above the average (medium) and more than 50% above the average (high).

References

Baranzelli, C., Jacobs-Crisioni, C., Batista E Silva, F., Perpiña Castillo, C., Lopes Barbosa, A., Arevalo Torres, J. & Lavalle, C. 2014. The Reference Scenario in the LUISA platform - Updated configuration 2014 - Towards a Common Baseline Scenario for European

Commission Impact Assessment procedures. (EUR - Scientific and Technical Research Reports). JRC - Institute for Environment and Sustainability[68]. De la Fuente, B., Mateo-Sánchez, M.C., Rodríguez, G., Gastón, A., Pérez de Ayala, R., Colomina-Pérez, D., Melero, M. & Saura, S. 2018. The connectivity backbone of forest green infrastructure. Land Use Policy (submitted). La Notte, A., Vallecillo, S., Polce, C., Zulian, G. & Maes, J. 2017. Implementing an EU system of accounting for ecosystems and their services. Initial proposals for the implementation of ecosystem services accounts (Report under phase 2 of the knowledge innovation project on an integrated system of natural capital and ecosystem services accounting in the EU). JRC107150[69]. Maes, J., Fabrega, N., Zulian, G., Barbosa, A., Vizcaino, P., Ivits, E., Polce, C., Vandecasteele, I., Marí-Rivero, I., Guerra, C., Perpiña-Castillo, C., Vallecillo, S., Baranzelli, C., Barranco, R., Silva, F.B.e., Jacobs-Crisoni, C., Trombetti, M. & Lavalle, C. 2015. Mapping and Assessment of Ecosystems and their Services: trends in ecosystems and ecosystem services in the European Union between 2000 and 2010. JRC Science and Policy Report. European Commission[70].
Comments • The analyses in this case study focused only on the key conservation corridors (those that most contribute to maintain the current levels of Natura 2000 connectivity), not on the restoration corridors (those that, if improved, would most significantly increase Natura 2000 connectivity). The restoration corridors, which were also identified by De la Fuente et al. (2018), tend to be thinner, more degraded and with more bottlenecks than the conservation corridors. The restoration corridors may provide, in their current conditions, a less substantial delivery of ecosystem services. Their assessment, following similar methods as in this case study, could significantly contribute to identify restoration opportunities and needs for a multi-functional GI. • This case study covered three different woodland habitats and determined the linkages between Natura 2000 sites that represent more than 90% of the total area covered by Natura 2000 in Spain. Future assessments could however consider additional habitat types as well as individual species of particular interest. • A larger number of ecosystem services, as well as updated maps on some of these services (ongoing work, see La Notte et al. (2017)), could be considered to provide a broader picture of the compatibility between the provision of Natura 2000 connectivity and ecosystem services in the key areas identified. • The assessment has to be refined at local scale, with complementary and more accurate data for ecosystem service models, before any implementation of actual green infrastructure deployment or restoration measures. • The demand of ecosystem services at regional level could be potentially integrated in future studies to prioritize restoration measures while increasing the contribution of ecosystems to human well-being.

5.2.4 *Ecosystem Services for a European GI: How to apply systematic conservation tools to identify priority areas for GI deployment.*

Keywords European, prioritisation, restoration, multi-functional GI, ecosystem services, all land cover types, support decision making.
General objective and policy relevance of method • Identify and assess multi-functional areas for the implementation of GI strategies, based on the supply of ecosystem services. • Assess synergies and conflicts between multiple alternatives for spatial planning of GI based on different types of relationship between ecosystems and socio-economic systems, where ecosystem services, beneficiaries (i.e. the human population) and drivers of change (i.e. ecosystem condition) are taken into account. • Assess the cost-effectiveness of ecosystem restoration using the removal of invasive alien species as a case study for all scenarios. • Provide a prioritization framework for the GI deployment and/or restoration.
What does the method provide answers to? Three scenarios are developed using different drivers to address the multi-purpose nature of GI: 1) 'Services in nature' (SIN): where no specific spatial driver was included. 2) 'Services for people' (S4P): preference given to areas that were closer to populated sites. 3) 'Services under concern' (SUC): where prioritization was favoured in areas with poorer ecosystem condition. The method provides answers to: • Where key multi-functional areas are under the different scenarios. • What the synergies and conflicts are between scenarios. • Under which scenario removal of invasive species would be more cost-effective.
Which stakeholders and practitioners does the method target? • Decision-makers at European level. • European/country/regional level by the environmental public institutions.
Data source used

[68] Retrieved from http://publications.jrc.ec.europa.eu/repository/bitstream/JRC94069/lb-na-27019-en-n%20.pdf

[69] Retrieved from http://publications.jrc.ec.europa.eu/repository/handle/JRC107150?mode=full

[70] Retrieved from http://publications.jrc.ec.europa.eu/repository/bitstream/JRC94889/lbna27143enn.pdf

- 11 ecosystem services are included: soil erosion control, water retention, net ecosystem productivity, pollination potential, potential pest control by birds, nursery habitat for farmland common birds, nursery habitat for forest common birds, nursery habitats for amphibians, birds and mammals of conservation concern and potential outdoor recreation (Zulian, 2013; Maes *et al.*, 2015; Vallecillo *et al.*, 2016).
- Population grid (Baranzelli *et al.*, 2014).
- Probability of favourable conservation status (Maes, 2013).
- European map of alien plant invasion (Chytrý *et al.*, 2009).
- Cost of removal of invasive alien plants at EU level based on the LIFE projects (Dietzel & Maes, 2015).

Description of method/tool

The identification of potential EU-wide GI was performed by means of Systematic Conservation Planning (SCP, Margules and Pressey (2000)) using the supply of ecosystem services. For this purpose, we used the software Marxan (Ball *et al.*, 2009) that facilitate a transparent, flexible and defensible decision-making process for the identification of key areas for either conservation or restoration.

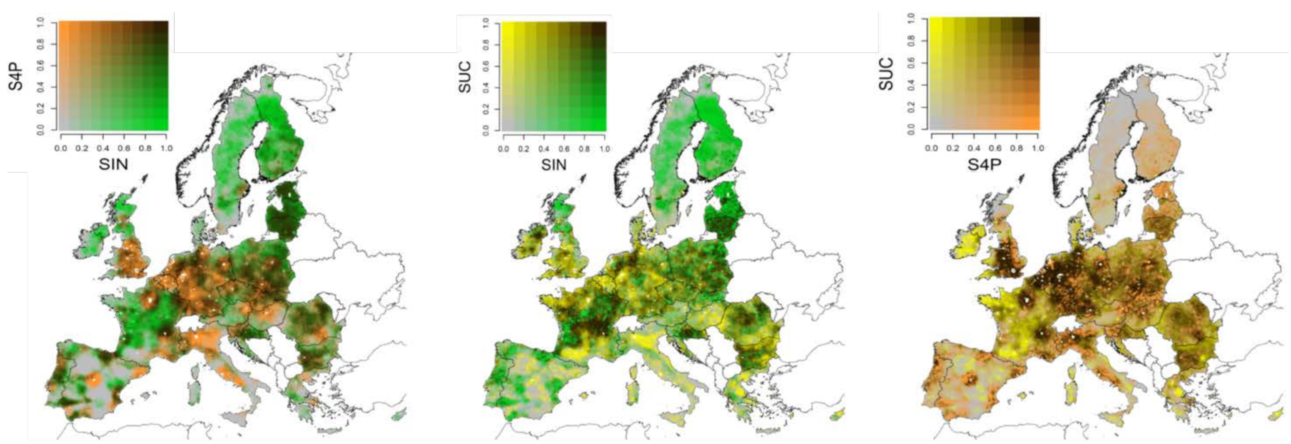
Application of method and main results

The prioritization framework that was developed is a step forward towards the support of the GI deployment. In particular, the assessment of the multi-purpose nature of GI considers different spatial planning solutions depending on the specific goals to be achieved. The spatial solutions are based on the prioritization of key areas for GI deployment in which the ecosystem service potential, beneficiaries (i.e. people) and ecosystem condition play different roles, matching different policy objectives.

The analysis of synergies and conflicts between the different spatial alternatives (scenarios) for GI shows that GI could also be efficiently implemented in peri-urban areas to satisfy the increasing demand for ecosystem services. However, the costs of ecosystem restoration, such as the removal of invasive alien species, in prioritized areas that are closer to the services beneficiaries are higher as a result of poorer ecosystem condition (Table 1). Investment in peri-urban areas was the most cost-effective, but only if beneficiaries (i.e. people) were accounted for in the assessment.

Although GI network typically serves many purposes and functions, the actual designation and deployment of new GI depends on specific policy or strategic plans. Therefore, the optimal allocation of new GI in a landscape calls for an evaluation of different spatial planning solutions (Figure 1). Given the scarcity of resources for investment in GI and ecosystem restoration, win-win situations are to be identified where GI development can support several policy objectives simultaneously (Figure 2). Figure 2 shows areas where areas prioritized under the different scenarios spatially match; those areas are of special importance under the different policy objectives.

Outcome products



A. 'Services in nature' and 'Services for people' tau=0.193

B. 'Services in nature' and 'Services under concern' tau=0.049

C. 'Services for people' and 'Services under concern' tau=0.278

Figure 1. Comparison of the important areas (i.e. how irreplaceable each cell is) for the different scenarios: 'Services in nature' (SIN), 'Services people' (S4P) and 'Services under concern' (SUC). Axis represent the 10% quantiles of the selection frequency. Kendall rank correlation coefficient (tau) between scenarios is also given.

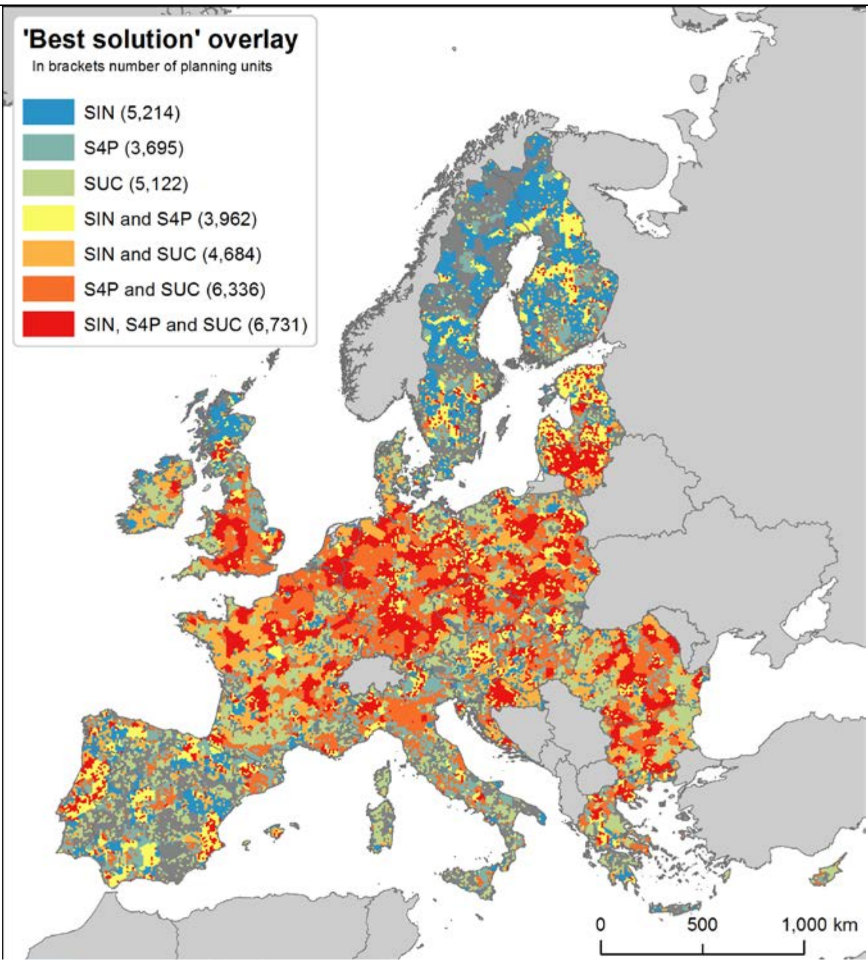


Figure 2. Overlay map of the 'best solution' of the three scenarios used for the spatial selection of the GI: 'Services in nature' (SIN), 'Services for people' (S4P) and 'Services under concern' (SUC). This map enables identifying potential areas for specific policy goals related to each scenario. The analysis is based on 100 km² hexagonal planning units, covering the EU.

Table 1. Cost-effectiveness assessment of invasive species control in the 'best solution' of each scenario: 'Services in nature', 'Services for people' and 'Services under concern'. Benefit[1] and cost[2] values are expressed per hectare to be restored. Two cost-effectiveness indicators are calculated: effectiveness-cost ratio (benefit/cost) and the per capita effectiveness-cost ratio (PC effectiveness/cost).

	Effectiveness/ha	Cost/ha (€)	Beneficiaries/ha	Effectiveness/cost	PC Effectiveness/cost
'Services in nature'	1.29	932	1.40	1.38	1.17
'Service for people'	1.42	1,058	2.07	1.34	1.38
'Services under concern'	1.56	1,100	2.09	1.42	1.21

[1]Effectiveness: changes in the probability of favourable conservation status weighted by the extent and the level of invasion.

[2]Cost: based on the average cost of 901 € per hectare and weighted by the extent and level of invasion.

References

Ball, I.R., Possingham, H.P. & Watts, M. (2009) Chapter 14: Marxan and relatives: Software for spatial conservation prioritisation. In A. Moilanen, K.A. Wilson and H.P. Possingham (Eds.), *Spatial conservation prioritisation: Quantitative methods and computational tools*, (pp. 185-195). Oxford University Press, Oxford, UK.

Baranzelli, C., Jacobs-Crisioni, C., Batista E Silva, F., Perpiña Castillo, C., Lopes Barbosa, A., Arevalo Torres, J. & Lavalle, C. (2014) *The Reference Scenario in the LUISA platform - Updated configuration 2014 - Towards a Common Baseline Scenario for EC Impact Assessment procedures*. (EUR - Scientific and Technical Research Reports). JRC - Institute for Environment and Sustainability. Retrieved from - http://publications.jrc.ec.europa.eu/repository/bitstream/JRC94069/lb-na-27019-en-n%20.pdf

Chytrý, M., Pyšek, P., Wild, J., Pino, J., Maskell, L.C. & Vilà, M. (2009) European map of alien plant invasions based on the quantitative assessment across habitats. *Diversity and Distributions*, 15, 98-107. doi - 10.1111/j.1472-4642.2008.00515.x

Dietzel, A. & Maes, J. (2015) *Costs of restoration measures in the EU based on an assessment of LIFE projects. Report EUR 27494 EN*. (JRC Technical Report). European Commission. Retrieved from - http://publications.jrc.ec.europa.eu/repository/bitstream/JRC97635/lb-na-27494-en-n.pdf

Maes, J. (2013) *A model for the assessment of habitat conservation status in the EU*. (JRC Scientific and Policy Reports). European Commission, Luxembourg. Retrieved from - http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/29853/1/lb-na-26186-en-n%20.pdf

Maes, J., Fabrega, N., Zulian, G., Barbosa, A., Vizcaino, P., Ivits, E., Polce, C., Vandecasteele, I., Marí-Rivero, I., Guerra, C., Perpiña-Castillo, C., Vallecillo, S., Baranzelli, C., Barranco, R., Silva, F.B.e., Jacobs-Crisoni, C., Trombetti, M. & Lavalle, C. (2015) *Mapping and Assessment of Ecosystems and their Services: trends in ecosystems and ecosystem services in the European Union between 2000 and 2010. JRC Science and Policy Report*. European Commission. Retrieved from - http://publications.jrc.ec.europa.eu/repository/bitstream/JRC94889/lbna27143enn.pdf

Margules, C.R. & Pressey, R.L. (2000) Systematic conservation planning. *Nature*, 405, 243-253. doi - 10.1038/35012251

Vallecillo, S., Maes, J., Polce, C. & Lavalle, C. (2016) A habitat quality indicator for common birds in Europe based on species distribution models. *Ecological Indicators*, 69, 488-499. doi - http://dx.doi.org/10.1016/j.ecolind.2016.05.008

Vallecillo, S., Polce, C., Barbosa, A., Perpiña Castillo, C., Vandecasteele, I., Rusch, G.M. & Maes, J. 2018. Spatial alternatives for Green Infrastructure planning across the EU: An ecosystem service perspective. *Landscape and Urban Planning* (in press).

Zulian, G., Maria Luisa Paracchini, Maes, J., Liquete, C., (2013) ESTIMAP: Ecosystem services mapping at European scale. *EUR 26474 EN. Luxembourg: Publications Office of the European Union*. doi -

Comments

- Flexibility to identify key multi-functional areas for GI implementation or restoration depending on specific goals.
- Spatially explicit solution.
- Supported by trade-offs analysis (including cost-effectiveness of removal of invasive species).
- Coarse spatial resolution. Also applicable to finer scale for GI framework to support local planning.
- Based on freely available tools that proved to optimize the prioritization of key areas for conservation and restoration.
- It does not identify a spatial network, but multi-functional areas to implement GI.
- Prioritization made at European level. Results would differ if made at national or regional level (finer resolution).

5.2.5 CULTURAL ECOSYSTEM SERVICES TO INFORM THE IMPLEMENTATION OF GI AT REGIONAL LEVEL

Keywords

Cross-scale approach, Cultural-Ecosystem Services (CES), co-produced knowledge, Regional, GI.

General objective and policy relevance of method

- To support the regional deployment of GI as a "*strategically planned network of natural and semi-natural areas" (EC, 2013)*.
- To support the implementation of the *Action Plan for nature, people and the economy* (2017), particularly:
    - Priority A: "*improving guidance and knowledge and ensuring better coherence with broader socio-economic objective*".
    - Priority C: "*Strengthening investment in Natura 2000 and improving synergies with EU funding instruments*" - Action 9 on synergies with EU funding instruments from the Common Agricultural Policy; Action 10 on an increased synergy with the Cohesion Policy founding; Action 12 on connectivity and Nature Based Solutions.
    - Priority D: "*Better communication and outreach, engaging citizens, stakeholders and communities*".
- To demonstrate how GI could be a provider *of "ecological, economic, social and cultural benefits*" by proposing spatially explicit measure of CES to support GI deployment.
- To demonstrate how a co-created CES map can support the policy and planning process in a cross-scale framework.

What does the method provide answers to?

The spatially explicit assessment of CES can be used to answer:

- How the capacity to provide CES is distributed within the GI.
- Where to improve the potential capacity to provide recreation services.
- If there is a potential conflict with nature protection.

Which stakeholders and practitioners does the method target?

- Advisory and service organisations of the agricultural and forestry sectors.
- Natural and Regional Park advisory boards.
- Decision-makers, national, regional, local stakeholders.

Data source used

The input data layer to the model has a 20 m resolution based on the Regional Land Use Map (DUSAF) (http://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioServizio/servizi-e-informazioni/Enti-e-Operatori/Territorio/sistema-informativo-territoriale-sit/uso-suolo-dusaf/uso-suolo-dusaf).

Ancillary data are derived from:

- Topographic databases Lombardy region (DBT) (http://www.geoportale.regione.lombardia.it/)
- Layer from GeoPortale of Lombardy region (http://www.geoportale.regione.lombardia.it/):
    - Natural features: monumental trees, sites of geological and geomorphological interest, mountain peaks and passes, viewpoints, cascades, springs, river areas with high landscape value, line trees.

- o Urban green areas.
- o Historical and cultural heritages.
- OpenStreetMap (25m) – tags of interest: natural (water related); natural (inland); point of interest (viewpoint); highways (local roads, bridleway, path for cycling unspecified paths).

Description of method/tool

The ESTIMAP-recreation model was developed at the JRC in 2013 (Zulian et al., 2013). The model has been applied for the assessment of recreation opportunities in different settings and at different scales (Baró et al., 2016; Liquete et al., 2016; Maes J., Fabrega N., Zulian G. et al., 2015; Zulian et al 2018 accepted).

The model is based on three consecutive steps that assess:

1. the *Recreation Potential*, i.e. the suitability to support different types of recreation activities based on the intrinsic characteristics of the areas;
2. the *Recreation Opportunity Spectrum*, which combines the Recreation Potential with information about accessibility, i.e. proximity to residential areas and transport infrastructure and leisure infrastructures;
3. the *Number of potential trips*, which adds information about the distribution of the potential users.

Application of method and main results

In this case study, the model has been applied to inform the deployment of the Regional GI of Region Lombardia, Italy (Arcidiacono et al., 2016).

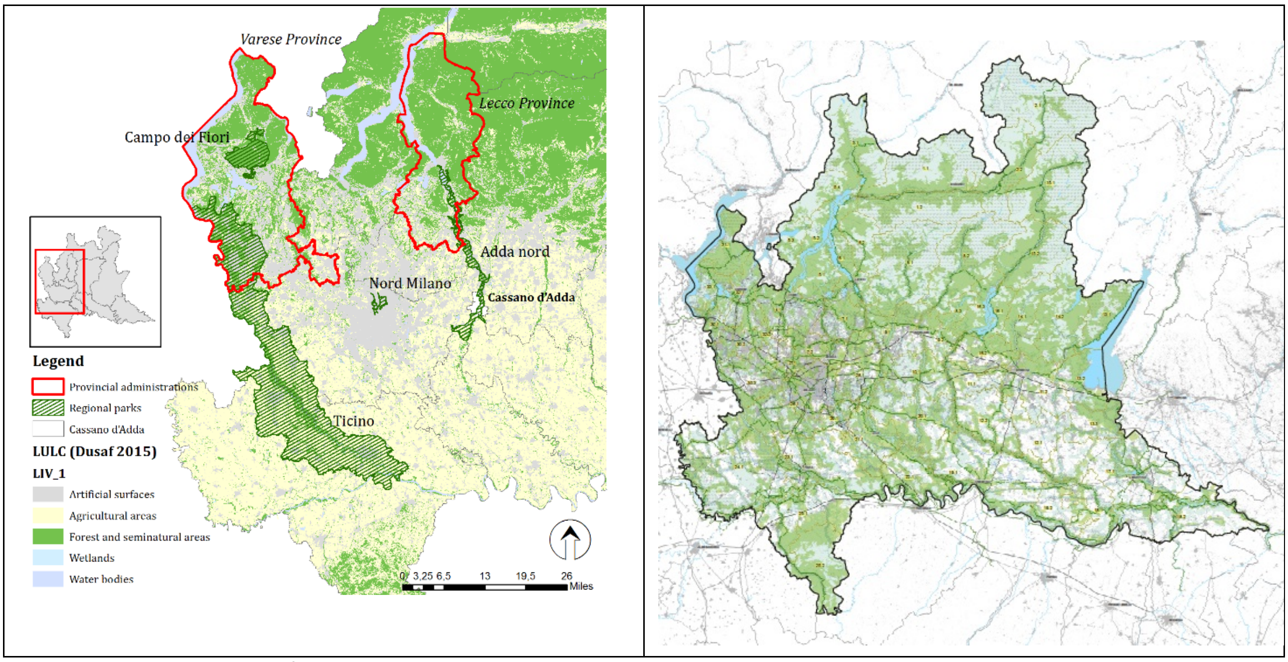


Figure 1. *Case study area (left); the* Lombardy GI (LGI) designed (right)

[source: *http://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioRedazionale/servizi-e-informazioni/Enti-e-Operatori/territorio/paesaggio/vas-della-variante-al-piano-paesaggistico-regionale-consultazione-elaborati-presentazione-osservazioni/vas-della-variante-al-piano-paesaggistico-regionale-consultazione-elaborati-presentazione-osservazioni.]*

The research activity adopted a sequential, qualitative, multi-method approach to engage local stakeholders in the final map production. Representatives from the provinces and regional parks participated to two interactive mapping sessions. The discussion focused on 4 relevant aspects:

1. key recreational activities (related to nature and cultural heritage);
2. users' categories (type of users [e.g. families/local recreationists; tourism]);
3. types of trips [short daily trips, long distance trips]);
4. types of use of the produced maps (policy support, management support, citizens awareness).

The results were combined with the new Lombardy GI (LGI) designed to incorporate the multi-functional use of natural capital, especially its naturalistic, recreational and landscape vocation.

The LGI strategy requires a cross-scale framework to include different scales of CES management: The European scale with the CES assessment elaborated in the framework of the EU Biodiversity strategy to 2020; the regional scale with LGI promoted by the Landscape Regional Plan; and the local planning for the definition of urban policies considering nature-based recreation opportunities.

Outcome products

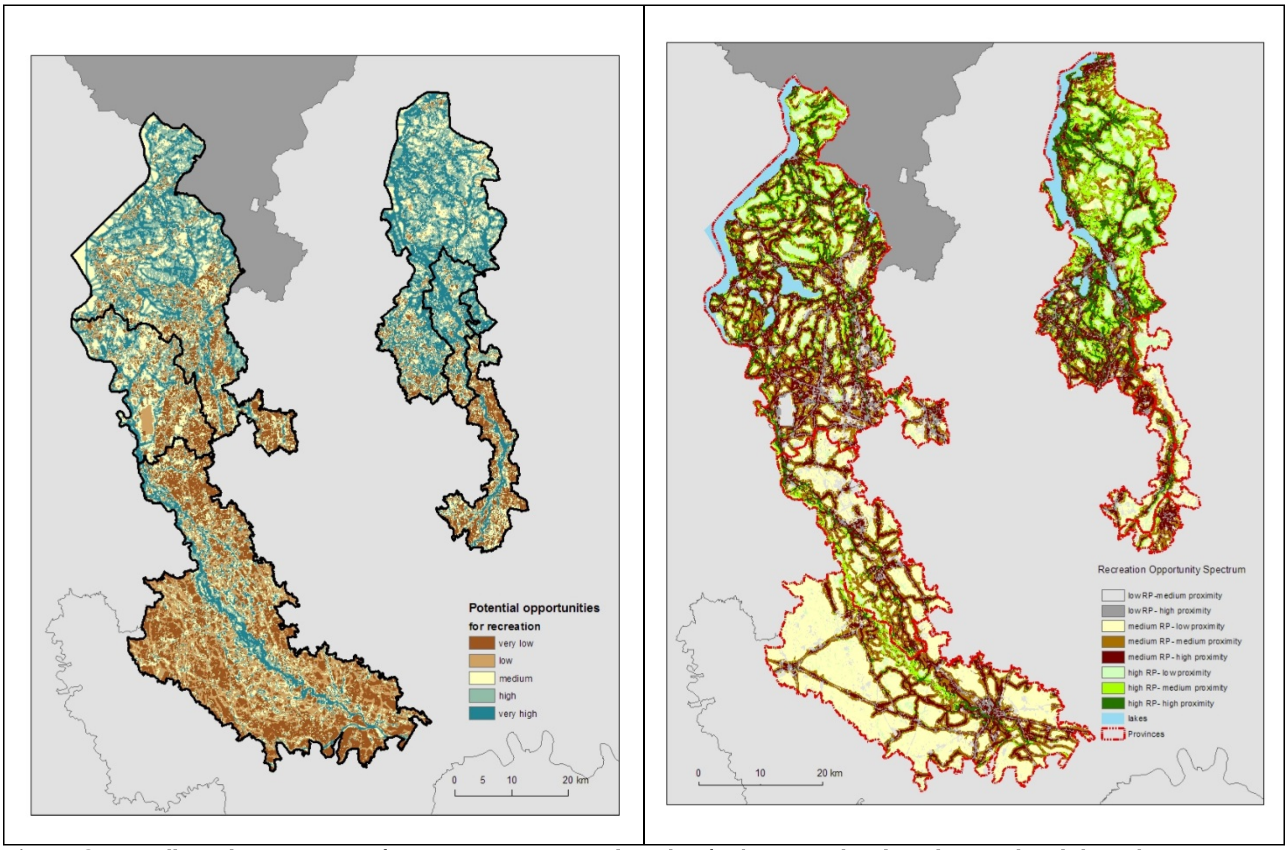


Figure 2. Spatially explicit outcomes of ESTIMAP-recreation adapted to fit the regional scale and co-produced through an interactive stakeholder consultation: (left) Recreation potential map; (right) Recreation Opportunity Spectrum.

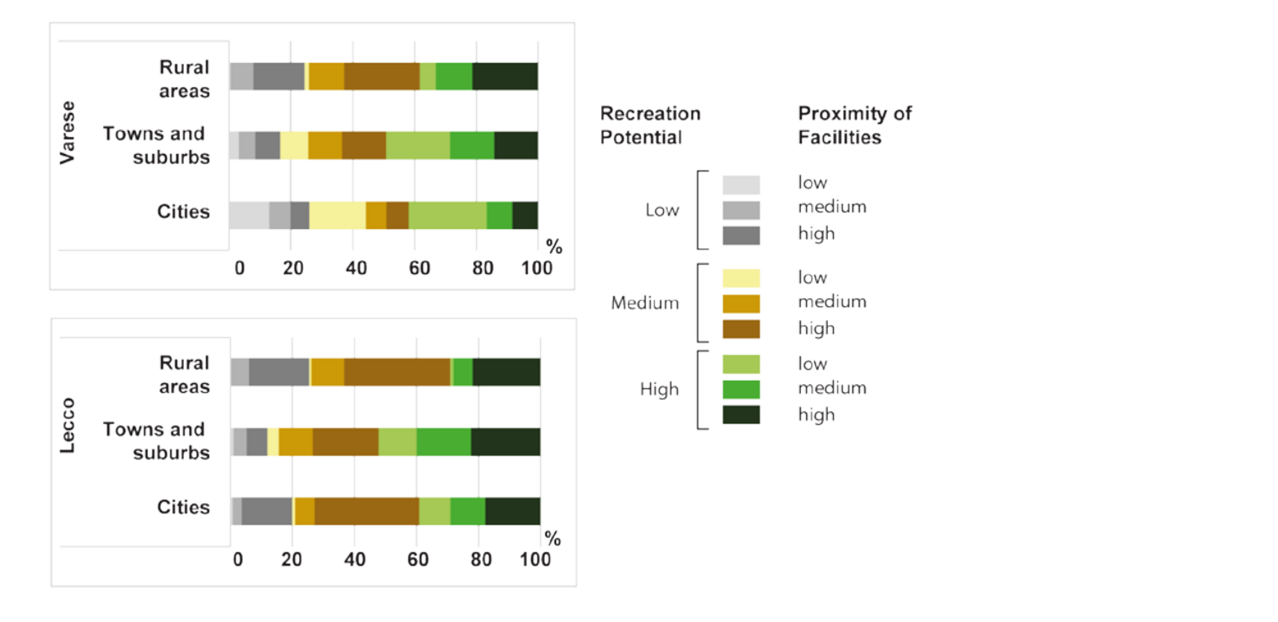


Figure 3: distribution of the Recreation Opportunity Spectrum values in the provinces of Varese and Lecco, by degree of urbanisation.

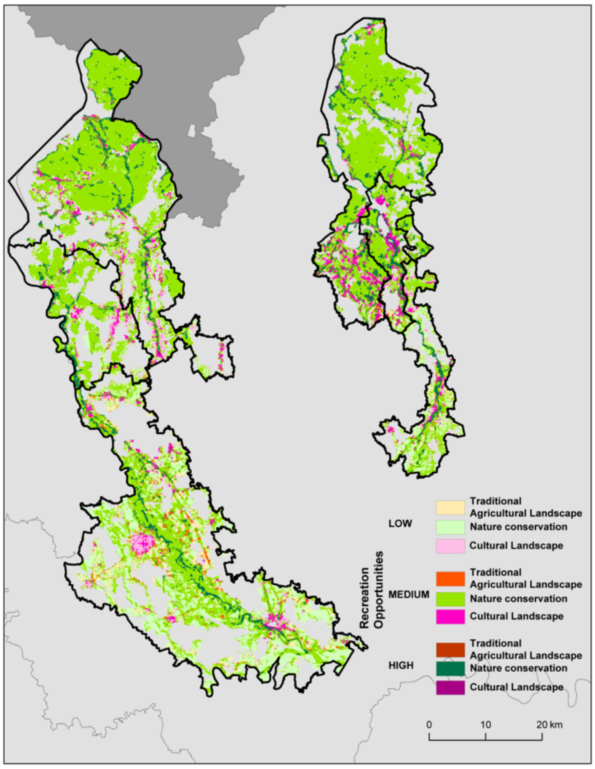


Figure 4. LGI classified by dominant function and combined with the potential capacity to support recreation.

References

Arcidiacono, A., Ronchi, S., Salata, S., 2016. Managing Multiple Ecosystem Services for Landscape Conservation: A Green Infrastructure in Lombardy Region. Procedia Eng. 161, 2297–2303. doi:10.1016/j.proeng.2016.08.831

Baró, F., Palomo, I., Zulian, G., Vizcaino, P., Haase, D., Gómez-Baggethun, E., 2016. Mapping ecosystem service capacity, flow and demand for landscape and urban planning: A case study in the Barcelona metropolitan region. Land use policy 57, 405–417. doi:10.1016/j.landusepol.2016.06.006

Liquete, C., Piroddi, C., Macías, D., Druon, J.-N., Zulian, G., 2016. Ecosystem services sustainability in the Mediterranean Sea: Assessment of status and trends using multiple modelling approaches. Sci. Rep. 6. doi:10.1038/srep34162

Maes J., Fabrega N., Zulian G., B.A., Vizcaino P., Ivits E., Polce C., Vandecasteele I., M., Rivero I., Guerra C., Perpiña Castillo C., V.S., Baranzelli C., Barranco R., B. e S.F., Jacobs-Crisoni C., Trombetti M., L.C., 2015. Mapping and Assessment of Ecosystems and their Services: Trends in ecosystems and ecosystem services in the European Union between 2000 and 2010. doi:10.2788/341839 (online)

Zulian, G., Paracchini, M.-L., Maes, J., Liquete Garcia, M.D.C., 2013. ESTIMAP: Ecosystem services mapping at European scale. European Commision. doi:10.2788/64713 (print); 10.2788/64369 (online)

Zulian, G. Erik Stange, E., Woods, E., Carvalho, L., Dick, J., Andrews, C., Baró, F., Vizcaino, P., Barton, D.N., Nowel, M., Rusch, G.M., Autunes, P., Fernandes, J., Ferraz, D., dos Santos, R.F., Aszalós, R., Arany, I., Czúczj, B., □Priess, J. A., Hoyer, C., Bürger-Patricio, G., Lapola, D., Mederly, P. Halabuk, A., Bezak, P., Kopperoinen, L. Viinikka, A., 2017. Practical application of spatial ecosystem service models to aid decision support. Ecosystem Services. Accepted

Comments

- Flexibility for the user to adapt the model configuration to fit specific needs in different settings. The model can be implemented using any GIS software.
- Computing time varies from seconds to few weeks depending on the spatial resolution of data input.

5.2.6 EU LEVEL GI NETWORK FOR CONSERVATION AND RESTORATION OF FOREST HABITATS

Keywords

Green infrastructure, Ecosystem services, Habitat modelling, Connectivity, Prioritization, Conservation, Restoration, Europe.

General objective and policy relevance of method

The objective is to identify potential GI elements through identifying areas that provide multiple and high-quality ecosystem services, and areas that provide key habitats to biota at landscape level. Specifically, the outcomes support:

- The provision of habitat to biota.
- The connectivity of habitats and their protection.

- The delivery of ecosystem services.
- The identification of potential areas for conservation and/or restoration.
- An integrated spatial planning by identifying multi-functional zones and by incorporating habitat restoration measures and other connectivity elements into various land use plans and policies.

What does the method provide answers to?

- Where conservation is essential to maintain connectivity of natural and semi-natural habitats to biota.
- Where restoration would increase the capacity of ecosystems to provide important ecological functions.

Which stakeholders and practitioners does the method target?

- Decision-makers at national and regional levels.
- DGs of the European Commission.
- Conservation planners.

Data sources used

- Regulating and maintenance ecosystem services were compiled or spatially adapted by using explicit information about the capacity to deliver each of them. Since the formats and spatial units of each model were different, all input data were transformed into grids of 1 km spatial resolution. In this case, eight ecosystem services were used:
  - Filtration of air pollutants by vegetation.
  - Erosion protection.
  - Water flow regulation.
  - Coastal protection.
  - Pollination.
  - Maintenance of soil structure and quality.
  - Water purification, carbon storage and sequestration.
- Maps were compiled from the MAES work (Maes et al., 2011).
- For habitat modelling, core habitats of at least 50% forest density and 500 km2 size were used – information on forest density was obtained from the global Landsat Vegetation Continuous Fields tree cover layer provided by the Global Land Cover Facility (Sexton et al., 2013). The actual presence of large mammals in those core habitats were based on the reporting of EU Member States for the Habitats Directive (HD), in particular on the distribution maps of large mammals present in Annex II of the HD. Habitat permeability and landscape resistance for the transit of large mammals were mapped based on CLC 2006 data (merged with the only available CLC 2000 information for Greece).

Description of method/tool

The proposed methodology is composed of two main steps:

- Assessment and mapping of areas with a good capacity to deliver regulating and maintenance ecosystem services.
- Identification of key habitats to biota and the analysis of connectivity among them (in this case, large forest-bound mammals).

The first step of the assessment starts with the identification of relevant regulating and maintenance ecosystem services for the study area. All these indicators (as described in data sources) are combined through an arithmetic mean, in which the highest values represent the highest combined capacity to deliver regulating and maintenance services across EU-27.

The second step of the assessment is the identification of core and transitional habitats for key functional groups. As core habitats and functional connectivity are species-related, the national/local authorities should identify their most relevant species. For the habitat connectivity analysis, the Linkage Mapper v1.0.3 tool (see Section 4.2) was used. This tool automates mapping of wildlife corridors using core habitat areas and maps of resistance.

The landscape elements from both steps are then aggregated into a final GI network that identifies potential areas for conservation ("C") or restoration ("R"), based on the delivery of good ecosystem services, key habitats and their connectivity: "C" areas are based on elements to be conserved because they perform key ecological roles for both wildlife and human well-being; "R" areas perform important ecological functions, but their capacity could be improved with the protection or restoration of their elements.

Application of method and main results

Ecosystem services

The results presented in Figure 1 (a) show that regions with a lower than average combined value of ecosystem services coincide with areas where land is predominantly covered by urban fabric and intensive crop production. Regions with a high proportion of forests and wetlands usually result in combined values that are higher than average. Dryer areas, where grasslands or shrub are dominant in the landscape but where also important agricultural activities take place, are characterized by lower combined values.

Core habitat services

Following this method, countries like Estonia, Slovenia, Latvia and Austria have approximately half of their territory under core habitats for large mammals, while others like Cyprus or Denmark have none (Figure 1 (b)). The analysis shows that 29 of the 91 actual core habitats linkages are shorter than 10 km, that is, more than 30% of the wildlife corridors are relatively feasible to be implemented and protected.

Green infrastructure networks

The results presented in Figure 1 (c) indicate that 27% of EU-27 might be part of the GI network "C", with the largest contribution coming from the areas with the highest capacity to provide ecosystem services. There is a large coincidence (spatial overlap) between the key service areas and the key habitats for mammals. Conversely, 17% of EU territory might correspond to the GI network "R", mainly defined by the limited service areas. The rest of European territory (56%) did not qualify to form part of any GI network (with the assumptions and thresholds fixed in this study).

Outcome products

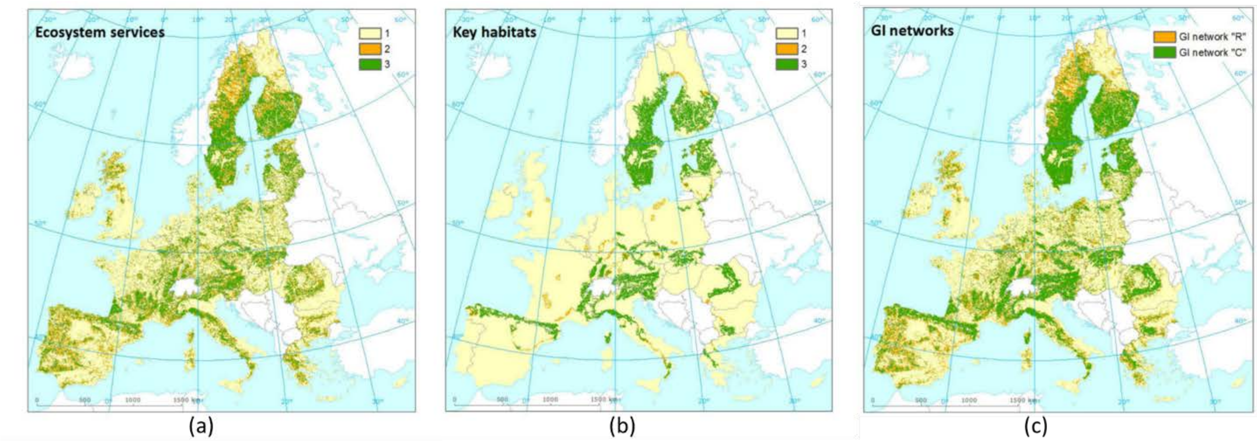


Figure 1. Mapping of (a) combined ecosystem services; (b) potential key habitats; and (c) potential European GI networks (Source: EEA, 2014).

References

EEA, 2014, Spatial analysis of green infrastructure in Europe. European Environment Agency Technical Report No. 2/2014, Publications Office of the European Union, Luxembourg. Available from: http://www.eea.europa.eu/publications/spatial-analysis-of-green-infrastructure.

Maes, J., Paracchini, M.L., Zulian, G., 2011. A European assessment of the provision of ecosystem services — Towards an atlas of ecosystem services. Publications Office of the European Union, EUR 24750 EN, doi:10.2788/63557.

McRae, B.H., Kavanagh, D.M., 2011, Linkage Mapper Connectivity Analysis Software, The Nature Conservancy, Seattle, WA, Available from: http://www.circuitscape.org/linkagemapper

Sexton, J.O., et al., 2013, Global, 30-m resolution continuous fields of tree cover: Landsat-based rescaling of MODIS vegetation continuous fields with lidar-based estimates of error. Int. J. Digit. Earth, 6, pp. 427-448.

Comments

The design of GI networks following this methodology may be tailored to the objectives and priorities of the practitioners. Numerous policies, particularly those related to the environment and territorial cohesion, may benefit from the definition and implementation of tailored GI networks.

There were data gaps identified during the implementation of the proposed methodological approach, namely the limited spatial and temporal availability of ecosystem services' information at EU level. Moreover, no information on the actual capacity (i.e. condition) of the ecosystems to provide services was available, but only information on their theoretical capacity (i.e. potential) to provide the services. A second issue found was the lack of homogenisation or intercalibration of Habitats Directive (HD) reporting among EU regions. Finally, one of the challenges when defining the GI networks (apart from selecting the most relevant input data sets) was establishing the right thresholds and criteria, as these clearly affect the final results.

5.2.7 CONTRIBUTION OF THE EUROPEAN GREEN BELT TO THE IMPLEMENTATION OF EU-LEVEL GI

Keywords

EU-level GI, ecosystem services, multifunctionality, protected areas, Natura 2000, habitat connectivity

General objective and policy relevance of method

The European Green Belt stretches about 12,500 km across Europe along the former Iron Curtain which separated Europe for almost four decades in East and West. Today, the European Green Belt connects 24 countries from the Arctic Ocean in the far north to the Mediterranean South (Adriatic Sea and Black Sea) and, due to former land-use restrictions, forms a Pan-European biological network. Several member states already recognize the European Green Belt as a relevant element contributing to the national GI. Within the German Federal Green Infrastructure concept for instance, the Green Belt is considered as a significant contribution to key elements such as national natural heritage and the ecological and habitat network, thus being an important backbone for the nationwide GI

(Heiland et al. 2017). In addition, the European Green Belt is often referred to as one example of an EU-level GI project, e.g. in the EU's Strategy of Green Infrastructure.

The main goal of this study is to assess the contribution of the European Green Belt to the implementation of EU-level Green Infrastructure, according to the following criteria of the "Guidance on a strategic framework for further supporting the deployment of EU-level green and blue infrastructure" (Draft: July 2018):

- Contribution of the European Green Belt to the provision of multiple ecosystem services, i. e. multifunctionality.
- Contribution of the European Green Belt to the goals of EU Nature legislation, i. e. analysis of existing Natura 2000 sites and proposed Emerald sites, and habitat connectivity.
- Level of strategic approach with EU-level impact of the European Green Belt Initiative, i. e. either a scale which is significant and transcends administrative boundaries; or involve a minimum of two Member States; or implement a national GI strategy or a national restoration prioritisation framework.

What does the method provide answers to?

- What are the main ecosystem services provided by the European Green Belt?
- What are contributions of the European Green Belt to multiple functions and benefits, i. e. ecosystem services?
- What are contributions of the European Green Belt to protected areas and protected area network?
- What are contributions of the European Green Belt to functional habitat connectivity potentials?

Which stakeholders and practitioners does the method target?

- Decision-makers at national and regional levels.
- Decision-makers at European level.
- Land use planners
- Conservation practitioners.
- NGOs.

Data sources used

The case study focuses on the European Green Belt. To represent the European Green Belt the "draft indicative spatial reference area of the European Green Belt" (Scope) was used, provided by the European Green Belt Association (state: July 2018). Furthermore, a comparison of spatial statistics was conducted along a gradient, representing distances from the border ("Green Belt Line"). Therefore, several corridors along the border (distances 10 km, 25 km, 50 km, 75 km) were defined. In addition, statistics are based on the total terrestrial land surface areas of adjacent countries. Parts of the analysis focus on the Balkan Green Belt as southernmost region of the European Green Belt (Albania, Bulgaria, Greece, Kosovo (in accordance with UNSCR 1244 and opinion of ICJ), FYR Macedonia, Montenegro, Serbia and Turkey (latter just part on the European continent) as well as the Central European Green Belt (Austria, Croatia, Czech Republic, Germany, Hungary, Italy, Slovakia, and Slovenia).

As a basis for this analysis, satellite-based CORINE Land Cover (CLC) data set 2012 (EEA, 2014) from the European Union was used with a resolution of 100 m x 100 m from the EEA website (http://dataservice.eea.europa.eu/). Besides, the ecosystem services assessment matrix of Burkhard et al. (2014) was applied that enables to link ecosystem services to land cover. For the analysis of the protected area network all designated Natura 2000 areas (Directorate-General for Environment (DG ENV)) and proposed Emerald sites (Secretariat of the Bern Conventions) were considered. The evaluation of functional connectivity potential is based on analysis undertaken for the Balkan Green Belt by Burkhardt and Hänel (2017) which applies a case based modified version of the „Habitat-Net" algorithm developed by Hänel (2007).

Description of method/tool

The method helps to assess the contribution of the European Green Belt to the implementation of EU-level Green Infrastructure by investigating the criteria according to the "Guidance on a strategic framework for further supporting the deployment of EU-level green and blue infrastructure" (state: July 2018).

In practice, we operationalized the criteria according to data availability and considering scale and dimension of the European Green Belt. European Green Belt as a matter of course fulfills the pre-requisite formulated in the guidance document "that such projects should carry out green infrastructure actions, i.e. actions which comply with the definition of GI embedded in the EU GI Strategy". In a first step we developed indicators for each of the following cumulative criteria which should be fulfilled by EU-level GI projects:

i) Enhance the delivery of multiple ecosystem services;
ii) Significantly contribute to the goals of EU Nature legislation;
iii) Projects should have a strategic approach with an EU-level impact: either a scale which is significant and transcends administrative boundaries; or involve a minimum of two Member States; or implement a national GI strategy or a national restoration prioritisation framework.

With regards to criterion i) Enhance the delivery of multiple ecosystem services, we investigated the relevance of different functions and benefits for the European Green Belt, while looking at two regions, Balkan and Central European Green Belt. Therefore, ecosystem service potential maps have been developed, based on the CORINE Land Cover data set and an ecosystem service assessment matrix that enables to link ecosystem service potentials (with values 0 = no relevant potential to 5 = very high (maximum) relevant potential) to land cover. In the next step, to consider the contribution of the European Green Belt to multifunctionality, two indices were built. One index considered all ecosystem service potentials considered as relevant according to the ecosystem service assessment matrix (values ranging from 1-5), while another one was selecting just functions with high or very high relevant potential, with values 4 and above according to the ecosystem services assessment matrix. Statistical analysis was conducted to give an overview on spatial relations of the ecosystem services potentials within the European Green Belt and in comparison with distance corridors along the border (10 km, 25 km, 50 km, 75 km distances) as well as with the total terrestrial land surface areas of adjacent countries

Criterion ii) Contribution of the European Green Belt to the goals of EU Nature legislation was investigated only for the Balkan Green Belt. Evaluation focuses on the function of the Balkan Green Belt as a backbone of a Natura 2000 and Emerald network of protected areas. In a first step, the share of designated Natura 2000 areas and proposed Emerald sites was calculated. In addition, the spatial coherence (i. e. spatial proximity) of designated Natura 2000 areas and proposed Emerald sites has been evaluated. A third analysis investigates connectivity potentials of selected habitat complexes within the Balkan Green Belt. This approach identifies potential areas of functional connectivity for the habitat complexes forests, grassland and wetlands. For analysis a functional connectivity potential index was built. Highest potential characterizes areas where potential connectivity areas of all three habitat complexes overlap. The index of the Balkan Green Belt was compared with distance corridors along the border (10 km, 25 km, 50 km, 75 km).

The third criterion was assessed based on a qualitative analysis.

Application of method and main results

The aim of this project was to assess if the European Green Belt applies to the criteria for EU-level Green Infrastructure by investigating the criteria laid down in the draft of the "Guidance on a strategic framework for further supporting the deployment of EU-level green and blue infrastructure". The analysis suggests that the European Green Belt serves as the backbone of a transnational ecological network of European level and can be considered as EU-level GI project according to the selected indicators:

i) Contribution of the European Green Belt to enhance the delivery of multiple ecosystem services (regulating, cultural and provisioning):

The analysis suggests that the European Green Belt shows significant potential contributions to a number of direct and indirect functions and benefits. In comparison with the potentials of the total terrestrial land surface area of all adjacent countries, the European Green Belt shows comparably higher contributions to all regulating and cultural services and a number of provisioning services. Number of functions in average is higher along the border and within the European Green Belt. Even more evident is the difference when looking at multiple functions regarding ecosystem services with high relevant potential. In particular, regulating and cultural services are significantly higher within the European Green Belt, up to 25% compared to the average potential across all adjacent countries (Figure 1).

ii) Contribution of the European Green Belt to the goals of EU Nature legislation:

In total, about 42.429 sqkm within the Balkan Green Belt are designated Natura 2000 areas and proposed Emerald sites, covering about 36 % of its area. Statistical analysis suggests that the highest proportion of protected areas is directly along the border and within the Balkan Green Belt, with proportion decreasing constantly with higher distances from the border. Hence, the Green Belt significantly contributes to function as core habitat for threatened species.

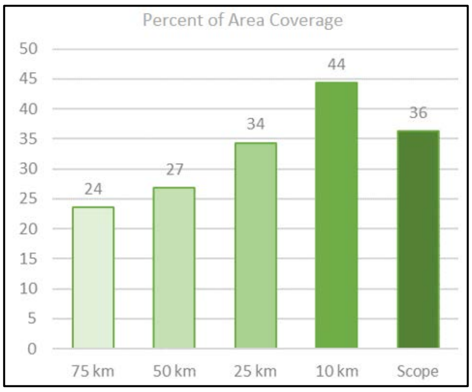


Figure 1: Proportion of Natura 2000 and proposed Emerald areas within the "draft indicative spatial reference area of the Balkan Green Belt" (Scope) and in the reference corridors

In addition, protected areas within the Balkan Green Belt are in average 2.122 meter closer to their nearest neighbour than protected areas within the 75 km corridor (used as reference area). This means that the protected area network of the European Green Belt is better developed than outside. Also the connectivity potential along the border and within the Balkan Green Belt is higher than within the 75 km distance corridor used as reference area (Figure 2). Almost one third (around 31,9 %) of the Balkan Green Belt offers connectivity potential for at least two habitat categories, underlining the importance of the Balkan Green Belt for maintenance and development of connectivity.

iii) have a strategic approach with an EU-level impact:

The analysis shows that the European Green Belt fulfils the third criteria due to several aspects such as its pan-European dimension, its route connecting 24 countries, the already established governance structure and the cooperation of governmental (GO) and non-governmental organizations (NGO) from all countries.

Outcome products

Several tables and maps were produced illustrating the different analysis steps and results.

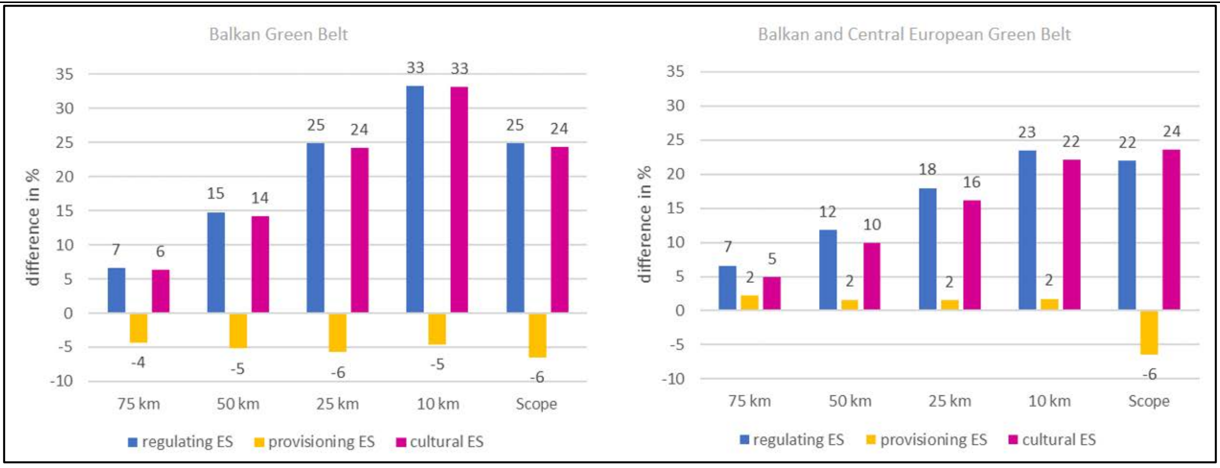


Figure 1: All functions and benefits with high and very high potentials according to the ecosystem service assessment matrix within Balkan Green Belt (Scope) in comparison to the total land surface area of all adjacent countries (left) and within Balkan Green Belt and Central European Green Belt (Scope) in comparison to adjacent countries (right)

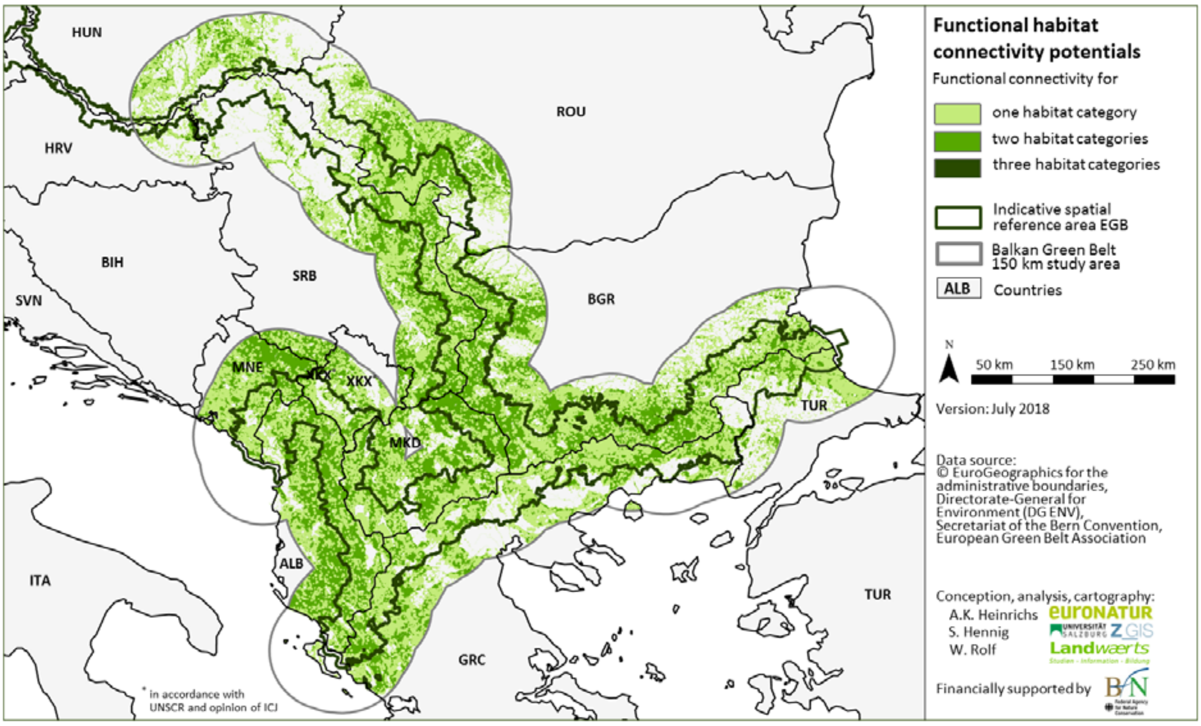


Figure 2: Functional habitat connectivity potentials of the three habitat categories wetlands, grasslands and forest along the Balkan Green Belt

References

Burghardt, R., Hänel, K. 2017: Spatial analysis of the coherent protected area network and the connectivity of potential habitats along the Balkan Green Belt. Final Report. 07. December 2017. EuroNatur (unpublished)

Burkhard, B., M. Kandziora, Y. Hou & F. Müller 2014. Ecosystem Service Potentials, Flows and Demands - Concepts for Spatial Localisation, Indication and Quantification. - Landscape Online 34: 1-32

Hänel, K. (2007). Methodische Grundlagen zur Bewahrung und Wiederherstellung großräumig funktionsfähiger ökologischer Beziehungen in der räumlichen Umweltplanung - Lebensraumnetzwerke für Deutschland. Kassel University Press, Kassel.

Heiland, S.; Mengel, A.; Hänel, K.; Geiger, B.; Arndt, P.; Reppin, N.; Werle, V.; Hokema, D.; Hehn, C.; Mertelmeyer, L.; burghardt, R.; Opitz, S. (2017): Bundeskonzept Grüne Infrastruktur – Fachgutachten. BfN-Skript 457. Bonn - Bad Godesberg.

Comments

- Approach to operationalize the criteria for EU-level GI according to data availability and considering scale and dimension of the European Green Belt.
- Habitat-based approach on ecosystem service assessment was applied.
- Due to lack of area-wide primary data (e.g. quality of habitat types, exact location of habitat types, species distribution) indicators based on available data have been applied.
- Results can be used for further securing and developing European Green Belt as EU-level GI (e.g. hot spots of multifunctionality, gaps).

6 GAPS IN KNOWLEDGE, DATA, AND TOOLS

6.1 FEEDBACK FROM STAKEHOLDERS AND PRACTITIONERS USED FOR IMPROVEMENT

The mapping of GI with the specific objective of achieving a well-connected network that delivers multiple ecosystem services calls for a novel integrated approach, underpinned by research and environmental policies. The concept is holistic and very challenging because it involves breaking sectorial 'silos' (forest, agri-environment, water, nature conservation, regional planning).

Stakeholder consultation can be very wide and, for instance, include policymakers, NGOs, practitioners in forestry, agriculture, and regional development, scientists, urban planners, and citizens. Many initiatives focus on forest and urban domains. In general, government funding to promote the GI concept is lacking. Limited technical know-how and capacity have been identified as a common barrier between practitioners. EU methodological guidance (e.g. a common or more consistent approach) is also needed.

For example, practitioners in the forestry sector mention the need for specific training on the methods, tools, and management options relating to connectivity. They regret the lack of precise information on species traits and their responses to landscape features (species movement abilities, distribution, habitat suitability, land cover permeability, etc.) to accurately guide decision-making on the connectivity of ecosystem services. Such comments could easily apply to other sectors affected by the agro-ecosystems and freshwater ecosystems.

GI demonstration case studies should be promoted in the private and public operational sectors, together with appropriate methodological guidance to encourage GI deployment. It is believed that spatially explicit harmonised GI maps over large areas and across borders in addition to dedicated maps at the scales of action (local and regional) could facilitate dialogue between different stakeholders and decision-making. The multi-faceted GI concept may initially be simplified and introduced in each ecosystem in a more structured manner in order to facilitate its understanding among stakeholders from the same sector. Data consistency and definition of common standards in each ecosystem would require significant effort, but seems feasible. The analysis and integration of recommended GI map layers for different ecosystems could also be facilitated by the integration of available tools in a shared GIS platform.

A list of main players, including their priorities for each sector, and for all sectors according to ecosystem and region, could support a more effective and transparent GI and nature-based solutions (NBS) process. The level of GIS expertise needed to use available tools may be a concern and prevent the dialogue. Practitioners and local 'in-situ' experts are very knowledgeable in the field and aware of local conflicts but are not GIS experts and are not familiar with mapping approaches and tools. The successful combination of the ecological and territorial dimensions underpinned by GI depends on recognising the value added by knowledge from both type of experts – standardised knowledge, GIS, and mapping on the one hand, and a more qualitative, often local, knowledge that is valuable in interpreting maps, on the other. The involvement of social scientists in the process of mapping cultural services proved to be very valuable in one case study.

GI development is difficult due to the competition between different land uses, and the need for trade-offs between services (cultural/regulating services and provisioning services). The lack of understanding or awareness of the potential benefits of GI (and its links to economic growth) is one of the reasons for underinvestment in GI (particularly in south-eastern Europe). That is why highlighting GI's economic, social, and other co-benefits as demonstrated in a few case studies is one way forward in encouraging increased uptake of GI over other infrastructure alternatives.

6.2 DATA AVAILABILITY AND IDENTIFIED GAPS

6.2.1 Landscape elements that qualify for GI

Spatially and thematically detailed land-use and land-cover data are the commonly used and available base layer for identifying recommended landscape elements for GI deployment and prioritisation. They are needed at multiple scales. The local and regional scales of assessment, which represent the scale of action and implementation of measures, require detailed data from different data sources, including land ownership, management plans, and the monetary cost of certain measures.

Large-scale and less thematically detailed data are often sufficient for the mapping of GI over large regions (national, transborder and European territory). They should concentrate on matters of national or transborder relevance like defragmentation measures, the planning of highways, connectivity of protected areas, resilience in the context of climate change, territorial cross-border coherence for the connectivity of woodlands, and the continuity of riparian vegetation along rivers.

In general, spatially explicit data is easily found on major land cover and land uses categories, water bodies, protected areas of different categories, and statistics supporting information for a series of ecosystem services. Data on species presence and behavioural traits to inform species dispersal requirements, as well as habitat maps and grid-based data on ecosystem conditions, are partially available. The consistency and harmonisation of data across regions remain a concern in facilitating comparison and in informing transboundary decisions. Core components of the GI networks are typically protected areas such as Natura 2000 sites, but there could be other valuable landscape elements that, protected or not, act as biodiversity pool.

Case studies have demonstrated that identification of GI elements is now feasible from a physical point of view at local scale down to a 5 x 5 m grid, particularly in the urban context, and at 100 m x 100 m (1 ha) over large regions, more suited to rural subjects. Broad thematic maps at 1 ha Minimum Mapping Unit (MMU) of recommended GI components (such as forest lands and other non-forested natural lands, riparian vegetation, and natural connectivity features in agricultural landscapes) could easily be made available from regional level up to the European level. Furthermore, the production of regional GI maps like the ones demonstrated in Italy and Spain (case study 5.1.4 and 5.1.6) revealed the share of targeted natural and semi-natural connectivity of additional features like grasslands and 'trees outside forest' in one hectare.

Land-use and land-cover maps do not provide qualitative data on the landscape elements that qualify for GI. This is also the case for urban natural elements that qualify as green spaces in cities. Consequently, data availability and knowledge on ecosystem condition is lacking, hampering the qualitative identification of GI elements in order to provide information on land use intensity, level of degradation, and the need for restoration. In particular, the forestry and agri-environment sectors have data available at national scale on intensively and extensively used arable land and on sustainable forest management that needs to be integrated and streamlined for GI purposes. Progress in knowledge is expected from the application of the MAES analytical framework for ecosystem conditions with key inter-related indicators (European Commission, 2018). Particular effort is needed for grasslands, heathlands, peatlands and wetlands, mountains and urban systems.

6.2.2 Landscape elements that do not qualify for GI

Landscape elements that do not qualify for GI are areas that are poor in biodiversity or intensively used, and human-dominated land. Transport infrastructures and settlements are now easily obtained from national maps, soil sealing data, and from open data sources such as OpenStreetMap. Information on intensive land uses are more difficult to obtain over large regions.

6.2.3 Data format

One problem encountered is the lack of ready-to-use harmonised data, hence the need for data preparation and integration to identify a suitable - and the most feasible - workable spatial and thematic resolution that integrates and streamlines available data (e.g. case study 5.1.6 and 5.2.3) with different spatial grids and different thematic resolutions. GI components from different ecosystems are typically identified from high resolution national and regional land-cover and land-use data as well as from European data sources.

Commonly used data across the EU are the CORINE Land Cover dataset and the reporting streams under the EU environmental directives, the newly available Copernicus High Resolution Layers (e.g. forest, grassland), the European Soil Database Maps, and the High Nature Value farmland layer (datasets references available in Table 4.1). Regional and national land-cover layers are often available only for certain ecosystems, forest being the ecosystem where more fine-grain and thematic detailed data are found.

Data can be input into models in two ways: a) as aggregated metrics over a unit of reference (e.g. population density statistics, ecosystem services data per administrative unit) and b) as fine-grain gridded data (e.g. land-cover/land-use maps, road networks). Aggregated metrics may be sufficient for a policy request such as reporting, in that it provides a single value indicator that translates a GI-related issue, and may also be sufficient to support decision-making for an entire region or country.

However, aggregated metrics cannot capture the spatial distribution of a process occurring at local scale, nor can they locate hotspots. Ecosystem services data are not easily found. When available, they are often aggregated at large scale and have to be refined at local scale using complementary and more accurate data before any actual green infrastructure deployment or restoration measures are carried out.

6.2.4 Ecosystem service approach rather than a species approach to deploying GI

In some cases, it seems easier and technically more feasible to approach the GI concept by ecosystem type. Each ecosystem 'integrates' the needs of several habitats and their associated species. This approach was demonstrated for the forest ecosystem and for the agro-ecosystem in case studies. Ecosystems, their condition, their connectivity, the main threats they face, the human-induced and natural drivers of changes, the characteristics of their natural environment as well as the services they provide should ideally be documented and mapped systematically in all countries.

Some ecosystems such as forests are more easily and better mapped than others. It is possible that the availability of ecosystem maps (mentioned below) could be further overlaid in the near future to support GI mapping at regional and European scales. Characteristics or knowledge gaps for each of these ecosystems are:

- *Map of wetlands*: There is a knowledge gap regarding the ecological benefit of physical mapping and ecosystem-service-based mapping of the connectivity of wetlands. Criteria for developing a GI map of wetlands are needed. The Global Surface Water Explorer[71] is useful for checking GI deployment in Europe.
- *Map of agricultural landscapes with focus on extensive arable lands:* Of interest are the mapping of linear and isolated landscape elements (hedges, isolated trees, trees outside forest) and the geo-localised information of High Nature Value farmland. If extensive agricultural areas qualify for GI, should agro-forestry landscape elements and complex cultivation patterns also qualify for GI?
- *Map of open natural landscapes, typically dominated by herbaceous vegetation and only a few shrubs*: Available maps do not always discriminate between main types of grasslands (e.g. mesophilous/thermophilous). Montane grasslands that suffer from land abandonment and where natural succession is common face different threats compared to humid meadows along river beds, over-grazed prairies or remnant prairies in an agricultural field.
- *Map of forest*: The fragmentation of blocks of forest (by roads for example) is a concern, as is the need to better connect woodlands in order to preserve the survival and dispersal of forest-dwelling species. Maps are generally well documented for broadleaved, coniferous, mixed forests and other wooded lands. Georeferenced information is still needed regarding the condition of forests, the services they provide, the tree species involved, the degraded woodlands to be restored, plantations, and high nature value forest.
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6.2.5 Fragmentation and connectivity

Maps can be made available at multiple scales to show the landscape fragmentation pattern and the structural and functional connectivity of recommended GI landscape components:

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[71] https://global-surface-water.appspot.com/

- Map of unfragmented natural lands, map of landscape mosaic patterns, map of linear landscape elements, and map of recommended core GI landscape elements (physical approach).
- Map of major natural and semi-natural recommended GI at 1 ha MMU based on structural and functional connectivity criteria. This map includes the main corridors provided by available GI, identifies gaps in connectivity, and proposes the establishment of new connecting paths, 'zones' for prioritising defragmentation, and permeability measures. Corridors between GI networks are the most favourable landscapes for species based on broad landscape permeability concepts and a range of dispersal distance (demonstrated for most terrestrial vertebrates, and for pollinators in case studies). The main bottlenecks are landscape features such as roads and settlements that are most hostile to species dispersal and habitat provision services. It is recommended that more accurate research is conducted on species responses to different types and levels of intensive land uses. Corridors represent structural and functional continuums of natural/semi-natural lands that are spatially explicit but ideally generic to most or a great many species, i.e. not necessarily species specific. It is further recommended that the analysis is refined by developing GI maps for each of the four main ecosystems: forest, freshwater and wetlands, non-forested ecosystems (e.g. grasslands representative of natural open landscapes), and agro-ecosystems, including particularly extensively used or heterogeneous arable lands with natural vegetation.
- Percentage of a country or region covered by protected and connected lands, which represents the degree to which the spatial arrangement of protected areas (PAs) is successful in ensuring the connectivity of protected lands. Contribution of different categories of land (protected, unprotected, transboundary) to the connectivity of PAs. Distance to the Aichi Target 11 connectivity element of having 17% of the land covered by well-connected systems of PAs, or to other current or future (post-2020) connectivity targets. It is recommended that the analysis and the accounting for landscape permeability between protected areas be refined.
- European countries and regions where additional efforts are most needed in expanding or reinforcing the connectivity of PA systems, in particular where to prioritise the creation of new designated PA and where to focus more on ensuring the permeability of the unprotected landscapes. Transnational and transregional PA linkages where the coordinated management of adjacent PAs involving different countries and regions is most needed.
- European regions which are most resilient to environmental pressure, and degree of protection of riparian corridors.
- Regional map showing where best to allocate greening subsidies (land reallocation) based on monetary cost and GI connectivity for pollinators and most terrestrial vertebrates. It is recommended that the analysis be replicated in different regions, showing the benefits for ecosystem services.
- Spatial pattern map of green spaces in European cities.
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6.2.6 Ecosystem services

The Common International Classification of Ecosystem Services (CICES) is broadly used as a flexible framework and hierarchical classification of ecosystem services within the MAES initiative because it links with the framework of the UN System of Environmental-Economic Accounting (SEEA) and integrates ecosystem values in accounting frameworks.

Ecosystem service data to map ecosystem services is derived from different modelling approaches, but there is still a great deal of uncertainty in the models used (Schulp et al., 2014). Biophysical models to map ecosystem services have been made available in different mapping tools such as InVEST or ESTIMAP. However, models still cannot cover the whole range of services. Review articles have typically found that regulating and provisioning services are most frequently mapped, but cultural services less so. As for regulating services, most efforts have focused on mapping climate regulation, while the most frequently mapped provisioning services relate to food, water and timber.

Furthermore, model outputs are highly variable due to the differences in indicator definition, level of process understanding, mapping aim, data sources, spatial resolution, and methodology (Schulp et al., 2014). Ecosystem service mapping could therefore be substantially advanced by a more systematic development of cross-case comparisons and methods. Local and regional expert knowledge proves to be very valuable in informing ecosystem services, particularly with regard to cultural services.

6.2.7 Static GI map versus dynamic GI map

GI mapping is usually addressed and proposed as a static map, but there is a need for dynamic GI mapping. Case study 5.1.5 illustrates the question of whether the network of protected areas, acting as the backbone for GI, could respond to the species range shifts in the context of climate change. The GI network should ideally be able to compensate the loss of climatically suitable areas over time.

6.2.8 Land-use scenarios

More studies should be developed on policy scenarios of land-use conversion that could impact GI networks in the coming decades. Further study of the resilience of potential GI to future land development scenarios is also needed.

6.2.9 Other gaps in knowledge

There are knowledge and data gaps about the potential benefits of GI (including monetary benefits and links to economic growth). Furthermore, due to poor data availability or insufficient data resolution, the connectivity of grassland ecosystems is not properly assessed over large regions. There is a knowledge gap on the relevance of the connectivity concept for wetlands. Species traits should be documented according to main ecosystem and species responses to landscape permeability. Furthermore, there is a huge gap in knowledge about the mapping and assessment of marine and coastal ecosystems and their services in general; difficulties are encountered in establishing a link between biophysical features of coastal ecosystems and the supply of services such as tourism and recreation. The GI concept is still poorly developed at the sea-land interface.

Valuable understanding of the extent of knowledge and data gaps over a diversity of regions and biomes in Europe was gained within the EU Project on Enhancing ecoSysteM Services mApping for policy and Decision mAking (ESMERALDA)[72]). The open access and publicly available textbook on "Mapping Ecosystem Services" (Burkhard and Maes 2017) provides guidance and background information on how to map ecosystem services. Further progress in deploying GI can be made by engaging with stakeholders and documenting lessons learnt (Burkhard et al., 2018).

6.3 TOOLS AND IDENTIFIED GAPS

6.3.1 Expertise in modelling and GIS is needed to use tools for GI mapping

The deployment of GI is based on technical, scientific, and data-driven approaches that require expertise in data management, modelling and GIS. The tools available can be used to assess fragmentation, landscape connectivity features, and connectivity including the mapping of corridors, as well as the provision of ecosystem services in both rural and urban settings. They demonstrate how to identify the main bottlenecks occurring in landscape habitat provision, and how to prioritise GI, restoration, and other improvement actions in the context of sustainable ecosystem management, particularly in forest and agri-environment.

6.3.2 Urban context

The GI concept is better known and applied in the urban local context, particularly for its benefits in regulating ecosystem services. Planning that develops and maintains green infrastructure can solve urban challenges and contributes significantly to the creation of future liveable cities that support biodiversity and human well-being (Balzan, 2018). Case studies have shown that there exist urban physical and ecosystem-service-based measures beyond the commonly used number and areas of green spaces in cities, and that the 'green' spatial pattern of cities in Europe can now be compared. Tools for urban mapping include connectivity measures and can assess the territorial and ecological coherence between urban and peri-urban areas. Knowledge is still lacking on species response to city disturbances such as noise.

3.3 Rural context

The GI concept in rural settings is better known in landscape ecology and nature conservation fields, and is often reduced to the more familiar 'ecological network' concept. Case studies have demonstrated tools promoting the value-added by considering multiple ecosystem services when mapping GI.

Modelling tools that identify rural/landscape GI elements according to physical criteria are now operational (spatial patterns of recommended GI landscape features (linear, small, and isolated), landscape mosaic patterns, and edge interfaces) and according to ecosystem-service-based criteria, including functional connectivity that favours habitat provision. Fragmentation and connectivity are easy criteria to measure when mapping and prioritising GI, such as defragmentation measures and habitat provision of ecosystem services (cf. case studies). These tools offer complete flexibility in defining landscape elements that qualify as GI components, and help identify the main bottlenecks to

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[72] http://esmeralda-project.eu/

GI connectivity in the landscape. Quantitative criteria of GI that address restoration are still not in use due to the lack of data on ecosystem condition. More insight focused on prioritising ecosystem restoration can be found in Lammerant et al., 2013.

6.3.4 Fragmentation, connectivity analysis and mapping of corridors

While fragmentation can be easily and rapidly computed (from seconds to minutes), connectivity analyses and the mapping of corridors are more computationally intense. Such calculations over large, high-resolution landscapes in reasonable times have, however, made good progress recently, thus rendering processing feasible at all scales (from hours to a few weeks). The setting of input parameters to the models and the interpretation of results require methodological guidance.

Mapping GI connectivity and mapping GI ecosystem services is handled separately in all but one case study because specific tools have been developed by different research disciplines and are not fully integrated yet. Their integration into a common methodological framework would be very valuable as suggest the promising results (case study 5.2.3) on the mutual benefit of connectivity and the delivery of ecosystem services. The approach needs to be developed at European level in the near future.

6.3.5 Monetary costs

The methodological framework in case study 5.1.6 incorporates the monetary costs involved for specific land reallocations as criteria for cost-effective enhancement of the connectivity of GI networks. This is particularly relevant in the agri-environment and forestry context, since it could help target the allocation of greening subsidies, and support decision-making on where to maximise connectivity and minimise the cost of the loss of agricultural land/production.

The tools available need to be integrated, and it should be shown how nature conservation, connectivity and the provision of multiple ecosystem services can be integrated with landscape and urban planning needs. Criteria and methods for identifying the trade-offs between different sectorial priorities and for better informed decision-making should be developed. More information and tools are needed to assess the economic value of ecosystem services, and promote the integration of these values into accounting and reporting. Methodological guidance is needed on how GI-related spatial layers can support and inform discussions between stakeholders and help resolve conflicts and make decisions.

6.3.6 Tools for multi-scale integration: bottom-up versus top-down approach for mapping GI

The top-down approach is to identify and map GI for issues that are relevant at national and European scales. Broad-scale GI maps such as those available in the case studies can then be used in regional-level analysis. Large-scale GI concerns would then be reflected in decision-making for regional and local landscape planning. This approach seems to be preferable and initially more feasible than bottom-up approaches that would require the synthesis of all local and regional detailed GI maps and understanding of each regional contribution over large territories. Methodological guidance is needed in the multi-scale integration of GI maps.

7 CONCLUSIONS

This report contributes to the knowledge base developed at the European level for the mapping of green infrastructure and ecosystem restoration. It offers avenues to support the mapping and assessment of green and blue infrastructure projects, with a view to establishing a strategic framework for EU-level projects and maximising the benefits provided. On the basis of case studies, best practices are illustrated of how the knowledge base can be further developed using spatial information and tools to support the restoration of degraded ecosystems and the deployment of green infrastructure. This includes restoring and better connecting functional ecosystems, and improving the connectivity of the Natura 2000 network and other areas of high value for biodiversity that are isolated or fragmented.

EU-level green infrastructure (GI) projects contribute to the goals of the EU nature legislation many ways. They should therefore not only be considered from a purely narrow perspective, e.g. from the physical mapping of 'GI corridors' only, but also from a dynamic perspective that includes both physical mapping and ecosystem service-based dimensions such as ecological robustness, the coherence of the Natura 2000 network, and the enhancement of the conservation status of species and habitat types of European importance. This also includes improving the overall condition of habitats, including Appendix I habitats and habitats outside the Natura 2000 network, for example, by restoration actions. GI can extend the 'ecosystem-service-based area' that species need in order to have good condition/favourable conservation status and ensure the long-term viability of the population.

The case studies included in this report provided methodological guidelines to tackling some of these issues:

1. *Mapping GI to support and enhance nature protection, beyond the borders of protected areas and across country borders, by answering questions such as: How well connected are protected areas? Can connectivity enhance the provision of ecosystem services? Where are the key corridors between Natura 2000 areas? Which corridors and landscapes should be prioritised to increase biodiversity and ecosystem services?*

   The Natura 2000 network, together with other networks of nature reserves, constitutes the backbone of EU GI. These case studies respond to the need identified in the 2016 Nature Fitness Check to harness the full benefits of EU nature legislation, demonstrating how and where GI can contribute to improving coherence of the Natura 2000 network, better habitat and landscape management, and the implementation of restoration measures. The studies also show how to compute and use the Biodiversity Aichi target 11 of at least 17% of terrestrial and inland water areas being conserved through well-connected systems of protected areas. One key message is that Europe is performing above average and has already met this target. For half of the EU countries, emphasis should be less on designating new protected areas for connectivity and more on developing priority strategies for landscape permeability of unprotected land and coordinated management of adjacent protected sites.

2. *Planning GI as a cross-border, dynamic, and resilient network to mitigate climate change.*

   One case study illustrated how to map GI as a dynamic network in order to account for climate change over time and make GI resilient to it. The example showed that the current network of protected areas cannot respond to the species range shift in the context of climate change, and highlighted where GI should be deployed to compensate for the loss of suitable climatic areas over time.

3. *Deploying a well-connected and multi-functional GI in the rural landscape, where to prioritise actions for conservation and restoration, where to enhance landscape permeability and prioritise defragmentation measures to mitigate the impacts of agricultural intensification and road infrastructure on species movement.*

   GI in rural areas includes nature reserves, grasslands, forests, and farmlands, and provides the links which bind ecosystems together, facilitating the flow of ecological processes and so ecosystem services. Today, GI networks can be mapped easily at the spatial resolution of one hectare in terms of core interior areas, corridors (defined as physically connected links between core components) and other natural connectivity features, small and linear-like hedges, field margins and woodland islets. Edge interface areas and landscape mosaics (more or less naturally or intensively used) can also be documented to assess landscape permeability.

   The assessment of multi-functionality relies on data to map ecosystem services (following the hierarchical CICES classification). Due to the lack of real “measurements”, most ecosystem service data are derived from modelling approaches that still have a degree of uncertainty and do not cover the whole range of services. Regulating climate-related services and food, water and timber provisioning services are the most frequently mapped, cultural services less so. The total GI coverage, its connectivity and fragmentation and the multiple services it delivers are mainly assessed by ecosystem and by geographical unit of interest (landscape, region, country). High resolution GI mapping of natural connectivity features will benefit from assessing ecological focus areas (EFAs) more accurately in the context of the new common agricultural policy (2014-2020) and progress towards the target of EFAs accounting for 5% of arable land holdings larger than 15 ha. Further benefit will certainly be derived from mapping ecosystem service provision such as erosion control or pollination in a more spatially explicit manner.

   Reconnecting fragmented landscapes through GI connectivity elements such as green corridors, ecoducts, and ecological buffer zones around nature reserves is essential to meeting the biodiversity Aichi targets 11 (having at least 17% of well-connected systems of protected terrestrial and inland water areas) and 15 (to restore at least 15% of degraded ecosystems). Artificial connectivity features are now partially mapped from open source data such as OpenStreetMap and enrich landscape permeability assessment. Case studies have shown how and where to develop new connectivity pathways, where to strategically plan the conversion of agricultural land use to semi-natural vegetation in agricultural landscapes, or land re-wilding through the restoration of interconnected large core (wilderness) areas on the basis of the regulatory role of species. Pollinators and other flying insects were modelled in agricultural landscapes while large mammals or connectivity-sensitive species were modelled at more regional scales. Connectivity gaps and places for road defragmentation measures were identified. Such approaches enable space to be found for the implementation of GI in Europe where possible conflicts arising from the overlap between human activity and wildlife are carefully considered.

4. *Deploying GI in large urban areas and regions, planning green and multi-functional urban spaces as well as human development infrastructure in an urbanisation context.*

   Green spaces (up to discriminating rows of trees in very high resolution maps) can now be compared in terms of number, area and pattern across large urban areas in Europe. Access to green areas is one common criterion used to link to societal benefits such as cleaner air, improved health and recreation. Furthermore, tools exist to measure the territorial and ecological coherence between urban, peri-urban areas, and regions in order to improve monitoring and plan human infrastructure development and make sure not to reduce connectivity of green areas. In the context of urbanisation, it has been demonstrated that the maintenance of ecosystem services often requires the efficiency of artificial land use to be improved by promoting a more compact design of cities, tools to measure compactness, and patterns in urban sprawl.

5. *Exploring GI and ecosystem service provision by spatial modelling land-use scenarios of demographic, economic, and agricultural developments in the next few decades in Europe, finding trade-offs and resolving conflicts in decision-making regarding land allocation involving all sectors.*

   Case studies demonstrate how to model scenarios of land use or climate-change impacts on the loss or gain of GI and find trade-offs and synergies across regions for the delivery of ecosystem services in the next few decades. Available models simulate land-use and land-cover maps at the best resolution of the one hectare grid. Ecosystem services are often aggregated by categories and by administrative regions, and are prioritised for GI development that is suitable at broad regional scales. To date, decision-makers and planners have not considered such modelling tools for designing GI at local and territorial scales. Apart from an obvious need for training on the use of these tools, this is also due to a lack of coordinated GI management and spatial planning between sectorial departments and groups and across scales at European, national, regional and local levels. Local authorities also play an important role in guiding urban and territorial GI planning. In order for decision-makers and planners to take informed decisions, GI must now be considered to be as important as other infrastructure planning activities.

6. *Monetary cost assessment of prioritisation measures and GI benefits for society.*

   Implementing GI does not come without cost, since GI requires the conversion of land used for other purposes. Promoting GI and finding spatially explicit trade-offs across sectors would benefit from bringing evidence on the monetary cost-benefit of actions and their economic benefit for society. Such information is not sufficiently available, is still partially found in regional GI projects and urban GI studies. Here, one case study provided methodological guidelines to quantify the monetary loss and proposed cost-benefit solutions for prioritising natural/semi-natural land reallocations in the agri-environment and forestry context. Solutions were based on minimising the monetary cost of changes in agricultural production based on greening measures and maximising GI connectivity. These approaches should be encouraged in other contexts.

7. *Multi-scale integration of GI maps.*

   Top-down GI mapping approaches are relevant to national and European scales and adapted to large-scale concerns (such as transnational road defragmentation). Available maps can now be included in regional or local decision-making processes and more detailed analyses. Sharing available knowledge, data and tools, and addressing the linkages between regional, national and EU scales, could contribute to building a common understanding of the usability of existing tools and promoting consistent and reproducible approaches across scales and regions.

The knowledge base on mapping a well-connected and multi-functional GI now and over the next few decades has been reported by listing data and tools and providing methodological guidance through best-practice cases at European, national, regional, and local levels that focused on the terrestrial environment. It can benefit Member States and other stakeholders by facilitating the use of spatial information and tools to support the deployment of GI, the coordination of decision-making across regions and countries, and the prioritisation of conservation and restoration efforts.

Gaps in knowledge, obstacles and problems with data collection and methodologies were identified for the terrestrial environment. While extensive data and information is available on the various aspects covered in this report, significant gaps remain. For example, there is a need to better link and target user needs (demand) with the delivery of ecosystem services (supply) in order to design tailored GI/nature-based infrastructure (NBI) interventions that meet wider user needs. Further research is needed on methodological approaches for such assessments as well as on practical approaches to integrating these findings in planning processes and mainstreaming their consideration in decision-making processes.

There is a significant gap in knowledge regarding the deployment of GI in the marine environment. A report by Boon et al. (2015) provides a conceptual framework for the mapping and assessment of marine ecosystems and their services (a marine MAES) that is in line with the implementation of the Marine Strategy Framework Directive and the other relevant EU Directives. A roadmap for a marine MAES would certainly help deploy a marine GI, particularly at the sea-land interface. Further information is needed regarding the nexus between blue-green infrastructure and between interconnected water bodies and their associated natural open spaces (those developed along water bodies) which serve several interrelated purposes such as water storage, regulators of the river system, etc. Further studies focusing on concept, data and tools should be carried out to assess and plan a blue GI network, including the blue-green infrastructure nexus and the marine environment.

Other gaps exist in applying cost/benefit analyses beyond the local scale as a means of attracting investment and guiding more landscape-oriented decision-making processes; understanding options for improving framework conditions to foster GI at different scales; and means for supporting improved policy coherence between sectors and scales.

In addition, no information was found on potential future markets and possibilities for increasing the delivery of benefits by sector. Further studies that include cross-sectorial considerations, such as policy coherency and linkages, could support the development of relevant parameters to help measure the contribution of GI projects to other environmental policies and relevant sectors. Moreover, studies that include policy-related recommendations, such as for new green urban policies and an agenda for future action, targeting city authorities, national governments, and the EU, and focusing on the integration of ecosystem-based approaches into existing sectorial policies, may provide helpful insights.

Several studies take account of ecosystem services in assessing the impact of GI and NBI and related concepts, focusing on the supply side of delivery and including different types of services and, to some extent, the ecosystem-service-based links between specific urban GI elements and ecosystem services. Tools such as the "Green Infrastructure for Tomorrow-Together" (GIFT-T)[73], which serves as 'Ecosystem Services Performance Mapping', can be used in planning processes to come to a shared vision, as well as a GIS method for mapping the types of GI in a study area, the services they provide, and the demand for services. Moreover, the European Horizon 2020 EKLIPSE project that aims to develop a support mechanism to facilitate linkages between science, policy and society addresses the 'Nature-based solutions (NBS) in cities. Their "NBS Impact Assessment Framework'[74] outlines 10 societal challenges and a description of each challenge, a list of potential NBS actions and their respective impacts, examples of indicators to measure impacts, and methods for assessing the indicators as well as potential success and limiting factors, etc.

There is a need for more public open data and more interoperability of data and information systems to support the deployment of GI, i.e. data and metadata that are prepared according to standards, easily accessible through the internet, and interoperable to facilitate the integration of different datasets, and develop customised products. Databases on the conservation status of species and habitats derived from reports made under Articles 12 and 17 of the Habitats Directive (Council Directive 92/43/EEC) or data submitted in the Natura 2000 reference portal[75] provide an initial basis for such data collection and retrieval. However, more open data are needed to assess the (potential) delivery of ecosystem services by GI and NBS in specific local or regional contexts. The deployment of GI involves several policy areas and the participation of stakeholders from multiple sectors e.g. ecological, health, socio-cultural and economic. Integrated information systems would allow stakeholders to interact, interconnect and work together. They would enable an easy sharing, processing and combination of quantitative and qualitative data and indicators. Furthermore, while sector specific indicator can be easy to implement for measuring progress towards certain policy targets, assessing the performance of GI is more challenging and implies setting a comprehensive and integrative framework across all types of GI and ecosystem services, thus comprising several indicators. This requires to understand the level of contribution and degree of importance of each indicator within the GI context and set targets. More research is also needed on how to implement specific criteria, such as ecological robustness/resilience as well as the ecosystem service base and physical coherence of the Natura 2000 network.

Several promising areas have been identified for the future pursuit and mainstreaming of GI and NBI

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73 http://www.gift-t.eu/

74 http://www.eklipse-mechanism.eu/nbs_report

75 http://cdr.eionet.europa.eu/help/natura2000

and related concepts as an alternative to traditional grey infrastructure solutions. The novelty and innovation underlying these topics warrant further research in order to increase the associated knowledge and evidence base. For example, several studies in the field of planning and participation have highlighted new approaches to ‘co-governance’, which have yet to be extensively implemented or tested (e.g. in ‘urban living labs’), giving increased room to non-governmental actors within steering processes.

Furthermore, following the approach of the EKLIPSE Impact Evaluation Framework[76], further research is needed based on a wider interpretation of the ecosystem service concept which moves beyond the more restrictive Millennium ecosystem service approach and promotes a participatory approach by involving stakeholders (cf. EU integrated projects such as Operationalisation of natural capital and ecosystem services (OpenNESS)[77], ESMERALDA[78], Enhancing Resilience of urban ecosystems through green infrastructure (EnRoute)[79], etc.). Such a framework should be utilised in GI planning and as evaluation of interventions, and contribute to the currently scattered evidence on costs and benefits. Novel sources of investment and funding have been identified as having great potential for supporting increased implementation, but require additional investigation. In particular, innovative co-financing models, new partnerships, and increased involvement of previously removed sectors (e.g. insurance) could be interesting. Existing EU financing mechanisms such as the European Structural and Investment Funds (ESIFs), Horizon 2020, the Natural Capital Financing Facility (NCFF), and the programme for Environment and Climate Action (LIFE) could further facilitate and support the integration of green and blue infrastructure projects at the EU level.

A large new body of evidence on GI, and in particular on NBS, can be expected from the current Horizon 2020 European research projects, the inter-regional cooperation projects funded by the INTERREG Europe programme[80], research projects funded by the trans-national network of organisations that programme and fund research on biodiversity and ecosystem services (BiodivERsA)[81], and by the ESPON 2020 programme which aims to promote and foster a European territorial dimension in development and cooperation. The ESPON-funded applied research project on “GReen Infrastructure: Enhancing biodiversity and ecosysTem services for territoriAl development” (GRETA)[82] is highly relevant to the analysis of the spatial distribution of GI. Within this vein, a working paper[83] has recently been released on the territorial potential for GI. These and other relevant projects should be closely monitored to improve knowledge and stimulate innovation at the EU level (e.g. under Horizon Europe,

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76 http://www.eklipse-mechanism.eu/eklipse_outputs

77 http://openness-project.eu/

78 http://esmeralda-project.eu/

79 https://oppla.eu/groups/enroute

80 www.interregeurope.eu

81 www.biodiversa.org

82 www.espon.eu/green-infrastructure

83 www.espon.eu/working-paper-territorial-potentials-green-infrastructure

the next EU framework programme for research and innovation) that can feed into relevant EU and national policy processes in a timely matter. This would support the development of an EU-level GI that responds to the three key GI principles of connectivity, multifunctionality, and spatial planning and management, as addressed in this report.

References

Bagstad, K. J., D. Semmens, R. Winthrop, D. Jaworski, and J. Larson. 2012. *Ecosystem services valuation to support decision making on public lands: a case study for the San Pedro River, Arizona*. Scientific Investigations Report 2012-5251, U.S. Geological Survey, Reston, Virginia, USA.

Ball, I.R., Possingham, H.P. & Watts, M. (2009) Chapter 14: Marxan and relatives: Software for spatial conservation prioritisation. In A. Moilanen, K.A. Wilson and H.P. Possingham (Eds.), Spatial conservation prioritisation: Quantitative methods and computational tools, (pp. 185-195). Oxford University Press, Oxford, UK.

Balzan, M.V. (2018). Ecology for the city: analysing the role of green infrastructure in creating liveable cities. Zenodo. doi.org/10.5281/zenodo.1165152

Baró, F., Bugter, R., Gómez-Baggethun, E., Hauck, J., Kopperoinen, L., Liquete, C., and Potschin, P., 2015. Green Infrastructure. In: Potschin, M. and K. Jax (eds): OpenNESS Ecosystem Service Reference Book. EC FP7 Grant Agreement no. 308428. Available via: www.openness-project.eu/library/reference-book

Benedict, M.A. and McMahon, E.T., 2002. Green Infrastructure: Smart Conservation for the 21st Century Renewable Resources Journal, 20, 12-17.

Boon, A.,Uyarra, M.C.,Heiskanen, A.S., van der Meulen, M.D., Galparsoro, I., Viitasalo, M., Mikel, J., Murillas, A., Borja, A. (2015). Mapping and assessment of marine ecosystem services and link to Good Environmental Status (phase 1) - Background document to the Roadmap for an integrated approach to a marine MAES. 10.13140/RG.2.2.28660.35204.

Burkhard, B., J. Maes (Eds.) (2017): Mapping Ecosystem Services, Pensoft Publishers, Sofia, 376 pp. doi.org/10.3897/ab.e12837

Burkhard B, Maes J, Potschin-Young MB, Santos-Martín F, Geneletti D, Stoev P, Kopperoinen L, Adamescu CM, Adem Esmail B, Arany I, Arnell A, Balzan M, Barton DN, van Beukering P, Bicking S, Borges PAV, Borisova B, Braat L, M Brander LM, Bratanova-Doncheva S, Broekx S, Brown C, Cazacu C, Crossman N, Czúcz B, Daněk J, Groot R, Depellegrin D, Dimopoulos P, Elvinger N, Erhard M, Fagerholm N, Frélichová J, Grêt-Regamey A, Grudova M, Haines-Young R, Inghe O, Kallay TK, Kirin T, Klug H, Kokkoris IP, Konovska I, Kruse M, Kuzmova I, Lange M, Liekens I, Lotan A, Lowicki D, Luque S, Marta-Pedroso C, Mizgajski A, Mononen L, Mulder S, Müller F, Nedkov S, Nikolova M, Östergård H, Penev L, Pereira P, Pitkänen K, Plieninger T, Rabe S, Reichel S, Roche PK, Rusch G, Ruskule A, Sapundzhieva A, Sepp K, Sieber IM, Šmid Hribar M, Stašová S, Steinhoff-Knopp B, Stępniewska M, Teller A, Vackar D, van Weelden M, Veidemane K, Vejre H, Vihervaara P, Viinikka A, Villoslada M, Weibel B, Zulian G (2018) Mapping and assessing ecosystem services in the EU - Lessons learned from the ESMERALDA approach of integration. One Ecosystem 3: e29153. doi.org/10.3897/oneeco.3.e29153

Chamberlain, J.L.; D. Mitchell; T. Brigham; T. Hobby (2009). "Forest Farming Practices". North American Agroforestry: an integrated science and practice (2nd ed.). Madison, Wisconsin: American

Society of Agronomy. pp. 219–254

Clerici, N., Vogt, P., 2013. Ranking European regions as providers of structural riparian corridors for conservation and management purposes. International Journal of Applied Earth Observation and Geoinformation 21: 477–483. doi:10.1016/j.jag.2012.07.001

Crossman, N.D., B. Burkhard, S. Nedkov, L. Willemen, K. Petz, I. Palomo, E.G. Drakou, B. Martín-Lopez, T. McPhearson, K. Boyanova, R. Alkemade, B. Egoh, M.B. Bunbar, J. Maes 2013. A blueprint for mapping and modelling ecosystem services. Ecosystem services, 4:4-14.

Davies C, MacFarlane R, McGloin C, Roe M (2006). Green infrastructure planning guide, pp. 45. Available from: http://www.scribd.com/doc/ 33007993/Green-Infrastructure-Planning-Guide, accessed 07 November 2017.

De Groot, R.S., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity, 7:260–272.

Dilts, T.E., Weisberg, P.J., Leitner, P., Matocq, M.D., Inman, R.D., Nussear, K.E., Esque, T.C. 2016. Multiscale connectivity and graph theory highlight critical areas for conservation under climate change. Ecological Applications 26: 1223–1237.

EEA, 2011. Green infrastructure and territorial cohesion, European Environment Agency Technical report, No 18/2011. Available from: https://www.eea.europa.eu/publications/urban-adaptation-to-climate-change.

EEA, 2012. Urban adaptation to climate change in Europe - Challenges and opportunities for cities together with supportive national and European policies, Technical report, No 02/2012.

EEA, 2014. Spatial analysis of green infrastructure in Europe. Technical Report No. 2/2014. Publications Office of the European Union, Luxembourg. Available from: http://www.eea.europa.eu/publications/spatial-analysis-of-green-infrastructure.

EEA, 2014. Developing a forest naturalness indicator for Europe. Concept and methodology for a high nature value (HNV) forest indicator. Technical Report No. 13/2014. Publications Office of the European Union, Luxembourg. Available from: http://www.eea.europa.eu/publications/developing-a-forest-naturalness-indicator.

EEA, 2015. Exploring nature-based solutions. The role of green infrastructure in mitigating the impacts of weather- and climate change-related natural hazards. Technical Report No12/2015.

EEA, 2016. Urban adaptation to climate change in Europe 2016 - Transforming cities in a changing climate. Technical Report No 12/2016. Available from: https://www.eea.europa.eu/publications/urban-adaptation-2016.

EEA, 2017. Green Infrastructure and Flood Management – promoting cost-efficient flood risk reduction via green infrastructure solutions. EEA Report No 14/2017.

EEA/FOEN, 2011. Landscape fragmentation in Europe — Joint EEA–FOEN report, EEA Report No

2/2011, European Environment Agency, Swiss Federal Office for the Environment.

Engelhard, S.L., Huijbers, C.M., Stewart-Koster, B., Olds, A.D., Schlacher, T.A., Connolly, R.M. 2016. Prioritising seascape connectivity in conservation using network analysis. Journal of Applied Ecology, DOI: 10.1111/1365-2664.12824.

Estreguil C., Caudullo G., de Rigo D. and San-Miguel-Ayanz J. 2012. "Forest Landscape in Europe: Pattern, Fragmentation and Connectivity". JRC scientific and policy report EUR 25717EN – http://dx.doi.org/10.2788/77842.

Estreguil C., Caudullo G., Whitmore C. 2011. Habitat landscape pattern and connectivity indices; Used at varying spatial scales for harmonized reporting in the EBONE project. Wageningen, Alterra, Alterra Report 2297. 80 pp. ISSN 1566-7197. (download at http://www.alterra.wur.nl/ .

Estreguil, C., Caudullo, G., de Rigo,D., 2014. Connectivity of Natura 2000 forest sites in Europe. F1000Posters 2014, 5: 485. DOI: 10.6084/m9.figshare.1063300. ArXiv: 1406.1501

Estreguil, C., Caudullo, G., Saura, S., Mateo-Sánchez, M.C., Gastón, A., García-Viñas, J.I. and López-Leiva,C., 2015. Pilot analysis of the connectivity of the Natura 2000 forest sites to guide forest conservation and restoration. Final report of SC16 contract in the framework contract reference N° 388432 with the Universidad Politécnica de Madrid (UPM) for the 'provision of forest data and services in support to the European Forest Data Centre'. Available for download at http://fise.jrc.ec.europa.eu/topics/ecosystem-services/

Estreguil, C., Caudullo, G., Rega, C., Paracchini, M.L., 2016. Enhancing Connectivity, Improving Green Infrastructure. EUR 28142 EN; doi:10.2788/170924

Estreguil, C., Caudullo, G., San-Miguel-Ayanz, J. 2013. Connectivity of Natura 2000 Forest Sites. JRC scientific and policy report EUR 26087EN. Luxemburg: Publications Office of the European Union. doi: 10.2788/95065.

Estreguil, C., de Rigo, D., Caudullo, G., 2013. A proposal for an integrated modelling framework to characterise habitat pattern. Environmental Modelling & Software, Vol. 52 (February 2014), pp. 176-191, ISSN 1364-8152, doi: 10.1016/j.envsoft.2013.10.011.

European Commission, 2010. "Towards a green infrastructure for Europe, Developing new concepts for integration of Natura 2000 network into a broader countryside", EC study ENV.B.2/SER/2007/0076. Available from: http://ec.europa.eu/environment/nature/ecosystems/docs/green_infrastructure_integration.pdf, accessed 06 November 2017.

European Commission, 2012. "The Multifunctionality of Green Infrastructure. Science for Environment policy", In-depth Reports, March 2012.

European Commission, 2013. "Building a Green Infrastructure for Europe". European Union, 2013, Belgium.

European Commission, 2013. Mapping and Assessment of Ecosystems and their Services. An analytical framework for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to

2020. Brussels.
http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/MAESWorkingPaper2013.pdf

European Commission, 2014. Mapping and Assessment of Ecosystems and their Services. Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. Brussels. http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/2ndMAESWorkingPaper.pdf

European Commission, 2016. Mapping and Assessment of Ecosystems and their Services. Mapping and assessing the condition of Europe’s ecosystems: Progress and challenges. Brussels. http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/3rdMAESReport_Condition.pdf

European Commission, 2016. Mapping and Assessment of Ecosystems and their Services. Urban ecosystems. Brussels.
http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/102.pdf

European Commission, 2017. “An Action Plan for nature, people and the economy”. COM(2017) 198 final. Brussels.
http://ec.europa.eu/environment/nature/legislation/fitness_check/action_plan/index_en.htm

European Commission, 2018. Mapping and Assessment of Ecosystems and their Services. An analytical framework for mapping and assessment of ecosystem condition in EU. Brussels.

http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/5th%20MAES%20report.pdf

Forest Europe, 2015. State of Europe's Forests 2015. Status and Trends in Sustainable Forest Management in Europe, Ministerial Conference on the Protection of Forests in Europe, Forest Europe, Liaison Unit Madrid, Madrid. http://foresteurope.org/state-europes-forests-2015-report/ (in particular, part II, criterion 4)

Frazier, A.E., Bagchi-Sen, S. 2015. Developing open space networks in shrinking cities. Applied Geography 59: 1–9.

Gartzia, M., Fillat, F., Pérez-Cabello, F., Alados, C.L. 2016. Influence of agropastoral system components on mountain grassland vulnerability estimated by connectivity loss. PLoS ONE 11(5): e0155193.

Giannini, T.C., Tambosi, L.R., Acosta, A.L., Jaffé, R., Saraiva, A.M., Imperatriz-Fonseca V.L., Metzger, J.P. 2015. Safeguarding ecosystem services: a methodological framework to buffer the joint effect of habitat configuration and climate change. PLoS ONE 10(6): e0129225.

Groot Bruinderink, G., Sluis, T. van der, Lammertsma, D., Opdam,P., & Pouwels, R. 2003. Designing a coherent ecological net-work for large mammals in northwestern Europe. Conservation Biology, 17: 549–557.

Gurrutxaga, M., Rubio, L., Saura S. 2011. Key connectors in protected area networks and the impact of highways: a transnational case study from the Cantabrian Range to the Western Alps. Landscape and Urban Planning 101: 310–320.

Gurrutxaga, M., Saura, S. 2014. Prioritizing highway defragmentation locations for restoring landscape connectivity. Environmental Conservation 41: 157–164.

Haines-Young, R.H., Potschin, M.P., 2010. The links between biodiversity, ecosystem services and human well-being. In: Raffaelli D. G., Frid C. L. J., editors. Ecosystem Ecology: A New Synthesis. Cambridge: BES Ecological Reviews Series, Cambridge University Press. pp. 110–139.

Ishiyama, N., Akasaka, T., Nakamura, F. 2014. Mobility-dependent response of aquatic animal species richness to a wetland network in an agricultural landscape. Aquatic Sciences 76:437–449.

Karlson, M., Karlsson, C.S.J., Mörtberg, U., Olofsson, B., Balfors, B. 2017. Design and evaluation of railway corridors based on spatial ecological and geological criteria. Transportation Research Part D Transport and Environment 46: 207–228.

Lafortezza, R., Davies, C., Sanesi, G., and Konijnendijk, C., 2013. Green Infrastructure as a tool to support spatial planning in European urban regions. iForest - Biogeosciences and Forestry, 6, 102–108.

Lammerant, J., Peters, R., Snethlage, M., Delbaere, B., Dickie, I., Whiteley, G. , 2013. Implementation of 2020 EU Biodiversity Strategy: Priorities for the restoration of ecosystems and their services in the EU. Report to the European Commission. ARCADIS (in cooperation with ECNC and Eftec). Available at http://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/2020/RPF.pdf

Larondelle, N., Haase, D., 2013. Urban ecosystem services assessment along a rural–urban gradient: A cross-analysis of European cities, Ecological Indicators, 29: 179–190.

Lavalle C., Baranzelli C., Mubareka S., Rocha GomesC., Hiederer R., Batista e Silva F., Estreguil C. 2011. Implementation of the CAP Policy Options with the Land Use Modelling Platform. A first indicator-based analysis. Scientific and technical report EUR 24909. ISBN 978-92-79-20917-8. doi: http://dx.doi.org/10.2788/44614. Luxembourg: Publications Office of the European Union.

Lavalle C, Mubareka S, Perpin˜a C, Jacobs-Crisioni C, Baranzelli C, Batista e Silva F, Vandecasteele I 2013. Configuration of a reference scenario for the land use modelling platform. EUR 26050. Publications Office of the European Union, Luxembourg.

Liquete, C., Kleeschulte, S., Dige, G., Maes, J., Grizzetti, B., Olah, B., Zulian, G., 2015. Mapping green infrastructure based on ecosystem services and ecological networks. A Pan-European case study. Environmental Science & Policy 54: 268–280.

Llausas A, Roe M., 2012. Green infrastructure planning: Cross-national analysis between the north east of England (UK) and Catalonia (Spain) European Planning Studies 20: 641–663.

Loro, M., Ortega, E., Arce, R.M., Geneletti, D. 2015. Ecological connectivity analysis to reduce the barrier effect of roads: an innovative graph-theory approach to define wildlife corridors with multiple paths and without bottlenecks. Landscape and Urban Planning 13: 149–162.

Matzdorf, B., Biedermann, C., Meyer, C., Nicolaus, K., Sattler, C., Schomers, S. 2014. Paying for

Green? Payments for Ecosystem Services in Practice. Successful examples of PES from Germany, the United Kingdom and the United States. Müncheberg. 208 pages. https://www.researchgate.net/publication/269629134

Maes, J., et al., 2015. More green infrastructure is required to maintain ecosystem services under current trends in land-use change in Europe. Landsc Ecol 30: 517–534.

Maes, J., Fabrega, N., Zulian, G., Barbosa, A., Vizcaino, P., Ivits, E., Polce, C., Vandecasteele, I., Marí-Rivero, I., Guerra, C., Perpiña-Castillo, C., Vallecillo, S., Baranzelli, C., Barranco, R., Silva, F.B.e., Jacobs-Crisoni, C., Trombetti, M. & Lavalle, C. (2015) Mapping and Assessment of Ecosystems and their Services: trends in ecosystems and ecosystem services in the European Union between 2000 and 2010. JRC Science and Policy Report. European Commission. Retrieved from - http://publications.jrc.ec.europa.eu/repository/bitstream/JRC94889/lbna27143enn.pdf

Maes, J., Paracchini, M.L., Zulian, G., 2011. A European assessment of the provision of ecosystem services: Towards an atlas of ecosystem services, JRC Scientific and Technical Report.

Maiorano, L., Amori, G., Montemaggiori, A., Rondinini, C., Santini, L., Saura, S., Boitani, L. 2015. On how much biodiversity is covered in Europe by national protected areas and by the Natura 2000 network: insights from terrestrial vertebrates. Conservation Biology 29: 986–995.

Mazaris, A.D., Papanikolaou, A.D., Barbet-Massin, M., Kallimanis, A.S., Jiguet, F., Schmeller, D.S., Pantis, J.D. 2013. Evaluating the connectivity of a protected areas' network under the prism of global change: the efficiency of the European Natura 2000 network for four birds of prey. PLoS ONE 8(3): e59640.

McRae, B.H., Kavanagh, D.M., 2011, Linkage Mapper Connectivity Analysis Software. The Nature Conservancy, Seattle WA (http://www.circuitscape. org/linkagemapper) accessed 30 December 2013.

Mell, I. C., 2008. Green infrastructure: concepts and planning. FORUM ejournal, 8, 69–80.

Mell, I. C., 2017. Green infrastructure: reflections on past, present and future praxis. Landscape Research, 42, 135–145.

Mubareka, S., Estreguil, C., Lavalle, C., Baranzelli C., Rocha Gomes C. , 2013. Integrated modelling of the impact of Natural Water Retention Measures on Europe's Green Infrastructure. International Journal of Geographical Information Science. Special Issue on Land Change Modelling: Moving Beyond Projections. http://dx.doi.org/10.1080/13658816.2013.782408

Mubareka, S., Koomen, E., Estreguil, C., Lavalle, C., 2011. Development of a composite index of urban compactness for land use modelling applications. Landscape Urban Plan. (2011), doi:http://dx.doi.org/10.1016/j.landurbplan.2011.08.012

Naumann, Sandra, McKenna Davis, Timo Kaphengst, Mav Pieterse and Matt Rayment, 2011. Design, implementation and cost elements of Green Infrastructure projects. Final report to the European Commission, DG Environment, Contract no. 070307/2010/577182/ETU/F.1, Ecologic institute and GHK Consulting.

Naumann, Sandra, Gerardo Anzaldua, Pam Berry, Sarah Burch, McKenna Davis, Ana Frelih-Larsen, Holger Gerdes and Michele Sanders, 2011a. Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe. Final report to the European Commission, DG Environment, Contract no. 070307/2010/580412/SER/B2, Ecologic institute and Environmental Change Institute, Oxford University Centre for the Environment.

Pereira, M., Segurado, P., Neves, N. 2011. Using spatial network structure in landscape management and planning: a case study with pond turtles. Landscape and Urban Planning 100: 67–76.

Rappaport, D.I., Tambosi, L.R., Metzger, J.P. 2015. A landscape triage approach: combining spatial and temporal dynamics to prioritize restoration and conservation. Journal of Applied Ecology 52: 590–601.

Raudsepp-Hearne, C., Peterson, G. D., & Bennett, E. M. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. Proceedings of the National Academy of Sciences, 107: 5242–5247. https://doi.org/10.1073/pnas.0907284107

Ribeiro, R., Carretero, M.A, Sillero, N., Alarcos, G., Ortiz-Santaliestra, M.,Lizana, M., Llorente, G.A. 2011. The pond network: can structural connectivity reflect on (amphibian) biodiversity patterns? Landscape Ecology 26: 673–682.

Rippa, D., Maselli, V., Soppelsa, O., Fulgione, D. 2011. The impact of agro-pastoral abandonment on the Rock Partridge Alectoris graeca in the Appennines. Ibis 153: 721–734.

Rodríguez-Pérez, J., García, D., Martínez, D. 2014. Spatial networks of fleshy-fruited trees drive the flow of avian seed dispersal through a landscape. Functional Ecology 28: 990–998.

Rüter, S., Vos, C.C., Van Eupen, M., Rühmkorf, R. 2014. Transboundary ecological networks as an adaptation strategy to climate change: The example of the Dutch – German border. Basic and Applied Ecology, 15: 639-650.

Santini, L., Saura, S., Rondinini, C. 2016. Connectivity of the global network of protected areas. Diversity and Distributions 22: 199–211.

Saura, S., Bastin, L., Battistella, L., Mandrici, A., Dubois, G. 2017. Protected areas in the world's ecoregions: how well connected are they? Ecological Indicators 76: 144–158.

Saura, S., de la Fuente, B. 2017. Connectivity as the amount of reachable habitat: conservation priorities and the roles of habitat patches in landscape networks, in: Gergel, S.E., Turner, M.G. (Eds.), Learning Landscape Ecology, 2nd edition. Springer-Verlag, New York. In press. DOI 10.1007/978-1-4939-6374-4.

Saura, S., Estreguil, C., Mouton, C., Rodríguez-Freire, M. 2011a. Network analysis to assess landscape connectivity trends: application to European forests (1990-2000). Ecological Indicators 11: 407–416.

Saura, S., Pascual-Hortal, L. 2007. A new habitat availability index to integrate connectivity in landscape conservation planning: comparison with existing indices and application to a case study. Landscape and Urban Planning 83: 91–103.

Saura, S., Torné, J. 2009. Conefor Sensinode 2.2: a software package for quantifying the importance of habitat patches for landscape connectivity. Environmental Modelling and Software 24: 135–139.

Saura, S., Vogt, P., Velázquez, J., Hernando, A. & Tejera, R. 2011b. Key structural connectors can be identified by combining landscape spatial pattern and network analyses. Forest Ecology and Management 262: 150–160.

Schulp, C.J.E., Burkhard, B., Maes, J., Van Vliet, J. & Verburg, P.H. (2014) Uncertainties in Ecosystem Service Maps: A Comparison on the European Scale. PLoS One, 9, e109643. doi - 10.1371/journal.pone.0109643

Schulz, J.J., Schröder, B. 2017. Identifying suitable multifunctional restoration areas for forest landscape restoration in Central Chile. Ecosphere 8 (1): e01644.

Scolozzi R, Morri E, Santolini R, 2012. Delphi-based change assessment in ecosystem service values to support strategic spatial planning in Italian landscapes. Ecological Indicators 21: 134–144.

Strassburg, B.B.N., Barros, F.S.M., Crouzeilles, R., Iribarrem, A., Santos, J.S., Silva, D., Sansevero, J.B.B., Alves-Pinto, H.N., Feltran-Barbieri, R., Latawiec, A.E. 2016. The role of natural regeneration to ecosystem services provision and habitat availability: a case study in the Brazilian Atlantic Forest. Biotropica 48: 890–899.

Tambosi, L.R., Martensen, A.C., Ribeiro, M.C., Metzger, J.P. 2014. A framework to optimize biodiversity restoration efforts based on habitat amount and landscape connectivity. Restoration Ecology 22: 169–177.

Vallecillo S, Polce C, Barbosa A, Perpiña Castillo C, Zulian G, Vandecasteele I, Rusch, G.M. & Maes, J. 2016. Synergies and conflicts between the delivery of different ES and biodiversity conservation: Spatial planning for investment in green infrastructure and ecosystem restoration across the EU. OpenNESS Deliverable D3.3 / WP3.

Vallecillo S, Polce C, Barbosa A, Perpiña Castillo C, Zulian G, Vandecasteele I, Rusch, G.M. & Maes, J. Spatial planning for investment in green infrastructure and ecosystem restoration across the EU. Landscape and Urban Planning, (under review).

Verweij, P., Winograd, M., Perez-Soba, M., Knapen, R., and van Randen, Y. 2012. *QUICKScan: a pragmatic approach to decision-support*. iEMSs 2012 International Congress on Environmental Modelling and Software, Managing Resources of a Limited Planet, Sixth Biennial Meeting. Leipzig.

Villa, F., K. J. Bagstad, B. Voigt, G. W. Johnson, R. Portela, M. Honzák, and D. Batker. 2014. A methodology for adaptable and robust ecosystem services assessment. *PLOS One* 9:e91001. http://dx.doi.org/10.1371/journal.pone.0091001

Vogt P., 2017. *GuidosToolbox*: Digital image analysis software collection available at: http://forest.jrc.ec.europa.eu/download/software/guidos

Vogt, P., Riitters, K.H., Iwanowski, M., Estreguil, C., Kozak, J., Soille, P., 2007. Mapping landscape corridors. Ecological Indicators 7, 481–488.

Wickham, J.D., Riitters, K.H., Wade, T.G., Vogt, P., 2010. A national assessment of green infrastructure and change for the conterminous United States using morphological image processing. Landscape and Urban Planning 94, 186–195.

Wright, H. (2011): Understanding green infrastructure: the development of a contested concept in England. Local Environment: The International Journal of Justice and Sustainability, 16, 1003–1019.

Xun, B., Yu, D., Liu, Y. 2014. Habitat connectivity analysis for conservation implications in an urban area. Acta Ecologica Sinica 34: 44–52.

Zozaya, E., Brotons, L., Saura, S. 2012. Recent fire history and connectivity patterns determine bird species distribution dynamics in landscapes dominated by land abandonment. Landscape Ecology 27: 171–184.

G. Zulian, C. Polce, and J. Maes (2014). ESTIMAP: a GIS-based model to map ecosystem services in the European Union. Annali di Botanica 4, 1.

ABBREVIATIONS

Abbreviation	Description
BiodivERsA	The network programming and funding research on biodiversity and ecosystem services across European countries and territories
7th EAP	Seventh Environment Action Programme
CAP	Common Agricultural Policy
CDDA	Common Database on Designated Areas
CCM2	Catchment Characterisation and Modelling (version 2)
CIF	Common Implementation Framework
CLC	CORINE Land Cover
Climate-ADAPT	European Climate Adaptation Platform
CORINE	Coordination of Information on the Environment
DG	Directorate General of the European Commission
DG CLIMA	Directorate-General for Climate Action
DG-ENV	Directorate General of the European Commission-Environment
DG Regional Policy	Directorate-General for Regional Policy
EAP	Environmental Action Programme
EC	European Community
EEA	European Environment Agency
EIA	Environmental Impact Assessment
EKLIPSE	Knowledge and Learning Mechanism on Biodiversity and Ecosystem Services
EMFF	European Maritime and Fisheries Fund
EnRoute	Enhancing Resilience of Urban Ecosystems through Green Infrastructure
ERDF	European Regional Development Fund
ESF	European Social Fund
ESIFs	European Structural and Investment Funds
ESMERALDA	Enhancing Ecosystem Services Mapping for Policy and Decision making
ETC/ET	European Topic Centre on Terrestrial Environment
ETC/LUSI	European Topic Centre Land Use and Spatial Information
ETC/SIA	European Topic Centre on Spatial Information and Analysis
ETC/ULS	European Topic Centre on Urban, Land and Soil
EU	European Union

FAO	Food and Agriculture Organisation of the United Nations
FOEN	Swiss Federal Office for the Environment
GAUL	Global Administrative Unit Layers
GBLI	Green Background Landscape Index
GI	Green infrastructure
GIFT-T	Green Infrastructure for Tomorrow-Together.
GIS	Geographical Information System
HNV	High Nature Value
Horizon 2020	EU Research and Innovation programme (2014-2020)
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre, European Commission
LIFE	EU's financial instrument supporting environmental, nature conservation and climate action projects
MAES	Mapping and Assessment of Ecosystems and their Services
MMU	Minimum Mapping Unit
MS	Member States
NBS	Nature-based solutions
NBI	Nature-based initiatives
NCFF	Natural Capital Financing Facility
NDVI	Normalised Difference Vegetation Index
NGO	Non-governmental organisation
NLEP	Net Landscape Ecological Potential
NUTS	Nomenclature of Territorial Units for Statistics
OpenNESS	Operationalisation of Natural Capital and Ecosystem Services
PA	Protected areas
PoM	Programme of Measures
ProtConn	Protected Connected
RBMP	River Basin Management Plans
REC	Regional Environmental Characterisation
SEA	Strategic Environmental Assessment
SFM	Sustainable forest management
SUDs	Sustainable drainage systems
SWOT	Strengths, weaknesses, opportunities and threats
TEEB	The Economics of Ecosystems and Biodiversity
UMZ	Urban morphological zones
UNEP	United Nations Environment Programme

WDPA	World Database on Protected Areas
WFD	Water Framework Directive

TERMINOLOGY

Terminology	Definition
Connectivity	"Connectivity" can be broken down into "structural connectivity" and "functional connectivity." Structural connectivity refers to the physical relationship between landscape elements whereas functional connectivity describes the degree to which landscapes actually facilitate or impede the movement or dispersal of species and other ecological flows among habitat areas. The lack or loss of connectivity reduces the capability of organisms to move and can interfere with pollination, seed dispersal, wildlife migration and breeding. Structurally connected habitats are physically connected and continuous. Functional connectivity is a function of both landscape structure and the behavioural response of organisms to this structure. Distinguishing between these two types of connectivity is important because structural connectivity may contribute but does not imply functional connectivity. The distance and the landscape matrix between natural habitat patches play a role in the isolation of habitat patches from a species – functional – perspective.
CORINE	CORINE means 'coordination of information on the environment' and is a prototype project working on many different environmental issues. The CORINE databases and several of its programmes have been taken over by the EEA. One of these is an inventory of land cover in 44 classes, and presented as a cartographic European-wide harmonized product, at a scale of 1:100 000, for years 1990, 2000, 2006 and 2012. This database is operationally available for most areas of Europe.
Disaster risk reduction	Disaster Risk Reduction (DRR) aims to reduce the damage caused by natural hazards like earthquakes, floods, droughts, etc.
Ecosystem	"Dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (Article 2 of the Convention on Biological Diversity)
Ecosystem condition	The physical, chemical and biological condition or quality of an ecosystem at a particular point in time. The concept of ecosystem condition is strongly linked to well-being through ecosystem services. Ecosystems need to be in good condition to provide multiple ecosystem services, which, in turn, deliver benefits and increase well-being. Drivers of change can have a positive (e.g. conservation) or negative (pressures) impact on ecosystem condition.
Ecosystems, degradation	Ecosystems can be lost or impoverished in two ways: i) loss refers to a conversion to a different ecosystem or land use type - the conversion of a native prairie to a corn field – and is in this case easily measured; ii) loss can be qualitative and in this case, involves a change or degradation in the structure, function, or composition of an ecosystem, and it is more difficult to measure. At some level of degradation, an ecosystem becomes damaged, it ceases to be natural like heavily grazed pastures. Degradation is a "subtle or gradual changes that reduce ecological integrity and health", while damage is an "acute and obvious changes in an ecosystem". An ecosystem is destroyed "when degradation or damage removes all macroscopic life, and commonly ruins the physical environment as well". The simplification or disruption of ecosystems and the loss of biodiversity are caused by disturbances that are too frequent or severe to allow natural ecosystem recovery. See http://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/2020/RPF.pdf
Ecosystem restoration	"The return of an ecosystem to its original community structure, natural complement of species, and natural functions" (European Commission Biodiversity Strategy Impact Assessment) ; "The process of actively managing the recovery of an ecosystem that has been degraded, damaged or destroyed as a means of sustaining ecosystem resilience and conserving biodiversity"(CBD). See http://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/2020/RPF.pdf
Green adaptation	Making use of ecosystem services for infrastructure solutions.
Green infrastructure (GI)	In this report we will use the definition of GI of the European Commission (European Commission, 2013):

	Green Infrastructure is a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings. GI includes river systems and other water bodies (also known as blue infrastructure). GI performs several functions in the same spatial area e.g. an healthy floodplain ecosystem that provide flood prevention and water filtration as well as habitat provision, recreation and carbon storage.
Green infrastructure features	GI depends on plants and ecosystem services but may also be constructed and artificial such as green roofs and walls in cities. In the urban environment, GI can include features like green roofs, residential gardens, trees along roads, parks and green spaces. In rural setting, GI includes core areas like protected areas, natural features acting as wildlife corridors like woodland strips, artificial features like eco-ducts and eco-bridges. Not all green spaces qualify for GI, only those of high quality and that have the potential to be part of an interconnected network. Intensively managed farmland normally does not form part of GI unless it supports local biodiversity or encourage multi-functional land uses (such as food, water purification and recreation for example).
Grey infrastructure	Grey infrastructure refers to man-made infrastructure, often performing a single objective and function. Familiar grey infrastructure refers to housing and transport infrastructure. In the context of floods, energy production, supply of water for irrigation, it refers to dams, dikes, channels, storm surge defences and barriers in general. It is called 'grey' because it is usually made of steel or concrete.
High Nature Value (HNV) farmland	High Nature Value (HNV) farming describes low-intensity farming systems, which are particularly valuable for wildlife and the natural environment. The EEA has identified three broad types of HNV farmland, as follows: • Type 1 – Farmland with a high proportion of semi-natural vegetation. • Type 2 – Farmland with a mosaic of low intensity agriculture and natural and physical elements, such as field margins, hedgerows, stone walls, patches of woodland or scrub, small rivers, etc. • Type 3 – Farmland supporting rare species or a high proportion of European or World populations.
High Nature Value (HNV) forest	Definitions of High Nature Value forests are based on the multi-criteria of biodiversity, conservation value, naturalness, hemeroby (degree of human influence on ecosystem), accessibility and connectivity. They are all forests, managed or non-managed, having characteristics and key elements of native forest ecosystems, in terms of composition, structure, and ecological functions that support a high diversity of native species and habitats including the presence of species of European, and /or national, and/or regional conservation concern.
Indirect benefits, co-benefits, ancillary benefits	In this report, the terms 'indirect benefits', 'co-benefits' and 'ancillary benefits' are used interchangeably. They refer to all benefits that can be achieved from e.g. flood protection measures, in addition to the initial flood protection objective itself like for example biodiversity improvements, water quality improvements, opportunities for recreation, etc.
Interreg Europe	Interreg Europe helps regional and local governments across Europe to develop and deliver better policy.
Landscape	A landscape has different definition depending on context. Landscape generally refers to land areas, at least few kilometres wide, where humans interact with their environments. They encompass a variety of natural, semi-natural and developed land cover types. They are defined by geophysical landform features (mountains, hills, water bodies ...), by the composition and spatial configuration of living elements of land cover including vegetation, and human elements of land use.
Landscape permeability	Landscape permeability refers to the easiness of species movement across the entire landscape. Its evaluation provides a measure of the landscape resistance to species movement, including the identification of potential barriers. It does not replace but is a complementary approach to connectivity measures.

Landscape suitability	Landscape suitability refers to the quality of the landscape from an ecological point of view, i.e. how the landscape responds positively (is suitable) to specific wildlife needs and sustains ecological processes.
MAES	The Biodiversity Strategy 2020 outlines a number of targets and precise actions to stop biodiversity loss. Target 2 Action 5 states: Member States are, with the assistance of the EU, working on the mapping and assessment the state of ecosystems and their services (MAES). This work will help informing policy decisions affecting the environment and set priorities areas for investments in GI. It will contribute to accounting and reporting systems at EU and national levels.
Multi-functional landscapes	Multi-functional landscapes are landscapes that are designed for multidimensional benefits. A multi-functional landscape design solution must embrace the various ecosystem services that have already been bequeathed to a land area. Sustainable multi-functional landscapes are landscapes created and managed to integrate human production and landscape use into the ecological fabric of a landscape maintaining critical ecosystem function, service flows and biodiversity retention (Farrell and Anderson, 2010).
Natura 2000 network	Natura 2000 is an EU-wide network of protected areas spanning all 28 countries. Today they are over 27,000 sites included in the network, covering approximately 18% of EU land territory. Natura 2000 form the backbone of a GI for Europe.
Natural capital	Biodiversity, including ecosystems that provide essential goods and services, from fertile soil and multi-functional forests to productive land and seas, from good quality fresh water and clean air to pollination and climate regulation and protection against natural disasters.
Nature-based solution	Nature-based solutions are measures designed to face a particular problem by bringing 'more nature and natural features and processes to cities, landscapes and seascapes' (EC, 2016a).
Restoration and Prioritization (RPF)	Restoration and Prioritization Frameworks, http://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/2020/RPF.pdf See also definition of ecosystem restoration.
Stepping stone corridors	A series of small, non-connected habitat patches which are used to find shelter, food, or to rest.

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