Spatial analysis of green infrastructure in Europe

European Environment Agency

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Contents

Acknowledgements

Glossary

CICES	Common International Classification of Ecosystem Services
CIF	Common Implementation Framework
CLC	Corine Land Cover
COPD	Chronic obstructive pulmonary disease
CORILIS	Corine Lissage
CWD	Cost-weighted distance
EEA	European Environment Agency
EFIMED	Mediterranean Regional Office of the European Forest Institute
ETM+	Landsat-t Enhanced Thematic Mapper Plus
EFISCEN	European Forest Information Scenario
ESDAC	European Soil Data Centre
FCS	Favourable conservation status
FSFCC	Forest Stock Final Carbon Content
GI	Green infrastructure
GIO	GMES/Copernicus initial operations
GLS	Global Land Survey
GREEN	Geospatial Regression Equation for European Nutrient
HNV	High Nature Value
IEEP	Institute for European Environmental Policy
JRC	Joint Research Centre
LUCAS	Land use/cover area frame survey
MAES	Mapping and assessment of ecosystems and their services
MAPPE	Multimedia Assessment of Pollutant Pathways in the Environment of Europe
NASA	National Aeronautics and Space Administration
NO_x	Nitrogen oxides
NUTS	Nomenclature of Territorial Units for Statistics
SEBI	Streamlining European Biodiversity Indicators
SEEA	System of Environmental-Economic Accounts
TEP	Theoretical ecosystem potential
TM	Thematic Mapper
USGS	U.S. Geological Survey
VOCs	Volatile organic compounds
WG RPF	Working Group on Restoration Prioritisation Framework

Executive summary

In the European Commission communication *Green Infrastructure – Enhancing Europe's Natural Capital* (EC, 2013), green infrastructure (GI) is described as a tool for providing ecological, economic and social benefits through natural solutions, helping us to understand the advantages nature offers human society and to mobilise investments that sustain and enhance these benefits. This explicitly relates to the exclusive use of expensive 'grey' infrastructure which typically only fulfils single functions such as drainage or transport, whereas nature often provides multiple solutions that are also cheaper, more robust, let alone more sustainable economically and socially.

This is not to say that grey infrastructure is dispensable. Viewed functionally, grey infrastructure facilitates the production of goods and services, and the distribution of finished products to markets. Grey infrastructure also facilitates the provision of basic social benefits such as accessibility to services, and enables the transportation of raw materials by road etc. We need the traditional infrastructure, but in many cases it can be reinforced with solutions provided by nature. The key attraction of natural solutions is its multi-functionality, i.e. its ability to provide several functions and benefits on the same spatial area (Figure ES. 1); this is recognised by the EU's research

Figure ES.1   GI provides multiple functions

Source: Ecotec & NENW, 2008.

and innovation programme for 2014–2020 (Horizon 2020), which calls for nature-based solutions.

These functions can be environmental (e.g. conserving biodiversity or adapting to climate change), social (e.g. providing water drainage or green space), and economic (e.g. supplying jobs and raising property prices). As such, GI has the potential to offer win-win solutions by tackling several problems and unlocking the greatest number of benefits within a financially viable framework (EC, 2012). GI can therefore be a highly valuable policy tool to promote sustainable development and smart growth by meeting multiple objectives and addressing various demands and pressures (EEA, 2011).

The objective of this report is to propose a feasible and replicable methodology for use by different entities and at varying scales, when identifying GI elements. The proposed methodology will help those policymakers and practitioners define a landscape GI network to identify areas where key habitats can be reconnected and the overall ecological quality of the area improved. It may also help identify healthy ecosystems in order to ensure a continuous supply of valuable services to society, like clean air and water. 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 GI networks.

Box ES.1 Main findings and recommendations in the EEA report on Green Infrastructure and Territorial Cohesion (No 18/2011)

Key principles of green infrastructure should be promoted
Green infrastructure is a strategically planned and delivered network of high quality green spaces and other environmental features. Land should be designed and managed as a multifunctional resource capable of delivering a wide range of environmental and quality of life benefits, including maintaining and improving ecological functions. It helps with place-making — recognising the character and distinctiveness of different locations and ensuring that policies and programmes (spatial planning and other sectors) respond accordingly. It also aids the achievement of 'smart' conservation — addressing the impacts of urban sprawl and fragmentation, building connectivity in ecological networks and promoting green spaces in the urban environment (including through adaptation and retrofitting).

Integration of green infrastructure into policy sectors should be encouraged
The concept of green infrastructure should be promoted to support both environmental policy goals and certain non-environmental policy goals, and seek opportunities to mainstream green infrastructure into other policies to realise the potential synergies. Existing legislation should be used to promote green infrastructure (e.g. the White Paper on Adaptation to Climate Change; Habitats and Birds Directives; Water Framework Directive; Floods Directive; Marine Framework Directive; and the Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) Directives). The role of spatial planning should be emphasised in facilitating and delivering green infrastructure, along with a whole range of other mechanisms such as the use of European and national legislation, guidance/management plans, direct and indirect funding, national and regional green infrastructural strategies, building control, strengthening the use of assessment, and communication and capacity building.

Monitoring systems for green infrastructure should be promoted and developed further
Approaches to identifying and mapping green infrastructure at the landscape and urban scales are both relatively simple and effective. It is recommended that these are developed and promoted further. Work on integrating the two scales of mapping is considered, including developing the approach to the analysis of green infrastructure at the urban level by investigating potential methods of linking the Urban Atlas codes to the benefits of green infrastructure. It is helpful to consider these benefits of green infrastructure in terms of ecosystem services as part of this development of the methodology. Green infrastructure relevant data sets should further be analysed and explored to reveal whether the data is suited and organised in such a way that it can be used for mapping green infrastructure. Definition of criteria to evaluate the suitability/usefulness of the data should be undertaken with respect to the individual objectives and benefits they support, the scale and the components they address. Using the opposite starting point should also be considered i.e. which information (data sets) are currently missing to address green infrastructure (gap analysis).

The EEA has engaged in GI research in order to support policymaking agents and the public. For example, in 2011, the EEA published the report *Green infrastructure and territorial cohesion* to inform policymakers and contribute to the development of the European Commission communication *Green Infrastructure (GI) — Enhancing Europe's Natural Capital* (EC, 2013). The report underlined the importance of developing tools to detect and measure green infrastructure, such as environmental assets and landscape quality. These tools are required for national and regional planning to set priorities and targets more effectively. The 2012 European Commission report *The multifunctionality of green infrastructure*, also refers to knowledge gaps concerning GI, in particular information gaps and challenges linked to the measurement of GI.

On the basis of these reflections, the methodology introduced in this study can shed some light on the links and connections related to the concept of GI and support its further development. Moreover, by 2015, the European Commission will review the extent and quality of the technical and spatial data available for decision-makers in relation to GI development, to which this study may contribute.

Land use and spatial planning in the EU is the exclusive competence of Member States, due to the subsidiarity principle. The goal of this study is not to define the 15 % restoration target settled in the European Union 2020 Biodiversity Strategy (see Box ES.2). Instead, this study aims to illustrate a spatially explicit methodology that can be tested by countries and local agencies to set priority areas for GI and to identify potential areas for conservation and restoration. This report also highlights the most important limitations, gaps and recommendations on this issue.

GI is evaluated in this report as an ecological and spatial concept for promoting ecosystem health and resilience, contributing to biodiversity conservation, and benefiting humans by promoting the delivery of ecosystem services. The multifunctionality of GI thus constitutes the backbone of this analysis; the relevant ecosystem services covered include climate change mitigation, provision of key habitats to biota, and habitat connectivity.

The proposed methodology has two entry points:

- one based on the assessment and mapping of areas with a good capacity to deliver regulating and maintenance ecosystem services (in this case, eight ecosystem services: 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), and

- another based on the identification of key habitats to biota and the analysis of connectivity among them (in this case, large forest-bound mammals).

The data needs, processing steps, results and interpretation, summarised in Figure ES.2, are detailed in this document.

Figure ES.2   Work flow of the methodology proposed in this report
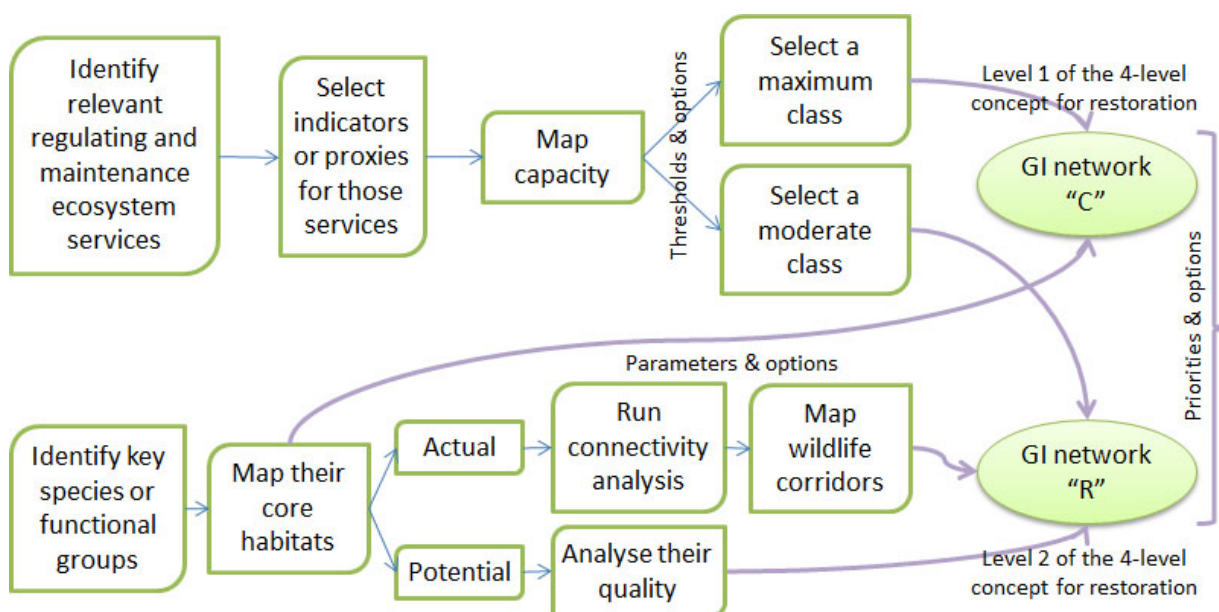
Box ES.2 Illustrative example of the 4-level approach on ecosystem restoration

The approach divides the continuum of ecosystem conditions from poor to excellent into four distinct levels. For each level there are sets of ecosystem descriptors and associated threshold values that are regarded as typical for that level. The 4 levels and the associated descriptors are tailored to each ecosystem type. For certain ecosystem types, in particular the 'transformed ecosystems' under level 4, it is recognised that the objective is not necessarily to restore a location to its original, natural conditions. In most cases, implemen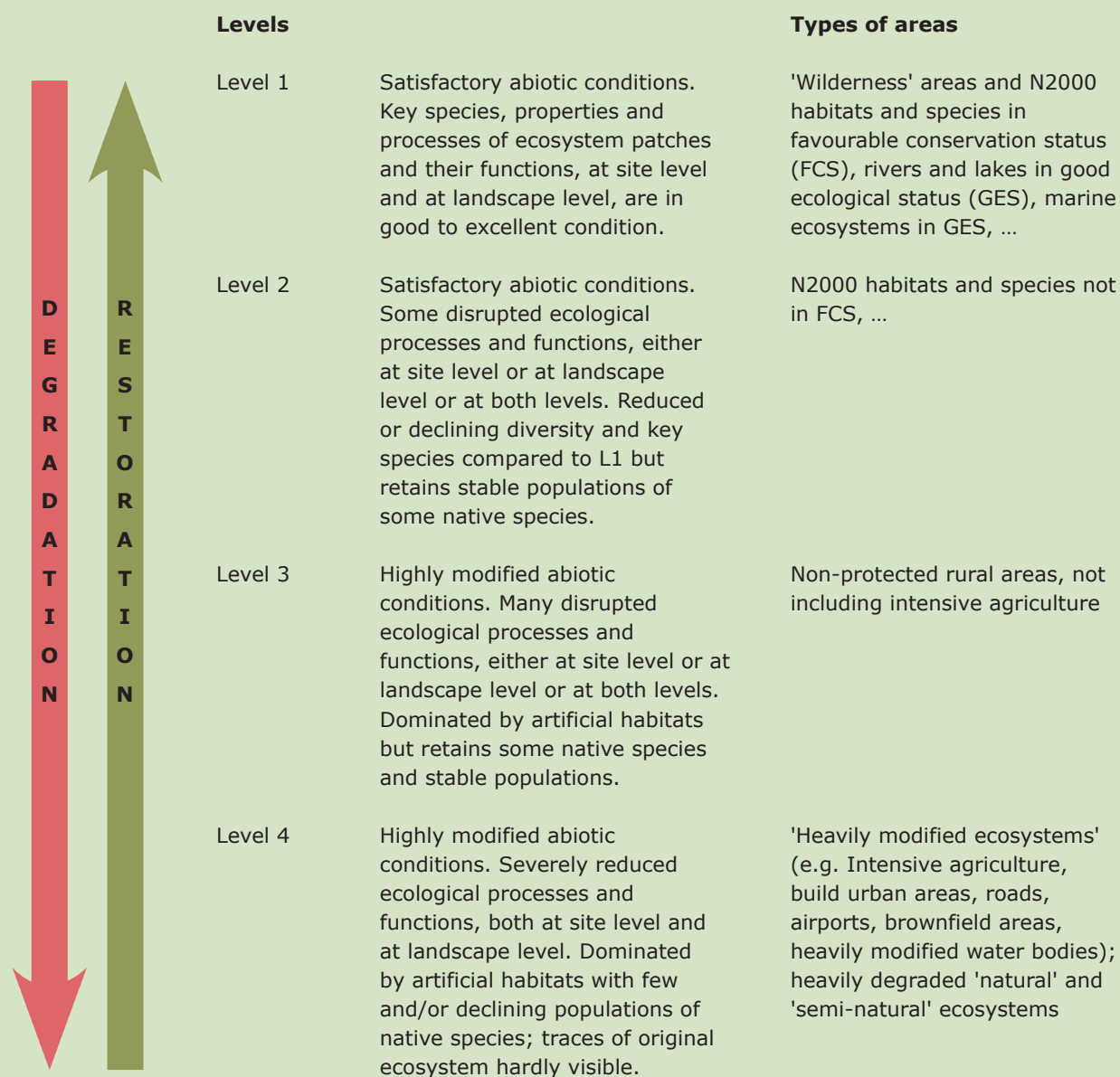tation of restoration measures in these transformed ecosystems will not result in a non-degraded situation, but degradation will be reduced to acceptable levels.

	Levels		**Types of areas**
	Level 1	Satisfactory abiotic conditions. Key species, properties and processes of ecosystem patches and their functions, at site level and at landscape level, are in good to excellent condition.	'Wilderness' areas and N2000 habitats and species in favourable conservation status (FCS), rivers and lakes in good ecological status (GES), marine ecosystems in GES, …
	Level 2	Satisfactory abiotic conditions. Some disrupted ecological processes and functions, either at site level or at landscape level or at both levels. Reduced or declining diversity and key species compared to L1 but retains stable populations of some native species.	N2000 habitats and species not in FCS, …
	Level 3	Highly modified abiotic conditions. Many disrupted ecological processes and functions, either at site level or at landscape level or at both levels. Dominated by artificial habitats but retains some native species and stable populations.	Non-protected rural areas, not including intensive agriculture
	Level 4	Highly modified abiotic conditions. Severely reduced ecological processes and functions, both at site level and at landscape level. Dominated by artificial habitats with few and/or declining populations of native species; traces of original ecosystem hardly visible.	'Heavily modified ecosystems' (e.g. Intensive agriculture, build urban areas, roads, airports, brownfield areas, heavily modified water bodies); heavily degraded 'natural' and 'semi-natural' ecosystems

(Left axis: **DEGRADATION** ↓ and **RESTORATION** ↑)

Source: ARCADIS, 2013.

This procedure has been tested using European Union territory as a case study. The resulting European GI networks are based on the best information currently available at European level; any improvements on the input data will further refine the results.

The identified and mapped GI elements are integrated into two GI networks, as aggregated and represented in Map ES.1. They represent an example of identification and mapping of GI networks in Europe using the methodology which is described in this report.

• GI conservation network ('C') comprises areas providing key ecological functions, both for wildlife and for human well-being. Conservation must be given priority in order to maintain essential connectivity of natural and semi-natural habitats.

• GI restoration network ('R') still provides important ecological functions, but its capacity could be improved with some protection or restoration ('R'). The upgrade of these GI elements to the GI network 'C' would increase its ecological and social resilience.

The results 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. The GI network 'C' can be ascribed to level 1 of the 4-level concept for restoration (see Box ES.2). Conversely, 17 % of EU territory might correspond to the GI network 'R', mainly defined by the limited service areas. This GI network could correspond to level 2 of the 4-level concept for restoration. The rest of European territory (56 %) did not qualify to form part of any GI network (with the assumptions and thresholds fixed in this example), and can be considered as levels 3 and 4 of the 4-level concept for restoration.

Map ES.1   Mapping of the potential European GI networks
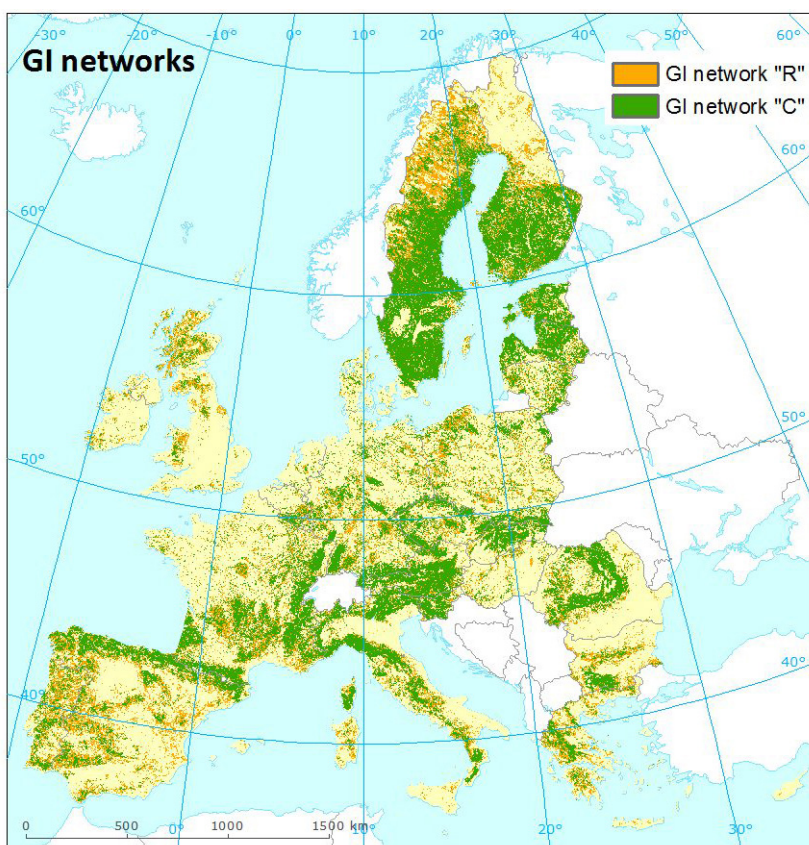
The delimitation of the GI elements shown in the figures of this report is a trial testing of the proposed methodology and should be adapted to the objectives and criteria of each practical land management case. The types of physical features that contribute to GI are diverse, specific to each location or place and very scale-dependent.

It should be noted at this point that European Commission policy does not propose using one or two GI networks in particular, like those mentioned above. The results from this study are based on current data availability and methodological work undertaken by the EEA. They capture, for the first time at EU level, two of the main elements for GI: the delivery of multiple ecosystem services, and the provision of habitat services to biota and habitat connectivity. This should invite further and more refined exercises and discussions on mapping possibilities for the GI concept, including the subject of whether the priorities for the two mapping strands outlined in this study adequately identify GI.

1   Introduction and objectives

The EU Biodiversity Strategy to 2020 ([1]) has an ambition to strengthen the knowledge base to underpin policy with up-to-date scientific data and information, including mapping and assessing the state of ecosystems and their services in Europe. Within this strategy, Target 2 aims at maintaining and restoring ecosystems and their services by 2020 by establishing a **Green Infrastructure (GI)** and restoring at least 15 % of degraded ecosystems (see Figure 1.1 and Box ES.2). Several actions support the realisation of Target 2. In particular, Action 5 aims to improve the state of knowledge on ecosystems and their services. More specifically 'Member States, with the assistance of the Commission, will map and assess the state of ecosystems and their services in their national territory by 2014, assess the economic value of such services, and promote the integration of these values into accounting and reporting systems at EU and national level by 2020' (EC, 2011). Many of these ecosystem services are being used as if their supply is unlimited and they are often considered free commodities; an understanding and recognition of their true value is lacking.

As stated in the communication *Roadmap to a Resource Efficient Europe* (EC, 2011a), failure to protect our natural capital and properly value our ecosystem services must be addressed as part of the drive towards smart, sustainable and inclusive growth — the EU's priority for Europe 2020. In this context, GI is clearly identified as an important step towards protecting our natural capital.

The Common Implementation Framework (CIF) of the Biodiversity Strategy 2020 includes six mutually supportive and interdependent targets (see Figure 1.1). Addressing the main drivers of biodiversity loss, these targets will reduce the main pressures on natural habitats and ecosystem services in the EU by anchoring biodiversity objectives in key sectoral policies.

For Action 5, which is to map and improve knowledge of ecosystems and their services in the EU, Member States and the European Commission recently developed and published an analytical framework for the mapping and assessment of ecosystems and their services (MAES) report ([2]). Action 6 sets priorities to restore GI (6a) and promote its use (6b). For Action 6a, Member States will assist the European Commission in developing a strategic framework to set priorities for ecosystem restoration at subnational, national and EU levels. For Action 6b, the European Commission has committed to develop a GI strategy that promotes the deployment of GI in the EU, both in urban and rural areas.

This GI proposal mainly feeds Action 6b of the EU Biodiversity Strategy to 2020. However, future improvements of this approach are expected from the integration of Action 5 maps and assessments and other on-going ecosystem assessments within the EEA. Moreover, the proposed methodology and results can help highlight priorities for restoration (Action 6a), testing the impact of biodiversity programmes (Action 7a) and planning a 'no net loss' strategy (Action 7b) (Figure 1.1). Hence, in the coming years the results of this report may be considerably improved by the integration of newly available information.

Similarly, this study in particular and Target 2 in general could be improved in quality and resolution in the near future with the results and conclusions coming from Targets 3, 4 and 5 ([3]) (e.g. state of particular forests, fish species distribution and interaction, relation of agricultural practices and biodiversity, spread and impact of invasive alien species). At the same time, Target 2 results can help to achieve Targets 1 and 6 (e.g. comparing data-poor and richer areas and approaches, integrating connectivity between protected areas and ecosystem

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[1] http://ec.europa.eu/environment/nature/info/pubs/docs/brochures/2020%20Biod%20brochure%20final%20lowres.pdf.
[2] http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/MAESWorkingPaper2013.pdf.
[3] Increase the contribution of agriculture and forestry to biodiversity (Target 3), ensure the sustainable use of fisheries resources (Target 4), and combat Invasive Alien Species (Target 5).

Figure 1.1 CIF of the Biodiversity Strategy 2020
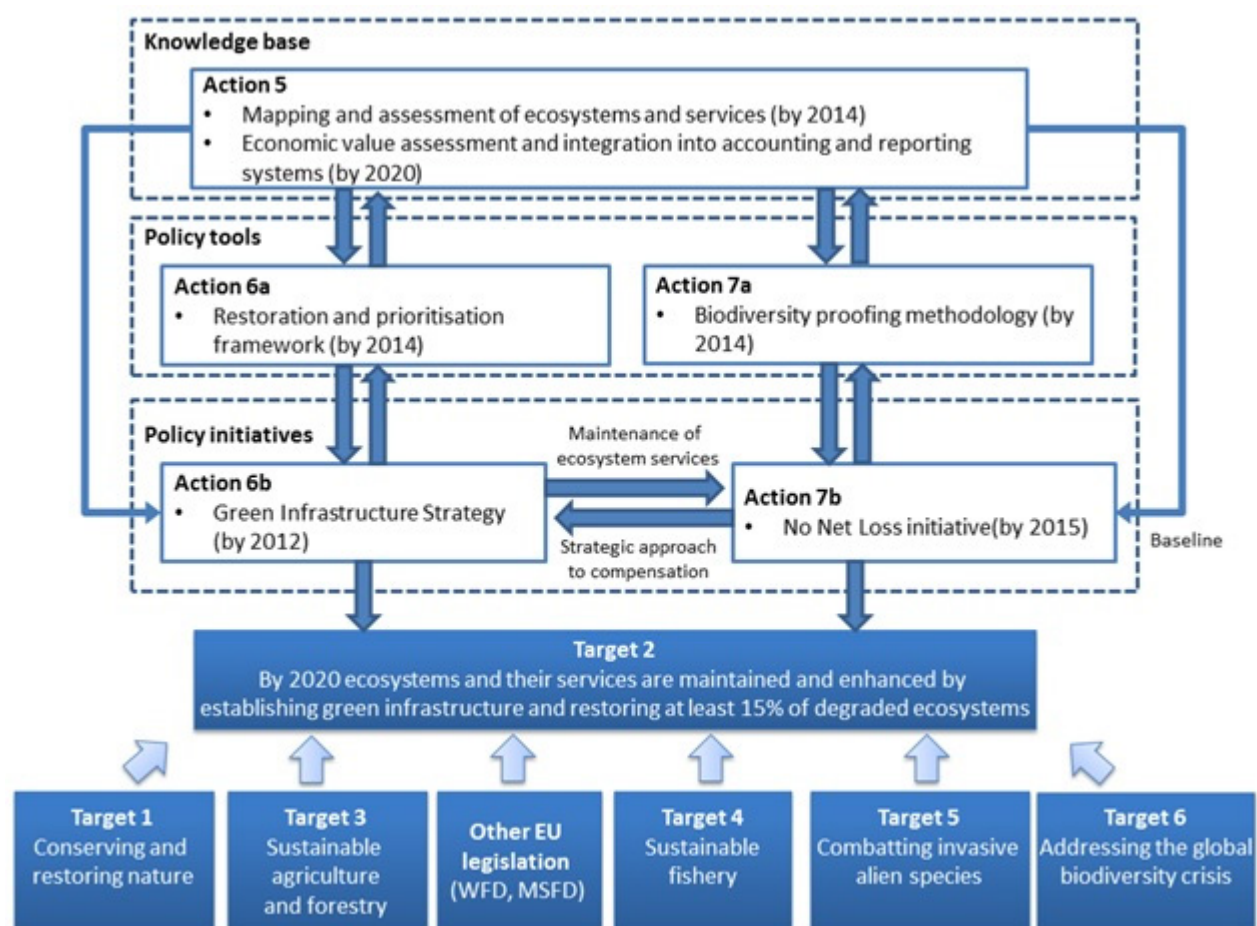
Note: WFD: the Water Framework Directive (Directive 2000/60/EC); MSFD: Marine Strategy Framework Directive (Directive 2008/56/EC); GES: Good Environmental Status.

services). Target 2 in general and GI in particular will benefit from the inputs and information produced under Targets 3-5. Thus, this report should be considered as a preliminary approach to define and map GI.

The European Commission Communication confirms that policy is already acknowledging GI. This communication proposes the a working definition of GI 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.

The use of GI can help effectively implement policies whose desired objectives call for nature-based solutions. In the Commission's proposals for the Cohesion Fund, the Common Agricultural Policy, Horizon 2020, LIFE, the European Maritime and Fisheries Fund, and the European Regional Development Fund ([4]), GI is specifically identified as one of the investment priorities ([5]). GI is recognised as contributing to Regional Policy and sustainable growth in Europe. Systematically including GI considerations in the planning and decision-making process will help reduce the loss of ecosystem services associated with future land take, and can help improve and restore soil and ecosystem functions.

The objective of the current report is to propose, develop and test a theoretical framework for the

identification and mapping of GI elements at landscape level, taking into consideration their multifunctional character and the potential of ecosystem services' supply.

In particular, the study focuses on GI support for the **provision of habitat to biota,** the **connectivity of habitats** and their protection, and the **delivery of ecosystem services**. It also promotes integrated spatial planning by identifying multifunctional zones and by incorporating **habitat restoration** measures and other connectivity elements into various land use plans and policies. Moreover, the study puts the GI analysis in the context of Biodiversity Strategy implementation (what can be done today, and what will future developments be), in terms of available data and connections with other targets and actions.

(⁴) COM(2011) 612 final/2, COM(2011) 614 final.
(⁵) http://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/guide_multi_benefit_nature.pdf.

2   Towards a conceptual framework

The ecosystem concept describes the interrelationships between living organisms and the non-living environment. The Convention of Biological Diversity (CBD) defines an ecosystem as a 'dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit'. The ecosystem approach aims at an integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way ([6]).

In the fields of nature conservation and biodiversity, the common meaning of the term 'habitat' is a group of animals and plants in association with their environment. Habitat services highlight the importance of ecosystems to provide habitat for migratory species and to maintain the procreation and viability of gene-pools. Habitats considered by experts to require particular attention at a European scale are covered by the EU Habitats Directive. There are currently 231 habitat types listed on Annex I of the Habitats Directive ([7]).

Ecosystem services are the contributions that ecosystems make to human well-being (see Box 2.1). These services are outputs of ecosystems (whether natural or semi-natural) that most directly affect the well-being of people. A fundamental characteristic is that they retain a connection to the underlying ecosystem functions, processes and structures that generate them ([8]).

One of the major attractions of GI is its ability to perform multiple functions on the same piece of land and/or water. The benefits are expressed in functions and services provided by ecosystems, which are the basis for GI. They include provisioning services such as fresh water and wood; regulating and maintenance services such as pollination and climate control; and cultural services such as recreation and cultural benefits.

The spectrum of services varies with scale and ecosystem type — not all GI elements need to deliver all services, but normally healthy ecosystems provide many of them. In other words, GI elements perform a number of broad functions such as protecting ecosystem state and biodiversity, improving ecosystem functioning and promoting ecosystem services, promoting societal health and wellbeing, and supporting the development of a green economy and sustainable land and water management (EC, 2012).

The roles of GI elements do not always fall into distinct categories during practical implementation. They are highly interdependent. For example, societal wellbeing in coastal and river areas depends on flood retention by wetlands or natural drainage systems, which in turn depend directly on the provision of ecosystem services, such as soil and water retention. These in turn are highly reliant on biodiversity to uphold the health of the ecosystems to provide ecosystem services (EC, 2012). Another example is the case of Natura 2000 sites which are key natural areas but, with the increasing emphasis on ecosystem protection, they tend also to include elements of ecological corridors and buffer zones.

Identification of GI elements can thus be approached at different scales (termed rural and urban in the EC communication on GI), depending on the study's objective.

- Landscape-level analysis (at a proposed resolution of 1 km) is to identify rural GI elements or ecosystem services' functions (capacity). The connectivity among different GI elements has to be analysed on a case-per-case basis, since it might not be necessary for all rural landscapes.

- Local-scale analysis (at a recommended resolution < 100 m) is to identify urban GI, parks and green patches, among others. Connectivity

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([6])   http://biodiversity.europa.eu/topics/ecosystems-and-habitats.
([7])   http://biodiversity.europa.eu/topics/ecosystems-and-habitats.
([8])   http://cices.eu/wp-content/uploads/2012/07/CICES-V43_Revised-Final_Report_29012013.pdf.

<div style="background-color:#d9e5c5; padding:1em;">

Box 2.1   Ecosystem services

The hierarchical structure of The Common International Classification of Ecosystem Services (CICES) [9] has been designed so that the categories at each level are non-overlapping and without redundancy. The following definitional structure has been recommended.

1. **Provisioning services:** All nutritional, material and energetic outputs from living systems. In other words, they are products obtained from ecosystems such as food, fresh water, wood, fibre, genetic resources, medicines, etc.

2. **Regulating and maintenance services:** Covers all the ways in which living organisms can mediate or moderate the ambient environment that affects human performance. It therefore covers the degradation of wastes and toxic substances by exploiting living processes; by reconnecting waste streams to living processes it is in this sense the opposite of provision. Regulation and maintenance also covers the mediation of flows in solids, liquids and gases that affect people's performance, as well as the ways living organisms can regulate the physico-chemical and biological environment of people.

3. **Cultural services:** Covers all the non-material — and normally non-consumptive — outputs of ecosystems that affect physical and mental states of people. It includes the benefits people obtain from ecosystems, such as spiritual enrichment, intellectual development, recreation and aesthetic values.

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can be essential in these networks. There are also some differences in the approach: urban GI includes green areas that provide multiple ecosystem services, while rural or landscape GI tries to prioritise within these. It should be recognised that urban areas often benefit from peri-urban GI services such as the provision of drinking water and fresh air. In rural areas, GI features may also be beneficial to the urban population, as services produced in rural areas, such as flood retention, can be consumed in urban spaces.

The development of a conceptual framework for the definition and mapping of GI elements should be considered as a first step to produce a methodology that can be used as a test case for assessing a number of ecosystem services, habitats and their connectivity. The advantage with this methodology is that it can be replicated when data availability improves and hence aids the identification of GI elements at lower scales. For the current task, the methodology is based on a number of prerequisites and assumptions, which are set out below.

- The work is focused on the landscape level of GI.

- The proposed spatial resolution is 1 x 1 km.

- The multifunctional character of GI is addressed by considering **ecosystem services delivery** (including **climate change** mitigation), **provision of habitat** to biota, and **habitat connectivity**.

- The assessment considers ecosystem services (in particular regulation and maintenance services) as well as key habitats as starting points for GI mapping.

- The framework proposes a general solution that works with today's knowledge and data, but is open for improvement as soon as more and better input data become available.

- The resulting GI network is based on the best information currently available at European level; any improvements on the input data side will help refine the resulting network of GI elements. Other approaches might also be used, depending on the goals of the mapping exercise. This methodology to identify GI elements can be used by different entities and at different scales; it can be tailored to the objectives and priorities of the practitioners.

The selection of regulating and maintenance ecosystem services for this first Europe-wide GI

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[9] http://cices.eu.

mapping exercise is linked to one of the aims of GI in the EC communication, specifically that of 'protecting and enhancing nature and natural processes'. This goal is covered in the areas that deliver regulating and maintenance services, while most of the provisioning and cultural services are driven by human inputs and needs, and do not necessarily enhance natural processes (see trade-off analysis and conclusions in Nelson et al., 2009; and Maes et al., 2012). By concentrating on regulating and maintenance services, an improvement in the GI network will enhance the state of the ecosystems and natural processes.

The overall concept of GI mapping is based on the steps summarised in Figure 2.1. The assessment has two entry points that illustrate the multi-functionality of GI: habitat provision and its connectivity, and ecosystem services) through two interconnected streams of analysis. The first stream of analysis is the assessment and mapping of regulating and maintenance ecosystem services. Here areas are differentiated by maximum and moderate capacity to deliver ecosystem services, which again are related to the condition of the ecosystems. The ecosystem services mapping

obtained from earlier results (see Section 3.1) usually requires prior mapping of ecosystem types, their quality and/or their functions. The second stream of analysis is habitat suitability mapping or mapping of key habitats for certain functional groups of interest (in this case, large mammals). The study differentiates between key/core habitats usually used as reproducing, wintering or foraging habitats, and temporal habitats used for migration or as secondary habitats.

Having identified the spatial coverage of the key ecosystem and ecosystem services, the next step in the assessment is the spatial analysis and the analysis of connectivity among habitats. This involves the identification of gaps and the establishment of specific thresholds and criteria, for example habitat suitability modelling which can includes the potential demand for a given service, the socio-economic factors, or consideration for endangered species. The resulting landscape elements are then aggregated for a proposal of a GI network that identifies potential areas for conservation and/or restoration based on the delivery of good ecosystem services, key habitats and their connectivity.

Figure 2.1 Overall methodological concept of the proposed analysis
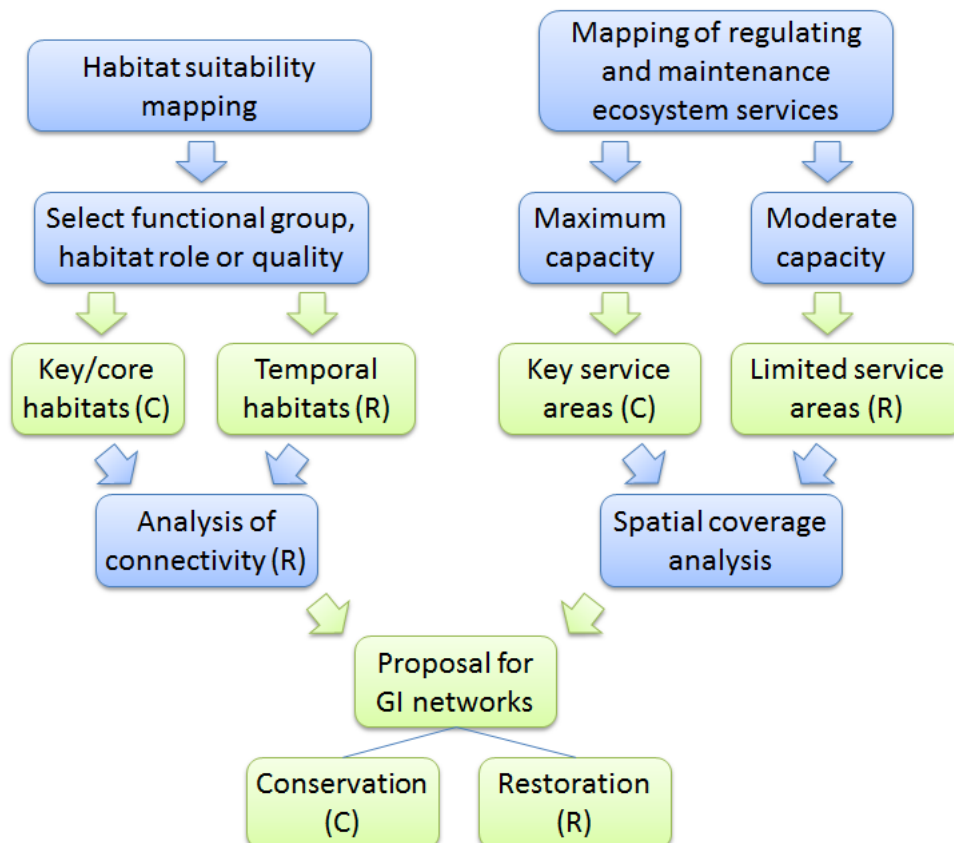
The study's anticipated outputs (green-shaded boxes in Figure 2.1) are as follows.

- **Key service areas** — ecosystems (GI elements) that have the highest potential to provide regulating and maintenance ecosystem services ([10]). These GI elements should be addressed for conservation and protection purposes.

- **Limited service areas** — GI elements that have moderate potential to provide regulating and maintenance ecosystem services. These GI elements could be improved or restored.

- **Key habitat areas —** GI elements that provide key habitats to different species or functional groups for shelter, food or reproduction. These GI elements should be addressed for conservation and protection purposes.

- **Connectivity** between those key habitat areas. The results from this connectivity analysis can be used for network development, and will potentially highlight areas for improvement or restoration.

These outputs and the terms used to define them are directly linked to the analysis developed in this report, and do not aim to define new categories of GI elements. If these outputs are linked with the GI multiscale elements defined by the EC ([11]), the

key service areas, limited service areas and key habitat areas would be mostly 'core areas — outside protected areas'. They may also overlap with 'core areas/protected areas' and with other categories in the table proposed by the EC. The connectivity among our key habitat areas could be considered 'natural connectivity features'.

This report intentionally differentiates between areas that deliver ecosystem services and key habitats for biota, in order to achieve the following.

- To be able to address the issue of GI multifunctionality.

- To differentiate between GI elements where connectivity is judged relevant (e.g. breeding areas for specific species) and those where connectivity might not be necessary (e.g. ecosystems providing pollination with ecosystems providing mass flow mediation, to mention just a couple of unrelated ecosystem services). Hence, the connectivity analysis here is exclusively related to habitats, and much less so to the areas that deliver other ecosystem services, since the latter must be analysed case by case.

- To accommodate the traditional conservation initiatives based on protected areas, as well as the recent requirements focused on natural capital.

([10]) The areas with the maximum capacity to deliver regulating and maintenance ecosystem services enhance beneficial natural processes, and may also boost the delivery of other provisioning and cultural services. On the contrary, the areas with high potential to deliver provisioning and cultural services are highly influenced by human interests and energy/capital inputs, and cannot be included directly as part of the GI. In the conceptual framework, those areas will form part of another GI level that could be called green use.

([11]) http://ec.europa.eu/environment/nature/ecosystems/docs/Table%203%20Gi.pdf.

3   Methodology for the identification of green infrastructure elements

The overall objective of this study 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. For the assessment of ecosystem services and their condition, the best available data describing services' capacity at European scale are used (see Table 3.1). The distribution of key habitats at landscape level is approximated by the potential living space of large forest-bound mammals, but other groups and species should be incorporated in future. The output of the different input layers (ecosystem services, key habitats, and habitat connectivity) are finally combined and interpreted to form a network of potential GI elements.

3.1   Ecosystems and selected services

GI is understood to be the result of a network of natural and semi-natural areas designed and managed to deliver a wide range of ecosystem services. In order to assess the contribution of landscapes and ecosystems to a GI network as healthy ecosystems delivering multiple services, it is important to consider the quality of their ecosystem services. This quality is related to the capacity or potential of ecosystems to deliver ecosystem services, as indicated in the 'cascade model' being followed in the implementation of Target 2: Action 5 of the Biodiversity Strategy (Maes et al., 2013), and in other scientific literature.

The cascade model links biodiversity and ecosystems to human well-being through the flow of ecosystem services (de Groot et al., 2010; Haines-Young and Potschin, 2010). This model is especially useful for framing indicators of ecosystem services with multiple perspectives, objectives and scales.

In the cascade model (see Figure 3.1) the ecological components are organised into ecosystem structures and they interact through ecosystem processes (Step no 1). The biophysical structure and processes of an ecosystem determine its functions (Step No. 2),

Figure 3.1 Ecosystem services cascade model
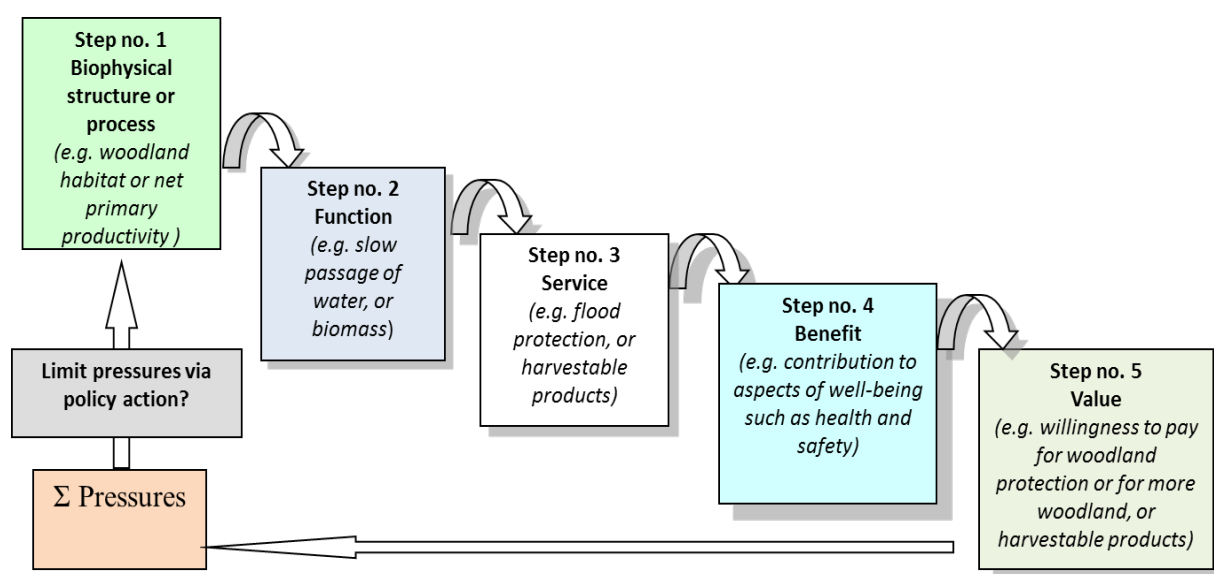
Note: Modified from de Groot et al., 2010, and from Haines-Young and Potschin, 2010.

Table 3.1 **Selection of regulating and maintenance services from the Common International Classification of Ecosystem Services (CICES) classification (v4.3) to define GI elements and available proxies for their quantification**

CICES V4.3			Green infrastructure approach	
Section	**Division**	**Group**	**Selected services and short definition**	**Available proxy for service capacity**
Regulation and maintenance of ecosystem services	Mediation of waste, toxics and other nuisances	Mediation by ecosystems	**Filtration of pollutants by vegetation** (also known as **air quality regulation**): capacity of ecosystems to capture and remove air pollutants in the lower atmosphere.	Deposition velocity of air pollutants on leaves, in particular dry NO_x deposition velocity (Maes et al., 2011)
	Mediation of flows	Mass flows	**Erosion protection:** potential of ecosystems to retain soil and to prevent erosion and landslides.	Erosion control map (Maes et al., 2011)
		Liquid flows	**Water flow regulation:** influence ecosystems have on the timing and magnitude of water run-off and aquifer recharge, particularly in terms of water storage potential.	Aggregated soil infiltration (Maes et al., 2011)
			Coastal protection: natural defence of the coastal zone against inundation and erosion from waves, storms or sea-level rise.	Coastal protection capacity (Liquete et al., 2013)
	Maintenance of physical, chemical and biological conditions	Lifecycle maintenance, habitat and gene pool protection	**Pollination:** potential of animal vectors (bees being the dominant taxon) to transport pollen between flower parts.	Pollination potential (Maes et al., 2011) and selected ecotones
		Soil formation and composition	**Maintenance of soil structure and quality:** the role ecosystems play in sustaining the soil's biological activity, physical structure, composition, diversity and productivity.	Soil structure indicator (Kleeschulte et al., 2012)
		Water conditions	**Water purification:** the role of biota in biochemical and physicochemical processes involved in the removal of wastes and pollutants from the aquatic environment.	In-stream nitrogen retention efficiency (Maes et al., 2011)
		Atmospheric composition and climate regulation	**Carbon storage and sequestration:** the influence ecosystems have on global climate by regulating greenhouse and climate active gases (notably carbon dioxide) from the atmosphere.	Carbon stocks from the carbon accounts (Simon et al., 2012)

Note: By adopting the CICES general structure, our integrated MAES classification can be directly linked with the framework of the UN System of Environmental-Economic Accounts (SEEA) and with several standard product and activity classifications, namely the International Standard Industrial Classification of All Economic Activities, the Central Products Classification, and the Classification of Individual Consumption by Purpose.

which are a subset of the ecological interactions defined in this context as 'the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly' (de Groot at al., 2002). Functions that ultimately contribute to human well-being create the actual flow of ecosystem services (Step No. 3), normally a rate or magnitude per time. This flow may be translated into specific societal benefits (Step No. 4); different methodologies then allow allocation of monetary or alternative values to those benefits (Step No. 5). Following this scheme, the potential of an ecosystem to deliver high-quality services is measured by its function or capacity (Step No. 2).

As a starting point for the establishment of a network of potential GI elements, the present study addresses multiple regulating and maintenance ecosystem services where spatially explicit data exist, and which can be differentiated with respect to the quality (capacity) of the service they provide. Normally there are no primary data for measuring regulating and cultural services, so their quantification and mapping must rely on different proxies (Maes et al., 2013). Hence, this study focuses on the available proxies or indicators that quantify the natural capacity to provide regulating and maintenance services, as summarised in Table 3.1.

3.1.1 Description of input data

Air quality regulation

Pollutants can be removed from the atmosphere through deposition or by conversion to other forms. Pollutants are deposited on the Earth's surface via dry deposition (mainly gaseous sulphur and nitrogen compounds) and wet deposition (namely aerosols and soluble gases). Direct deposition to vegetation (dry deposition) is an important pathway for cleansing the atmosphere, and is mainly affected by the height of the vegetation and the leaf area index.

Data from Maes et al. (2011) are used on deposition velocity as an indicator of the capacity of ecosystems to capture and remove air pollutants, as proposed in previous studies (Escobedo and Nowak, 2009; Karl et al., 2010). Maps representing the dry deposition velocity of nitrogen oxides across Europe are based on parameterisation as used in the Multimedia Assessment of Pollutant Pathways in the Environment of Europe (MAPPE) model (Pistocchi, 2008).

Potential relevance of this ecosystem service for policy: Air quality is a significant factor affecting human well-being. Low air quality is one of the factors triggering diseases like asthma and chronic obstructive pulmonary disease (COPD). These diseases are observed at increasing rates in Europe and present important health and economic costs for national economies.

Erosion protection

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

The Soil Erosion Risk Assessment (MESALES) model from the European Soil Data Centre (ESDAC) uses data on land use, slope, soil properties and climate to predict seasonal and annual averaged soil erosion. The map of annual soil erosion risk was intersected with a map that retains the Corine Land Cover (CLC) classes with natural vegetation. The resulting map was used to spatially identify ecosystems that are situated in areas of different erosion risk, giving more weight to ecosystems in areas with high erosion risk (five classes, ranging from very low to very high). This indicator is assumed to represent the capacity of ecosystems to provide erosion control services.

Potential relevance of this ecosystem service for policy: Soil erosion due to water and wind causes a qualitative degradation of agricultural areas. It may generate losses in productivity, water and

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Box 3.1   Benefits of GI: air quality regulation

GI such as vegetation can reduce ground-level ozone by lowering air temperatures, reducing power plant emissions associated with air conditioning and removing air pollutants, among other benefits. Particulate matter refers to the tiny bits of dust, chemicals, and metals suspended in the air. Because particulate matter is so small, it can enter into the lungs and cause serious health effects. Forests, parks and other green infrastructure features can reduce particulate pollution by absorbing and filtering particulate matter ([12]).
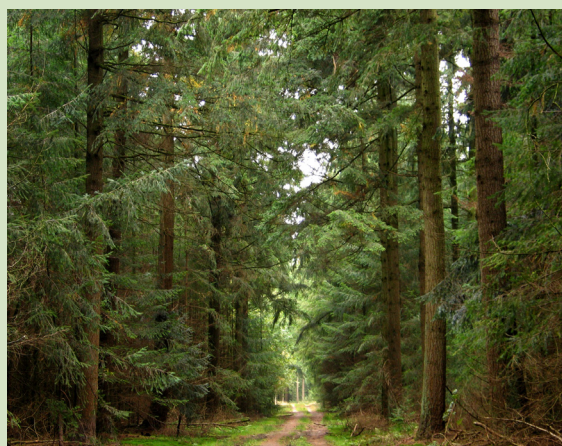

Photo: © Pawel Kazmierczyk

([12]) http://water.epa.gov/infrastructure/greeninfrastructure/gi_why.cfm.

<div style="border:1px solid #ccc; background:#dce8cc; padding:10px">

Box 3.2   Benefits of GI: erosion protection

The rate at which soil erosion occurs depends critically on the land's vegetative cover. GI like forests, plants and other flora stabilise the soil, prevent erosion, enhance the land's capacity to store water, and moderate air and soil temperatures. Bare soil offers no protection against wind and rain and is at a high risk of soil erosion, sedimentation in streams and rivers, clogging of waterways and land degradation. This eventually undermine the productive resource base of the soil.

Photo: © EEA

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nutrition capacity, with important consequences for agricultural and food costs. Knowledge on areas susceptible to erosion allows for anticipation of this risk and reduction of erosion potential, thanks to preventive land use and land management.

Water flow regulation

The annually aggregated soil infiltration (measured in mm) is an indicator for the capacity of terrestrial ecosystems to temporarily store surface water (Maes et al., 2011). The data used are derived from the MAPPE model (Pistocchi et al., 2008 and 2010). MAPPE comprises models that simulate pollutant pathways in air, soil sediments and surface and sea water, at European continental scale. Monthly infiltration of precipitated water in soils is calculated by distributing the net precipitation over run-off and infiltration.

Potential relevance of this ecosystem service for policy: The soil capacity for water retention is a prerequisite for the continuous storage of water in natural areas or in areas used for agriculture and

<div style="border:1px solid #ccc; background:#dce8cc; padding:10px">

Box 3.3   Benefits of GI: water flow regulation

GI such as rain gardens, swales, green roofs and walls capture water flow runoff from impervious cover before it reaches overburdened sewer systems. Manchester University did an experiment measuring the effects of trees and grass on surface water runoff. Trees reduced runoff by 60 % across the whole plot, despite covering only 35 % of it (water infiltrated the hole). Grass reduced runoff by 98 %. This indicates the importance of greenery as a tool for preventing storm water runoff ([13]).

Photo: © Town and Country Planning Association (TCPA), Malmö

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([13]) http://www.emonfur.eu/public/pub_files/Efuf/presentazioni/venerdi/Ennos_-_Milan_Talk.pdf.

forestry. Areas with sufficient soil moisture are less susceptible to droughts, and may contribute to a continuous harvest without needing additional irrigation. Water retention capacity is an important factor for reducing flood risk. Knowledge on water retention capacity is mandatory for the assessment of flood retention capacities in river catchments.

Coastal protection

The indicator of coastal protection capacity is defined as the natural potential of coastal ecosystems to protect the coast against inundation or erosion. The geomorphological and ecological characteristics likely to mitigate extreme physical processes are coastal geomorphology, slope and the presence of protective habitats (e.g. dunes and reefs) — both in the submarine and in the emerged coastal zone. The coastal zone under consideration covers the area potentially affected by extreme hydrodynamic conditions, which is delimited in general by a 50-metre–depth isobath and a 50-metre–height contour line (Liquete et al., 2013).

Potential relevance of this ecosystem service for policy: The erosion of coastal zones due to sea currents, tides, pounding of waves and sea level rise leads to large losses of land masses in Europe and poses risks for coastal infrastructures and assets. Compensation measures like the creation of new

land surfaces or the maintenance of protection works have high investment costs. The natural resilience of coastal habitats against erosion and inundation is therefore an important economic factor that should be identified and monitored to maintain and improve coastal protection capacity.

Pollination

The indicator showing the capacity of natural ecosystems to provide pollination services was originally defined in Maes et al. (2011).

They mapped pollinator visitation rate as a function of distance to natural areas using the three inputs described below.

- A European map of land use, which includes the spatial distribution of crops.

- Crop dependency ratios, indicating the dependency of crops on pollination (0–100 %) (Klein et al., 2007; Gallai et al., 2009).

- The distance from each crop land use pixel to the nearest potentially pollinator-rich ecosystem. The visitation probability (the probability that a crop gets visited by a pollinator) was modelled using the Ricketts et al. (2008) regression model. For each crop land use pixel, the crop

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Box 3.4   Benefits of GI: coastal protection

GI such as wetlands, marsh areas, mangroves, peatlands, seagrasses and other natural features serve to protect coastlines against storm surges and flooding. In many locations, these ecosystems suffer from increasing pressure from expanding human populations and from a lack of long-term management. Integrating GI (e.g. wetlands) into coastal protection management could benefit urban populations in particular. These potential benefits include protection from storm surges and flooding, as well as other provisioning and regulating ecosystem services that natural infrastructure can provide ([14]).

Photo: © EEA

([14]) http://ec.europa.eu/environment/integration/research/newsalert/pdf/IR3.pdf.

<div style="background-color:#dde5c8">

Box 3.5   Benefits of GI: pollination

GI provides substantial opportunities for the conservation of pollinating insects within urban and rural landscapes. Greening cities (e.g. green roofs) and provision of wildflower meadows, mixed grasslands and hedgerows can provide suitable habitats for insect pollinators that rely on nectar and pollen from local crops and plants. Pollinators play an important role in maintaining plant diversity [15]. Insects are pollinators of 80 % of all plant species in Europe, including most fruits, many vegetables and some biofuel crops.

Photo: © Monica Rzeszot

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dependency and visitation probability were multiplied, and this value was subsequently assigned to the nearest ecosystems assumed to sustain pollination. The sum of these contributions was finally considered as the pollination potential or the capacity of the natural ecosystem to provide pollination services.

An ecotone is a transition area between two adjacent but different patches of landscape, such as forest and grassland. Ecotones have been mapped in Europe by the EEA, but the results were still undergoing quality assurance at the time of writing [16]. For this study ecotones were selected between arable land, permanent crops, irrigated agriculture and pastures or mosaic farmland on the one side, and standing forests on the other side. These ecotones promote the presence, nesting and activity of pollinators.

Potential relevance of this ecosystem service for policy: Many wild and agricultural crops depend on pollinating insects, in particular fruits and vegetables suitable for human consumption. However, declines of pollinator species are reported in Britain, the Netherlands and Central Europe. The absence of insect pollination would result in a reduction of between 25 % and 32 % of the total production of crops which are partially dependent

on insect pollination (Zulian et al., 2013). The accounting and mapping of actual pollination activities in Europe can spotlight areas with reduced pollination services. These services could be improved through changes in land use management and restoration of suitable habitats for pollinating insects.

Maintenance of soil structure and quality

The dataset produced by the EEA and ETC/SIA (Kleeschulte et al., 2012) compares two soil threats (soil compaction and soil erosion) with good soil management practices or preservation measures (top-soil organic carbon), following the ideas of Jones et al. (2012). These three parameters describe the negative effects (compaction and erosion) or positive effects (organic carbon) on soil structure. For the description of the theoretical ecosystem potential (TEP), these parameters were classified and ranked based on expert judgment. The TEP was then overlaid with information on High Nature Value (HNV) farmland data as an indicator for sustainable soil management practices. The final results highlight ecosystems providing best services for soil structure (i.e. areas with low risk for soil erosion and compaction, in combination with good organic matter content and sustainable management practices).

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[15] http://www.eea.europa.eu/soer/synthesis/synthesis/chapter3.xhtml.
[16] For more information, contact AlexRichard.Oulton@eea.europa.eu or view the visualisations at http://www.eyeonearth.org/Templates/StoryBook2/?appid=38a6e7686d354e05b9e016c8ddd536e4&webmap=a6f1bc85613f44dab4f427d558102abc.

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Box 3.6   Benefits of GI: soil structure and quality

GI such as woody perennials and nitrogen-fixing vegetation close to or intercropped with agricultural crops maintains or improves the fertility of arable land. Vegetation increases the soil's ability to absorb and retain water, produce nutrients for plants, maintain high levels of organic matter, and moderate its temperatures. Soil carbon is a key indicator of soil quality in all ecosystems ([17]).

Photo: © EEA

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Potential relevance of this ecosystem service for policy: Fertile and healthy soils are a prerequisite for the sustainable and long-term production of food and feed. In addition, undisturbed soils may store and sequestrate large quantities of carbon. Soils are crucial for the conservation of biological diversity, for water management and for landscape management.

Water purification

The capacity of freshwater ecosystems to remove nitrogen can be expressed using in-stream retention efficiency (%), which assesses what portion of the nitrogen entering rivers is retained (Maes et al., 2011). The results have been produced using the Geospatial Regression Equation for European Nutrient losses (GREEN) model, a statistical model developed to estimate nitrogen and phosphorus fluxes to surface water in large river basins (Grizzetti et al., 2007). The GREEN model has been successfully applied in Europe (Grizzetti et al., 2008). Fractional nutrient removal is determined by the strength of biological processes relative to river hydrological conditions (residence time, discharge, width and volume).

Potential relevance of this ecosystem service for policy: The availability of water in sufficient amount and quality is one of the most critical aspects for the health of human populations, animals and plants.

<div style="border:1px solid #000; background:#e3ead0; padding:10px;">

Box 3.7   Benefits of GI: water purification

GI such as forest conservation and restoration averts the need for new water filtration plants to maintain clean water flows to city residents. Rainwater harvesting and infiltration-based practices increase the efficiency of our water supply system. Water collected in rainwater harvesting systems can be used for outdoor irrigation and some indoor uses, and can significantly reduce municipal water use. Water infiltrated into the soil can recharge groundwater, an important source of water in Europe.
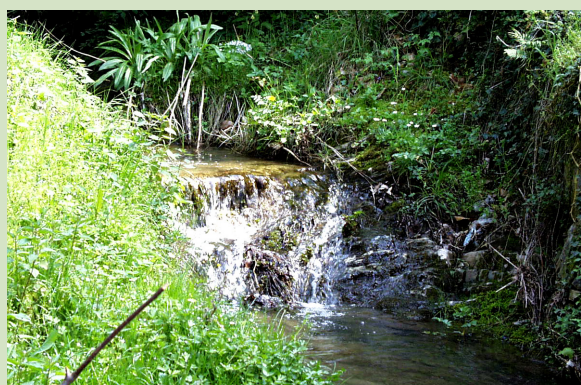

Photo: © EEA

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([17]) http://thegirg.org/future-research.

The natural supply of drinking water and water for domestic and industrial usage from groundwater and surface water is dependent on the filtering potential of microorganisms, plants and sediments. These elements retain and absorb toxic and harmful substances. This natural process reduces the costs of technical water treatment for human usage.

Carbon storage and sequestration

Within the framework of the 'fast track implementation of ecosystem capital accounts', ecosystem accounts describe the European environment's biophysical reality by measuring ecosystem capital in physical units. Data on stocks and flows of this capital are used to estimate the quantity of ecosystem resources that are accessible without degradation, the actual intensity of its use and the detected spatial changes over time.

Biomass or carbon stocks from the Carbon Accounting model (Simon et al., 2011 and 2012) [18] are assumed as a proxy of the capacity of ecosystems to contribute to climate change mitigation. The study uses currently available information on above-ground carbon stocks in forests and in other vegetation (i.e. shrubs, wetlands and other CLC-relevant classes). Forest carbon estimations are based on the statistical disaggregation/downscaling of European forest data from different sources (European Forest Information Scenario (EFISCEN) model, national forest information and the Mediterranean Regional Office of the European Forest Institute (EFIMED)). The results are converted into carbon content using carbon conversion factors derived from literature. The variable used here is the Forest Stock Final Carbon Content (FSFCC). The carbon content in other vegetation is calculated from land cover classes using Corine Lissage (CORILIS) methodology and conversion factors derived from the literature. The combination of FSFCC and carbon in other vegetation is used as an indicator of potential carbon storage and sequestration by ecosystems.

Potential relevance of this ecosystem service for policy: A stable and predictable climate is essential for salubrious living conditions for humans and for our use of natural resources. The continuous sequestration of carbon dioxide by plants, soils and sediments is a key factor contributing to stable climatic conditions. Knowledge of the carbon content in vegetation and the respective sequestration rates underpin measures for future climate-adapted and optimised land use management.

Box 3.8   Benefits of GI: carbon storage and sequestration

Terrestrial ecosystems store almost three times as much carbon as is in the atmosphere. GI such as tropical and boreal forests represent the largest stores. The maintenance of existing carbon reservoirs is among the highest priorities in striving for climate change mitigation [19]. Different ecosystem types store different amounts of carbon depending on their species compositions, soil types, climate and other features. Restoration of GI such as degraded peatlands could help to reduce carbon emissions.
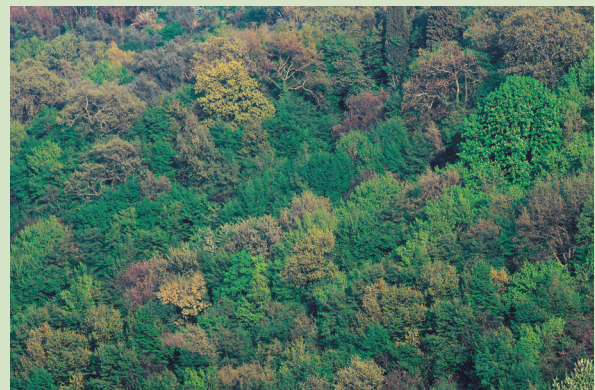

Photo: © EEA

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[18] New updates and developments available in the EEA Fast Track Implementation of Ecosystem Capital Accounts.
[19] http://www.grida.no/publications/rr/natural-fix/page/3724.aspx.

3.2 Core habitat services

The second criterion for the identification of a GI network, besides the provision of ecosystem services, is the provision of key habitats and their connectivity. As habitat areas and their connectivity are species related, the right species or functional groups with relevance at landscape level needed to be identified. Large forest-based mammals were selected as focal species, as they normally have high demands in terms of habitat area, and are able to cover large migration distances. Still, they require suitable links (migration corridors) for the connection of individual habitat patches. In order to maintain the animal population and its genetic diversity, they need core areas that can provide living space, food, shelter and reproductive grounds, as well as corridors between different core areas to enable an exchange of individuals and the spread of populations.

Typical requirements in habitat sizes (Birngruber et al., 2012) of individual animals of respectively small groups range from 100 km^2 to 1 000 km^2. As the size of the group of animals is more decisive than the individual, a sustainable population of lynx, for instance, would need a minimum population of 20 adult animals, thus assuming a minimum area of the territory of 2 000 km^2.

The habitat model used in Section 3.3 is based on studies on wild animal corridors in Austria (Birngruber et al., 2012), Germany (Hänel and Reck, 2011), and the Czech Republic (Anděl et al., 2010). The modelling of potential habitat areas for large forest-based mammals mainly follows the habitat model for the focal species *lynx*, with a slightly less strict minimum size of habitat (following Hänel and Reck (2011)), as follows.

- Habitat core areas are represented by forest densities of 50 % or more, and a minimum size of 500 km^2 contiguous area.

- Forests with a density of between 30 % and 50 % are not suited as core habitat areas; rather, they serve mainly as potential migration routes, as the animals prefer sheltered corridors.

- CLC classes were classified according to their permeability for large mammals.

3.2.1 Description of input data

Forest density

Information on forest density was obtained from the global Landsat Vegetation Continuous Fields tree cover layer provided by the Global Land Cover Facility ([20]). This layer estimate the percentage (0–100%) of horizontal ground covered by woody vegetation greater than 5 m in height, aggregated to 1-kilometre grid cells. The data represent two nominal epochs, 2000 and 2005, compiled from the National Aeronautics and Space Administration (NASA)–U.S. Geological Survey (USGS) Global Land Survey (GLS) collection of Landsat data. The product is derived from all seven bands of Landsat-5 Thematic Mapper (TM) and/or Landsat-t Enhanced Thematic Mapper Plus (ETM+), depending on the GLS image selection (Sexton et al., 2013).

In future, this information set may be replaced by data provided by the GMES/Copernicus initial operations (GIO).

Landscape resistance

For the assessment of landscape resistance, the CLC classes were reclassified into habitat permeability for mammals following the approach used in Birngruber et al. (2012). Habitat permeability for mammalian wildlife describes the extent to which landscape forms permit (or restrict) the movement of large mammals in different directions. Values for CLC classes not present in Austria (the original case study) were filled in using expert judgment. All the CLC forest classes are considered to have maximum permeability values, since they are defined as forest trees higher than 5 m with a canopy closure of at least 30 % ([21]), the same threshold proposed by Birngruber et al. (2012) for suitable migration zones.

The landscape resistance values for modelling purposes are estimated as the inverse of the habitat permeability. Resistances are scaled, i.e. values of 1 represent ideal habitat, and increase to 100 for barriers (Beier et al., 2011) (see Table A1.1 in Annex 1).

([20]) http://landcover.org.
([21]) ETC-SIA (2006). CORINE land cover nomenclature illustrated guide. Available at http://sia.eionet.europa.eu/EAGLE/ EAGLE_6thMeeting_g2_Malaga/04d_Nomenclature_CLC.pdf.

Species occurrence

Under Article 17 of the Habitats Directive, reporting from EU Member States to the European Commission for the first time includes assessments on the conservation status of the habitat types and species of Community interest for the period from 2001 to 2006. This information was compiled by the ETC/BD in 2009 ([22]).

One of the monitoring parameters reported by Member States was the distribution (presence) of some species specified in Annex II of the Habitats Directive. Eight species of large mammals are selected within the orders Carnivora and Artiodactyla (*Alopex lagopus, Canis lupus, Cervus elaphus corsicanus, Gulo gulo, Lynx lynx, Lynx pardinus, Rangifer tarandus fennicus* and *Ursus arctos*), and their available distribution maps are extracted. These species do not cover the entire range of large mammals present in Europe, and are not equally distributed across Member States (some are even endemic species). However, the Habitats Directive is the only available continental (mapping) reporting of its kind to be used as 'ground truth' in this report. For example, in the Habitats Directive the European bison (*Bison bonasus*) is not listed, despite matching the selected functional group. To overcome these limitations, the habitats results (core habitats for large mammals and their connectivity) are indicated both with and without overlaps, in line with the Habitats Directive reporting data.

3.3 Processing of data for ecosystem and core habitat services

3.3.1 Ecosystem services

The processing of ecosystem service information involves the extraction and homogenisation of each of the datasets described in Section 3.1. The geoprocessing involved (when necessary) aggregation at 1-kilometre cell size, alignment, projection to Lambert Azimuthal Equal Area projection (EPSG 3035), correct identification and reclassification of null values (zero capacity) and no data (lack of coverage) that were not recognised in the original data sets, among others. Thus, 10 layers covering 8 ecosystem services are obtained, with pollination and carbon sequestration having 2 sources of information.

In the case of pollination, the coverage of ecotones promoting the activity of pollinators is estimated (as specified in Section 3.1), and hence is overlaid with the pollination potential from Maes et al. (2011) after the normalisation of both input layers. The resulting pollination capacity map takes the maximum value (maximum potential capacity) from any of the two layers on a pixel-by-pixel basis.

For carbon storage and sequestration, the carbon content (stock in tonnes of carbon) extracted from the FSFCC and the carbon in other vegetation (the total amount coming from 14 layers of different vegetation types) is summed up, taken from the carbon accounting exercise for the year 2006.

Once the spatial distribution of the capacity to deliver each of the eight regulating and maintenance ecosystem services in eight maps is obtained, the original biophysical units were reclassified into five ranks, ranging from minimum (1) to maximum (5) (Map 3.1). The specific classification used (i.e. the thresholds between those ranks) depends on the distribution of each data set al.ng Europe, ranging from natural breaks, to quantiles ([23]) or standard deviations. The selection of different thresholds provides different illustrations using the same data, meaning that the user needs to consider what is needed before producing a map of GI. Using the right threshold for the right objective is probably the most important step in the analysis of data for GI.

To illustrate this effect, the previous report of this task (Kleeschulte et al., 2012) compared different maps for each selected data set, using different class distributions and ranges (specifically quantiles, deviation from the average and linear stretch). Classifying the same data into five different classes provided a different spatial configuration of the results. In this case, the capacity to deliver air quality regulation was classified into five ranks using a natural breaks distribution; maintenance of soil structure using a reclassification from the original ecosystem potential; and the rest of ecosystem services using an equal area distribution.

In order to get an integrated result, the most simple and straightforward combination of the eight ranked ecosystem services' layers is based on the addition of the ranked capacity with grid cell statistics. The higher the final result, the larger the combined capacity of the pixel to deliver regulating and

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([22]) Related websites: see http://bd.eionet.europa.eu/article17.
([23]) Equal number of members per class.

**Map 3.1   Input maps of the biophysical capacity to deliver eight regulating and maintenance ecosystem services re-classified into five ranks ranging from minimum ecosystems' capacity (value 1) to maximum ecosystems' capacity (value 5)**
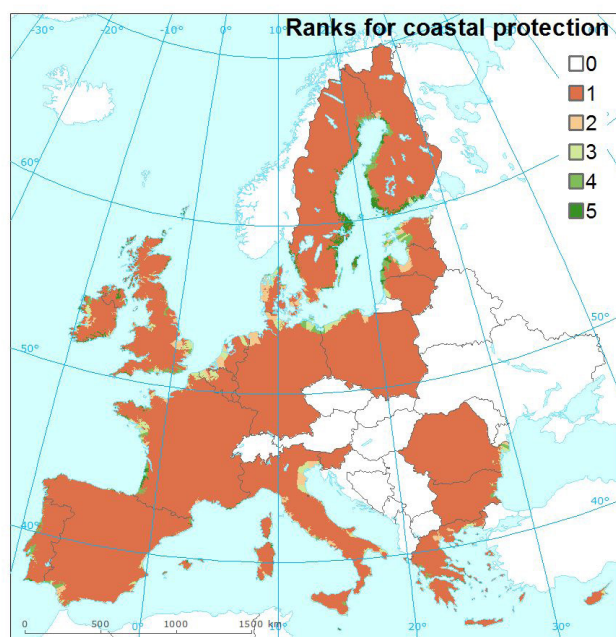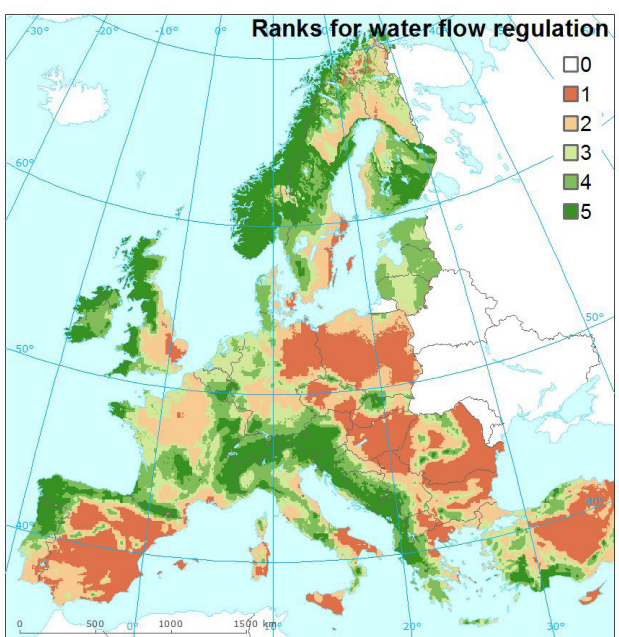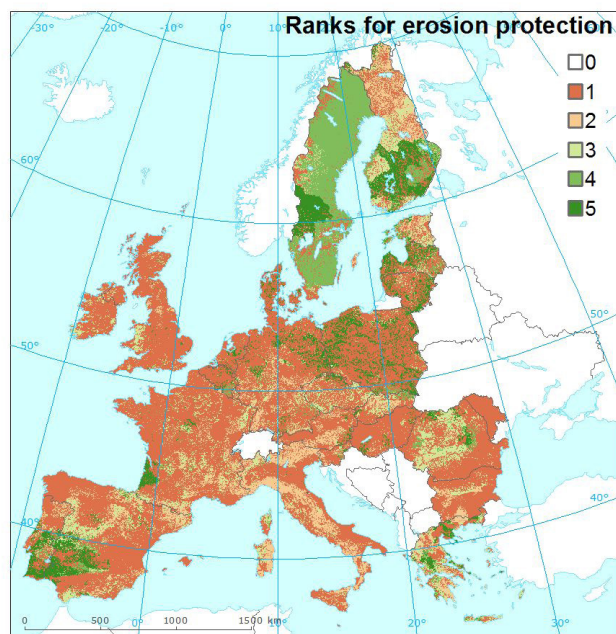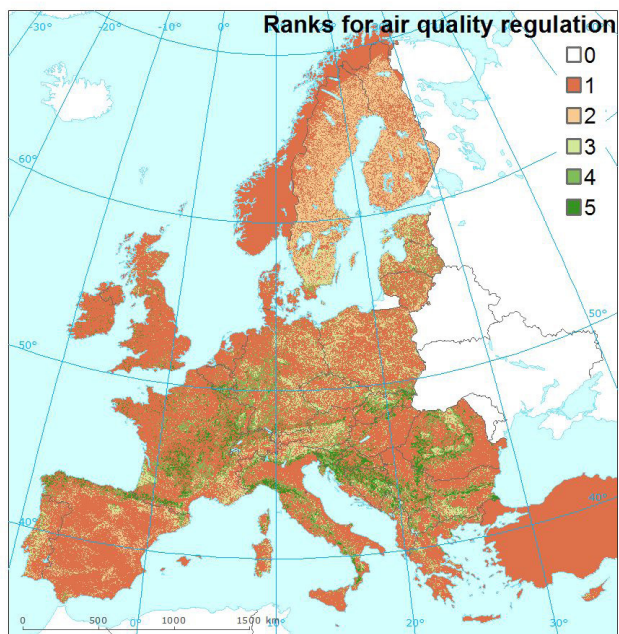
Note: 0 values indicate no data.

Map 3.1 **Input maps of the biophysical capacity to deliver eight regulating and maintenance ecosystem services re-classified into five ranks ranging from minimum ecosystems' capacity (value 1) to maximum ecosystems' capacity (value 5) (cont.)**
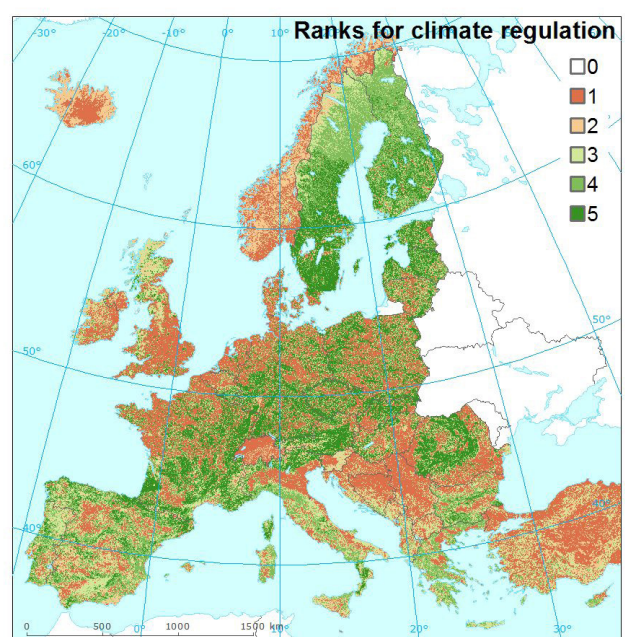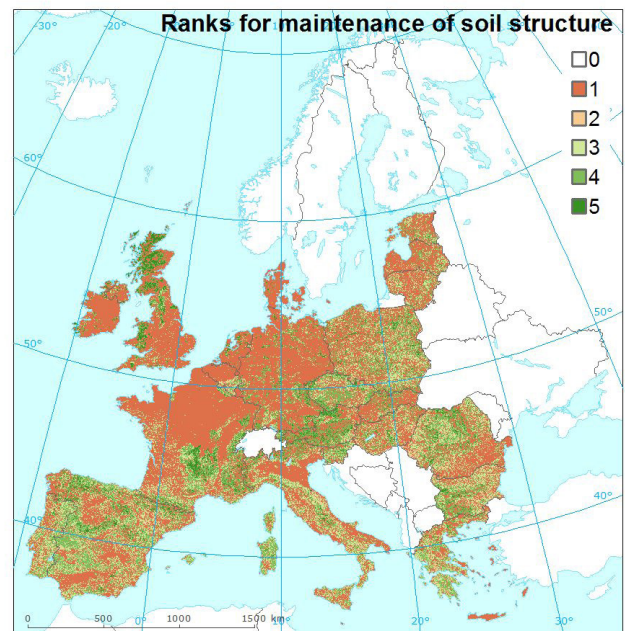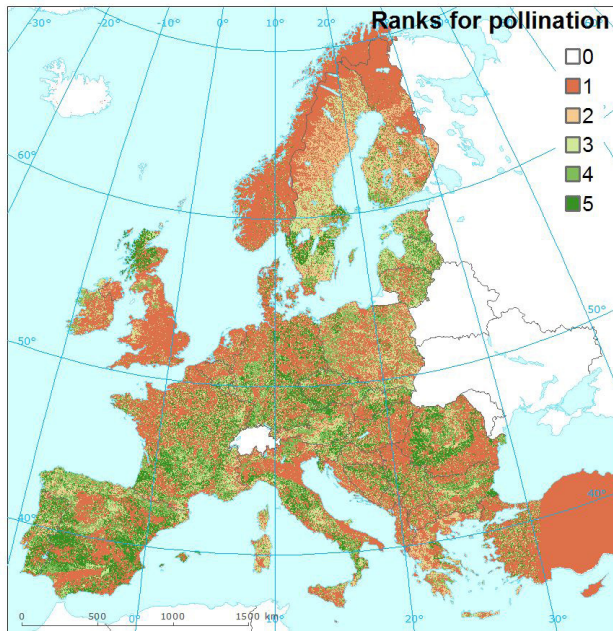

Note: 0 values indicate no data.

maintenance services (Map 3.2). There is a need to take into account the data availability (or data gaps) on the inputs (Map 3.3). Thus, the final integration is the total addition of ecosystem services' capacity, divided by the number of input data sets in each pixel (these are the final results shown in Map 4.1).

In order to guarantee the multidimensionality of the approach, those areas with more than two data gaps (i.e. containing information of five or less ecosystem services, shown in red in Map 3.2) are excluded from the results.

Map 3.2   Example of calculating accumulated capacity to provide regulating and maintenance ecosystem services
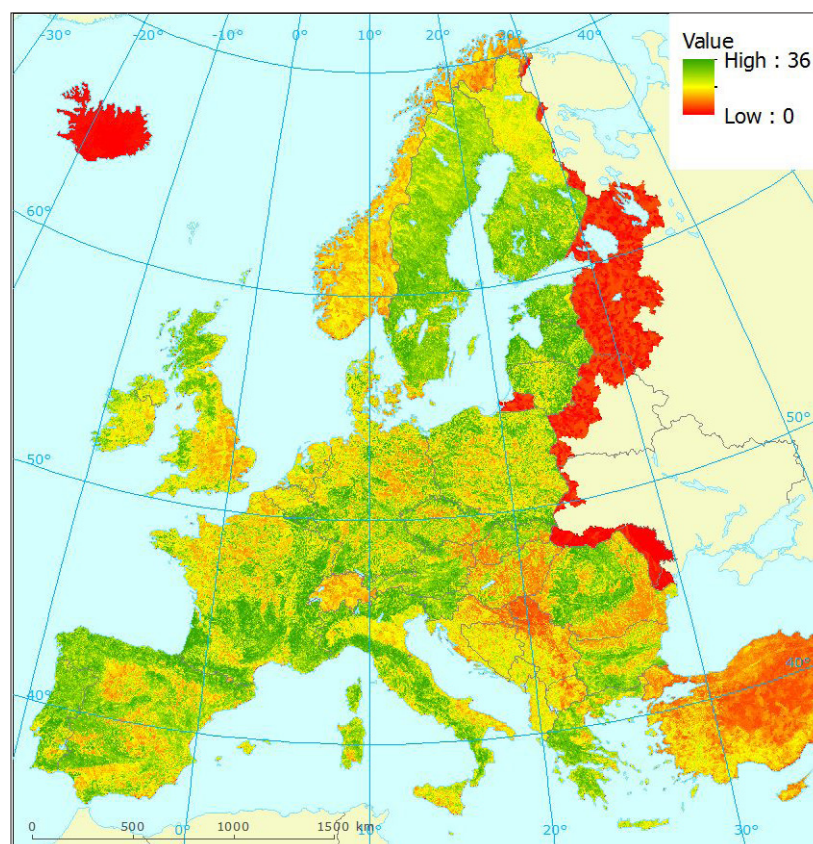
Note: Minimum values (red areas) can be generated either by a deteriorated natural potential to deliver ecosystem services, or by the absence of multiple input data sets to measure it (e.g. Iceland). These values have to be normalised by the actual data availability.

Map 3.3   Number of valid input data related to ecosystem services' mapping in the entire study area
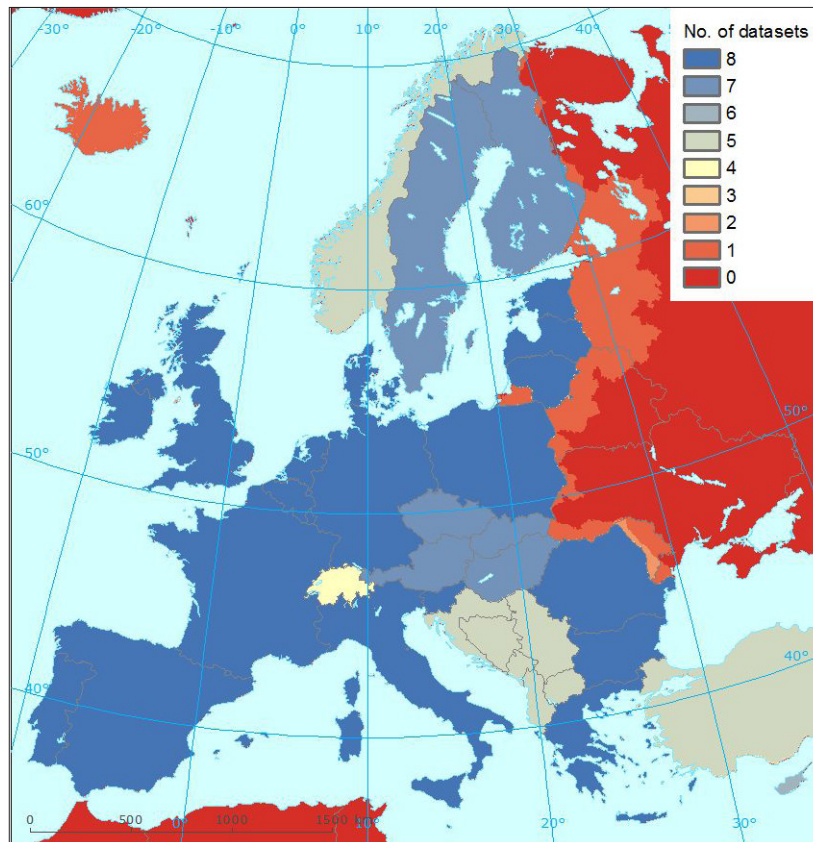
Note: This calculation is used to derive the final indicator on capacity to deliver regulating and maintenance ecosystem services.

3.3.2   *Core habitat services*

To find out the core habitat services the **potential core areas** are mapped for large forest-based mammals in Europe as forest patches with canopy densities over 50 % and continuous coverage over 500 km^2 based on the Landsat Vegetation Continuous Fields tree cover layer (Map 3.4). Then, to map the **actual core areas**, those potential habitats are overlapped with the areas where at least one of the eight selected species of large mammals have been reported by Member States following Article 17

of the Habitats Directive (see Section 3.2). Only these actual core areas will be used for the final GI network mapping since they are the only ones with some kind of ground truth or validation for species distribution.

The quality of the potential core habitats for mammalian wildlife is evaluated in terms of narrowness, dispersion and presence of bottlenecks, with an indicator based on the ratio of polygon perimeter/polygon area (Map 3.5). This gives an idea of the exposed border area versus remote

Map 3.4   Tree cover (canopy) density for Europe, extracted from the Landsat Vegetation Continuous Fields
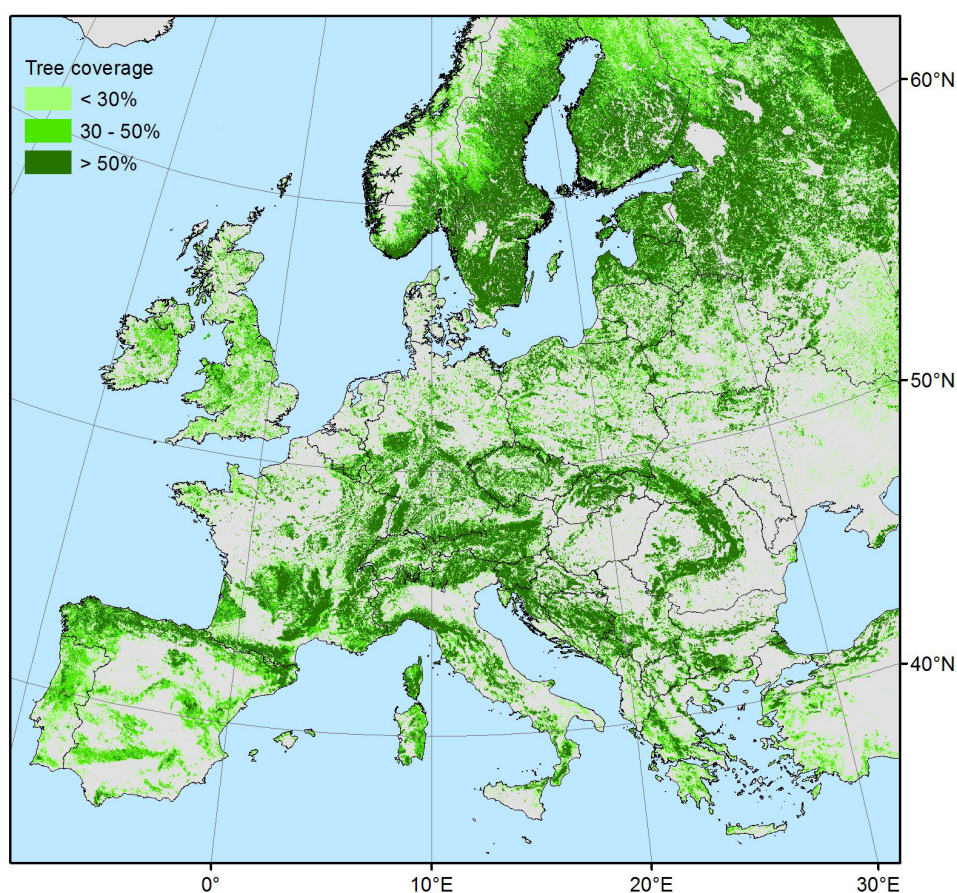

Note: See Section 3.2.

or protected zones. Future restoration activities can focus on smoothing and widening the core habitats to improve their quality and suitability for supporting wildlife. This approach can clearly be improved by taking into account more groups of animals at better resolution.

Second, the CLC 2006 data and part of the CLC 2000 data (covering Greece) in a 1-kilometre grid are combined. Based on the land cover data (44 classes), the Streamlining European Biodiversity Indicators (SEBI) correlation of those classes to

habitats, and measures found in the literature (Beier et al., 2011; Birngruber et al., 2012), the CLC data set (see Annex 1) are reclassified to derive a habitat permeability layer for mammalian life and a continuous landscape resistance layer (Map 3.6). The landscape resistance input used for the connectivity analysis represents the degree to which the landscape facilitates or impedes movement among different patches, as a combined product of structural and functional connectivity (i.e. the effect of physical structures and the actual species use of the landscape).

Map 3.5   Distribution of potential core habitats for large forest-based mammals in Europe, classified by their quality (ratio perimeter/area)
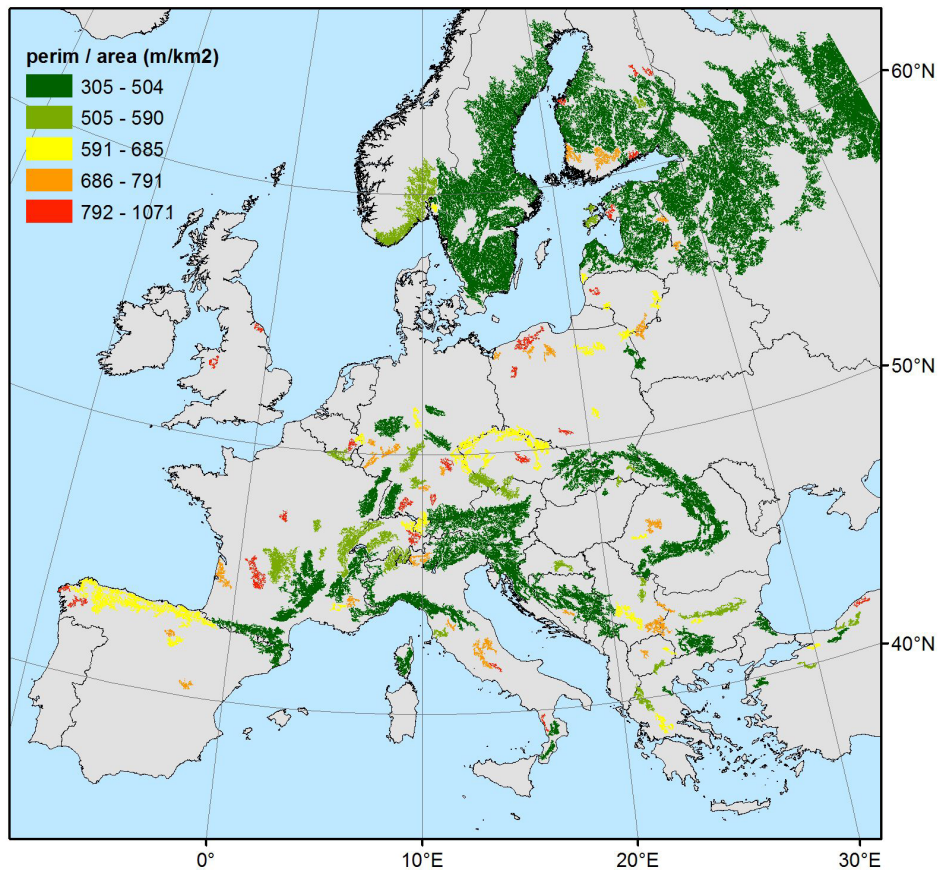
Note: According to the parameters found in the literature, these areas can host functional populations of large mammals like lynx or red deer. Still, the patches with a high ratio of perimeter versus area (reddish colours) represent relatively vulnerable habitats for those populations. The potential core habitats have been crossed with the actual distribution of large mammals reported under the Habitats Directive to select only the actual core habitats (those presently hosting large mammals) for the connectivity analysis.

On the basis of the identification of the core areas and landscape resistance for large forest-based mammals in Europe, a connectivity analysis is carried out. For this purpose, a Linkage Mapper v1.0.3 tool (McRae and Kavanagh, 2011, last updated in July 2013) is used. This tool is designed to support regional wildlife habitat connectivity analyses; it uses several Python scripts that automate mapping of wildlife habitat corridors. Linkage Mapper uses core habitat areas and maps of resistance to movement to identify and map least-cost linkages between core areas. Each cell in a resistance map is attributed a value reflecting the energetic cost, difficulty, or mortality risk of moving across that cell. The cost distance tools apply distance in cost units rather than geographic units.

After several runs, and following guidance from the Linkage Mapper support documentation, the following environment variables and parameters are selected to run the connectivity analysis between the key habitats for large mammals in Europe.

Map 3.6   Landscape resistance for mammalian life derived from land cover, habitats and literature data
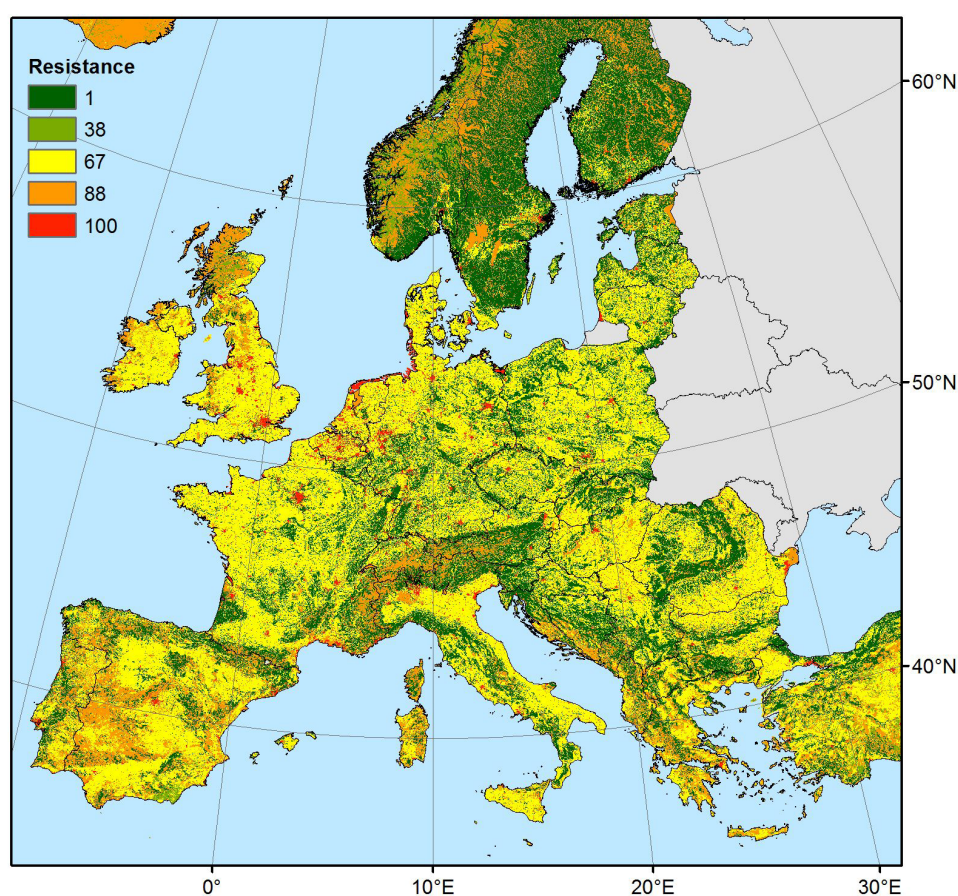
Note: Maximum resistance values represent barriers or places where the landscape impedes the movement of large mammals, as a combined effect of physical structures and the mammal species' use of the landscape.

- Two different sets of core areas in different runs: potential and actual core areas.

- The landscape resistance layer derived from CLC.

- The remoteness among core areas is measured both in Euclidean ([24]) and cost-weighted distance.

- Corridors that intersect intermediate core areas between a pair and those whose Euclidean distance is over 300 km are dropped; this is the maximum migration distance suggested in Hänel and Reck (2011).

- Not only the least-cost paths are illustrated; so are the corridors proposed by the Linkage Mapper tool, limited to a cost-weighted distance (width) of 10 km.

([24]) Euclidean distance is linear distance (actual distance), which differs from the 'cost distance' of the Linkage Mapper model.

4   Results and discussion

4.1   Ecosystem services

The integration of results from the analysis of ecosystem services is shown in Map 4.1. Green indicates zones with the maximum combined capacity to provide regulating and maintenance ecosystem services ('key service areas'), while orange highlights zones with moderate capacity to provide those services ('limited service areas').

'Key service areas' will form part of the GI network 'C' (for Conservation), because their protection or conservation will guarantee the delivery of regulating ecosystem services. 'Limited service areas' might be included in the GI network 'R' (for Restoration), since they perform important ecological functions (as demonstrated by their moderate ecosystem services' delivery) that could be boosted by protection or restoration actions.

Map 4.1   Distribution of GI elements, based on the capacity to deliver ecosystem services

Note: 'Key service areas' hold the maximum capacity to deliver regulating ecosystem services and, therefore, they should be protected and conserved to maintain natural capital. They could be ascribed to level 1 of the four-level concept on ecosystem restoration. In the 'limited service areas' ecosystem functioning is providing ecosystem services at a moderate rate that could be boosted by restoring or enhancing those natural habitats. They could be qualified as level 2 of the four-level concept on ecosystem restoration. The 'low service areas' are zones with relatively low capacity to deliver the selected ecosystem services, either owing to their functional roles or due to the intensity of human use. These areas include the most degraded ecosystems, embracing Levels 3 and 4 of the four-level concept on ecosystem restoration. The thresholds that define our three categories can be modified and adapted for regional assessments (e.g. an Irish assessment could enlarge the 'key service areas' category, while a Swedish assessment could define a more restricted one).

There are no zones in Europe that qualify as maximum providers (rank = 5.0) for all the eight ecosystem services analysed. The upper class category ('key service areas') has been set with values from 2.9 to 4.7, and the moderate class ('limited service areas') with values from 2.5 to 2.9. The lower class category ('low service areas') has a range between 1 and 2.5. Readers should bear in mind that both the thresholds and the input data used to define the areas mapped in Map 4.1 are just proposals that can be modified. The quality and resolution of the input data — mainly the lack of full coverage, intercalibration and homogenisation at European scale — generate significant differences among countries. The thresholds selected to define 'key service areas' and 'limited service areas' affect the extension and distribution of the final GI networks. The limits in the study have been selected based on technical and environmental factors — for the practical application of this methodology, however, the selection should be also based on policy priorities and socio-economic aspects. It is recommended that the methodology be applied at national or regional scale (the scale at which decision-making or spatial planning will be applied) with the highest resolution information available, in order to obtain comparable results and coherent networks.

The outlined classification in this study can be adapted to the framework recently proposed by the Working Group on Restoration Prioritisation Framework (WG RPF). This group is exploring the best means of implementing Action 6a of Target 2 of the EU Biodiversity Strategy to 2020. The proposed framework is described as a four-level concept on ecosystem restoration (ARCADIS, 2013), although it has not been completely defined yet in terms of descriptors and threshold values.

Our 'key service areas' could correspond to level 1 of the restoration concept, and the 'limited service areas' to level 2; the 'low service areas' would include both Levels 3 and 4. However, it is proposed that the four-level concept for restoration be tailor-made for each ecosystem type; our approach assesses all ecosystem types together, focusing only on their capacity to deliver services.

4.2 Core habitat services

The second part of the analysis involved habitat connectivity modelling of large mammals at European scale. The key habitats (actual core areas) that provide living space, food, shelter and reproductive grounds for the European forest-bound mammals' populations are identified as part of the GI network 'C' for the key ecological role they perform for wildlife. Moreover, the actual core areas scoring the least quality values (i.e. areas with a perimeter-to-area ratio of over 792 m/km^2 in Map 3.5) have been identified; a 5-kilometre buffer zone around them is included in the GI network 'R', with the aim of increasing their protecting potential for biota.

The final result of the connectivity analysis between actual core areas is illustrated in Map 4.2. The background map shows the cost-weighted distance (CWD) range in kilometres. CWD is a pixel attribute resulting from the pixel's resistance plus the resistance of a chain of pixels reaching to each terminus (core areas). It is therefore not only a single pixel's content, but also includes the landscape context. The least-cost path lines in the map represent the suggested paths for mammals' migration, and they are colour-coded by their total CWD. To define wildlife corridors, the study uses not only least-cost paths (conservation advice should not be based on single pixel lines), but also corridor swaths (natural patches of a certain width) such as those illustrated in Map 4.3. Corridor swaths are analysed to help determine whether habitats surrounding the least-cost paths are appropriate for migration, and thus whether they are biologically relevant and likely to be used by biota. Detailed information on designing and evaluating corridors is available in CorridorDesign (2007–2013) ([25]).

Even if not discernible in the continental-scale map (Map 4.2), the main result of the connectivity modelling is the design and assessment of 88 linkages connecting the 67 actual core areas. Of those linkages, 37 are shorter than 10 km (these are the ones most feasibly protected and implemented), while another 16 are longer than 100 km. The soundness of this model run is demonstrated in


([25]) http://corridordesign.org/designing_corridors/corridor_modeling/cost_distance and http://corridordesign.org/designing_corridors/corridor_modeling/evaluating_corridors.

Map 4.2 by the position of paths labelled A, B and C, which flow across potential core habitats for mammals (the same locations and labels are available for comparison in Map 4.4). The area covered by the wildlife corridors (e.g. the black corridor swaths shown in Map 4.3) should be considered for potential restoration or at least protection actions; hence, this area is included in the GI network 'R'. The connectivity among core habitats for large mammals will enhance the genetic flow across Europe, something particularly important for helping species adapt to the environmental transformations brought about by climate change.

Map 4.2   Main results from the connectivity modelling between actual large mammals' core habitats
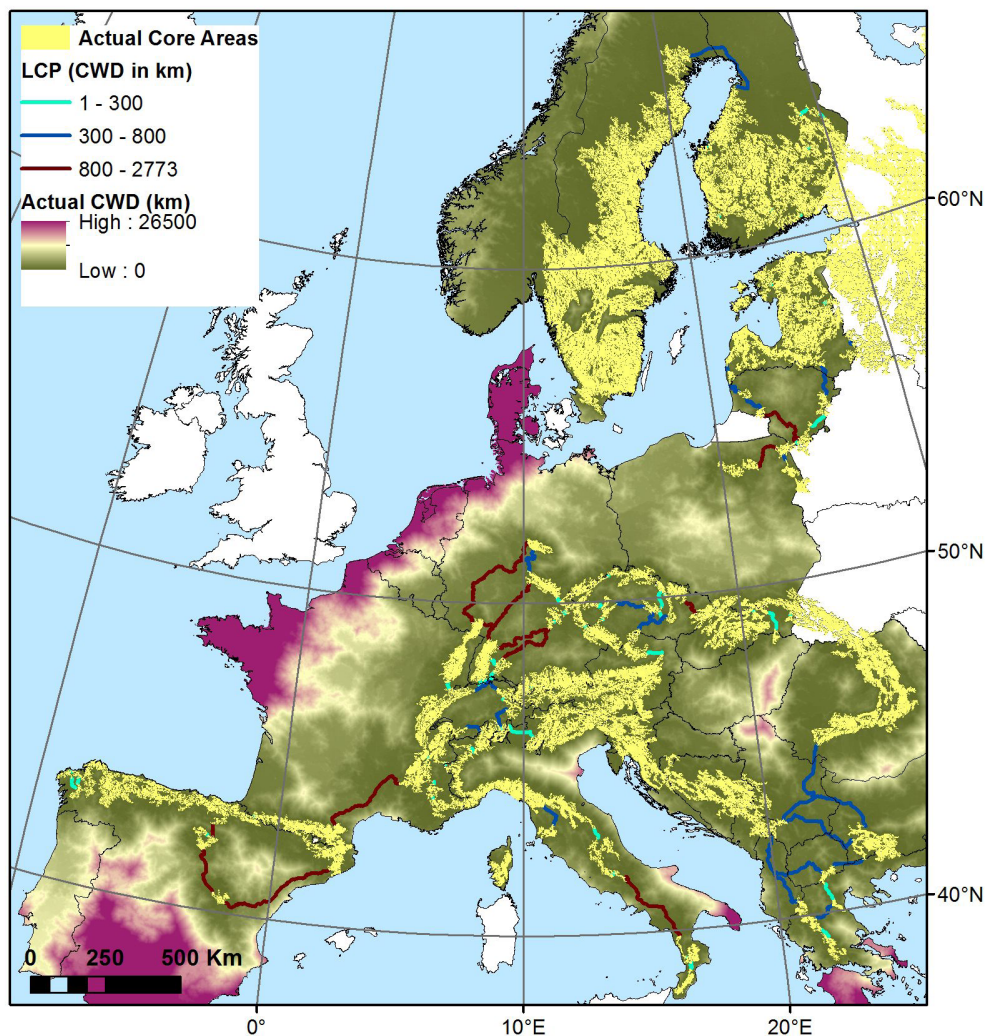
Note: The CWD map shows the difficulty (in terms of energy, mortality, etc.) for the large mammals to travel across each pixel. 'Costs' here mean natural effort, and are unrelated to economic costs. Only the lowest CWD areas qualify for potential wildlife corridors; the best options are highlighted by the least-cost paths in the map. The lower the cost of each path, the more feasible it is for it to be used by large mammals. The dashed square points to the location of Map 4.3. Corridors labelled with A, B and C follow paths crossing potential core habitats for mammals (see Map 4.4), confirming the validity of the results.

Map 4.3   Detail of the results from the connectivity modelling shown in Map 4.2
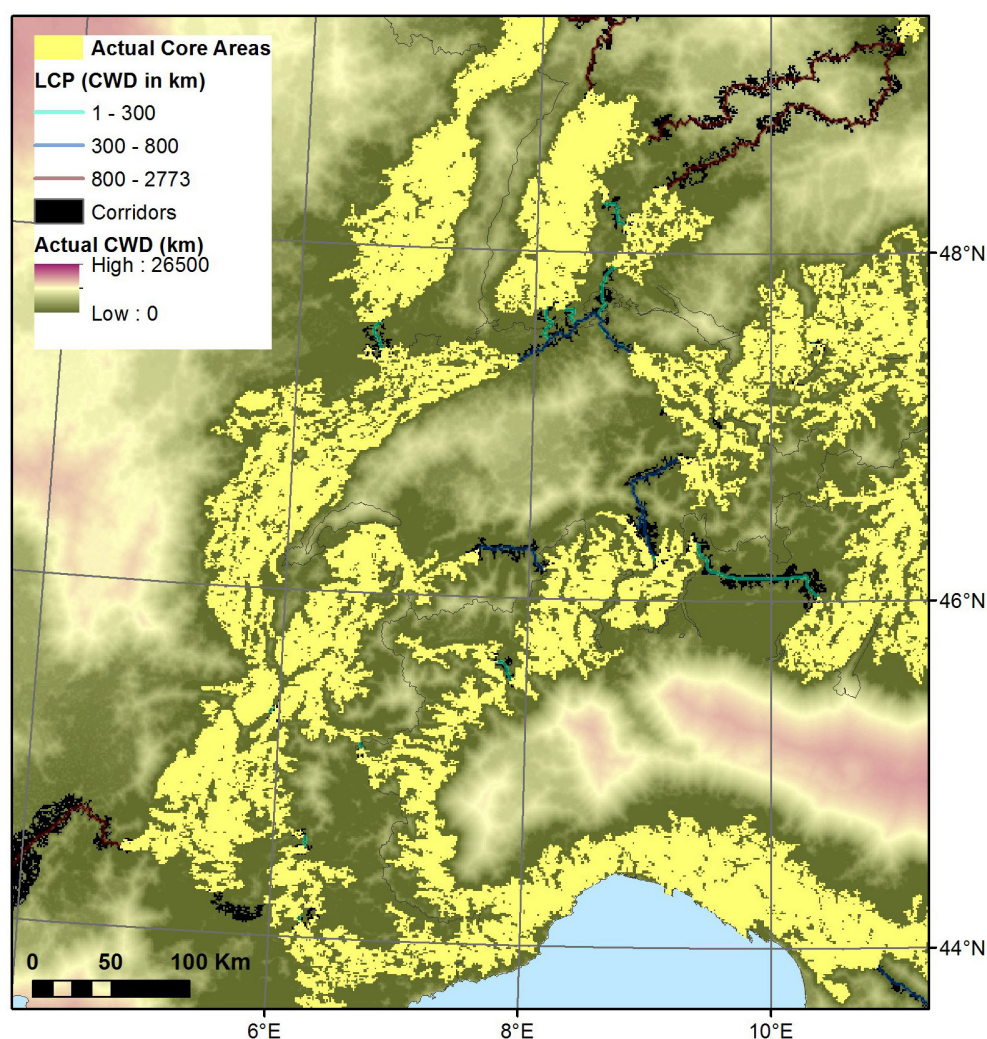
Note: Here, not only the least-cost paths but also the proposed wildlife corridors (black shaded areas) are illustrated. The protection or restoration of those corridors would enhance the mammal population (number of individuals, genetic pool, etc.) and promote biodiversity. A similar effect is expected from the improvement of the core habitats' quality (see Map 3.5).

For comparison and exploratory purposes, the study also runs the connectivity analysis among the **potential core areas** that could host large mammal populations. These areas may contain some mammal species that were not reported under the Habitats Directive, or they may have been the home of large mammals in the past. As a result, they could eventually be promoted to perform ecological roles similar to those played by **actual core areas**.

However, these results are merely illustrative and are not included in the final proposal of GI networks. Map 4.4 is equivalent to Map 4.2, but the results connect all the potential core habitats across Europe. It includes 210 linkages connecting

136 core areas, 75 of which are shorter than 10 km in Euclidean distance, and another 28 which are longer than 100 km. Map 4.5 shows a zoom-level shot covering the same area as Map 4.3.

This kind of habitat connectivity modelling can be replicated for any other functional group or area of interest, as far as the core habitats for the species and the resistance values for their mobility can be defined and mapped. If the aim of this exercise is to detect potential zones for conservation or restoration, analysis at higher resolution per management unit is recommended and transboundary core areas and corridors should be also considered.

**Map 4.4   Main results from the connectivity modelling between potential large mammals'
core habitats**
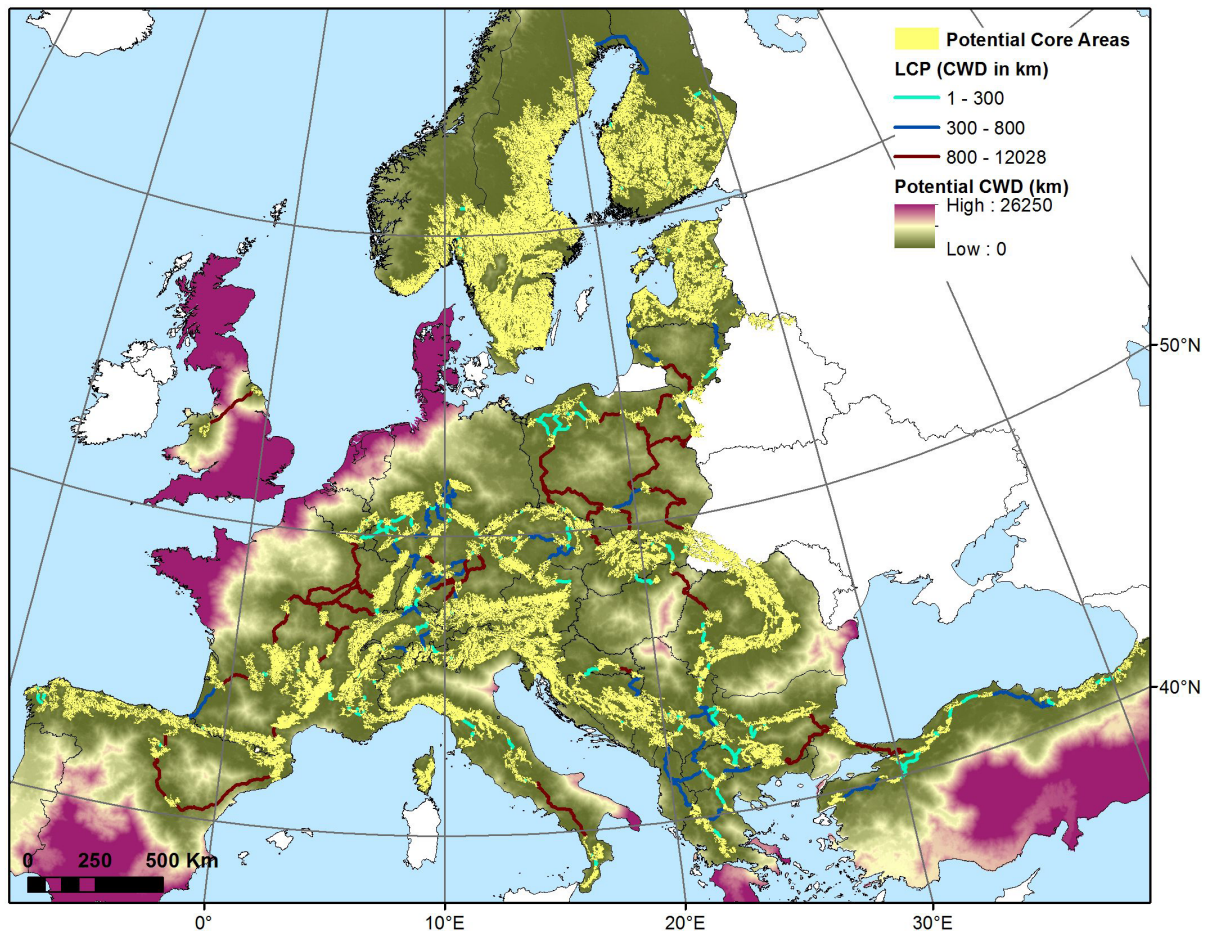
Note: This map is trying to compare the actual situation with a potential one that could be defined as a scenario. The CWD map
shows the difficulty (in terms of energy, mortality, etc.) for the large mammals to travel across each pixel. 'Costs' here mean
natural effort and are not related with any economic term. Only the lowest CWD areas qualify for potential wildlife corridors;
the best options are highlighted by the least-cost paths in the map. The lower the cost of each corridor, the more feasible it is
to be used by large mammals. Labels A, B and C correspond to least-cost paths highlighted in Map 4.2.

4.3   Green infrastructure networks

All the identified GI elements were mapped
and integrated into the GI networks 'C' (for
Conservation) and 'R' (for Restoration). The
GI network 'C' comprises the 'key' service areas
and the core habitats for large forest-bound
mammals, whilst the GI network 'R' includes the
limited service areas, the surroundings of the
lowest-quality core habitats and the proposed
wildlife corridors. The individual GI elements were
selected and extracted from previous results, and
subsequently integrated. Whenever an overlap
occurs, the highest protection level prevails, i.e. an
area classified as maximum capacity (value = 3) by

one of the inputs will have a maximum protection
value (network 'C') in the output. The integrated
results are summarised and illustrated in Table 4.1
and Map 4.6, and they represent an example of
identification and mapping of GI networks in
Europe elaborated following the methodology
described in this report.

The results summarised in Table 4.1 indicate that
27 % of EU-27 might form part of the GI network 'C',
with the largest contribution coming from areas with
the highest capacity to provide ecosystem services.
It is worth noting the large coincidence (spatial
overlap) between the key service areas and the key
habitats for mammals (value 3 x 3 in Table 4.1).

Map 4.5   Details of the results from the connectivity modelling shown in Map 4.4
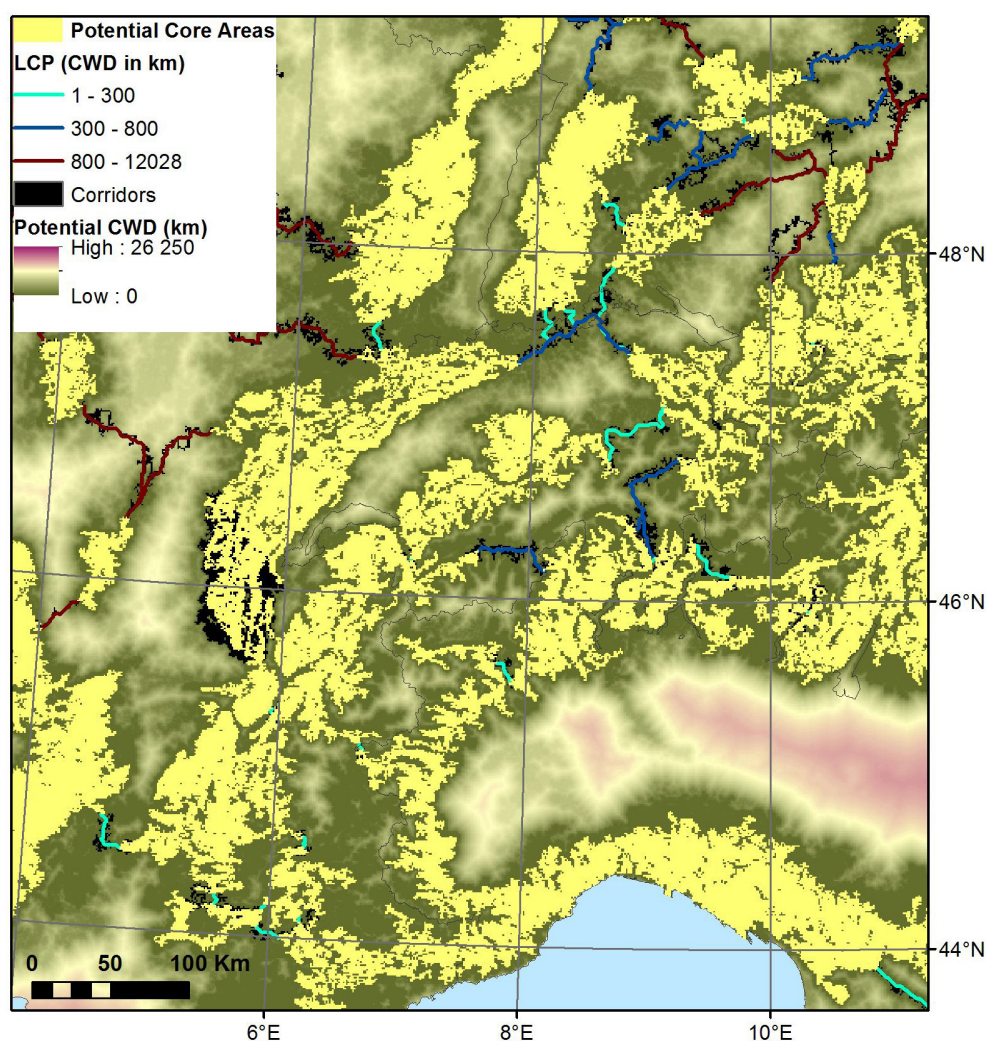
Note: Note the higher amount of least-cost paths of all categories found, compared to Map 4.3.

Table 4.1   Geographical analysis of the GI elements identified in this study, integrated into the final GI networks

		Key habitats (large mammals)		
		1	2	3
Ecosystem services	1	2 439 296 (56)	24 088 (1)	93 441 (2)
	2	628 442 (15)	21 884 (1)	169 396 (4)
	3	529 352 (12)	29 405 (1)	365 523 (8)

Note: Units represent area as km^2 (%). The two inputs to the table are the results coming from the analysis of ecosystem services' capacity and large mammals' habitats. Value 1 corresponds to the lowest input values and is not part of any GI network; Value 2 forms the GI network 'R' (limited service areas, wildlife corridors and zones to improve the quality of core areas for mammals); and value 3 forms the GI network 'C' (key service areas and mammals' core areas). These results show an example of a European trial elaborated following the methodology described in this report.

Map 4.6   Mapping of the potential European GI networks derived from this methodological report
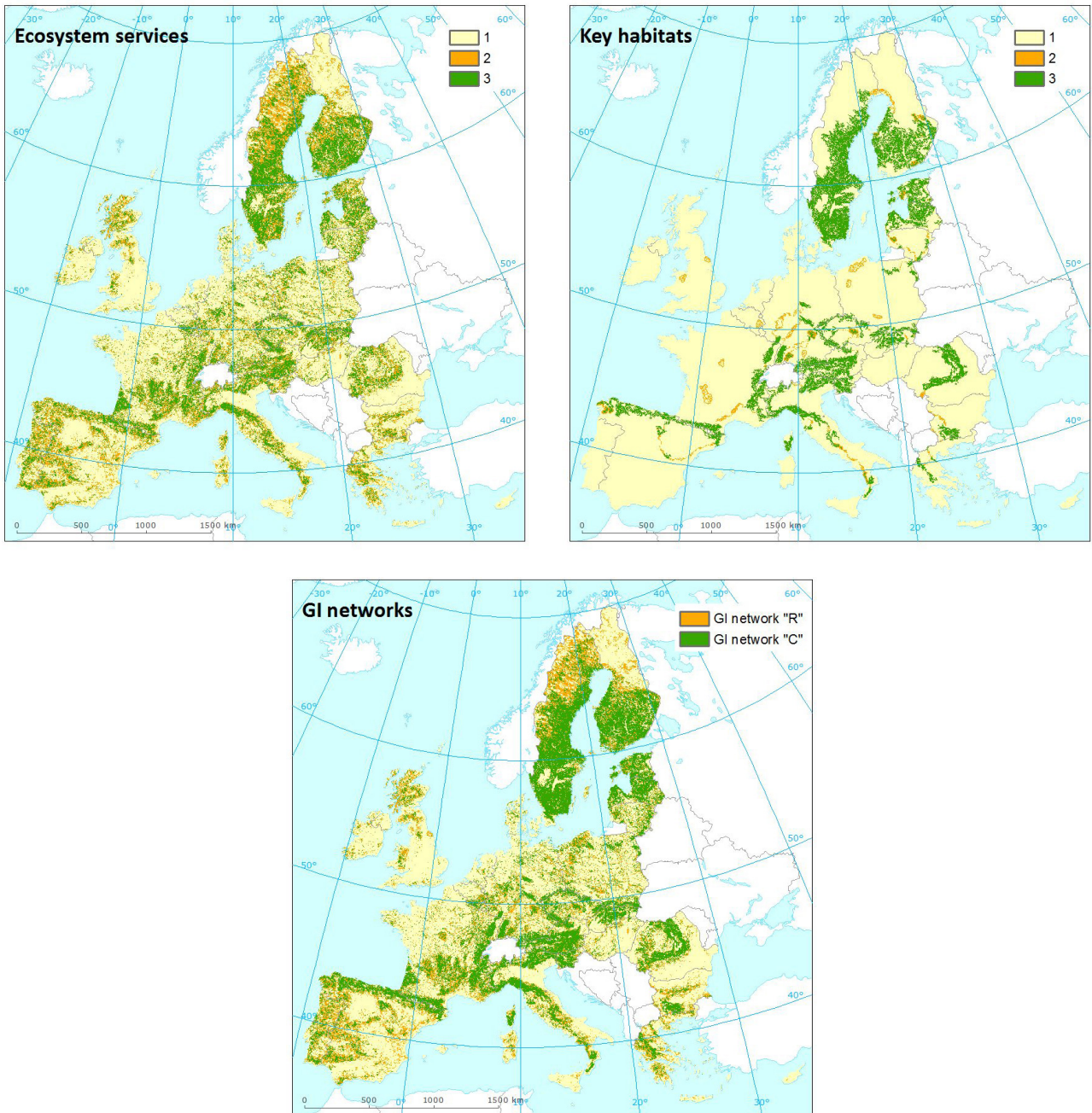
Note: The GI network 'C' consists of areas to be conserved because they perform key ecological roles for both wildlife and human well-being. It can be ascribed to level 1 of the four-level concept for restoration proposed by the WG RPF. The GI network 'R' performs important ecological functions, but its capacity could be improved with some protection or restoration It could correspond to level 2 of the four-level concept for restoration. The non-GI area covers the rest of the territory not identified as a GI network. The quantitative results are summarised in Annex 2.

The GI network 'C' can be ascribed to level 1 of the four-level concept for restoration proposed by the WG RPF (ARCADIS, 2013). Conversely, 17 % of EU territory might correspond to the GI network 'R', mainly defined by limited service areas. This GI network could correspond to level 2 of the four-level concept for restoration. The rest of the European territory (56 %) did not qualify to form part of any GI network ([26]) (under the assumptions and thresholds fixed in this example), and is considered to be at Levels 3 and 4 of the four-level concept for restoration.

It is important to highlight that the delimitation of GI elements shown in the figures and maps of this report is for the purposes of a trial test of the proposed methodology; it needs to be adapted to the objectives and criteria of each practical land management case. The types of physical features that contribute to GI are greatly scale dependent, diverse and specific to each location or place ([27]).

4.4 Findings for decision-making support

In most European countries, regional or local authorities are responsible for spatial planning decisions. Their role is crucial in defining and deploying GI. There are numerous policy examples that can be supported by the definition and implementation of a European GI network ([28]):

- integration of GI into the forthcoming EU Forest Strategy;

- development and implementation of all targets of the Biodiversity Strategy;

- reporting under different directives, such as the Habitats Directive or the Water Framework Directive;

- promotion of soil protection and climate change mitigation;

- promotion of GI as inter-territorial tool;

- use of GI for integrated spatial planning;

- use of GI for ecosystem-based disaster risk reduction;

- contribution to current discussions on options for territorial cohesion policy after 2014, and later discussions on measuring Member States' performance;

- promotion of the EU-wide policy framework to deliver sustainable development fostered in EC communications from 2001 and 2005.

Several crucial principles describing GI (as has already been highlighted by the European Commission (2012)) are covered in this methodological report: for instance, GI aims include promoting ecosystem health and resilience, contributing to biodiversity conservation and enhancing ecosystem services (Naumann et al., 2011). Thus, while an environmental focus on GI is fundamental to securing its objectives (Wright, 2011), it is not sufficient. What defines GI is the inclusion of goals for protecting ecological functions alongside goals for providing benefits to humans (McDonald et al., 2005). By strengthening and maintaining the good functioning of ecosystems, GI can promote the multiple deliveries of ecosystem services. It has also been proved that measures targeting biodiversity and the provision of ecosystem services are higher in restored systems than in systems that had been degraded (Rey-Benayas et al., 2009).

Figure 4.1 summarises the proposed steps to define and map GI networks at landscape level. EU Member States will individually determine how to apply the 15 % restoration target settled in the Biodiversity Strategy. The goal of this study is not to define that target nor any location, but rather to illustrate a mapping methodology that can be tested by countries and local agencies when setting priority areas for GI and identifying potential areas for conservation and restoration. A next step in the methodological development might be to model or forecast the impact of different restoration actions in the provision of ecosystem services.
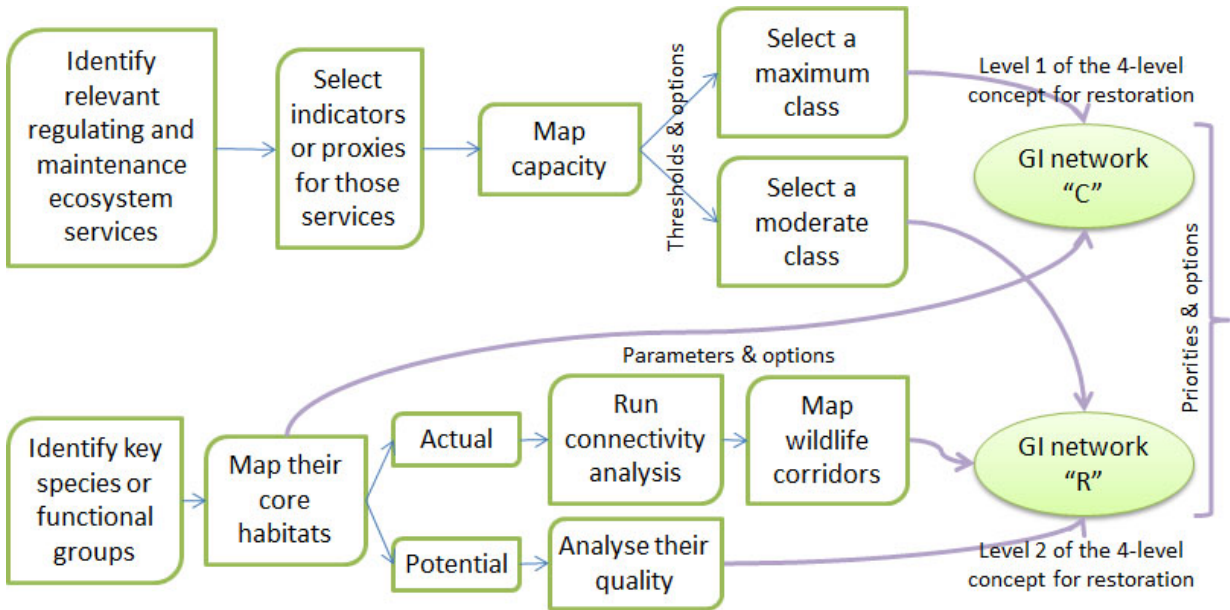
This study does have some limitations (these will be described fully in Chapter 5). For instance, the methodology covers the landscape level of GI, and needs to be adjusted to different spatial scales. Also, in order to support decision-making, it is highly recommended that users consider stakeholder involvement and feedback in the first steps of GI design (McDonald et al., 2005; Hostetler et al., 2011).

([26]) Excludes all urban GI networks.
([27]) Commission staff working document SWD(2013) 155 final (Technical information on Green Infrastructure) accompanying the document COM(2013) 249 final.
([28]) Commission staff working document SWD(2013) 155 final (Technical information on Green Infrastructure) accompanying the document COM(2013) 249 final.

Figure 4.1   Workflow of the methodology proposed in this report

Moreover, in this environmental approach, no attempt was made to include the socio-economic aspects and population dynamics that must be considered for the design of GI, including the geographical analysis of the demand for ecosystem services (i.e. where the services are mainly produced, and where are they consumed). This might foster an interest in undertaking place-based assessments of ecosystem services and GI. Political priorities should also be added for consideration of real applications of the approach.

These added views or priorities can be integrated into the methodology through the three 'options' in Figure 4.1 ('thresholds & options', 'parameters & options' and 'priorities & options). For example,

depending on stakeholder feedback concerning the definition of natural versus relatively degraded ecosystems in a certain area, the 'thresholds & options' that will define the final key service areas can be changed. Depending on the environmental characteristics (e.g. maximum forest density) or socio-economic context (e.g. historical farming practices) of a certain area, the 'parameters & options' that will locate the final wildlife corridors can be modified. Depending on the political agenda and interests (e.g. willingness to fulfil the international requirements on biodiversity conservation), the 'priorities & options' to enlarge or reduce the final GI network can be altered. To sum up, each perspective and priority option applied will alter the final result and mapping of the GI networks.

5 Limitations, gaps and recommendations

One of the main data gaps identified in this work is the availability of ecosystem services' information. Some of the available maps do not have full European coverage (especially EEA/EU-39 coverage), mainly because at least one of the input variables in their definition is not accessible at continental scale (e.g. the Land use/cover area frame statistical survey (LUCAS) data set only covered the EU-15, EU-25 and EU-27 in 2006, 2009 and 2012 respectively). This compromises the results of a continental comparison, since the eight regulating and maintenance services can be assessed in some countries only. To avoid inconsistency in the results, all countries with information for less than six ecosystem services have been masked out in the final results map.

This situation is expected to improve with the ongoing mapping and assessing efforts undertaken by the European Commission MAES exercise, under Action 5 of the Biodiversity Strategy. Users are advised to substitute the continental-scale inputs used in this report with more detailed national or regional data sets, to replicate the methodology, and to identify GI elements at lower scales.

A second issue found in the ecosystem services proxies and Habitats Directive reporting is the lack of homogenisation or intercalibration among Nomenclature of Territorial Units for Statistics (NUTS) regions. Some statistical analyses could be performed to smooth the divergences across borders (e.g. grouping in clusters and aligning averages or standard deviations), but it was considered preferable to avoid modification of the original data for this work. The goal was to test the proposed methodology, rather than to present definite results. As already highlighted by the Pan-European Ecological Network, variation in habitat data across Europe presents one of the biggest challenges to developing a common approach for the agencies responsible for biodiversity conservation, which number more than 100 across Europe (Jongman et al., 2011).

Furthermore, one of the major gaps in the results of this study that should constitute the next step

in the analysis is the temporal assessment of GI networks. Ecosystems are not stable entities, but rather continuously developing dynamic systems that provide services depending on their ecosystem health. Temporal changes in ecosystem condition will affect the capacity of ecosystems to supply services and, thus, the delimitation of 'key service areas' and 'limited service areas'.

Also, land cover and land use changes may severely affect the distribution of suitable habitats for biota and GI elements. These changes can be at least roughly monitored and quantified with the information presently available.

Large forest-based based mammals are probably one of the best-known functional groups in terms of ethology and habitat needs. Information on other key species or functional groups has to be compiled, and their core areas and landscape resistance assessed and mapped. Such landscape-scale approaches are not designed to support the specific management of individual sites. However, individual sites can benefit from landscape approaches since they take into account the site's relationship and functional connectivity with wider habitat networks (Kettunen et al., 2007). Increasing connectivity among key habitats will increase their overall resilience.

This report highlights the importance and impact of selecting both the right input (reference data set) according to the objective of the study, and the appropriate thresholds for displaying the range of values in each of the selected relevant data sets. The thresholds used in this work to define different categories (e.g. key service areas) depend on the specific data distribution (one may use deviation from the average, natural breaks, or quantiles in the different input data sets), since the aim of this continental-scale analysis is to provide a representative picture across Europe. However, the approach of classifying each variable or indicator can be modified and adapted regionally. Depending on class ranges, the same geographic region (grid cell) will be put into different classes, and the visual impression of the resulting GI network will differ.

Thus, one of the challenges when defining GI networks (apart from selecting the most relevant input data sets) is establishing the right thresholds and criteria, as these will clearly affect the final results. For example, with a more strict classification of 'key service areas' and similar thresholds for 'limited service areas', the final area for conservation will decrease while the area for restoration increases. To apply this methodology for management plans, a balance should be established between the environmental definitions (provided here), the socio-economic context and the political willingness.

In this report, GI is interpreted as a network to support and enhance nature, natural processes and natural capital (based on the EC communication on GI). The promotion of regulating and maintenance services supports these endeavours. A further step in the development of this work involves considering how to integrate the demand for ecosystem services as well as the delivery of provisioning and cultural services in a nature-protection GI network. Factors that could be taken into account include the sustainable flow of each service (e.g. the maximum level of delivery at which ecosystems are not degraded), the geographical and temporal distribution of demand, and the energy and capital inputs (Maes et al., 2013).

The EC communication on GI describes rural and urban GI elements. These two network levels cannot be approached using the same methodology, data and time scale, because the identification of GI elements (both by definition and by resolution) is too diverse. In this report, the rural GI network has been addressed. Significant efforts still have to be invested in the development of urban GI networks and, subsequently, in the analysis and comparison of these two multiscale approaches.

This work's future prospects in the context of the EU Biodiversity Strategy include integrating connectivity between protected areas (e.g. Natura 2000 sites) and core areas (as defined in this report), or overlaying the areas delivering maximum ecosystem services with the presently protected areas.

As mentioned previously, the multifunctional character of GI is partially addressed by considering, amongst other ecosystem services, **climate regulation**, specifically carbon storage and sequestration. However, broadly speaking, there are other examples of services associated with adaptation to and mitigation for climate change: regulation of storm-water run-off, water capture, flood prevention, storm-surge protection, defence against sea-level rise, accommodation of natural hazards, reduced ambient temperatures and urban heat island effects. This multidimensional and multiscale aspect of GI could be explored in another dedicated study.

Future research should work to establish a comprehensive spatial analysis of synergies and trade-offs between the selected ecosystem services (factor analysis, covariance and correlation matrices, etc.), especially when provisioning and cultural services are also considered. This may lead to the development of additional connectivity analyses among 'key service areas' when relevant, both conceptually and spatially. For example, analysing linkages between 'key service areas' for recreation may be relevant for land planning and social well-being; these areas may be closely linked to air quality regulation 'key service areas'. Therefore, it could be relevant to assess their correlation and study the potential benefits obtained from the integration of both networks. It was not possible to develop this idea further in the framework of the present study, as was highlighted in Chapter 2. Research will also need to explore further the possible interactions, conflicts and trade-offs between different functions (Horwood, 2011). It should be noted that discussions are already taking place on these issues, including knowledge and information-gathering ([29]).

([29]) See, for instance http://ec.europa.eu/environment/nature/ecosystems/docs/Green_Infrastructure.pdf.

References

Aněl, P., Mináriková, T. & Andreas, M. (eds.), 2010, *Protection of Landscape Connectivity for Large Mammals*. Evernia, Liberec, 134 pp.

ARCADIS, 2013, *Priorities for the restoration of ecosystems and their services in the EU*. Workshop 29–30 May 2013, Final report.

Beier, P., Spencer, W., Baldwin, R., McRae, B., 2011, 'Toward Best Practices for Developing Regional Connectivity Maps.' *Conservation Biology*, *25*(5), 879–892.

Birngruber, H., Böck, C., Matzinger, A., Pöstinger, M., Söllradl, A., Wöss, M., 2012, *Wildtierkorridore in Oberösterreich*. Oö Umweltanwaltschaft, Linz.

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*(3), 260–272.

De Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002, 'A typology for the classification, description and valuation of ecosystem functions, goods and services.' *Ecological Economics*, *41*(3), 393–408.

EC, 2011, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'Our life insurance, our natural capital: an EU biodiversity strategy to 2020' (COM(2011) 244 final of 3 May 2011) (http://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/2020/1_EN_ACT_part1_v7%5B1%5D.pdf) accessed 30 December 2013.

EC, 2011a, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'Roadmap to a Resource Efficient Europe' (COM(2011) 571 final of 20 September 2011) (http://ec.europa.eu/environment/resource_efficiency/pdf/com2011_571.pdf) accessed 30 December 2013.

EC, 2012, The Multifunctionality of Green Infrastructure. Science for Environment Policy, In-depth Reports, March 2012 (https://docs.google.com/viewer?docex=1&url=http://ec.europa.eu/environment/nature/ecosystems/docs/Green_Infrastructure.pdf) accessed 30 December 2013.

EC, 2013, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'Green Infrastructure (GI) — Enhancing Europe's Natural Capital' (COM(2013) 249 final of 6 May 2013) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0249:FIN:EN:PDF) accessed 30 December 2013.

Ecotec & NENW, 2008, *The Economic benefits of Green Infrastructure*.

Escobedo, F.J., Nowak D.J., 2009, 'Spatial heterogeneity and air pollution removal by an urban forest.' *Landscape and Urban Planning*, *90*(3), 102–110.

European Commission, 2013, Green Infrastructure (GI) — Enhancing Europe's Natural Capital. COM(2013) 249 final, Brussels, 6.5.2013.

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

European Environment Agency, 2011, *Green Infrastructure and Territorial Cohesion. The concept of green infrastructure and its integration into policies using monitoring systems*. EEA Technical report No 13/2011. Luxembourg: Publications Office of the European Union, 2011.

European Environment Agency, 2012, 'Assessment on Green Infrastructure — Analysis of data sets potentially relevant for measuring green infrastructure' (internal draft report).

Gallai, N., Salles, J.M., Settele, J., Vaissière, B.E., 2009, 'Economic valuation of the vulnerability of world

agriculture confronted with pollinator decline.' *Ecological Economics*, 68(3), 810–821.

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

Grizzetti, B., Bouraoui, F., De Marsily, G., 2008, 'Assessing nitrogen pressures on European surface water.' *Global Biogeochemical Cycles*, 22(4, doi:10.1029/2007GB003085.

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.

Hänel, K., Reck, H., 2011, *Bundesweite Prioritäten zur Wiedervernetzung von Ökosystemen: Die Überwindung straßenbedingter Barrieren.* Ergebnisse des F+E-Vorhabens 3507 82 090 des Bundesamtes für Naturschutz. Naturschutz und Biologische Vielfalt 108. Bonn Bad-Godesberg.

Horwood, K., 2011, 'Green infrastructure: reconciling urban green space and regional economic development: lessons learnt from experience in England's north-west region.' *Local Environment* 16(10), 963–975.

Hostetler, M., Allen, W., Meurk, C., 2011, 'Conserving urban biodiversity? Creating green infrastructure is only the first step.' *Landscape and Urban Planning*, 100(4), 369–371.

Jones, A., Panagos, P., Barcelo, S., Bouraoui, F., Bosco, C. et al., 2012, *The state of soil in Europe — A contribution of the JRC to the European Environment Agency's Environment State and outlook Report SOER 2010*. Publications Office of the European Union, EUR 25186 EN.

Jongman, R.H.G., Bouwma, I.R., Griffioen, A. et al., 2011, 'The Pan European Ecological Network: PEEN.' *Landscape Ecology*, 26, 311–326.

Karl, T., Harley, P., Emmons, L., Thornton, B., Guenther, A., Basu, C., Turnipseed, A., Jardine, K., 2010, 'Efficient atmospheric cleansing of oxidized organic trace gases by vegetation.' *Science*, 330(6005), 816–819.

Kettunen, M., Terry, A., Tucker, G., Jones, A., 2007, *Guidance on the maintenance of landscape features of major importance for wild flora and fauna — Guidance on the implementation of Article 3 of the Birds Directive (79/409/EEC) and Article 10 of the Habitats Directive (92/43/EEC)*, Institute for European Environmental Policy (IEEP), Brussels, 114 pp. & Annexes.

Kleeschulte, S., Bouwma, I., Hazeu, G., Banko, G., Nichersu, I., 2012, 'Ecosystem services and Green Infrastructure — Regional policies implementation.' Draft Final Report of project 4#2.4_1 Green Infrastructure, EEA.

Klein, A.M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., 2007, 'Importance of pollinators in changing landscapes for world crops.' *Proceedings of the Royal Society: Biological sciences*, 274(1 608), 303–313.

Liquete, C., Zulian, G., Delgado, I., Stips, A., Maes, J., 2013, 'Assessment of coastal protection as an ecosystem service in Europe'. *Ecological Indicators 30*, 205–217.

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.

Maes, J., Paracchini, M.L., Zulian, G., Dunbar, M. B., Alkemade, R., 2012, 'Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe'. *Biological Conservation*, 155, 1–12.

Maes, J., Teller, A., Erhard, M., Liquete, C., Braat, L., et al., 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.* Publications office of the European Union, Luxembourg.

McDonald, L.A., Allen, W.L., Benedict, M.A., O'Conner, K., 2005, 'Green Infrastructure Plan Evaluation Frameworks.' *Journal of Conservation Planning* 1(1), 6–25.

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.

Naumann, S., McKenna, D., Kaphengst, T. et al., 2011, *Design, implementation and cost elements of Green Infrastructure projects*. Final report. Brussels: European Commission.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H. et al., 2009, 'Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales.' *Frontiers in Ecology and the Environment*, 7(1), 4–11.

Pistocchi, A., 2008, 'A GIS-Based Approach for Modeling the Fate and Transport of Pollutants in Europe.' *Environmental Science and Technology* 42(10), 3 640–3 647.

Pistocchi A., Bouraoui F., Bittelli M., 2008, 'A Simplified Parameterization of the Monthly Topsoil Water Budget.' *Water Resources Research*, 44(12), W12440.

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

Rey-Benayas, J.M., Newton, A.C., Diaz, A., Bullock, J.M., 2009, 'Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis.' *Science*, 325 (5 944), 1 121–1 124.

Ricketts, T.H., Regetz, J., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Bogdanski, A., et al., 2008, 'Landscape effects on crop pollination services: Are there general patterns?' *Ecology Letters*, 11(5), 499–515.

Sexton, J.O., Song, X.-P., Feng, M., Noojipady, P., Anand, A., Huang, C., Kim, D.-H., Collins, K.M., Channan, S., DiMiceli, C., Townshend, J.R.G., 2013, 'Global, 30-m resolution continuous fields of tree cover: Landsat-based rescaling of MODIS Vegetation Continuous Fields with lidar-based estimates of error.' *International Journal of Digital Earth* (ahead of print), 1–22.

Simón, A., Marín, A., Schröder, C., Gregor, M., 2011, 'Working paper on compatibility of the data and integration in LEAC.' Version 1.0 Final report, EEA.

Simón Colina, A., Schröder, C., Abdul Malak, D., 2012, Compilation of carbon account datasets. Deliverable for Task 262-5#2.5_2 'Prototype carbon accounts', EEA.

Wright, H., 2011, 'Understanding green infrastructure: the development of a contested concept in England.' *Local Environment*, 16(10): 1 003–1 019.

Zulian, G., Maes, J., Paracchini, M.L., 2013, 'Linking Land Cover Data and Crop Yields for Mapping and Assessment of Pollination Services in Europe.' *Land* 2 (3), 472–492.

Annex 1   CLC–Resistance translation

Table A1.1 Conversion table from CLC classes to habitat permeability and landscape resistance for the transit of large forest-bound mammals

CLC code	Level 3	Permeability	Resistance
111	Continuous urban fabric	1	100
112	Discontinuous urban fabric	1	100
121	Industrial or commercial units	1	100
122	Road and rail networks and associated land	4	88
123	Port areas	1	100
124	Airports	1	100
131	Mineral extraction sites	9	67
132	Dump sites	1	100
133	Construction sites	1	100
141	Green urban areas	4	88
142	Sport and leisure facilities	4	88
211	Non-irrigated arable land	9	67
212	Permanently irrigated land	9	67
213	Rice fields	4	88
221	Vineyards	9	67
222	Fruit trees and berry plantations	9	67
223	Olive groves	9	67
231	Pastures	9	67
241	Annual crops associated with permanent crops	9	67
242	Complex cultivation patterns	9	67
243	Land principally occupied by agriculture, with significant areas of natural vegetation	9	67
244	Agro-forestry areas	4	88
311	Broad-leaved forest	25	1
312	Coniferous forest	25	1
313	Mixed forest	25	1
321	Natural grasslands	4	88
322	Moors and heathland	4	88
323	Sclerophyllous vegetation	4	88
324	Transitional woodland-shrub	4	88
331	Beaches, dunes, sands	4	88
332	Bare rocks	4	88
333	Sparsely vegetated areas	16	38
334	Burnt areas	4	88
335	Glaciers and perpetual snow	4	88
411	Inland marshes	4	88
412	Peat bogs	4	88
421	Salt marshes	4	88
422	Salines	1	100
423	Intertidal flats	1	100
511	Water courses	4	88
512	Water bodies	4	88
521	Coastal lagoons	1	100
522	Estuaries	1	100
523	Sea and ocean	1	100

Source: Derived from Beier et al., 2011; and Birngruber et al., 2012.

Annex 2 Example of application

Distribution of the proposed GI networks in the EU-27 territory. Data show the percentage of each national territory and correspond to the results illustrated in Map 4.6. The total coverage in each country can sum to less than 100 % when pixels of data gaps are present. The discrepancies in coverage across countries highlight that the thresholds and criteria used to define the GI networks have to be adapted to national or regional circumstances.

To understand the '0.0' values for Cyprus and Malta, the size of the islands and their Mediterranean characteristics (lack of dense forest, etc.) does not help for GI networks. However, the first part of the analysis (the ecosystem services part) covers all ecosystems. This means that, when compared with the European average, neither Cyprus nor Malta have areas that can be classified as optimum/maximum ecosystem service providers. This is what the study is highlighting, indicating that the thresholds between maximum-medium-poor should be adapted to national or regional characteristics.

Table A2.1 Distribution of the proposed GI networks in the EU-27 territory

Country (ISO code)	Country name	Non GI (%)	GI network 'R' (%)	GI network 'C' (%)
AT	Austria	28.9	10.1	60.9
BE	Belgium	70.7	11.1	18.1
BG	Bulgaria	69.2	16.5	14.0
CY	Cyprus	95.3	1.1	0.0
CZ	Czech Republic	43.7	15.1	41.3
DE	Germany	64.7	14.1	20.9
DK	Denmark	81.9	6.4	6.8
EE	Estonia	21.0	10.4	65.6
ES	Spain	59.6	20.6	18.0
FI	Finland	45.2	14.1	39.6
FR	France	59.9	14.2	25.6
GR	Greece	61.3	20.2	15.5
HU	Hungary	81.1	11.0	7.7
IE	Ireland	85.0	9.3	3.6
IT	Italy	59.0	13.0	27.0
LT	Lithuania	55.2	15.9	28.1
LU	Luxembourg	50.6	22.0	27.4
LV	Latvia	26.3	10.1	63.0
MT	Malta	75.4	0.0	0.0
NL	Netherlands	88.5	5.3	5.3
PL	Poland	67.3	15.2	17.4
PT	Portugal	42.7	29.5	23.8
RO	Romania	65.3	9.5	25.0
SE	Sweden	22.0	22.3	54.7
SI	Slovenia	25.0	11.6	62.1
SK	Slovakia	44.1	9.0	46.9
UK	United Kingdom	75.8	14.6	7.4

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