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Contributions to building a coherent Trans-European Nature Network

What is the contribution of GI to improving the conservation status of species of Community interest and the delivery of ecosystem services in Europe? Strengthening the GI network with a view to enhance its multiple benefits.

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TABLE OF CONTENTS

List of Figures

List of Tables

EXECUTIVE SUMMARY

The second target of European Union (EU) Biodiversity Strategy to 2020 focuses on maintaining and enhancing ecosystem services and restoring degraded ecosystems across the EU. This is in line with the global goal set in 2010, which aims at restoring at least 15% of degraded ecosystems[1]. Healthy ecosystems provide a stream of goods and services vital to society, such as food, fibres, clean water, healthy soils, protection against floods and erosion, as well as diversified recreation experiences to people. The achievement of Target 2 is underpinned by the EU initiative on Mapping and Assessment of Ecosystems and their Services (MAES), which is implemented by Member States (MS) with the assistance of the EU.

Unfortunately, many of EU's ecosystems are now heavily degraded, which drastically reduces their ability to deliver valuable services to society. The problem is further exacerbated by the fact that Europe is one of the most fragmented continents in the world. Thirty percent of the land is moderately to highly fragmented due to urban sprawl, infrastructure developments and changing land uses[1]. This not only affects biodiversity, but also undermines the many services that healthy ecosystems provide to society. Building a green infrastructure (GI) can help to overcome many of the enumerated challenges. It can reconnect fragmented natural areas and improve their functional connectivity with the "wider landscape". It can also encourage a better use of nature-based approaches to tackle climate change and to improve resource efficiency, for instance through more integrated spatial planning and the development of multifunctional zones that are capable of delivering benefits to both biodiversity, the land user, and to society at large.

The study presented in this narrative aims at exploiting the available spatial data and most recent methodological developments to envisage an integrated GI assessment framework at EU level. It contributes to the EU Biodiversity Strategy to 2020, which calls for the strategic deployment of GI supported by a robust evidence base developed through the MAES process. Overall, this study aims at assessing the contribution of GI to improving the conservation status of species of Community interest and the delivery of multiple ecosystem services in Europe (see Box 1).

Box 1. Integrated assessment of the GI network: summary of main input elements for the analysis.

Natura 2000 sites covered mainly by "Forest and woodland" (F&W) MAES ecosystems[2] were considered as the backbone of the GI network.

Medium-large mammal species were selected as the network functional group, provided that they respect a set of criteria, particularly:

- *considered for reporting under Article 17 of the Habitats Directive;*
- *in need of spatial connectivity;*
- *transboundary;*
- *F&W should be at least one of their preferred habitats.*

Three regulating and cultural ecosystem services were taken into consideration to evaluate the multifunctionality of the network, namely:

- *pollination potential;*
- *flood control potential;*
- *recreation potential.*

[1] http://ec.europa.eu/environment/nature/info/pubs/docs/brochures/2020%20Biod%20brochure%20final%20lowres.pdf

[2] Please see the 1st MAES technical report, page 24, for a complete description of MAES ecosystem types: https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/MAESWorkingPaper2013.pdf
Please note that "Woodland and forest" ecosystem type was renamed as "Forest and woodland" in the 5th MAES technical report, page 21: https://catalogue.biodiversity.europa.eu/uploads/document/file/1673/5th_MAES_report.pdf

The proposed assessment is divided in two main steps and 4 sub-phases that aim at evaluating the connectivity of core GI elements to the "wider landscape" (subsection 2.1), the provision of multiple ES by the network (subsection 2.2), the relative conservation status of species of Community interest within the network (subsection 2.3), and finally landscape hotspots for GI prioritisation, including the identification of areas prone for conservation and/or restoration (subsection 2.4). The outcomes of the different assessment stages are self-explanatory and can be used individually for specific analyses concerning the broad ecosystem assessment performed in the framework of MAES. Still, the overarching assessment framework is based on the combination of all mapping outcomes defined within the first step and fully integrated in the second step.

The results from the current assessment show that an EU level GI network of F&W Natura 2000 sites connected by natural and semi-natural landscape elements in the year of 2012 extended over 33% of the EU-27[3] territory (subsection 3.1). More than 50% of the selected Natura 2000 sites were connected by contiguous patches of unprotected forest and woodland ecosystems, and around 80% of the sites were connected by other natural and semi-natural (including agro-forestry) terrestrial ecosystems across all EU-27 MS. Moreover, it was found that 15% of the disconnected F&W Natura 2000 sites were less than 1km apart from the mapped GI segments[4].

Regarding the supply of multiple ecosystem services, the results indicate that by 2012 almost 70% of the EU-27 MS territory was covered by ecosystems providing medium and important service areas (subsection 3.2). Still, low service areas were predominating over key service areas. Notwithstanding, a comparative analysis between the terrestrial ecosystems within and outside the GI network across the whole EU-27 MS territory has shown that percentwise the GI network contains 2% more of key service areas and 10% less of low service areas. Therefore, and overall, the results disclosed by this study seem to indicate that by 2012 the ecosystems within the GI network were able to provide 12% more of multiple ecosystem service areas, as compared to the non-GI landscape elements.

Detailed knowledge about the conservation status of selected mammal species at the EU-27 MS level and for the areas within and outside the GI network is also of paramount importance for determining the distance to the goals of Target 2 of Biodiversity Strategy to 2020 (subsection 3.3). The results of the current assessment have shown that the predominance of conservation status' values for selected mammal species is overall high at the EU-27 MS level. In detail, around 80% of the assessed area at EU-27 MS level shows spatial associations of favourable conservation status for selected mammal species, as defined in the Article 17 database of the Habitats Directive. More important though is the fact that areas with a predominance of favourable conservation status for two or more mammal species are 11% higher inside the GI network, as compared to the outside situation.

Finally, the results from this integrated GI assessment allowed to describe the capacity of the GI network to simultaneously provide benefits from nature to people and contribute to biodiversity preservation, both inside and outside of the Natura 2000 network (subsection 3.4). Although the persistence of favourable conservation status for selected mammal species is very high inside and outside the GI network, the level of ecosystem pressure outside the GI network is considerably higher as compared to the inside situation. Still, around 81% of GI neighbouring regions could be linked to the network with little or very low-level management intervention.

[3] The reference date for this study is 2012; EU-27 is used to mean all the member states from 2007 to 2013 (Croatia joined only in 2013).

[4] GI segments are portions of the network that were intersected by highways, so as to adequately estimate the impact of artificial infrastructures on species movements. Please see subsection 2.1 for a detailed description and analysis.

1 INTRODUCTION

The European Union (EU) has a comprehensive policy framework established to protect biodiversity. This framework – comprised largely of the Birds and Habitats Directives and EU Biodiversity Strategy to 2020 – aims to halt the loss of biodiversity, achieve good conservation status for targeted species and halt the deterioration of ecosystems and their services. The central tool for achieving these objectives is Natura 2000, the world's largest network of protected areas covering more than 18% of the EU's land surface and 6% of its marine area[5]. Natura 2000 was established to maintain the natural and semi-natural habitat types and species listed in the EU Habitats and Birds Directive Annexes and restore them to a good conservation status.

Despite this strong framework and significant efforts by Member States (MS) to halt biodiversity loss and ecosystem degradation in Europe, the conservation status of protected species and habitats continues to decline alongside ecosystem service provisioning. There is thus an urgency to restore degraded ecosystems in order to meet the conservation needs of European habitats and species. In particular, the European Commission highlights the need to protect species of Community interest such as the *Iberian lynx*, the world's most endangered feline species (Fordham et al. 2013).

While the Natura 2000 network and the sites contained therein have been designated to conserve such species, high fragmentation and ongoing habitat loss and deterioration limits the network's effectiveness. Green infrastructure (GI)[6] is recognized as a valuable tool for increasing the level of connectivity of natural and semi-natural areas both within but also outside of the network to support species movement and population viability. If enhanced and managed as a multifunctional resource, GI can also deliver a range of further benefits and services to wider species, society and the economy.

In the context of the EU Biodiversity Strategy, GI is defined as being a key step towards the successful implementation of Target 2. This target requires that "by 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems". Moreover, GI is expected to contribute to the full implementation of the Birds and Habitats Directives (Target 1) by conserving existing biodiversity-rich ecosystems in good condition and restoring the conservation status of degraded ecosystems.

The present study thus aims to assess the contribution of GI to improving the conservation status of species of Community interest and the delivery of ecosystem services in Europe. An integrated assessment on the distribution of GI, its multifunctional areas and the conservation status of a particular set of mammal species enable a mapping and prioritisation of where GI should be preserved, restored or further deployed, both within and outside of the Natura 2000 network. Thus, the work presented in this report is intended to improve and strengthen the information about GI mapping, and contributes to *"reviewing the extent and quality of the technical and spatial data available for decision-makers in relation to GI deployment*" identified in the EU Strategy on Green Infrastructure (European Commission, 2013). It also contributes to the EU Biodiversity Strategy to 2020, which calls for the strategic deployment of GI supported by a robust evidence base developed through the Mapping and Assessment of Ecosystems and their Services (MAES) process (Maes et al. 2013). Finally, the results may be used as a basis for drawing conclusions on how to most effectively strengthen the GI network to deliver biodiversity and wider co-benefits and contribute to EU policy targets, not least the EU Biodiversity Strategy 2030 target on restoration[7].

[5] https://ec.europa.eu/environment/nature/natura2000/faq_en.htm

[6] "Green Infrastructure is 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." (European Commission, 2013)

[7] https://ec.europa.eu/commission/sites/beta-political/files/political-guidelines-next-commission_en.pdf

2 METHODOLOGICAL APPROACH

The integrated assessment proposed in this narrative aims at prioritizing the preservation and spatial deployment of an EU level GI network according to the conservation needs of existing biodiversity-rich ecosystems, as well as the urgency in the restoration of degraded ecosystems both inside and outside of the Natura 2000 network. The approach includes two main processing steps, i.e. (1) Mapping and (2) Prioritisation, as shown in Figure 1. The first step (1) can be further divided into three preliminary phases (A to C) that provide the necessary inputs for the prioritization phase (D), which is performed in the second step (2).

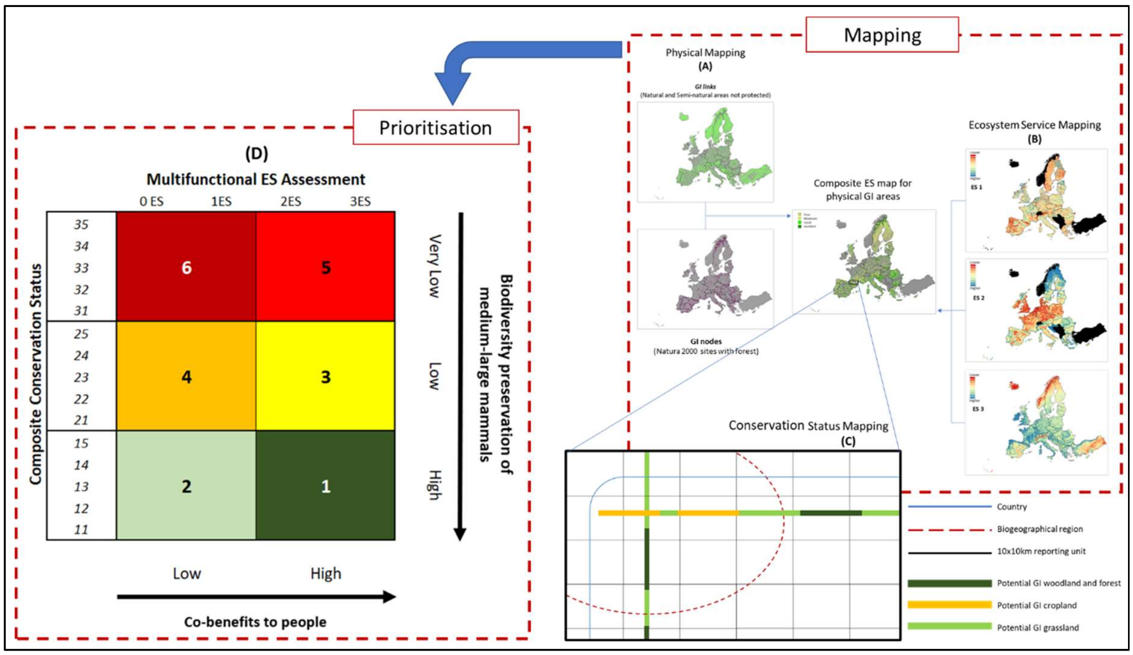

Figure 1. The integrated GI assessment for biodiversity preservation and co-benefits to people.

Phase A aims at mapping the main physical elements of the GI network, i.e. forest and woodland ecosystems in Natura 2000 sites, and defining the optimal means for linking them. This includes maximizing the connection between selected Natura 2000 sites and exploring opportunities for including other natural and semi-natural landscape elements (e.g. shrubs and grasslands) located in non-Natura 2000 protected geographical areas. Phase B aims to evaluate the ability of protected and non-protected natural and semi-natural terrestrial ecosystems to provide multiple benefits to people that are compatible with the objectives of EU Biodiversity Strategy. This includes mapping the potential capacity of the GI network to provide several ecosystem services (ES) in the same spatial area. Phase C is targeted at mapping the composite conservation status of a set of mammal species of Community interest occurring within the spatial reporting units of the Article 17 database of the Habitats Directive[8]. This includes the stratification of the potential GI network according to ecosystem types and relating them to the condition of occurring mammal species, particularly those that are transboundary, in need of connectivity and have F&W as one of their preferred habitats. Finally, in phase D, the capacity of the network to provide multiple ES (output of phase B) and the composite conservation status (output of phase C) are combined to assess GI and detect hotspot areas where restoration is a priority or that would benefit from some conservation measures.

[8] https://ec.europa.eu/environment/nature/knowledge/rep_habitats/index_en.htm

2.1 PHASE A: MAPPING THE PHYSICAL GI NETWORK

The first phase of the assessment concentrated on mapping a potential EU level GI network. Specifically, this consisted of identifying key habitats (i.e. **nodes**) and establishing their linkages across heterogeneous landscapes (i.e. **links or connectors**). As habitat areas and their connectivity are species related, then appropriate species or functional groups with relevance at landscape level first needed to be selected. The set of selected species for the current analysis was defined according to the following criteria (Annex 1):

- medium and large mammals;
- in need of spatial connectivity (van der Sluis et al. 2018);
- be present in 2 or more EU-27 MS (Condé et al. 2017);
- forest and woodland (F&W) MAES ecosystems should be at least one of their preferred habitats[9].

The GI function for mammals will depend very much on the species behaviour (flying or not), and species type/size, which is closely linked to its home range and dispersal capacity. The small mammals (mice mostly, as well as some squirrels) were not considered here because usually they have limited habitat requirements and in general there is no need for GI as corridor for their dispersal. Also, the bats were excluded since generally not enough is known on their use of corridors and the dispersal distance (van der Sluis et al. 2018). Therefore, medium and large mammal species were selected as focal species, as they normally have high demands in terms of habitat areas, which are also important for the dispersion of other species and ecological fluxes[10] (Beier et al. 2008a,b), are particularly sensitive to the barrier effect caused by artificial surfaces (Gurrutxaga et al. 2011), and are able to cover large migration distances (Gurrutxaga et al. 2010).

Nodes in the GI network corresponded to Natura 2000 protected sites dominated by forest and woodland MAES ecosystem types, which is the common preferred habitat of the species selected for this analysis. Indeed, according to the European Commission (2019), the sites and functions of the Natura 2000 network are the backbone of the EU GI network. Therefore, the European spatial and descriptive databases on Natura 2000 sites[11] for the year 2012[12] were used as input data for the analysis. Two or more contiguous protected sites dominated by forest and woodland ecosystems were considered as a unique node. Following the works of de la Fuente et al. (2018), European Environment Agency (EEA 2014) and Gurrutxaga et al. (2011), only nodes with at least 3500 ha of forest and woodland ecosystems were selected. This allowed for a feasible processing of the large study area and to focus the analysis on those protected areas that are more relevant at a wide transboundary scale.

To identify the links of the GI network, a resistance-surface[13]-based connectivity approach was used. As a result of this analysis, all non-protected natural and semi-natural landscape elements (i.e. not included in Natura 2000) connecting two or more nodes were considered as part of the GI network. This included also agro-forestry areas that are considered as non-intensive cropping systems or high-nature value farmlands. The portions of the network that were intersected by highways were counted as individual GI segments, so as to adequately estimate the impact of artificial infrastructures on species movements. Therefore, the outcome of this process allowed to identify the Natura 2000 sites

[9] The linkages of all species considered for reporting under Article 17 of the Habitats Directive to MAES ecosystems can be found here: https://www.eea.europa.eu/data-and-maps/data/linkages-of-species-and-habitat

[10] Such as the carbon flux.

[11] https://www.eea.europa.eu/data-and-maps/data/natura-10

[12] Due to a number of data limitations for the year of 2018, the reference year for the full assessment is 2012.

[13] A resistance surface represents the degree to which some landscape features impede or facilitate some movement process (Adriaensen et al. 2003), typically represented as a cell (pixel) value in a grid (raster) layer.

that are isolated due to road fragmentation, as well as those that are connected at different functional levels according to the resistance of land cover types to selected mammal species movements.

A resistance surface with a spatial resolution of 1ha was used to characterize the movement difficulty of selected mammal species through different land cover types. The values of the resistance surface were parameterized as proposed and described in previous studies (e.g. Gurrutxaga et al. 2011, EEA 2014, and de la Fuente et al. 2018). The resistance surface was optimized so that the minimum value (equal to 1) was found when the landscape was covered by forest and woodland ecosystems. Resistance values increased when animal movements had to occur outside forest and woodland ecosystems (e.g. intensively managed croplands), up to a value of 1000 for urban ecosystems, as previously proposed by Gurrutxaga et al. (2011) and the EEA (2014). Resistance values were assigned to the land cover types as defined in the CORINE Land Cover (CLC) map of 2012[14] and refined for the grid cells that contained highways (also reclassified into urban ecosystems), as mapped in the OpenStreetMap of 2012 (www.openstreetmap.org) – see reclassification matrix of CLC classes into resistance surface in Annex 2.

2.2 PHASE B: MAPPING THE CO-BENEFITS OF THE GI NETWORK TO PEOPLE

According to the definition provided and endorsed by the European Commission (2013), a GI network should also deliver multiple valuable ecosystem goods and services to people. Therefore, the goal of this assessment phase was to evaluate the capacity of the physical network and surrounding areas to supply multiple ES, provided that these services are also compatible with biodiversity conservation. According to Liquete et al. (2015), Lanzas et al. (2019) and Barbosa et al. (2019), services can be classified as “incompatible” or “compatible” with biodiversity, depending on whether they do or do not represent conflicts with conservation goals. The later correspond mainly to regulating and cultural services, whereas most of the provisioning services are driven by human inputs like energy (e.g. fertilisers) or capital (e.g. labour), and do not necessarily enhance biodiversity conservation.

A composite indicator of multiple ES was computed to evaluate the capacity of the GI network to provide co-benefits to people. To derive this indicator, three regulating and cultural ES indicators provided by the JRC for the year 2012 in the context of MAES[15], i.e. **pollination potential, flood control potential and recreation potential** (Annex 3) were collected[16] and combined. A threshold approach based on the average value of the selected ES for each MAES ecosystem type[17] was used to adequately combine ES values and evaluate whether multiple services were simultaneously performing at high levels for each grid cell. The ES datasets were harmonized to a grid with a common spatial resolution of 1ha and four performance classes were defined to evaluate multifunctionality at each grid cell:

- ***Low service areas*** – all ES values below the respective averages;
- ***Medium service areas*** – one service above the average;
- ***Important service areas*** – two services above the averages, and;
- **Key service areas** – all ES values above the respective averages.

[14] https://land.copernicus.eu/pan-european/corine-land-cover/clc-2012
[15] https://data.jrc.ec.europa.eu/collection/maes
[16] Only these three regulating and cultural ES were available on the MAES database at the time of this study.
[17] MAES ecosystem types were derived for the year of 2012 by reclassifying the CLC land cover classes according to the table in page 50 of the first MAES technical report:
https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/MAESWorkingPaper2013.pdf

2.3 PHASE C: MAPPING THE RELATIVE CONSERVATION STATUS OF SPECIES OF COMMUNITY INTEREST

In addition to the evaluation of the co-benefits from GI to people (subsection 2.2), the goal of this phase was to evaluate the contribution of GI to the conservation status of species listed under the Article 17 of the Habitats Directive[18,19]. To achieve this goal, a composite indicator of conservation status (ciCS)[20] covering the EU-27 MS was developed and computed based on the Article 17 database for the 2007-2012 period[21]. The analysis was performed at a grid level of 10x10km and fully based on the information about the conservation status (CS, i.e.: Favourable [FV], Unfavourable-Inadequate [U1] and Unfavourable-Bad [U2]) of the set of selected mammal species (see Annex 1 for complete list) reported within each spatial observation unit of the Article 17 database of the Habitats Directive.

The output composite indicator is presented as a 10x10km raster layer with 15 classes, as shown in Table 1. The classification scheme of the ciCS is categorical and varies between 11 (the highest) and 35 (the lowest). For example, if the majority of selected mammal species in a grid cell are favourable (i.e. "maxCS==FV"), the number of species is larger than 1 (i.e. "numReg > 1") and their proportion is between 75-100% ("propFV >= 0.75 & propFV < 1"), then the corresponding composite conservation status (ciCS) for that cell is 13. Finally, according to the majority of CS present in each cell, then 3 major groups of ciCS can also defined, i.e. *Very low*, *Low* and *High*. The raster layer at 10x10km was resampled to 1ha spatial resolution, in order to match the outputs of subsections 2.1 and 2.2.

Detailed ciCS classes	Aggregated ciCS classes	Description
35		maxCS=="U2" & numReg > 1 & propU2 == 1
34		maxCS=="U2" & numReg == 1
33	**Very Low**	maxCS=="U2" & numReg > 1 & propU2 >= 0.75 & propU2 < 1
32		maxCS=="U2" & numReg > 1 & propU2 >= 0.5 & propU2 < 0.75
31		maxCS=="U2" & numReg > 1 & propU2 < 0.5
25		maxCS=="U1" & propU1 < 0.5 & (propFV <= propU2)
24		maxCS=="U1" & propU1 >= 0.5 & propU1 < 0.75 & (propFV < propU2)
23	**Low**	maxCS=="U1" & propU1 >= 0.5 & propU1 < 0.75 & (propFV == propU2) OR maxCS=="U1" & propU1 >= 0.75
22		maxCS=="U1" & propU1 >= 0.5 & propU1 < 0.75 & (propFV > propU2)
21		maxCS=="U1" & propU1 < 0.5 & (propFV > propU2)
15		maxCS=="FV" & numReg > 1 & propFV < 0.5
14		maxCS=="FV" & numReg > 1 & propFV >= 0.5 & propFV < 0.75
13	**High**	maxCS=="FV" & numReg > 1 & propFV >= 0.75 & propFV < 1
12		maxCS=="FV" & numReg == 1
11		maxCS=="FV" & numReg > 1 & propFV == 1

Table 1. The combined conservation status classes: their detailed description and generic groups. "maxCS" stands for majority; "numReg" stands for number of species; "prop" stands for proportion.

[18] https://www.eionet.europa.eu/etcs/etc-bd/activities/reporting/article-17/reference-material-for-reporting-period-2007-2012-art-17

[19] https://www.eea.europa.eu/data-and-maps/data/linkages-of-species-and-habitat

[20] Constructed measure that aggregates the individual conservation status of multiple species coexisting in the same spatial area into a single categorical value of conservation status.

[21] https://www.eea.europa.eu/data-and-maps/data/article-17-database-habitats-directive-92-43-eec-1/article-17-database-zipped-ms-access-format

2.4 PHASE D: PRIORITISING GI DEPLOYMENT

GI deployment can be achieved through both the **conservation** of existing biodiversity-rich ecosystems in good condition and the **restoration** of degraded ecosystems, both inside and outside of the Natura 2000 network (European Commission 2019), in order to ensure a more effective network of protected areas in Europe. Therefore, the last phase of the integrated assessment was to prioritize the spatial allocation of the GI network to maximize co-benefits between important areas for biodiversity preservation and ES for people that are compatible with conservation priorities. The prioritisation framework is based on a multiple-criteria decision matrix (Figure 2) that estimates the capacity of the GI network to simultaneously supply multiple ecosystem services and secure biodiversity conservation, with a special focus on areas that connect protected Natura 2000 sites. Figure 2 provides a pragmatic method for ensuring that an effective level and type of conservation/restoration intervention is applied as necessary. This involves the use of a comprehensive assessment of the level of ecosystem pressure and need for management on the one hand, and the probability of biodiversity persistence[22] or recovery on the other hand. Table 2 provides a detailed description of the various management and intervention options that would be available for different categories present in Figure 2.

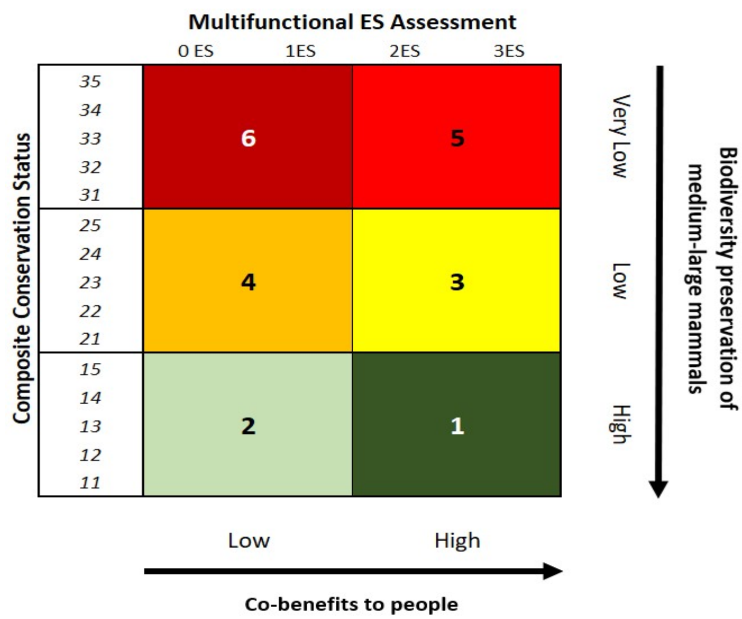

Figure 2. The biodiversity preservation and co-benefits of GI: the proposed integrated framework.

Level of Intervention	Type of Intervention	Description
1	Pressure prevention and/or minimisation	An area that currently is under little pressure should need minor immediate management action, but its condition should be at least monitored and steps taken to ensure that the impact of future pressures is prevented and/or minimized.
2	Low-level management of pressures	An area in relatively good condition and with a very high chance of persistence, which may require some low-level management of pressures to ensure that they do not increase in importance.

[22] Persistence is defined here as the "sustained existence of biodiversity".

Level of Intervention	Type of Intervention	Description
3	Prompt protection and/or restoration	An area in this category could have a number of management needs that require prompt attention, but has a high chance of persistence.
4	Active pressure reduction	In this case, an area might be subject to a number of pressures that have degraded it to some extent, but may retain the ability to recover following the removal of the threatening pressure.
5	Urgent protection and restoration	An area in this category would be in a high-risk situation, but still in a reasonable condition, which, if treated, has potential for long-term persistence or complete recovery.
6	Fast-tracked management intervention	An area in this category might be [chronically] degraded by a variety of pressures and have lost much of its value in terms of habitat quality or species complement, which, if treated, might have a potential for long-term persistence.

Table 2. Description of categories presented in the matrix of Figure 2 (adapted from Hobbs and Kristjanson 2003).

3 RESULTS AND DISCUSSION

3.1 CONNECTIVITY OF SELECTED NATURA 2000 SITES

- The GI network of selected Natura 2000 sites and connecting natural and semi-natural landscape elements extends over 33% of the EU-27 territory;
- More than 50% of the Natura 2000 sites selected for this analysis are connected by contiguous patches of unprotected forest and woodland;
- 80% of the selected Natura 2000 sites are connected by natural and semi-natural (i.e. agro-forestry) terrestrial ecosystems across all EU-27 MS;
- Around 15% of the disconnected Natura 2000 sites selected in the framework of this study are less than 1km apart from the mapped GI segments.

Figure 3 presents the network of individual GI segments connecting Natura 2000 sites covered mainly by forest and woodland ecosystems (i.e. forest and woodland patches larger than 3500 ha) across the EU-27 MS in 2012. The landscape connectors between the selected Natura 2000 sites correspond to all non-protected natural and semi-natural terrestrial ecosystems, thus excluding intensively managed croplands, urban ecosystems, as well as water, wetlands and coastal areas. Selected sites for the analysis correspond to only 5% of the total number of Natura 2000 sites established by 2012, and approximately to 32% of the total area for the sites designated at the end of that year. The computed GI network presented in Figure 3, including the Natura 2000 sites and the links across the heterogeneous landscapes, extends over 33% of the EU-27 territory. The rest of the European territory (67%) did not qualify to form part of the GI network (with the assumptions and thresholds fixed in this narrative).

Table 3 presents several statistics characterizing the segments of the GI network presented in Figure 3, including the average number of connected Natura 2000 sites in each individual segment, as well as the type of land cover offering resistance to the movement of selected mammal species. The results show that around 80% of the selected Natura 2000 sites are connected by natural and semi-natural (i.e. agro-forestry) terrestrial ecosystems across all EU-27 MS. From the map presented in Figure 3, a total number of 735 Natura 2000 sites are connected by contiguous patches of unprotected forest and woodland ecosystems, which constitutes more than 50% of the sites selected for this analysis. On average, each site is connected to other three sites only by unprotected patches of forest and woodland ecosystems, which means that a complete forest and woodland GI network at the EU level would be constituted by 170 GI segments.

The results also show that sparsely vegetated areas contribute to the connection of only 1% of the selected Natura 2000 sites. In other words, the selected mammal species would need to cross sparsely vegetated areas to reach 1% of the selected Natura 2000 sites. On the other hand, whereas water and wetland ecosystems separate 1% of the selected Natura 2000 sites, urban areas and highways break the connection to 9% of those sites. Therefore, if one takes into account all natural and semi-natural ecosystems, then on average each selected Natura 2000 site is linked to other five selected sites, constituting a network with a total of 196 individual GI segments distributed across the full EU-27 territory in 2012.

The results presented in Figure 3 also show the distances between selected but non-connected Natura 2000 sites and the segments of the GI network, as well as the connectivity bottlenecks between computed GI segments, particularly those referring to the breaks in the network caused by urban areas and highways. The outcomes seem to indicate that a large number of breaks within the network of GI segments are occurring in the southwestern and eastern regions of Europe, in particular over the

Iberian Peninsula and the Carpathian region. This pattern is also noticeable, but to a less extent, in the Grand Est region of France towards Luxembourg. Regarding the distances between the GI network and disconnected Natura 2000 sites, the results in Figure 3 seem to indicate that about 15% of the disconnected sites are less than 1km apart from the GI segments, and 40% less than 10km.

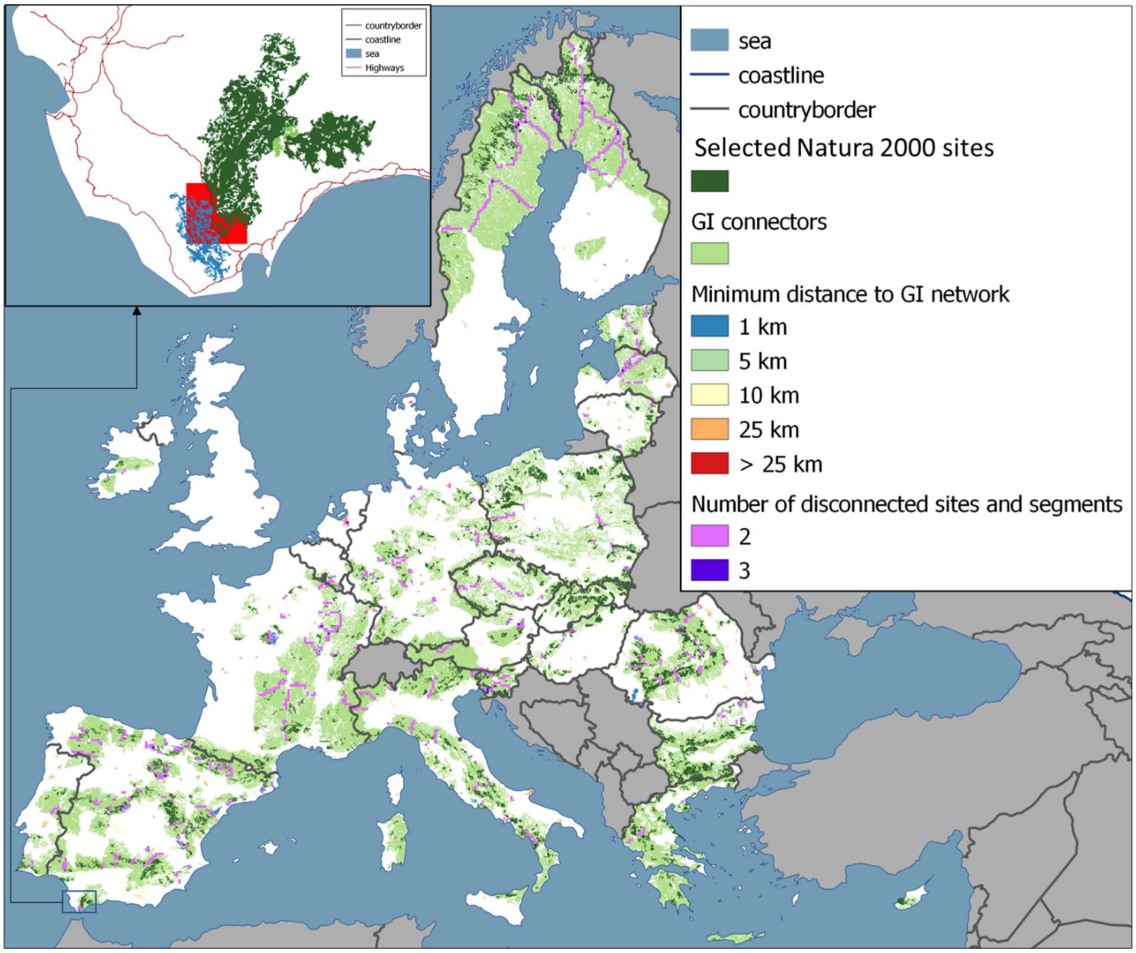

Figure 3. Network of GI segments connecting Natura 2000 sites dominated by forest and woodland patches larger than 3500ha. Network discontinuities impending the link between GI segments and/or non-connected Natura 2000 sites within 10km distance are shown in purple colours. The elements in the box show a non-connected Natura 2000 site (blue feature) that is closer than 1km to an individual segment of the GI network.

Land use/ cover class	Surface Resistance Value	Connected N2K sites (no.)	Connected N2K sites (%)	Connected N2K sites (acc. no.)	Connected N2K sites (acc. %)	GI segments (no.)	Connected N2K sites (avg. no.)
Forest & woodland	1	735	51	735	51	170	4.3
Heathland & shrub	5	140	10	875	61	185	4.7
Agro-forestry	15	148	10	1023	71	203	5.0
Grassland	30	135	9	1158	81	199	5.8
Sparsely vegetated areas	40	13	1	1171	82	196	6.0
Cropland	60	112	8	1283	90	171	7.5

Land use/ cover class	Surface Resistance Value	Connected N2K sites (no.)	Connected N2K sites (%)	Connected N2K sites (acc. no.)	Connected N2K sites (acc. %)	GI segments (no.)	Connected N2K sites (avg. no.)
Water, wetlands and coastal areas	100	19	1	1302	91	155	8.4
Urban ecosystems	1000	131	9	1433	100	-	-
No. of N2K sites with F&W area > 3 500ha		1433					

Table 3. Statistics for the network of GI segments presented in Figure 3.

More interestingly though are the results for Italy and neighbouring countries shown in Figure 4. The GI segments defined from southern Calabria in Italy to the Provence-Alpes-Côte d'Azur region in France, as well as from the Italian southern Alpine region connecting with Austria and Slovenia are almost always distant apart by less than 8km. Only the area marked with the yellow circle appears to be a major bottleneck in the network, as three main highways extending from north to the coast could hamper the movement of the selected mammals. Still, as no information about highway bridges for animal crossing, as well as small woody feature landscape elements were taken into account in this analysis, it can be that the real situation is less problematic than shown in these results.

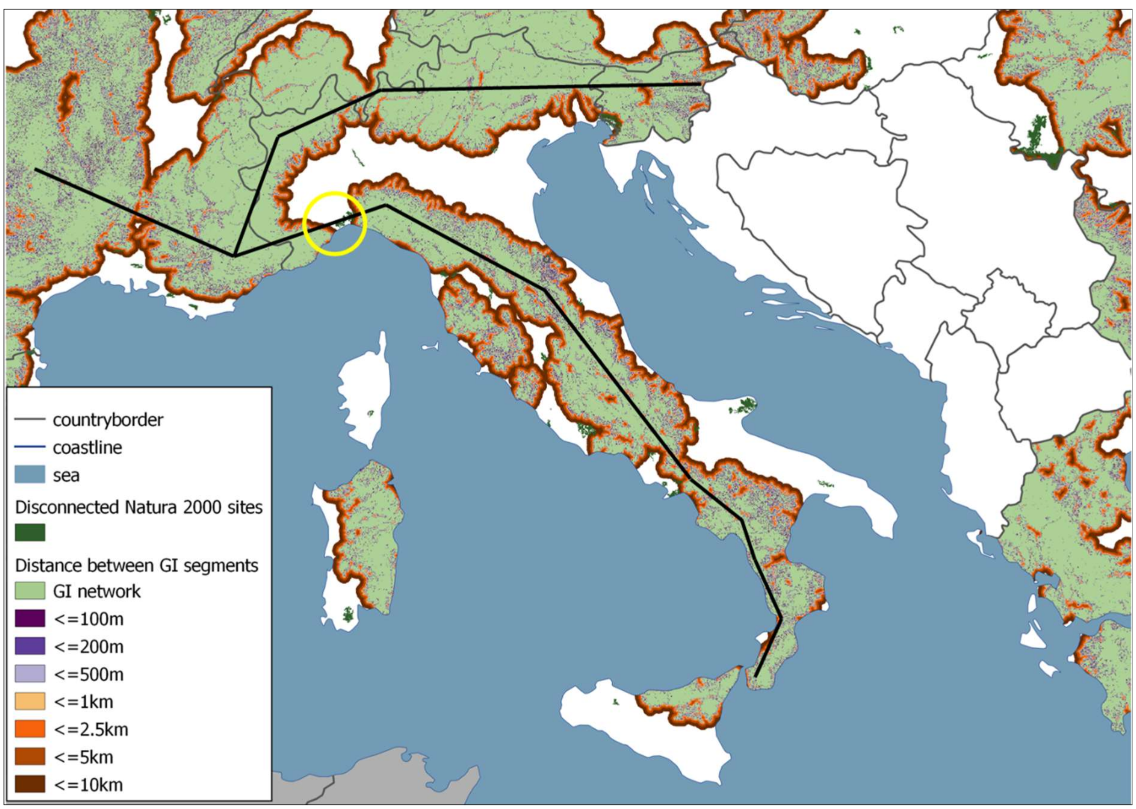

Figure 4. Network discontinuities impending the link between GI segments in Italy and neighbouring countries. Black straight lines indicate the centre "sector" of a potential countrywide network; the yellow circle represents an area with major bottlenecks between segments of the network.

3.2 CAPACITY OF ECOSYSTEMS TO DELIVER MULTIPLE ECOSYSTEM SERVICES TO PEOPLE

- Around 70% of the EU-27 MS territory is covered by ecosystems providing medium and important services;
- Low service areas predominate over key service areas across EU-27 MS;
- Key service areas inside the GI network are 2% more than in other landscape elements;
- Low service areas inside the GI network are 10% less as compared to the non-GI landscape elements;

The map in Figure 5 shows the capacity of ecosystems to provide multiple services to people. As described in subsection 2.2, the ecosystem services considered in this narrative are only regulating and cultural, and correspond to pollination potential, flood control potential and recreation potential.

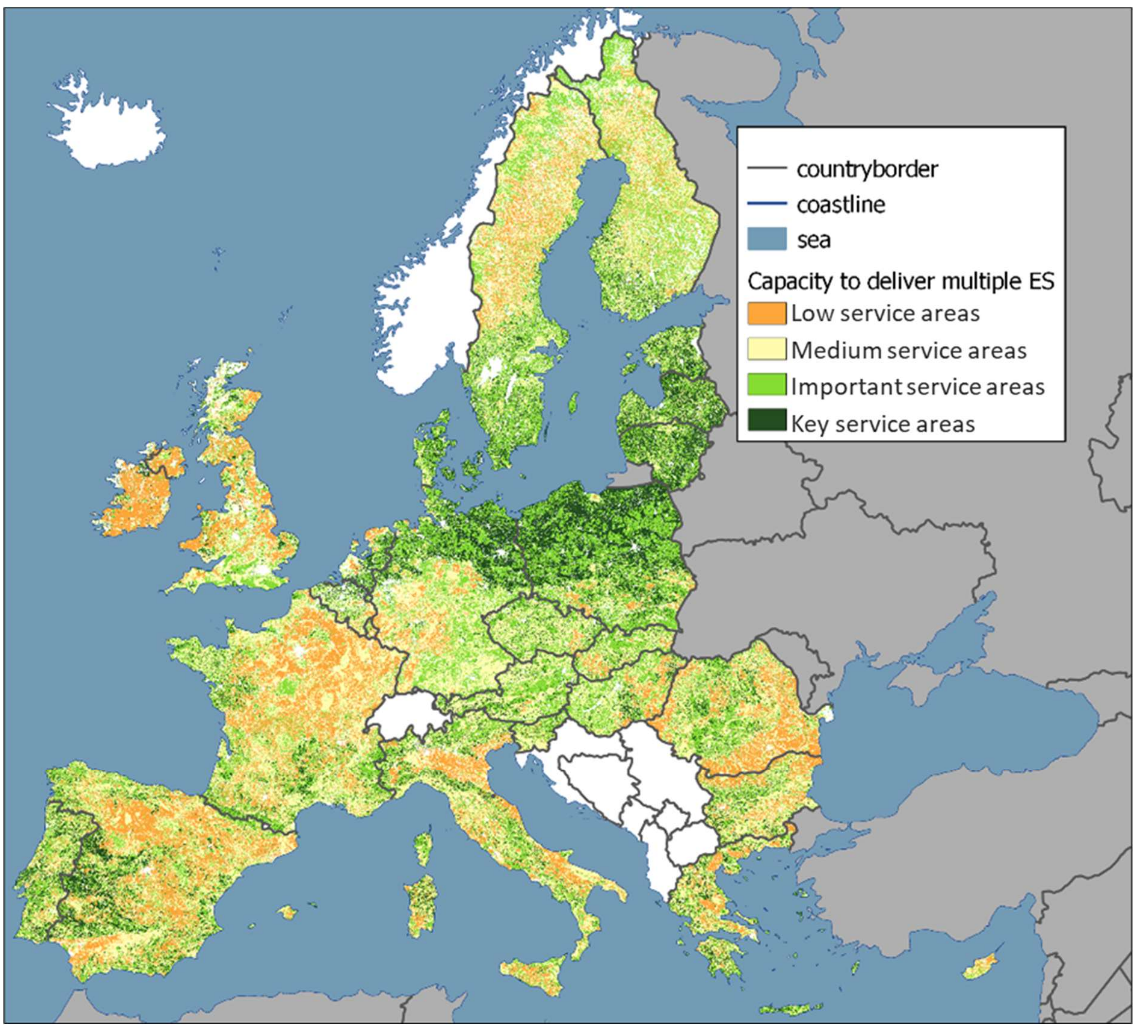

Figure 5. The provision of multiple ecosystem services to people in EU-27 MS; please see subsection 2.2 for detailed description of the classes presented in the map.

The analysis of Figure 5 seems to indicate that key service areas dominate in the countries around the Baltic Sea and in the Iberian Peninsula, mainly across the border between Portugal and Spain. Interestingly, this territory in the Iberian Peninsula is covered to a large extent by "*dehesa*" and "*montado*" systems, i.e. agro-forestry systems. It is quite remarkable that such systems, which are based on mixed uses and specific management schemes are among the key service areas, at least in the Mediterranean region, since they are exploited for agricultural purposes and to a large extent they are under private ownership. Moreover, these systems are very relevant for lynxes and other selected mammals, as well as migratory birds.

On the other hand, important service areas are mainly located across major mountain areas, such as the Alpine, the Carpathian, the Apennine, and the Pyrenees regions, but also covering large country areas, such like in Portugal and central-eastern European countries. Medium and low service areas are, as already somewhat expected, mainly representative of large intensively used agricultural regions, such like in Spain, France and Italy. Since the study does not consider provisioning services, such as crop production that are the most representative of agricultural regions, then agricultural areas will show mainly poor in terms of benefits to people. The same pattern is visible for almost all Ireland, as according to the CLC 2012 statistics, 54% of the country was simply covered by managed grassland.

Figure 6 presents the statistical distribution of different service areas across the EU-27 area, as derived from the map presented in Figure 5. The results seem to indicate that the supply of ES is approximately normal and centred between medium and important service areas. Still, the percentage area distribution is leaning towards the lower limit of the scale and the benefits from ecosystems to human tend to be scarcer than abundant.

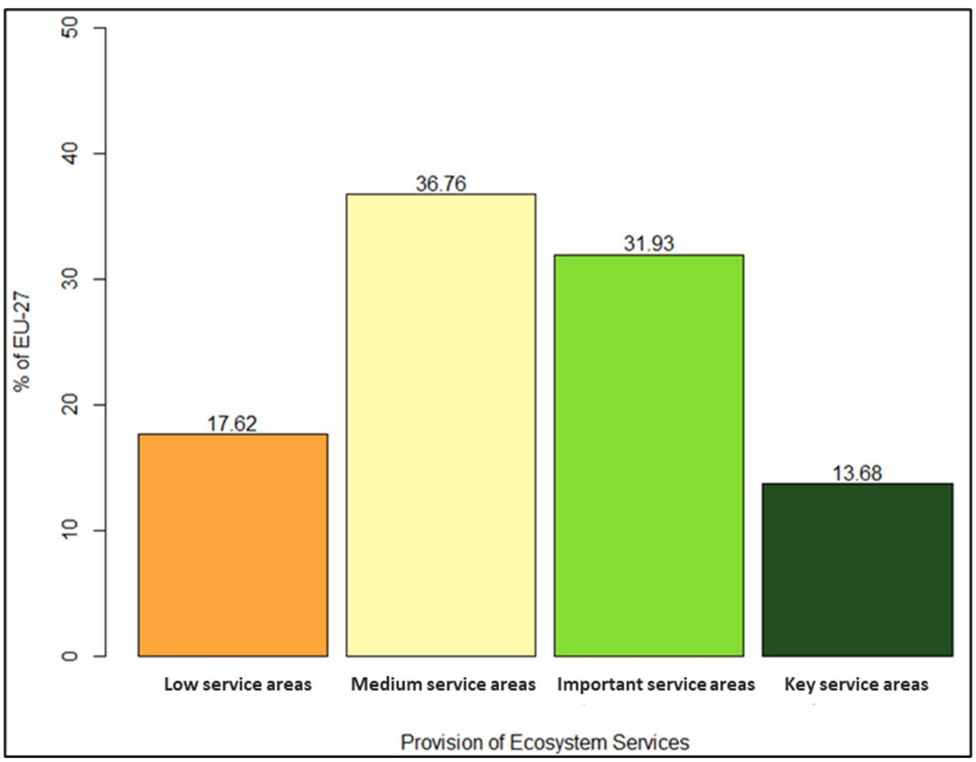

Figure 6. The percentage distribution of multiple ES across EU-27, as derived from the map of Figure 5; please see subsection 2.2 for detailed description of the classes presented in the plot.

In Figure 7, the percentage distributions of multiple ES outside (a) and inside (b) the GI network mapped in Figure 3 are compared. The results seem to indicate that the GI network improves the provision of multiple ecosystem services (i.e. 2 or 3) in the same spatial area by almost 4%, as compared to the landscape areas not included in the GI network mapped in Figure 3. In addition, the provision of at least one ES in medium service areas also increases by almost 6% inside the GI network, as compared to the outside situation. Therefore, these results highlight the capacity of connected Natura 2000 sites to provide around 10% more co-benefits to people, as compared to non-protected and disconnected landscape elements.

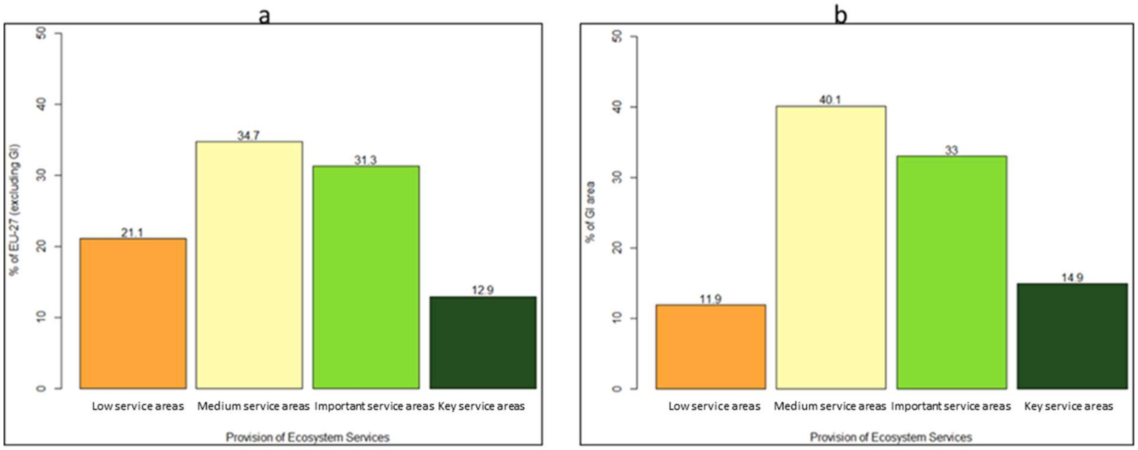

Figure 7. The percentage distribution of multiple ES outside (a) and inside (b) the GI network mapped in Figure 3, please see subsection 2.2 for detailed description of the classes presented in the plots.

3.3 SPATIAL DISTRIBUTION OF BIODIVERSITY VALUES IN EU-27[23]

- The predominance of ciCS values for selected mammal species is high at the EU-27 MS level;
- 80% of the assessed area at EU-27 MS level shows spatial associations of favourable conservation status for the selected mammal species considered for reporting under Article 17 of the Habitats Directive;
- Areas populated with two or more mammal species and a predominance of favourable conservation status are 11% higher inside the GI network, as compared to the outside situation.
- The proportion of areas with very low ciCS values is almost 3% higher outside the GI network, as compared to the inside situation.

The map in Figure 8 shows the spatial distribution of the composite indicator of conservation status (ciCS) for selected mammal species computed across the EU-27 MS. The bar plot of Figure 9 disclosures the share of the different categories of the ciCS across the whole territory, as shown in the map of Figure 8. The analysis of both figures reveals that around 80% of the area that was reported to have the presence of at least one of the selected mammal species, as derived from the Article 17 database for the period 2007-2012, have values in high ciCS categories, whereas only around 17% of the area is

[23] The reference date for this study is 2012; EU-27 is used to mean all the member states from 2007 to 2013 (Croatia joined only in 2013).

distributed across low ciCS categories; values in very low ciCS categories are covering less than 3% of the EU-27 MS territory.

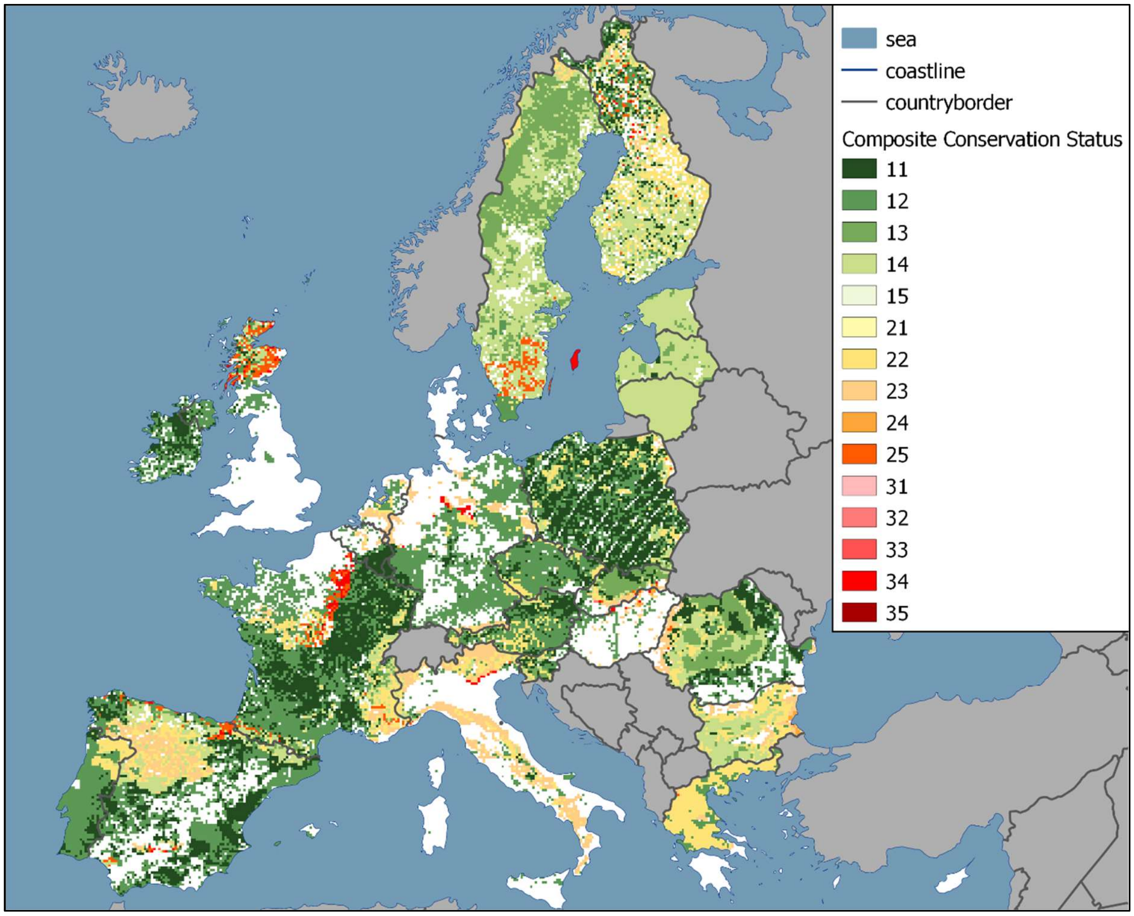

Figure 8. The spatial distribution of the combined conservation status (ciCS); selected mammal species were not reported for white areas; please see Table 1 for detailed description of numerical classes presented in the map.

Three ciCS categories dominate the map in Figure 8 and the bar plot in Figure 9: 12 (i.e. FV CS for a single species) with almost 30% of coverage, 14 (i.e. proportion of FV CS between 50-75%) with 21% of coverage, and 11 (i.e. FV CS for two or more species) with 20% of coverage. Looking now in more detail at the spatial patterns of the ciCS categories, it can be seen that these are not similarly distributed across the EU-27 MS. The general interpretation is that the predominance of ciCS values is high, with around 80% of the assessed area showing spatial associations of selected mammal species with favourable conservation status (green classes), as defined in the Article 17 database. For example, the Baltic states, as well as Poland, Czech Republic, Austria and Romania have generally high ciCS classes. Similar ciCS categories are also dominating in the centre and south of Portugal, north-western and south-eastern Spain, and almost all south-centre France towards Luxembourg and the bordering regions of Belgium and Germany. Interestingly, most of Ireland is characterized by classes 11 and 12, which are indicative of the presence of selected mammals' species with only favourable conservation status. On the other hand, north-eastern Portugal and the bordering Spanish region of Castile and León, Italy and the bordering French region of Provence-Alpes-Côte d'Azur, as well as the full Greek territory have generally low ciCS values. The northern region of San Sebastian in Spain, as well as the southern territory from Seville to Cordoba (i.e. the major area for *Iberian lynx*) show areas with very low ciCS values that represent a predominance of Unfavourable-Inadequate and Unfavourable-Bad conservation status for the majority of selected mammal species. This situation is also remarkable and extending largely over other regions in France, such as the Île-de-France and Centre-Val de Loire, as well as in Scotland and southern Sweden. While for the first two this condition respects mainly the unfavourable situation of the wildcat, for the last it is due to the mountain hare.

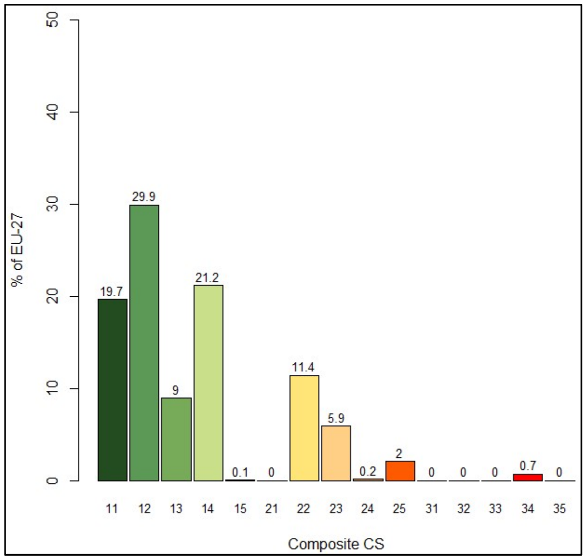

Figure 9. The percentage distribution of ciCS, as shown in the map of Figure 8 ; please see Table 1 for detailed description of numerical classes presented in the plot.

In Figure 10, the percentage distribution of ciCS categories inside and outside the GI network, as mapped in Figure 3, are compared. Although the results indicate that the percentage of areas classified as 1x are similar and around 80% inside and outside the GI network, the distribution of the values across the categories with a predominance of two or more species with CS FV (i.e. 11, 13, 14 and 15) is 11% higher inside the GI network (i.e. 56% inside and 45% outside). Indeed, whereas the GI network seems to promote a joint distribution of multiple mammal species in favourable conditions, for the outside territory the favourable conditions seem to predominate largely for areas with single mammal species (i.e. category 12). Also, looking at the very low ciCS categories (i.e. 25 to 35), it can be seen that the conservation status inside the GI network is improved by around 3%, as compared to the outside condition. Therefore, these results seem to suggest that connected Natura 2000 sites have more potential to provide a favourable conservation status of selected mammal species, as compared to non-protected and disconnected landscape elements.

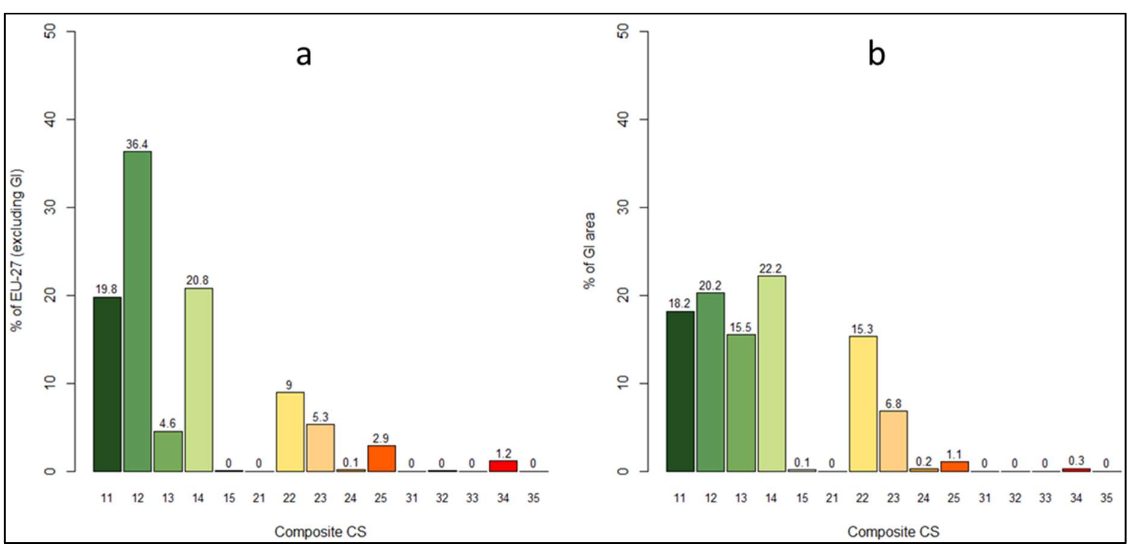

Figure 10. The percentage distributions of multiple ES outside (a) and inside (b) the GI network mapped in Figure 3; please see Table 1 for detailed description of numerical classes presented in the plots.

3.4 GI PRIORITIZATION IN EU MEMBER STATES

- The persistence of favourable conservation status for the selected mammal species is very high inside and outside the GI network;
- The level of ecosystem pressure outside the GI network is higher as compared to the inside situation;
- Around 81% of GI neighbouring regions could be linked to the network with little or very low-level management intervention.

A single appraisal or statistic describing the capacity of the GI network to simultaneously provide benefits from nature to people and contribute to biodiversity preservation in EU-27 is presented in this section. As explained in subsection 2.4, the results are derived by combining the outcomes from subsections 3.1 (Figure 3), 3.2 (Figure 5) and 3.3 (Figure 8) and aim to characterize the GI elements in terms of priority areas for conservation or restoration interventions. Figure 11 shows a schematic representation of the integrated assessment phases.

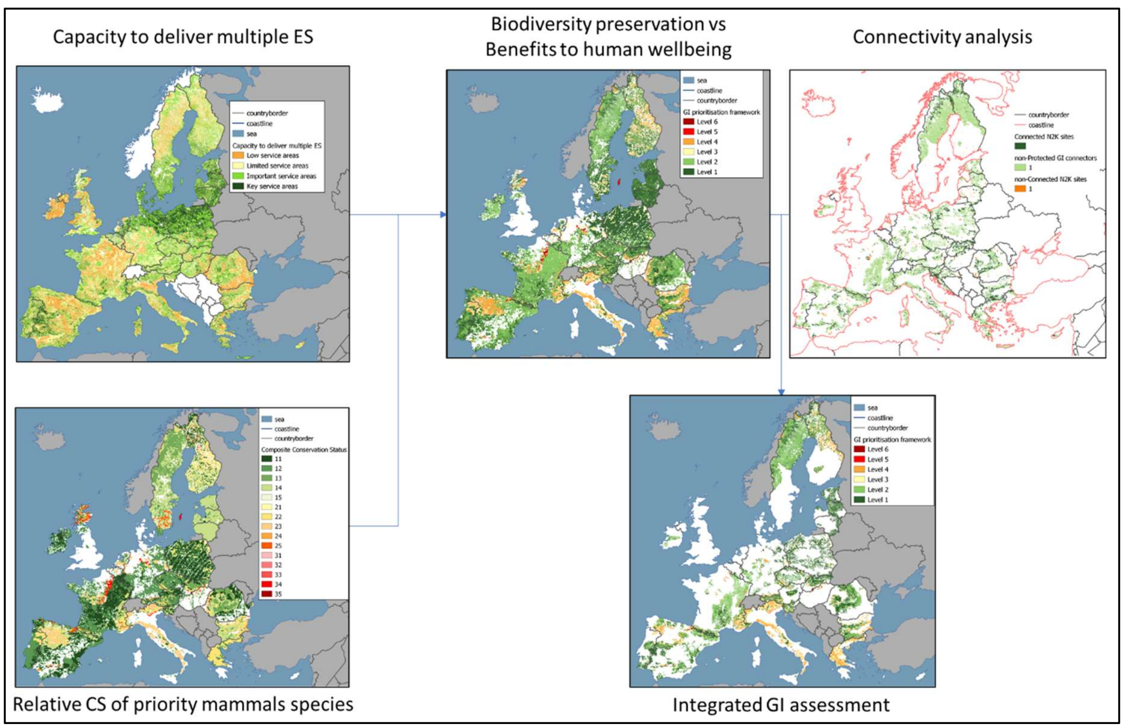

Figure 11. The integrated GI assessment framework.

The results of the integrated GI assessment framework are presented in detail in Figure 12. The displayed spatial areas include the core Natura 2000 sites and the respective natural and semi-natural connector elements (i.e. excluding urban surfaces, water, wetlands and intensive agricultural areas) in the "wider landscape". The patterns show that more than 40% of the GI network is providing good conditions for both the preservation of selected mammal species, and supplying important co-benefits to people. This condition is predominating in the Baltic countries, Poland, Slovakia, the Carpathian, the central territory of Austria, the Spanish Extremadura region in the border with Portugal, as well as the Pyrenees. Therefore, the GI elements in these areas should be subject to little conservation management practices (Level 1 of prioritisation – please see Table 2 for detailed description of the prioritisation levels), in addition to those that are already in place. However, this situation does not discard the development and application of a dedicated monitoring systems to mitigate and prevent future pressures on ecosystems condition and conservation status of selected mammal species on those geographical areas.

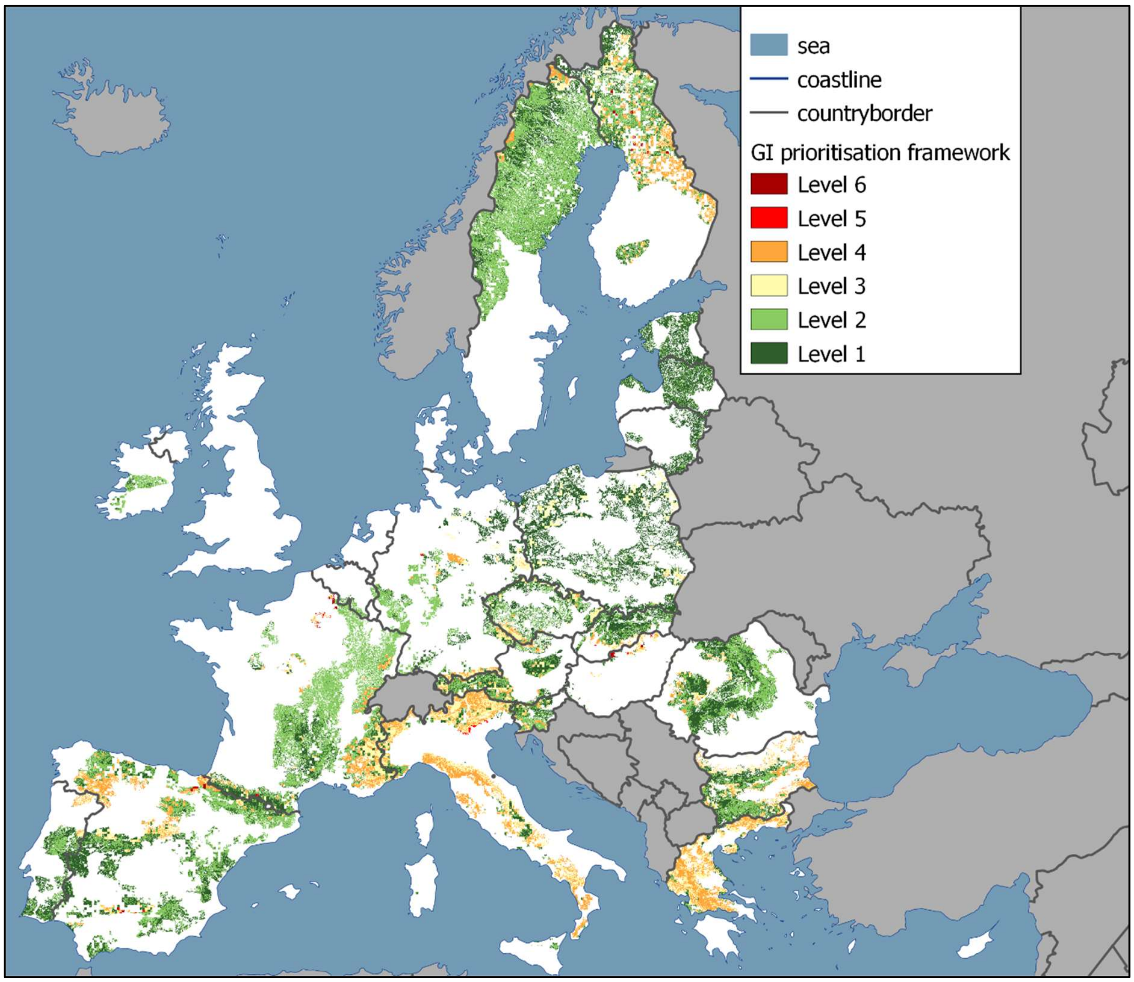

Figure 12. Prioritization for GI conservation and restoration; please see Figure 2 and Table 2 for a detailed description of the classes presented in the map.

On the other hand, major problematic areas within the GI network are very few (i.e. less than 1%) and are located in the north-eastern region of Paris, in the northern border of Hungary close to Slovakia, around Pamplona in the north of Spain close to France, as well as in the south-central territory of Spain. Although few of these areas provide co-benefits to people (as depicted in the map of Figure 5), most of those territories need some active and urgent protection measures (Levels 5 and 6 of intervention – please see Figure 2 and Table 2), associated with local restoration plans to re-establish the favourable conservation status of some analysed mammals species, e.g. the *Iberian lynx* in Spain, and improve the type and quality of co-benefits from nature to people. The remaining GI segments across the EU-27 territory seem to have medium capacity to sustain the conservation status of selected mammals and simultaneously to provide co-benefits to people in terms of regulating ecosystem services. Most of these areas are at Levels 2 and 4 of intervention according to the proposed integrated framework for GI prioritization (Figure 2 and Table 2). The ecosystems covered by these GI elements are subject to a number of pressures that need to be identified and actively reduced in order to recover their ability to provide multiple ecosystem services and serve better biodiversity conditions.

In Figure 13, the results of the integrated assessment are presented for the natural and semi-natural landscape elements neighbouring the GI network, as mapped in Figure 3. This figure includes other territories where the selected mammal species were identified in EU-27 MS, namely those depicted in the map of Figure 8, as well as the location of the core Natura 2000 sites and the discontinuities in the computed GI network. The elements in Figure 13 allow to better understand how to prioritize the enlargement of the current GI network according to the ES provided by the respective ecosystems, as well as the conservation status of existing mammal species in each area.

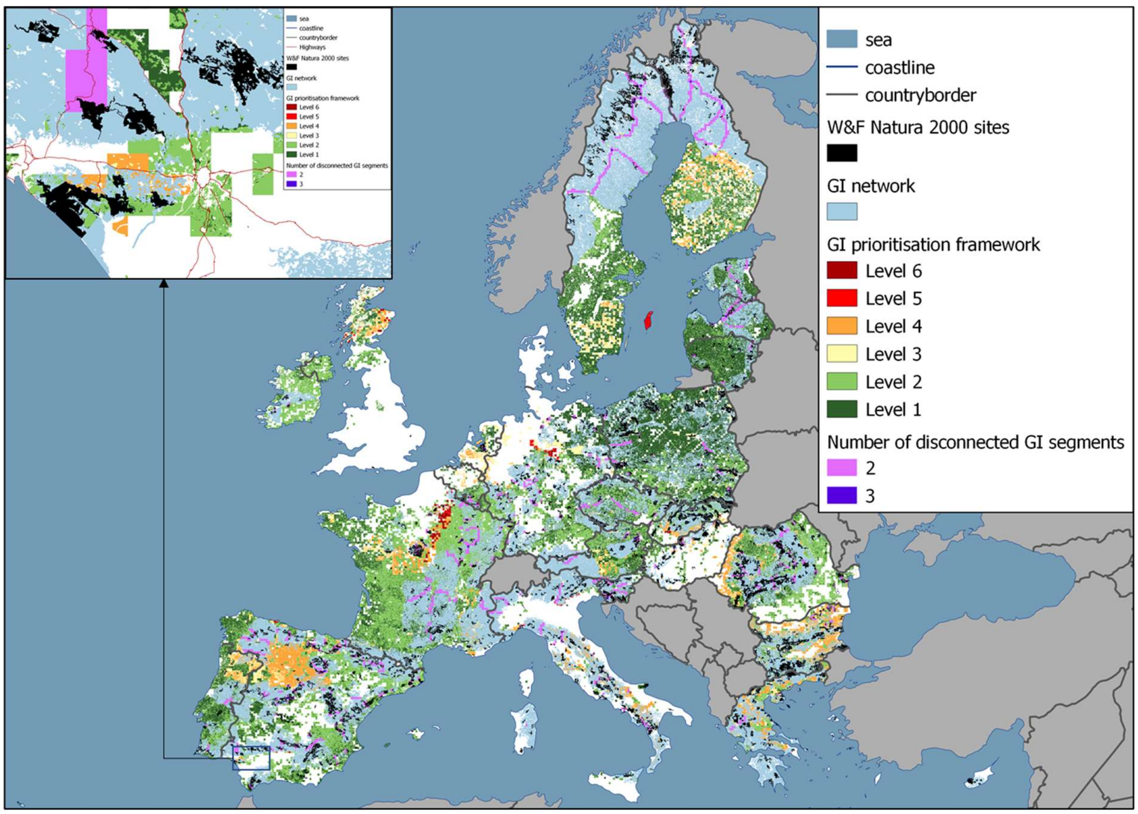

Figure 13. Priority interventions for GI deployment in natural and semi-natural areas in EU-27; please see Figure 2 and Table 2 for a detailed description of the GI prioritisation classes presented in the map.

The results displayed in Figure 13 seem to indicate that natural and semi-natural landscape elements in north-eastern Portugal and the bordering Spanish region of Castile and León, the Île-de-France and Centre-Val de Loire regions of France, the Hungarian territory in the border with Romania, as well as the Romanian provinces bordering with Hungary are subject to more pressures than those in Galicia and northern Spain, western regions of Portugal and France, Poland and the Baltic territories, as well as eastern Austria and Ireland. Therefore, the inclusion of the former unprotected landscape elements within the current GI network implies not only deploying the required physical/structural and functional links, but also the planning of additional restoration activities that allow to establish effective co-benefits from those ecosystems to people. On the other hand, establishing the physical/structural links of the network to the natural and semi-natural landscape elements in the

European conterminous territories might be a sufficient action to increase their contribution to GI and the targets of the BD Strategy 2020. Notwithstanding, from the analysis of Figure 13 it can be seen that the former territories were not included in the GI network because they are conterminous and without core Natura 2000 sites. Therefore, additional protection actions to minimize and prevent future pressures can also be a good practice to maintain the full potential of those ecosystems in supplying services, as well as the conservation status of selected mammal species. This includes the creation of larger Natura 2000 sites in those territories.

To complement the analysis of Figure 12 and Figure 13, it is presented in Figure 14 the percentage distribution of areas that should be subject to different levels of intervention and prioritization inside and outside the GI network. Overall, the results show that the likelihood of persistence of favourable conservation status is very high for selected mammal species (i.e. Level 1 and Level 2) inside and outside the GI network. Notwithstanding, it is extremely important to know that outside the GI network there are around 81% of spatial areas that can be included with little or very low-level management intervention. More important though is the fact that the areas inside the GI network seem to subject to less ecosystem pressures (i.e. percentage area under Level 5 and Level 6 prioritization).

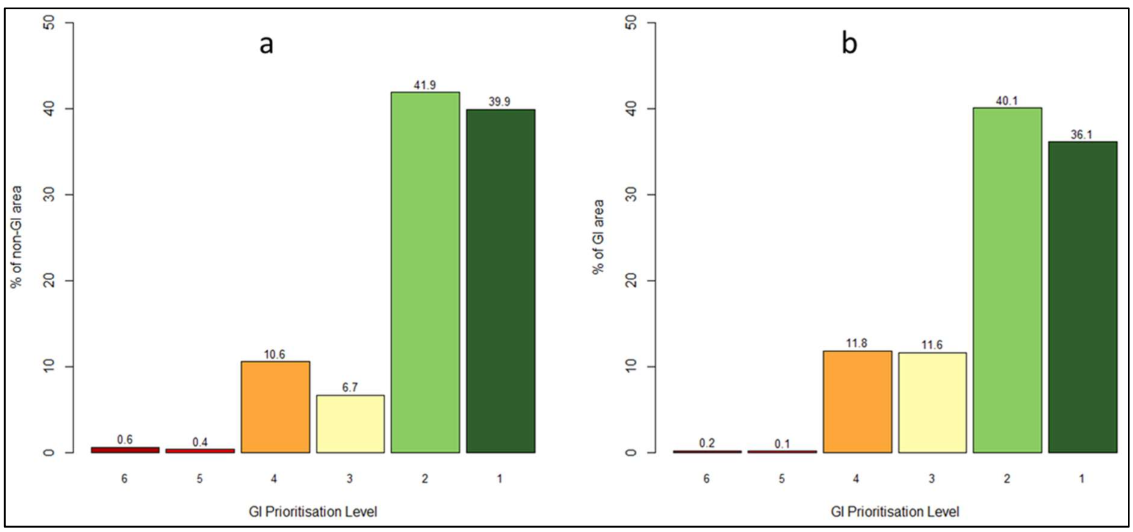

Figure 14. Percentage distribution of priority interventions for spatial areas outside (a) and inside (b) the GI network; please see Figure 2 and Table 2 for a detailed description of the GI prioritisation Levels.

Finally, and apart from the EU-level outcomes, the integrated assessment can also be used to collect indicative information for managing the prioritization of GI actions at a more local level. For example, it can be seen from the integrated assessment in Figure 13 that part of the GI segment covering the *Doñana* National Park in southern Spain might be subject to pressures that limit the provision of services by the local ecosystems, which consequently are not sufficient to maintain a favourable conservation status of the selected mammal species. Moreover, the link of this area to other GI segments, namely those covering the Protected Areas in the *Sierra Morena* mountain range (e.g. *Sierra de Hornachuelos, Sierra Norte de Sevilla,* and *Sierra de Aracena* Natural Parks) in the north, as well as those covering the *Parque Natural do Vale do Guadiana* (Portugal) in the west, seem to be extremely thin and vulnerable. Although the Green Corridor "Guadiamar" was established in this region to enhance the ecological connectivity between the two major *Iberian Lynx* areas in southwest Spain, i.e. *Doñana* and *Sierra Morena*, the results of this assessment seem to indicate that an active pressure reduction action to fully restore the potential of this GI segment is urgent. For example, this could include the improvement of the structural connection of the area with the neighbouring Natura 2000 sites, which in turn could regenerate the functional characteristics of local ecosystems and improve the conservation status of the native mammal species selected for this analysis.

4 IMPLICATIONS FOR POLICY

The results of this analysis show that GI has a positive impact on the conservation status of species and habitats. In cases where the green infrastructure is located within protected areas (e.g. the Natura 2000 network), this impact is even higher. Protection of GI additionally serves to augment the delivery of ecosystem services and decrease pressures on species and habitats. However, natural and semi-natural non-protected landscape elements are also important factors in determining conservation status as these areas serve as connectors. Finally, the study reveals different opportunities for strengthening the existing GI network and its multifunctionality in terms of delivering multiple services.

To foster this potential and a more effective GI deployment, the following policy implications can be derived. In combination, the following actions can lead to an improved, more ecologically coherent and better-connected network within and outside of Natura 2000 sites and therewith substantially contribute to maintaining and achieving good conservation status of species and habitats and halting the loss of biodiversity.

Establish a guiding EU framework for the development, management, assessment and monitoring of the GI network

- The EU and its MS should deploy a **holistic approach building on spatial data to identify, select and manage GI priority areas** that are essential for the network's connectivity, its delivery of multiple ecosystem services and its maintenance or improvement of species and habitats' good conservations status. Relevant spatial data includes, for example: mapping the GI network (including key habitats (nodes) and connecting landscape elements (links/connectors)), mapping and assessing ecosystem services which are compatible with biodiversity protection targets, and mapping the conservation status of habitats and species (e.g. listed under the Nature Directives).
- Identified GI priority areas may or may not already have a protected status. Depending on its level and type of protection, GI can fall under different ownership structures and have diverse biodiversity or other competing priorities. In these different cases, there are **various intervention options** that should be applied:
    - Restore the area to ensure improved habitat condition and delivery of ecosystem services and
    - Create new connecting landscape elements to physically or functionally connect existing GI elements
    - Maintain and manage the area in a sustainable way by defining and implementing targeted conservation measures, which may allow for different low impact land uses
    - Designate the GI area/element as a protected area

Such interventions should primarily address biodiversity issues, but can also be designed to contribute to other goals, such as climate change adaption and improved human health.

- A **common EU prioritization framework** should be developed to guide the selection of different types of interventions in the identified areas and guide actions in the Member States. In addition, local and regional conditions should be considered in these decision-making processes and in deriving recommendations and targeted actions.

- A **systematic assessment and frequent monitoring** of the GI network at EU level (linking to the conservations status of habitats and species and the assessment of ecosystem services) should be established. This will enable an assessment of the GI network's performance and its contributions to policy targets, while also highlighting gaps and remaining needs.

Integrate GI interventions into existing biodiversity policies at EU and MS level

- EU and MS policies need to clearly **recognize and outline the importance of a robust GI network** for halting the loss of biodiversity and providing multiple benefits to people. Specific links to respective measures and interventions should be highlighted in the respective policies.
- **Design, integrate and implement targeted interventions options** (as listed above) through existing biodiversity policies at EU and national level, including i.e. the Nature Directives (and respective management plans for the protected areas and the Action Plan for Nature, People and the Economy), the Biodiversity Strategy 2020 and national Prioritised Action Frameworks (PAFs) for Natura 2000 and national restoration activities.

Inform and shape the European Biodiversity Strategy to 2030 and its action plan

- Establish **binding quantitative (short, medium and long-term) targets with corresponding indicators to track the restoration of degraded areas and the creation of new connecting landscape elements** to ensure a coherent and well-connected EU-level GI network. Such targets should show ambition, consider the quality of the GI network, and be in line with or go beyond global targets in order to significantly contribute to halting biodiversity loss in the EU. Corresponding interventions in the accompanying action plan should also take account of "low-hanging fruits"[24] and other necessary interventions and indicate targeted actions that can be taken at different spatial levels as part of a holistic approach.
- EU targets should be supported by **binding national targets**, which need to be set by the MS and followed by respective and targeted interventions.
- The Fitness Check has revealed that the Natura 2000 network cannot deliver the Directives' objectives on its own, but need to be supported by appropriate management and restoration measures through GI, both within and outside Natura 2000 (European Commission 2017: 28). This requires setting **clear targets for the expansion of the Natura 2000 network** which allow for a more effective protection and management of biodiversity (prioritizing improved connectivity, designation of larger areas etc.).
- Adequate **EU-level strategic investments in GI** should be designated to provide even greater benefits per euro invested than is currently the case (European Commission 2017: 28).

Contribution to MAES at EU and national level

The MAES work at EU level could be used to guide the decisions to be made for the prioritisation of areas to select for the 15% restoration target, namely:

- Using the ecosystem condition assessment results as a guiding principle for habitats in different ecosystem types, which condition values and trends in condition values are poor, as well as high pressures and / or increasing pressure trends. Such areas, in all ecosystem types, already identified at European level, could be used as priority areas for restoration;

[24] As results have shown there is a high share of GI neighbouring areas that could be linked to the network with very little management intervention.

- This assessment identifies priority areas for restoration per biogeographic region, thus allowing balancing investments and funds over the territory and to boost the ecosystem services as conceived important for each biogeographic region and ecosystem type (e.g. reduce forest fires risks in the Mediterranean region, increase active restoration of wetland ecosystems in the boreal region to restore the carbon sequestration capacity of peatlands through rewetting, increase green spaces in urban areas to reduce heat islands, increase air quality, …);
- As for improving, completing the Natura 2000 network, the ecosystem condition assessment results reveal the types of habitats that are underrepresented in the actual network as a potential basis for prioritisation of GI development.

Integrate GI targets and activities into wider policies and financing instruments to secure long-term support and successful mainstreaming

- GI interventions contributing to the protection of species and habitats and provisioning of ecosystem services should not only be a key element in the **LIFE programme**, but also in other EU financing programmes, such as the **EU Common Agricultural Policy** (i.e. agri-environmental-climate measures, Natura 2000 support measures) or the **European Regional Development Fund** and the corresponding INTERREG programme.
- A clear focus on GI should be outlined in these funding programmes, including **earmarking funding for GI interventions**.

5 CONCLUSIONS

The European Union (EU) Biodiversity Strategy to 2020 aims through Target 2 to "*maintain and enhance ecosystems and their services by establishing green infrastructure and restoring at least 15% of degraded ecosystems".* The achievement of Target 2 is underpinned by the EU initiative on Mapping and Assessment of Ecosystems and their Services (MAES), which is implemented by Member States (MS) with the assistance of the EU, and aims to reinforce the knowledge base – including the assessment and valuation of the benefits that nature provides to human society – and to set a baseline against which progress related to GI and restoration can be measured.

This report is intended to improve and strengthen the knowledge about GI mapping approaches, and contributes to *"reviewing the extent and quality of the technical and spatial data available for decision-makers in relation to GI deployment*" identified in the EU Strategy on Green Infrastructure (European Commission, 2013). Moreover, it also contributes to the EU Biodiversity Strategy to 2020, which calls for the strategic deployment of GI supported by the robust evidence base developed through the MAES process.

In this report, an integrated assessment framework is proposed to map, characterize and prioritize the optimal allocation of a GI network connecting protected areas (i.e. core Natura 2000 sites) across the whole EU territory. This approach includes the assessment of which elements of the green infrastructure are more valuable, either in their current conditions or after restoration, to support the connectivity of the protected areas, as well as to determine the potential of ecosystems to supply multiple services and guarantee the sustainability of favourable conservation status of species of Community interest in the EU. In particular, it focuses on Natura 2000 sites, which are considered as the backbone of the EU level GI network, and on set of medium-large mammal species of Community interest, which were selected as the functional group of analysis in terms of ethology and habitat needs.

The use of an integrated GI assessment and prioritisation framework provided a holistic view of the opportunities and potential conflicts when managing "wider landscapes" for different, and often incompatible objectives. The results demonstrate how this integrated assessment for multiple simultaneous objectives can be used to prioritize the spatial allocation of different management zones for achieving the goals of biodiversity conservation, as well as the sustainable maintenance of ES that grant the access of nature benefits to people. The proposed approach is suitable for designing GI networks that enhance connectivity between biodiversity conservation areas and areas devoted to the maintenance of ES for cultural and regulating purposes. Since provisioning services are driven by human inputs like energy (e.g. fertilisers) or capital (e.g. labour), they are not in line with biodiversity conservation requirements and were not taken int account for this assessment.

The attained results suggest that in 2012 more than 80% of the Natura 2000 sites of interest for the current assessment are interconnected by forest and woodland ecosystems, as well as other natural and semi-natural features in the "wider landscape". The percentage of ecosystems providing multiple services inside the GI network is 12% higher as compared to the outside ecosystems. Similarly, areas populated with two or more mammal species that have a predominance of favourable conservation status are 11% higher inside the GI network, as compared to the outside situation. Finally, the presented results indicate that around 81% of GI neighbouring regions could be linked to the network with little or very low-level management interventions.

This study presents some gaps and limitations, which should be enumerated and explained for a detailed understanding of the results and, if that is the case, any contradictory statements with the results of studies performed at different spatial and temporal resolutions. For example, temporal variability could not be covered in this assessment. Due to limitations mainly in the provision of regulating and cultural ES, the reference date for the study is 2012. A temporal assessment of ecosystems and ecosystem services could have helped to understand, analyse and even predict the GI evolution between the reference year of 2012 and the present date of 2019, as well as to better understand the contribution of GI to the targets of Biodiversity Strategy to 2020.

Also, it is important to mention that the attained results are empirical and based on existing spatial data on ecosystems distribution, ecosystem services supply, and conservation status of protected species. This implies that results are driven by the technical limitations and availability of input data. For example, the identification of connectivity paths is constrained to the 100m width of landscape elements mapped in the CORINE Land Cover map of 2012. Therefore, smaller animal bridges and other landscape features of interest for local applications are not mapped and could not be depicted by this study.

Similarly, standardized ES indicators available at the EU-level are those provided by the JRC in the framework of MAES initiative. For some regions and local analyses, the selected ES indicators might not be the most relevant to characterize the benefits from nature to people and the condition of habitats to maintain and support the sustainability of selected mammal species.

Finally, the conservation status of species listed in the Article 17 database is reported at 10x10km and fixed for all grid cells within a specific country and biogeographical region. This implies that variability in the species condition within those strata cannot be determined and to a certain extent might bias the results on the spatial distribution and level of conservation status of selected species.

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ANNEX 1

Species name	Species code	Preferred MAES ecosystem type *(**)*	IUCN RED LIST https://www.iucnredlist.org/
Bison bonasus	2647	Grassland; Forest & Woodland	Optimal habitats for the European bison are deciduous and mixed forests
Canis lupus	1352	Heathland & Shrub; Forest & Woodland	In general, large forest areas are particularly suitable for wolves in Europe, although wolves are not exclusively a forest species
Castor fiber	1337	Rivers & Lakes; Wetland; Forest & Woodland	They generally prefer freshwater habitats surrounded by woodland, but may occur in agricultural land or even suburban and urban areas
Felis silvestris	1363	Heathland & Shrub; Forest & Woodland	European wildcats are primarily associated with forest and are found in highest numbers in broad-leaved or mixed forests with low densities of humans
Genetta genetta	1360	Heathland & Shrub; Forest & Woodland	The genet tends to prefer all types of wooded habitats (deciduous and evergreen), where it is often associated with rivers and brooks, but it is a generalist and can be found in other habitats where there is suitable prey.
Gulo gulo	1912	Grassland; Heathland & Shrub; Forest & Woodland	Wolverines inhabit a variety of habitats in the alpine, tundra, taiga, and boreal forest zones. They are found in coniferous, mixed, and deciduous woodlands, bogs, and open mountain and tundra habitats.
Lepus timidus	1334	Grassland; Heathland & Shrub; Forest & Woodland	Mountain hares occupy tundra and open forest, particularly of early successional stages. In Scotland and Ireland heather moors and bogland are favoured habitats
Lynx lynx	1361	Heathland & Shrub; Forest & Woodland	Throughout Europe and Siberia, the Eurasian Lynx is primarily associated with forested areas which have good ungulate populations and which provide enough cover for hunting. It inhabits extended, temperate and boreal forests from the Atlantic in Western Europe to the Pacific coast in the Russian Far East. In Europe, it can be found in Mediterranean forests up to the transition zone of taiga to tundra and lives from sea level up to the tree line. In the far north of Scandinavia lynx can also make extensive use of open alpine tundra habitats.
Lynx pardinus	1362	Heathland & Shrub; Forest & Woodland	The Iberian Lynx is also a habitat specialist that breeds only in Mediterranean shrubland containing dense rabbit populations. On the other hand, forestry landscapes, farmland or other open land devoid of native shrubs are rarely used by resident lynx but occasionally used by subadults during natal dispersal.
Martes martes	1357	Heathland & Shrub Forest & Woodland	It inhabits deciduous, mixed, and coniferous woodlands, as well as scrub. Optimal habitat appears to be woodlands with an incomplete canopy and dense understorey vegetation.
Mustela putorius (*)	1358	Cropland; Grassland; Wetland; Forest & Woodland; Urban;	A generalist, it is found in almost every type of lowland habitat. It is often found in lowland woods in riparian zones, and in areas close to farms and villages in the winter; but it also uses wooded steppe, sand dunes, marshes and river valleys, agricultural land, forest edge and mosaic habitats
Ursus arctos	1354	Heathland & Shrub; Forest & Woodland	Brown Bears occupied not only forests, but also steppes and tundra.

Table 4. List of medium-large mammal species retrieved with the selection criteria presented in subsection 2.3, namely: 1) need of spatial connectivity, 2) present in two or more EU-27 countries, and 3) forest and woodland is one of their preferred habitats.

(*) Please note that *Mustela putorius* was not used for the spatial analysis described in subsection 2.3 because it is a generalist and can be found in almost all types of ecosystems listed in MAES.
(**) Please see the 1st MAES technical report, page 24, for a complete description of its ecosystem types:
https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/MAESWorkingPaper2013.pdf;
Please note that "Woodland and forest" ecosystem type was renamed as "Forest and woodland" in the 5th MAES technical report, page 21:
https://catalogue.biodiversity.europa.eu/uploads/document/file/1673/5th_MAES_report.pdf

ANNEX 2

CLC Code	CLC Label	Land cover/use resistance class	Resistance factor
111	Continuous urban fabric	Urban ecosystems	1000
112	Discontinuous urban fabric	Urban ecosystems	1000
121	Industrial or commercial units	Urban ecosystems	1000
122	Road and rail networks and associated land	Urban ecosystems	1000
123	Port areas	Urban ecosystems	1000
124	Airports	Urban ecosystems	1000
131	Mineral extraction sites	Urban ecosystems	1000
132	Dump sites	Urban ecosystems	1000
133	Construction sites	Urban ecosystems	1000
141	Green urban areas	Urban ecosystems	1000
142	Sport and leisure facilities	Urban ecosystems	1000
211	Non-irrigated arable land	Cropland	60
212	Permanently irrigated land	Cropland	60
213	Rice fields	Cropland	60
221	Vineyards	Cropland	60
222	Fruit trees and berry plantations	Cropland	60
223	Olive groves	Agro-forestry	15
231	Pastures	Grassland	30
241	Annual crops associated with permanent crops	Cropland	60
242	Complex cultivation patterns	Cropland	60
243	Land principally occupied by agriculture, with significant areas of natural vegetation	Agro-forestry	15
244	Agro-forestry areas	Agro-forestry	15
311	Broad-leaved forest	Forest and woodland	1
312	Coniferous forest	Forest and woodland	1
313	Mixed forest	Forest and woodland	1
321	Natural grasslands	Grassland	30
322	Moors and heathland	Heathland and shrub	5
323	Sclerophyllous vegetation	Heathland and shrub	5
324	Transitional woodland-shrub	Forest and woodland	1
331	Beaches, dunes, sands	Sparsely vegetated areas	40
332	Bare rocks	Sparsely vegetated areas	40
333	Sparsely vegetated areas	Sparsely vegetated areas	40
334	Burnt areas	Sparsely vegetated areas	40
335	Glaciers and perpetual snow	Sparsely vegetated areas	40
411	Inland marshes	Water bodies, wetlands and coastal areas	100
412	Peat bogs	Water bodies, wetlands and coastal areas	100
421	Salt marshes	Water bodies, wetlands and coastal areas	100
422	Salines	Water bodies, wetlands and coastal areas	100
423	Intertidal flats	Water bodies, wetlands and coastal areas	100
511	Water courses	Water bodies, wetlands and coastal areas	100
512	Water bodies	Water bodies, wetlands and coastal areas	100
521	Coastal lagoons	Water bodies, wetlands and coastal areas	100
522	Estuaries	Water bodies, wetlands and coastal areas	100
523	Sea and ocean	Water bodies, wetlands and coastal areas	100

Table 5. Resistance values were assigned to the land cover types as defined in the CORINE Land Cover (CLC) map of 2012.

ANNEX 3

Maps of ecosystem services covering the full EU MS for the year of 2012, as provided by the JRC in the framework of MAES[25].

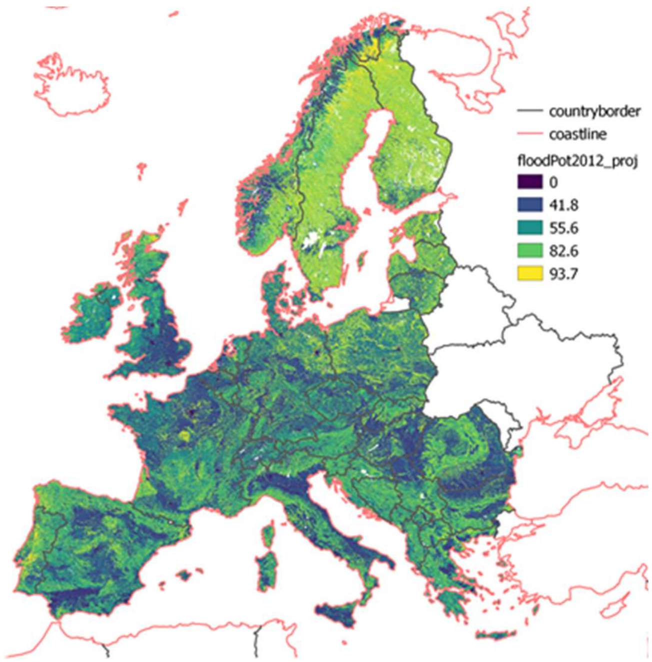

Figure 15. Flood control potential in 2012.

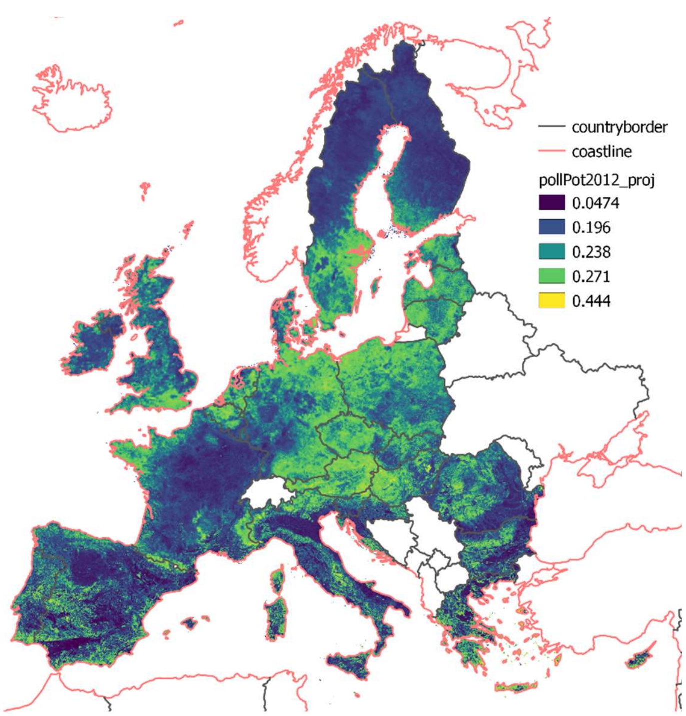

Figure 16. Pollination potential in 2012.

[25] https://data.jrc.ec.europa.eu/collection/maes

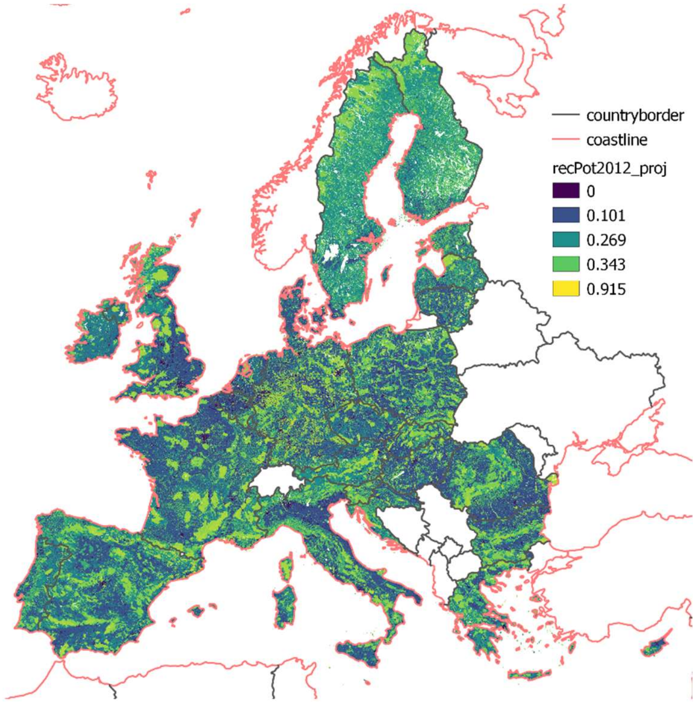

Figure 17. Recreation potential in 2012.