OpenNESS

Operationalisation of natural capital and ecosystem services: from concepts to real-world applications

Synergies and conflicts between the delivery of different ES and biodiversity conservation: Spatial planning for investment in green infrastructure and ecosystem restoration across the EU

Deliverable D3.3 / WP3

1 December 2016

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SEVENTH FRAMEWORK PROGRAMME

Prepared under contract from the European Commission
Contract n° 308428
Collaborative project
FP7 Environment

Project acronym:	OpenNESS
Project full title:	Operationalisation of natural capital and ecosystem services: from concepts to real-world applications
Start of the project:	01 December 2012
Duration:	54 months
Project coordinator:	Finnish Environment Institute (SYKE)
Project website	http://www.openness-project.eu

Deliverable title:	Synergies and conflicts between the delivery of different ES and biodiversity conservation: Spatial planning for investment in green infrastructure and ecosystem restoration across the EU.
Deliverable n°:	D3.3
Nature of the deliverable:	Paper
Dissemination level:	Public
WP responsible:	WP3
Lead beneficiary:	Joint Research Centre
Citation:	EU FP7 OpenNESS Project Deliverable D3.3: Sara Vallecillo, Chiara Polce, Ana Barbosa, Carolina Perpiña Castillo, Grazia Zulian, Ine Vandecasteele, Graciela M. Rusch and Joachim Maes. Synergies and conflicts between the delivery of different ES and biodiversity conservation: Spatial planning for investment in green infrastructure and ecosystem restoration across the EU. European Commission FP7, 2016.
Due date of deliverable:	Month 42
Actual submission date:	Month 48

Deliverable status:

Version	Status	Date	Reviewed by	Author(s)
1.0	Final	1 December 2016	Paula Harrison	Sara Vallecillo, Chiara Polce, Ana Barbosa, Carolina Perpiña Castillo, Grazia Zulian, Ine Vandecasteele, Graciela M. Rusch and Joachim Maes

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Foreword

The overall objective for WP3 is to develop and refine approaches for mapping and modelling the biophysical control of ES which can be used to assess the effectiveness of mechanisms, instruments and best management practices for sustaining ES delivery in the face of multiple uncertain drivers whilst conserving biodiversity. This will be achieved through the following sub-objectives:

- To analyse the contribution of NC stocks to ES flows by identifying the structural and functional factors that link them in different contexts;
- To develop a range of spatially-explicit methods for investigating the effects of multiple drivers on ES supply;
- To develop methods for comparing ES supply with biodiversity conservation objectives to inform sustainable
- management practices and test the effectiveness of financial and governance instruments for conserving both ES and biodiversity;
- To create a set of guidelines for application of the WP3 methods in the WP5 case studies.

This deliverable is a result of Task 3.3: Methods for comparing ES supply with biodiversity conservation objectives to inform sustainable management practices.

This task aims to use the outputs from the models and methods for investigating the effects of multiple drivers on ES supply (from Task 3.2) and compare them with environmental objectives and policy targets to identify synergies and conflicts and to prioritize investments in natural capital.

In this report EU wide data on ecosystem services and biodiversity were considered together with the conservation status of habitats reported under the EU Habitats Directive to guide investments for ecosystem restoration and development of Green Infrastructure.

Abstract

Target 2 of the EU Biodiversity Strategy to 2020 aims at the deployment of Green Infrastructure (GI) and the restoration of at least 15% of degraded ecosystems. We present a framework to identify priority areas for GI across the EU-28 countries. Systematic conservation planning tools were used to prioritize multi-functional areas, contributing to the supply of ecosystem services and support biodiversity. We developed three scenarios using different drivers to address the multi-purpose nature of GI: 1) 'Nature for nature': where no specific spatial driver was included. 2) 'Nature for people': areas closer to populated sites were preferentially selected. 3) 'Nature to restore': where prioritization was favoured in areas with poorer ecosystem condition. We also assessed the cost-effectiveness of ecosystem restoration using the removal of invasive alien species as a case study. Here, changes in habitat conservation status were used as a proxy for benefit valuation.

The comparative assessment of the spatial alternatives (scenarios) for GI show synergies and conflicts. We found that GI could be efficiently established close to densely populated areas. However, restoration costs in these areas are typically higher given the poor ecosystem condition resulting from degradation. Investment in those places was the most cost-effective, but only if beneficiaries (i.e. people) were accounted for in the assessment.

Given the scarcity of resources for investment in GI and ecosystem restoration, win-win situations should be identified where GI development can deliver to several policy objectives simultaneously.

1. Introduction

The need for healthy ecosystems is becoming widely recognised, not just to halt the loss of biodiversity, but also to benefit from the many valuable services they provide. An essential condition for healthy ecosystems is the maintenance of ecological integrity. Habitats throughout Europe are becoming increasingly fragmented and degraded due to an increase in environmental pressures (Millennium Ecosystem Assessment, 2005). Given the scale of the challenge, more needs to be done at European level for the benefit of all, people as well as nature. In this sense, Green Infrastructure (GI) planning is a policy tool that stands to improve human well-being through its environmental, social and economic values, based on the multi-functional use of natural capital. GI implementation is a key step towards the success of the EU 2020 Biodiversity Strategy. The Strategy's Target 2 (European Commission, 2011) requires that *'by 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems'*. Ecosystem restoration has been shown to enhance not only biodiversity, but also the supply of ecosystem services (Rey Benayas *et al.*, 2009; Barral *et al.*, 2015). Therefore, setting priorities to restore and promote the use of GI is essential at both European Union and Member State level.

GI has been described 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*' (European Commission, 2013a). Different spatial alternatives for GI could then be designed depending on the '*strategic plan*' chosen to identify or implement the network. At EU level the European Environment Agency has proposed for the first time a methodology to identify multi-functional GI based on the delivery of multiple ecosystem services, key habitats for target species and connectivity (European Environment Agency, 2014; Liquete *et al.*, 2015). This approach does not explicitly consider socio-economic systems in the identification of potential GI, preferring the development of GI in rather remote areas, where anthropogenic pressure is relatively low but where the beneficiaries of ESs are scarce. In these areas, benefits derived from nature would reach only a small proportion of the EU population, and hence the overall contribution of ecosystem services to human well-being would be limited (Figure 1).

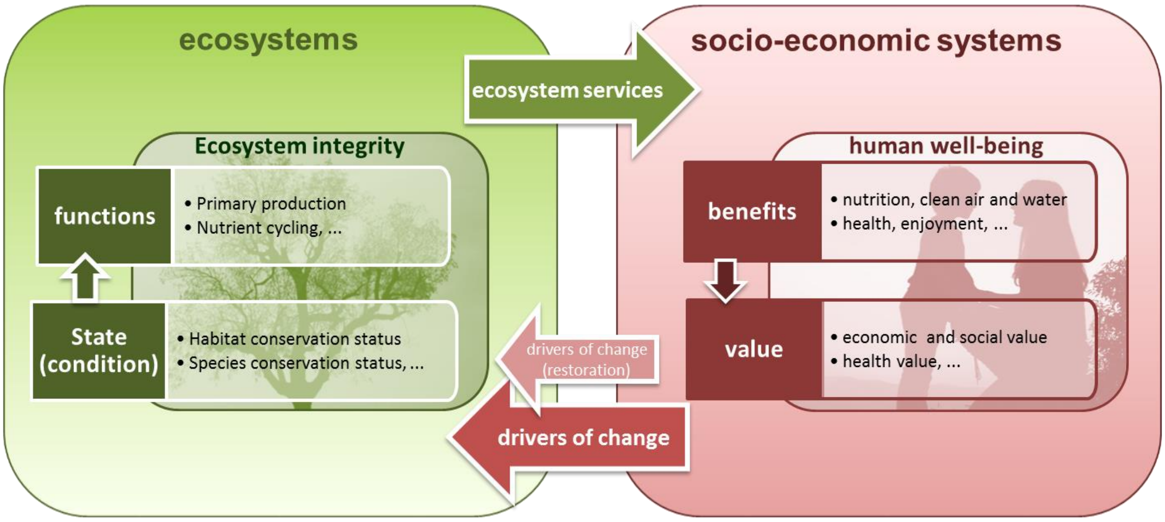


Figure 1. Conceptual framework for EU wide ecosystem assessments linking socio-economic systems with ecosystems via ecosystem services and drivers of change, modified from European Commission (2013b).

Other GI initiatives at EU level are targeting the mitigation of the impacts of weather- and climate change-related natural hazards (European Environment Agency, 2015). This last approach, although setting aside biodiversity and other ecosystem services not directly related to climate change, integrates the principle that GI is not only based on the protection and enhancement of ecosystem services, but also on the benefits human society receives from nature (European Commission, 2013a). Therefore, promoting societal well-being and health is also considered a key function of GI (DG Environment, 2012). According to this last example, integrating population into spatial planning would result in a GI network with added benefit to human society. Such a network would significantly contribute to human well-being, reinforcing the link between ecosystem and socio-economic systems, and therefore increasing the provision of benefits and value of nature.

The dependency of human well-being upon ecosystem services is widely acknowledged (Millennium Ecosystem Assessment, 2005; TEEB, 2012). Nevertheless, socio-economic systems are also key drivers of ecosystem changes, exerting pressures either through the direct exploitation of ecosystem services or through the impacts caused by human activities in general (drivers of change arrow, Figure 1). This may negatively affect ecosystem condition, compromising the functioning of ecosystems and hence the benefits society can get from them resulting in a negative effect on several components of human well-being (Millennium Ecosystem Assessment, 2005). In planning a multi-functional GI network capable of maintaining biodiversity and ensuring the delivery of ecosystem services, ecosystem condition should therefore also be taken into consideration. Areas with poor ecosystem condition may hinder the long-term provision of multiple ecosystem services (Benayas *et al.*, 2009; Frélichová & Fanta, 2015).

In this context, the implementation of GI closer to key socio-economic areas (i.e. cities) or those with poor ecosystem condition would require larger restoration efforts to cope with the different pressures or impacts when comparing to more intact (or remote) areas. Restoration measures constitute an important investment (Tucker *et al.*, 2013), but bring multiple benefits from the ecosystem services perspective (de Groot *et al.*, 2013). However, cost-effectiveness will be spatially variable depending on the location chosen

to be restored. In this context, a spatially explicit assessment of the cost-effectiveness would support decision-making and guarantee that economic resources allocated to ecosystem restoration are invested in the most cost-effective way.

The main goal of this study is to identify and assess multi-functional areas for the implementation of GI strategies, based on the supply of ecosystem services, while continuing to maintain threatened and vulnerable species. Since multiple alternatives of GI are available depending on the specific goal to be achieved, we compared three different scenarios for the identification of areas in which the supply of ecosystem services and support to biodiversity, beneficiaries (i.e. people) and ecosystem condition play different roles. In this way, the 'Nature for nature' scenario aims to identify multi-functional areas based solely on the supply of ecosystem services and the land use suitability for threatened and vulnerable species. This scenario is based on the principle of GI aiming at '*protecting and enhancing nature and natural processes*' (European Commission, 2013a). The 'Nature for people' scenario aims to identify GI that would primarily enhance natural processes but also contribute to human well-being in a more direct way, so that a higher number of people may benefit from ecosystem services. This would reinforce the link between ecosystems and socio-economic systems (Figure 1, green arrow). The 'Nature to restore' scenario prioritises multi-functional areas that are preferentially under poor ecosystem condition. The selected areas, therefore, would be closely related to socio-economic systems where drivers of change might compromise the multi-functionality in the long run (Benayas *et al.*, 2009; Frélichová & Fanta, 2015) (Figure 1, red arrow).

The scenarios were also compared in terms of the restoration effort that would be needed to improve the habitat conservation status, also assessing the cost-effectiveness of the restoration measures. We focused on the removal of invasive alien species as a case study to explore spatial priority setting criteria for ecosystem restoration.

Given that GI is inherently a spatial concept, we apply methods of Systematic Conservation Planning (SCP) to prioritize areas important for ecosystem services supply and biodiversity maintenance (Schröter *et al.*, 2014). These methods have been increasingly refined and used during the last two decades (Snäll *et al.*, 2016). SCP facilitates a transparent, flexible and defensible decision-making process for the identification of key areas for either conservation or restoration (Margules & Pressey, 2000). It also allows the integration of multiple objectives that shape the complexity of GI, as in the case of our study: ecosystem services, biodiversity, beneficiaries and ecosystem condition.

2. Methods

2.1. Selection of priority areas for GI implementation

The identification of potential EU-wide GI was performed by means of SCP (Margules & Pressey, 2000) using the supply of ecosystem services and the suitable land uses for threatened and vulnerable species as prioritization features (described below). For this purpose we used the software Marxan (Ball *et al.*, 2009), that aims to optimize the selection of priority areas through an iterative process to meet specific levels of representation of the prioritization features. We quantified the prioritization features in hexagonal planning units (PU) of 100 km^2 covering the 28 Member States of the EU, with a total of 41,608 PUs. We set a level of representation of 50% of the total amount of each prioritization feature, similarly to other studies applying SCP for ESs (Chan *et al.*, 2006; Adame *et al.*, 2014). When optimizing the achievement of 50% for

each prioritization feature, the algorithm will prioritize areas with high number of features, reducing therefore the area required for GI implementation. In this way, multi-functional areas are identified by means of SCP.

For the spatial selection of PU we removed those with a share of artificial area above 50% because planning of GI in predominantly urban areas would require a more detailed scale of analysis (Norton *et al.*, 2015).

2.1.1. Prioritization features

We included ecosystem services and suitable land uses for threatened and vulnerable species as prioritization features (Table 1). They were quantified based on the land-use map for 2010 of the Updated Configuration-2014 of the EU 'Reference Scenario' (Baranzelli *et al.*, 2014) that includes 13 land use categories (Appendix 1). The 'Reference Scenario' is fully compliant with the 'EU Energy, Transport and GHG emission trends until 2050 – Reference Scenario 2013' (European Commission, 2010) and has been simulated in the Land-Use based Integrated Sustainability Assessment (LUISA) modelling platform. LUISA was developed in order to provide EU-wide projected land-use maps at a detailed geographical scale (1 ha), translating policy scenarios into land-use changes (e.g. afforestation; deforestation; abandonment of agricultural areas; urbanization) for different time periods.

We modelled seven regulating and maintenance, and one cultural ecosystem services (Table 1, Appendix 2) using the EU 'Reference Scenario' for 2010. More details of the models can be found in Maes *et al.* (2015) and Vallecillo *et al.* (2016).

Table 1. Prioritization features for the multi-functional assessment of green infrastructure prioritization

ECOSYSTEM SERVICES		
Section	**Indicators (units)**	**Spatial resolution**
Regulating and maintenance	Capacity of ecosystems to avoid soil erosion (dimensionless between 0-1)	100 x 100 m
	Capacity to retain water (dimensionless between 0-10)	100 x 100 m
	Net ecosystem productivity (normalised index between 0-1)	10 x 10 km
	Capacity of ecosystems to sustain insect pollinators (dimensionless between 0-1)	100 x 100 m
	Potential pest control by bird species (species richness)	10 x 10 km
	Habitat quality for farmland common birds (dimensionless ratio)	10 x 10 km
	Habitat quality for forest common birds (dimensionless ratio)	10 x 10 km
Cultural	Capacity of ecosystems to provide outdoor recreation opportunities	100 x 100 m
BIODIVERSITY		
Suitable land uses for species of Community interest	**Groups**	**Spatial resolution**
	Amphibians	100 x 100 m
	Birds	100 x 100 m
	Mammals	100 x 100 m

In this study we did not include provisioning ecosystem services because they are mainly driven by human inputs like energy (e.g. labour, fertilisers), and they constitute important trade-offs for biodiversity and other ecosystem services (Maes *et al.*, 2012).

Land-use suitability maps were produced for amphibians, birds and mammals of Community interest (i.e. listed in the so-called 'Habitats Directive' (Council Directive 92/43/EEC) and 'Birds Directive' (Council Directive 2009/147/EC). For each group of species (amphibians, birds and mammals) we estimated the suitability of each land-use type (Appendix 1) by summing the suitability scores per species provided by BioScore (Louette *et al.*, 2010) according to equation 1:

$$\text{LU type suitability} = \sum \text{Suitability Value per species} \quad \text{(Eq. 1)}$$

The 'Suitability Value' is equal to 2 when the land use has high suitability and 1 for land uses with medium suitability. In this way, the more species with higher suitability values, the higher the suitability for each land-use type (LU type suitability).

The land-use map was rescaled for each group of species from 0 to 5 according to the suitability for each land-use type obtained by Eq. 1. We obtained three different land-use suitability maps, one for each group of species, which were then weighted by the richness in species of Community interest, also rescaled from

0 to 5. Maps of species richness were derived from overlaying polygons representing species' geographic ranges (IUCN, 2008; BirdLife International and NatureServe, 2014). These maps represent the overall land-use suitability for threatened species, grouped in amphibians, birds and mammals (Table 1 and Appendix 2). Thus, it does not substitute the information related to the species ranges, as other studies focusing on biodiversity do (Lung *et al.*, 2014; Venter *et al.*, 2014).

2.2. Scenarios definition

In addition to the prioritization features included in the SCP, which are the same across scenarios, Marxan allows the setting of different penalties for the selection of a given area (Figure 2). In this study, different spatial constraints were used to drive GI prioritization to diverse locations, corresponding with the specific goals of the three scenarios (Figure 2): 1. 'Nature for nature' (N4N): the goal of this scenario is to identify priority areas for GI implementation where the only inputs are the prioritization features (i.e. ESs and suitable land uses for threatened species), without including any spatial constraints. 2. 'Nature for people' (N4P): while meeting the goal stated in the N4N scenario, areas closer to populated places are preferentially selected. To do this, a spatial constraint was calculated as the distance of the PU to beneficiaries by applying a kernel density function to urban patches (each one represented by a point). We assigned a weighting factor to each point, calculated as the product of mean population density and area of urban use within each urban patch. In this way, we accounted for three different components characterizing populated areas: density of urban areas in the neighbourhood (i.e. point density of the kernel function); mean population density of each polygon with urban use, and size of the urban areas. The kernel density function was based on a 100 km radius; the distance over which is considered long distance travel. Population distribution for 2010 was taken from the 'Reference Scenario' in Baranzelli *et al.* (2014). 3. 'Nature to restore' (N2R): this scenario prioritises multi-functional areas, but favours the selection of areas with poor ecosystem condition. As a proxy of ecosystem condition we took the probability of habitats being under favourable conservation status, as estimated by Maes (2013). The model was built on Article 17 data of the Habitats Directive and identified the share of artificial land use, arable land, pastures, the proportion of land covered by Natura 2000 areas and the annual average exceedance of the critical load for nitrogen as the main factors determining habitat conservation status. In this way, areas with low probability of habitats being under favourable conservation status, considered here as poor condition, are preferentially selected for the identification of multi-functional areas.

Hence, all three scenarios identify multi-functional areas based on the same prioritization features (Table 1), but differ in the spatial constraint used to influence the final solution (Figure 2).

2.3. Analysis of scenarios outcomes

Marxan was run 100 times for each scenario using the simulated annealing algorithm (Ball *et al.*, 2009), delivering each time a network of selected areas or PUs. This provides two useful outputs for the comparison of scenarios: the 'best (near-optimal) solution' and the selection frequency. The 'best solution' shows the selected PUs that best reached the prioritization features of the 100 runs. The total area and average ecosystem condition for the PUs selected by the 'best solution' was calculated for each scenario.

The selection frequency is the number of times that each PU was selected from the 100 runs (ranging from 0 to 100). It indicates how irreplaceable that unit was to accomplish the required level of the prioritization features. PUs which were selected more than 90 times were considered as 'irreplaceable area'. A small

total irreplaceable area will be indicative of large flexibility, i.e. larger choice of alternative good solutions, for the GI implementation. We also characterized the irreplaceable areas by quantifying the relative amount of each prioritization feature represented in those locations, revealing the most important feature driving irreplaceability in the spatial prioritization. For the N4P and N2R scenarios we also identified prioritized PUs (i.e. high selection frequency) that have been selected regardless of the spatial constraints applied, closer to populated areas and under poor ecosystem condition respectively, contributing to identify critical multi-functional areas at EU level.

Finally, we analysed differences between scenarios by performing pairwise comparisons of the selection frequency of PUs and conducted correlation analysis by means of the Kendall's rank correlation coefficient.

2.4. Cost-effectiveness of restoration measures

Restoration of terrestrial habitats can take many forms and includes measures such as rewetting, extensive grazing and mowing, replanting vegetation and/or removing invasive alien species. We compared the three scenarios outcomes in terms of their cost-effectiveness using the removal of invasive alien plants as an example of a restoration measure. We chose this restoration measure for the following reasons: (1) the relevance of the pressure at EU level (European Commission, 2008); (2) the availability of EU-wide data on the distribution of invasive plant species (Chytrý *et al.*, 2009); (3) the relationship between the presence of invasive alien species and habitat conservation status (Maes, 2013); and (4) the availability of cost estimates for the removal of invasive alien species at EU level (Dietzel & Maes, 2015).

For the purpose of this particular analysis, we used the European map of alien plant invasion as base information in our approach (Chytrý *et al.*, 2009). The map defines an increasing level of invasion from 1 to 3 based on both the habitat properties and the propagule pressure. Within each PU we quantified the level of invasion and defined a threshold above which restoration measures would be applied. This threshold was set when the highest level of invasion (level 3) covers more than 25% of the total extent of the PU or when intermediate level of invasion (level 2) covered over 75% of the PU area. According to these thresholds, invasive species control was simulated for 19,079 PUs (this corresponds to the 45% of the total PUs for which the European map of alien plant invasion presented data. This excludes Cyprus).

We quantified the benefit resulting from the removal of invasive alien plants as the improvement in the habitat conservation status arising after implementing the restoration measure, in this case removal of invasive species. Better conservation status of habitats has been shown to lead to an enhancement of the supply of ecosystem services and to support the conservation of threatened species (Maes *et al.*, 2012; Egoh *et al.*, 2014). Changes in the habitat conservation status were quantified by using the model developed by Maes (2013), grounded on the Article 17 data of the Habitats Directive. The model describes habitat conservation status as a function of different pressures including the presence of invasive alien species. The 'invasive species' factor in the model took value of 1 when records of invasive species were present in the PU (i.e. in 19,079 PU as described above) and -1 when absent, as in Maes (2013). The implementation of invasive species control was then simulated in those PUs with invasive species by simply changing the value of 1 into -1 and recalculating habitat conservation status. We estimated the benefit of the restoration measure in each PU based on the changes in the habitat conservation status obtained before and after simulating the implementation of the invasive species control and weighting by the extent and level of invasion within each PU (equation 2). Higher levels of invasion will give rise to a lower probability of successful outcome following invasive species control (Higgins *et al.*, 2000). To take this into

account, we assumed that the probability of successful outcome under invasion level 3 is 2-fold lower than the probability of success under invasion level 2:

$$\text{Benefit} = \frac{(\Delta\,\text{Pr FV}*\,ha_{level\,2}) + \left(\left(\frac{\Delta\,\text{Pr FV}}{2}\right)*ha_{level\,3}\right)}{ha_{level\,2} + ha_{level\,3}} \qquad \text{(Eq. 2)}$$

Where ‘Δ Pr FV’ is the difference in the habitat conservation status before and after simulating the implementation of invasive species control.

The cost of removal of invasive alien plants (invasive species control from here onwards) at EU level was based on the LIFE projects assessment carried out by Dietzel and Maes (2015), which estimates an average cost of 901 € per ha. Since established invaders lead to high control costs (Epanchin-Niell & Hastings, 2010), we doubled the costs for invasive species control in areas under level 3, where they are likely to be more frequent. In this way, the final cost per PU was calculated according to equation 3:

$$\text{Cost Invasive species control} = (901 \text{ x ha}_{\text{level }2}) + (901 \text{ x } 2 \text{ x ha}_{\text{level }3}) \qquad \text{(Eq. 3)}$$

Finally, the cost-effectiveness of invasive species control was estimated for each scenario to assess where restoration investments would be more profitable. We summed the costs and the benefits of applying the restoration measure for the PUs of the ‘best solution’ given by each scenario in the Marxan analysis. Total cost (equation 3) and benefit for the ‘best solution’ (equation 2) were expressed in relative terms to the number of hectares to be restored for each scenario. We calculated two different indicators of cost-effectiveness: benefit-cost ratio (the higher the ratio the more cost-effective is the scenario) and the per capita benefit-cost ratio. This last indicator addresses the benefit in relative terms accounting for population living in the PUs identified by the ‘best solution’ that would benefit from the improvement in the habitat conservation status.

3. Results

3.1. Comparison of scenarios for spatial planning of GI

3.1.1. Best solution and selection frequency

The three scenarios delivered different outcomes in terms of the best solution and the selection frequency of the PUs to achieve the 50% of the total amount of each prioritization feature (Figure 2).

		'Nature for nature'	'Nature for people'	'Nature to restore'
MARXAN INPUTS	Prioritization features	7 Regulation and maintenance and 1 cultural ecosystem services 3 Types of suitable areas for threatened amphibians, birds and mammals		
	Spatial constraints	No spatial constraint	Favouring areas closer to beneficiaries	Favouring areas under poorer ecosystem condition

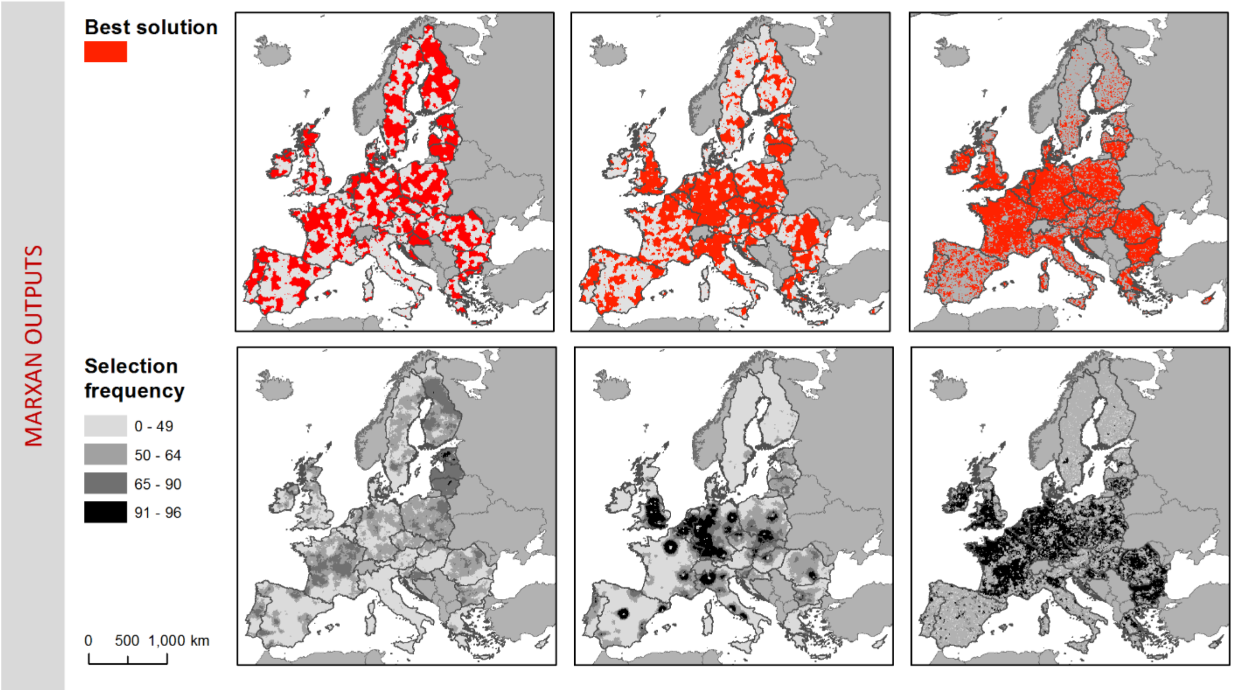


Figure 2. Scenarios used for the GI prioritization according to their inputs (prioritization features and spatial constraints) and the outputs of the spatial prioritization (best solution and selection frequency) based on systematic conservation planning

While the best solution of the N4N and N4P scenarios require practically the same amount of GI areas to guarantee an equivalent level of multi-functionality (50% of the total amount of the prioritization features), the N2R scenario would need an area that is about 10% larger to reach the same level of achievement of the prioritization features (Table 2). In addition, GI in the N2R scenario would have the poorest ecosystem condition (average probability of favourable habitat conservation status 0.09), as expected, where the selection of areas under a poorer ecosystem condition was explicitly coerced by the spatial constraint of

this last scenario. The N4P scenario, which favours the selection of PUs close to populated areas, resulted, on average, in a value of ecosystems condition closer to the N4N scenario (Table 2).

Table 2. GI solutions under the different scenarios

		Nature for nature	Nature for people	Nature to restore
Area best solution (thousands km^2)		2,059	2,072	2,287
Ecosystem condition*		0.19	0.16	0.09
Irreplaceable area** (thousands km^2)		8	385	1,154
Level of representation of the prioritization features in relative terms	Soil erosion control	8%	**10%**	9%
	Capacity to retain water	10%	**10%**	10%
	Net ecosystem productivity	9%	**10%**	10%
	Relative pollination potential	7%	6%	7%
	Potential pest control	11%	9%	10%
	Habitat quality for farmland birds	11%	9%	10%
	Habitat quality for forest birds	9%	**10%**	8%
	Outdoor recreation potential	8%	9%	9%
	Suitable areas for amphibians	5%	**10%**	**11%**
	Suitable areas for birds	**13%**	8%	9%
	Suitable areas for mammals	9%	7%	7%

*Calculated as the average probability of habitats of being under favourable conservation status for the best solution. The Dunn-test showed significant differences among scenarios for 1,000 subsamplings of 5% of the data

**Planning units selected in more than 90 out of the 100 runs for the spatial prioritization with Marxan. They were characterized by the level of representation of the prioritization features (ecosystem services and suitable land uses for threatened species) in relative terms (in bold the largest percentages for each scenario)

The small irreplaceable area for the N4N scenario shows that there are many alternatives or solutions to implement GI, since only 8,000 km^2 (80 PUs) were selected in more than 90 runs (Table 2). Irreplaceable area in N4P and especially in the N2R was notably larger given the spatial constraints imposed in these two scenarios, which are practically driving the selection frequency towards the preferential areas. Some exceptions can be found in the N4P scenario, where areas in sparsely populated countries (such as Estonia, Latvia and Lithuania) were selected in spite of the spatial constraint used (areas in orange, Figure 3). The selection of these areas suggests that the multi-functionality provided by PUs in these countries is unique within the EU (mainly due to the suitable land uses for threatened birds present in these countries) and cannot be found near populated areas (N4P scenario).

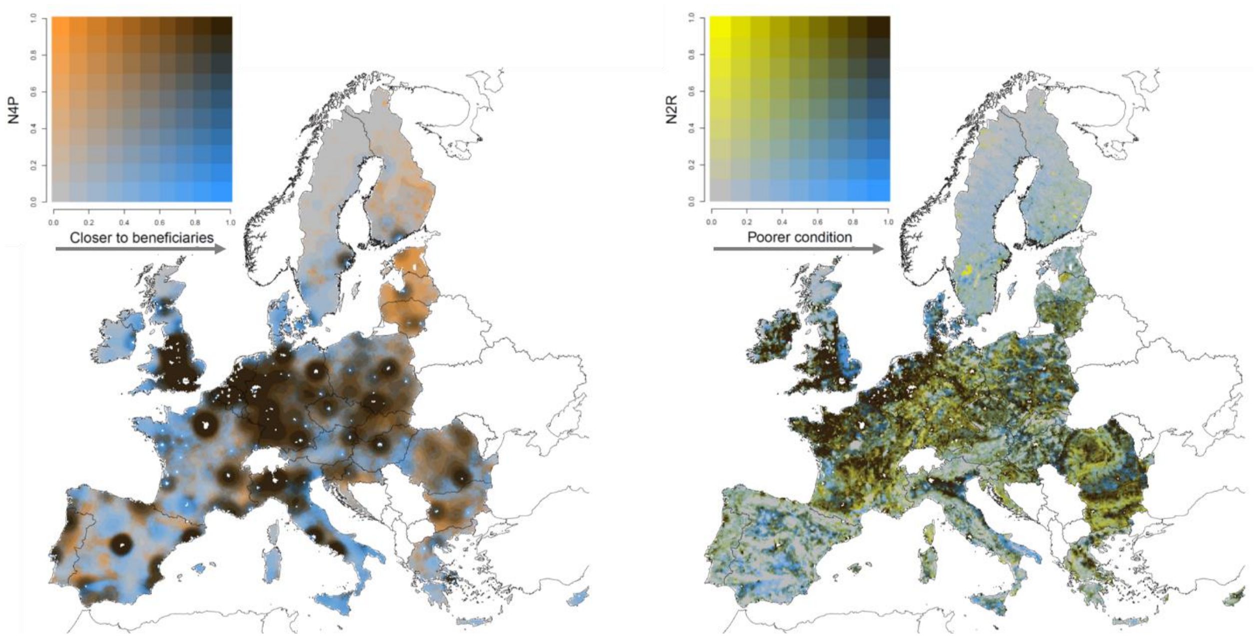


Figure 3. Selection frequency of the 'Nature for people' and 'Nature to restore' scenarios against the spatial constraint used favouring the selection of areas closer to beneficiaries and under poorer ecosystem condition respectively. Axis represent the 10% quantiles of the axis values

In the case of the N2R scenario we can also identify areas under poor condition that were not selected because they would not significantly contribute to fulfil the required level of representation of the prioritization features (areas in blue, Figure 3). On the contrary, there are some areas that are especially important because they present high selection frequency in spite of being under good ecosystem condition (areas in yellow, Figure 3). For instance, the yellow patch in Sweden shows high selection frequency because of the importance of this area for amphibians.

The relative contribution of the prioritization features in the irreplaceable areas shows that in the N4N scenario the irreplaceable area is mainly concentrated in farmland habitats. In this scenario suitable land uses for threatened birds (mostly farmland species), habitats for farmland common birds and potential pest control show the largest contribution.

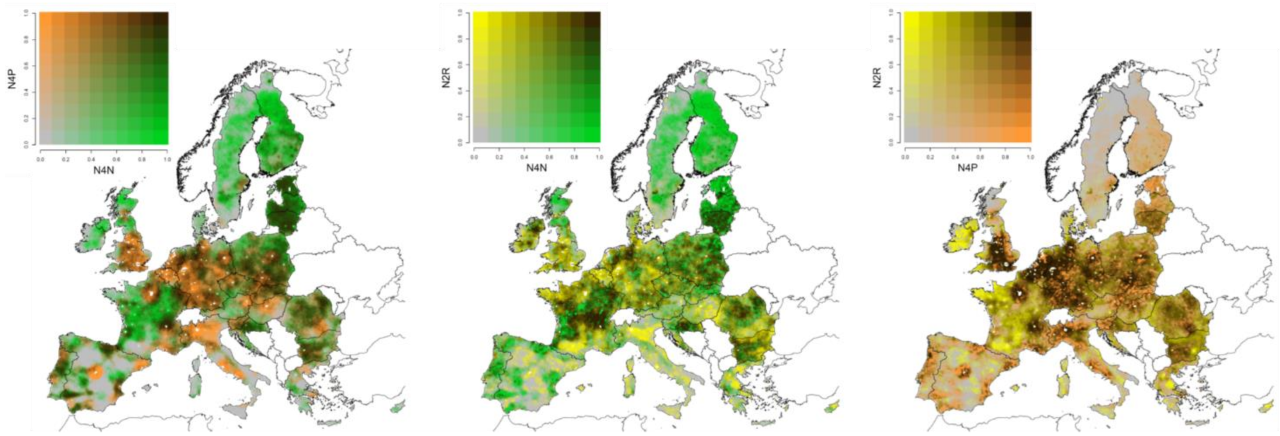
After including the spatial constraints, the irreplaceable areas are notably larger and suitable land uses for amphibians, net ecosystem productivity and water retention become the most important features in terms of relative representation. Therefore, if the irreplaceable area of the N4P scenario is chosen for GI implementation, there might be an underrepresentation of multi-functional farmlands. It is important to note here that irreplaceable areas include only the most important areas (selected in more than 90 runs) to meet the required level of prioritization features. However, it does not mean that all ESs are properly represented there. For instance, pollination and suitable land uses for mammals would be, on average, the less abundant across the three scenarios. It means that their availability is more widespread and their representation more easily achievable when searching for a solution for spatial planning of GI.

3.1.2. Pairwise comparisons among scenarios

Pairwise comparisons of the selection frequencies of the different scenarios highlight synergies and conflicts between them (Figure 4). For instance, the selection frequency of the N4N plotted against the selection frequency of the N4P scenario (Figure 4 A) depicts priority GI areas where not many people

benefit from them (in green); while other areas are prioritized for GI implementation because they are closer to many beneficiaries (in orange). In dark brown appear those areas that are important under both scenarios. By comparing all three maps (Figure 4), we identified some regions with high selection frequency in all three scenarios, for instance Lithuania, North of Croatia and Bulgaria.

The correlation analysis of the PUs selection frequency between scenarios shows that the N4P and N2R are the most similar ones (tau=0.278) given that urban areas are also a pressure included in the ecosystem condition. The large similarity between the N4P and N2R scenarios was also confirmed by the large overlap of the best solution for these two scenarios (Appendix 3). In contrast, the N4N and N2R scenarios show the weakest correlation for the selection frequency suggesting larger conflicts among the spatial planning under these two scenarios (Figure 4).



A. 'Nature for nature' and 'Nature for people' tau=0.193

B. 'Nature for nature' and 'Nature to restore' tau=0.049

C. 'Nature for people' and 'Nature to restore' tau=0.278

Figure 4. Pairwise comparisons of the selection frequencies (i.e. how irreplaceable that planning unit was to accomplish the required level of the prioritization features) for the different scenarios: 'Nature for nature' (N4N), 'Nature for people' (N4P) and 'Nature to restore' (N2R). Axis represent the 10% quantiles of the selection frequency. Kendall rank correlation coefficient (tau) between scenarios is also given

3.2. Case study: cost-effectiveness of invasive species control

The cost-effectiveness assessment confirms that restoration costs per hectare are higher for the 'best solution' of the N4P and N2R scenarios as compared to the N4N scenario (about 14% and 18% higher cost for the N4P and N2R scenarios respectively, Table 3). In spite of having the highest cost per hectare, the N2R scenario yields the largest benefit-cost ratio (Table 3). In this scenario, selection of areas under poor ecosystem condition was favoured, but it does not necessarily mean that the level of invasion is high everywhere. For instance, areas in Ireland were prioritized because of the relatively poor ecosystem condition (Maes, 2013), but has a moderate level of invasion (Chytrý *et al.*, 2009), contributing to a higher benefit after simulating the measure of invasive species control.

Table 3. Cost-effectiveness assessment of invasive species control in the 'best solution' of each scenario: 'Nature for nature' (N4N), 'Nature for people' (N4P) and 'Nature to restore' (N2R). Benefit[1] and cost[2] values are expressed per hectare to be restored. Two cost-effectiveness indicators were calculated[3]: benefit-cost ratio (benefit/cost) and the per capita benefit-cost ratio (PC benefit/cost)

	Benefit/ha	Cost/ha (€)	Beneficiaries/ha	Benefit/cost	PC Benefit/cost
N4N	1.29	932	1.40	1.38	1.17
N4P	1.42	1,058	2.07	1.34	1.38
N2R	1.56	1,100	2.09	1.42	1.21

[1]Benefit: changes in the probability of favourable conservation status weighted by the extent and the level of invasion (see equation 2)
[2]Cost: based on the average cost of 901 € per hectare and weighted by the extent and level of invasion (see equation 3)
[3]Given that the benefit is dimensionless, the required number of zeros were added when the benefit was part of the numerator to get an order of magnitude equivalent to the denominator

Differences in cost-effectiveness among scenarios become more important when population benefitting from the restoration measures is taken into account. The N4P scenario becomes the most cost-effective given the large population that would benefit from the restoration measure, followed by the N2R scenario.

4. Discussion

Although GI typically serves many purposes and functions, the actual designation and implementation of new GI depends on specific policy or project objectives. The optimal allocation of new GI in a landscape therefore calls for an evaluation of different spatial planning solutions (Madureira & Andresen, 2014). In this study we have developed a prioritization framework, making a step forward towards the support of the implementation of GI. In particular, we addressed the multi-purpose nature of GI by assessing different spatial planning solutions depending on specific goals to be achieved. Our alternatives for spatial planning of GI were based on different types of relationship between ecosystems and socio-economic systems, where both beneficiaries (i.e. the human population) and drivers of change (i.e. ecosystem condition) were taken into account by means of systematic conservation planning.

Comparisons between scenarios have shown that important areas for the supply of ecosystem services and biodiversity conservation can also be found in the vicinity of urban areas. Contrary to our expectations, the required area for GI implementation was practically the same in both the N4P and the N4N scenarios (Table 2). Therefore, GI might also be efficiently implemented in these peri-urban areas to satisfy the increasing demand for ecosystem services. However, restoration costs in these areas are typically higher as a result of poorer ecosystem condition. Our results are based on an EU-wide analysis and are useful to guide policy decisions and investments at EU level. This scale is too large for detailed planning of restoration activities, which should be performed at a smaller scale and based on local information on ESs and biodiversity, and also designed with a wide stakeholder involvement. However, the priority setting and scenarios analysis framework we have presented here could be applied at smaller spatial scale to support local planning.

The larger extent of GI required under the N2R scenario, as compared to the other two scenarios, confirmed that areas with poor ecosystem condition (i.e. as measured here by the probability of favourable habitat conservation status) have a lower capacity to supply ecosystem services per unit area. This finding is in agreement with the results of Maes *et al.* (2014) and also supports the application of (positive) changes in habitat conservation status as a proxy for the non-monetary benefit of the restoration measures.

In our attempt to quantify cost-effectiveness of restoration measures at EU level, it was quite difficult to answer where removal of invasive species would be more cost-effective. The answer largely depends on how cost-effectiveness is defined, with or without the beneficiaries' perspective. If the final goal of implementing GI and ecosystem restoration is to contribute to human well-being, beneficiaries should be considered (Zorrilla-Miras *et al.*, 2014). When accounting for the cost-effectiveness in per capita terms, we found the GI identified in the N4P scenario to be more beneficial, given the large share of the population that would potentially benefit from the ecosystem restoration. This supports the vision that implementation of ecosystem restoration may contribute to improving multi-functionality while providing increased benefits for society. In turn, it can be expected that an approach based on enhancing benefits for people may results in more financial incentives for restoration (Adame *et al.*, 2014). However, it is important to bear in mind that ecosystem restoration implemented closer to people or in areas which have unfavourable ecosystem condition will likely fail to bring ecosystems to favourable status at the level of natural ecosystems (Benayas *et al.*, 2009; Schneiders *et al.*, 2012).

The cost and benefit assessment methodology presents a number of limitations given the assumptions made with respect to the level of invasion (see methods section): the higher the invasion level, the more expensive and less effective the restoration measure will be. Although this assumption has an ecological basis, more evidence is necessary to support it and to improve our assessment. Based on the negative relationship between the presence of invasive species and habitat conservation status (Maes 2013) we

assumed that removing invasive species improves habitat conservation status and that this improvement has a positive impact on ecosystem services (Maes *et al.*, 2012). However, the role of removal of invasive species may have a variable influence depending on the ecosystem service type (Dickie *et al.*, 2014). The cost-effectiveness assessment illustrates some of the trade-offs that arise when multiple options to implement GI are available. Yet, win-win situations are possible where different alternatives meet their goals (Chan *et al.*, 2007), as in the 'best scenario' overlay (Appendix 3).

4.1. Different priorities for ecosystem management?

Our results show that important areas which may contribute to the enhancement of both biodiversity and ecosystem services are widespread across Europe. As a consequence, many different alternatives can be identified to set priorities for GI implementation. This was evidenced by the relatively small irreplaceable area for the N4N scenario and by the influence of the spatial constraints on the final allocation of the irreplaceable area in the N4P and N2R scenarios (Figure 2).
Although we included three different types of suitable land uses for threatened species, a much more rigid (less flexible) solution would have been obtained by including the species distribution ranges separately, as other studies focussing on threatened species do (Lung *et al.*, 2014; Venter *et al.*, 2014). Higher selection frequency would have been assigned to those areas where species distribution ranges are smaller because of the limited spatial representation of these ranges across the EU-28. Comparison of our results (i.e. the 'best solution' overlay for all scenarios, Appendix 3) with other studies identifying important conservation areas for threatened species (Lung *et al.*, 2014; Venter *et al.*, 2014; Hermoso *et al.*, 2016) shows rather opposing results. Most areas in our study which are identified as important for GI implementation, especially in the N4P and N2R scenarios, contradict the priorities identified in the studies based on threatened species only (most of them with restricted distribution ranges).
This lack of spatial match at EU level between conservation of threatened species and important multi-functional areas (while benefiting society) stresses the need for an ecosystem-based management system framed along a gradient of land-use intensity (Schneiders *et al.*, 2012). Areas which are characterized by low land-use intensity and high biodiversity values (in the sense of Lung *et al.* (2014) and Hermoso *et al.* (2016)) have high capacity to deliver ESs as well, especially regulating and cultural services (Chan *et al.*, 2011; Schneiders *et al.*, 2012). In these areas, by conserving and/or restoring biodiversity some ESs are also indirectly enhanced (Cimon-Morin *et al.*, 2013). However, with this study we shifted the focus towards areas of higher intensity of human use (either those in peri-urban areas in the N4P scenario, or under poor ecosystem condition in the N2R scenario), where overall supply of ESs becomes more important (Schneiders *et al.*, 2012), especially when considering their large demand. Improvement of the ecosystem condition and investments in GI in those locations may create extra opportunities to get closer to the conditions of natural areas, becoming more suitable for specific threatened species, increasing their biodiversity value (Schneiders *et al.*, 2012).

5. Conclusions

The European Commission in its GI strategy defines GI as a network contributing to improving environmental conditions and therefore citizens' health and quality of life. It also aims to support a green economy, create job opportunities and enhance biodiversity. This definition clearly underscores the multiple purposes that GI serves with respect to achieving different policy targets on biodiversity, climate

change, human well-being and employment. Our study shows that the design of a GI network depends heavily on the policy priorities. Under the scenario of a limited budget, a network which is designed to deliver ecosystem services mainly as benefits to people will have a different spatial configuration than networks which are planned to achieve favourable habitat and species conservation status as required by the Habitats Directive. There is unlikely to be a single, cost effective solution that fits all the different objectives formulated in the EU GI strategy given a realistic budget. Still, an exercise such as that presented in this study can help define priority areas. Given the scarcity of resources for investment in GI and ecosystem restoration, win-win situations should be identified where GI development can deliver to several policy objectives simultaneously.

6. Acknowledgment

This study is a contribution to the OpenNESS project and has received funding from the European Union's Seventh Programme for Research, technological development and demonstration under Grant agreement No. 308428. Thank you to Eva Ivits who kindly provided the data of net ecosystem productivity and to the LUISA team (JRC- Territorial Development Unit) for the simulated land use maps and the population projections.

7. References

Adame, M.F., Hermoso, V., Perhans, K., Lovelock, C.E. & Herrera-Silveira, J.A. (2014) Selecting Cost-Effective Areas for Restoration of Ecosystem Services. *Conservation Biology*, 29, 493-502. doi - http://dx.doi.org/10.1111/cobi.12391

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

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

Barral, M.P., Rey Benayas, J.M., Meli, P. & Maceira, N.O. (2015) Quantifying the impacts of ecological restoration on biodiversity and ecosystem services in agroecosystems: A global meta-analysis. *Agriculture, Ecosystems & Environment*, 202, 223-231. doi - http://dx.doi.org/10.1016/j.agee.2015.01.009

Benayas, J.M.R., Newton, A.C., Diaz, A. & Bullock, J.M. (2009) Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis. *Science*, 325, 1121-1124. doi - 10.1126/science.1172460

BirdLife International and NatureServe (2014) Bird Species Distribution Maps of the World. Birdlife International. Cambridge, UK and NatureServe, Arlington, USA.

Chan, K.M.A., Hoshizaki, L. & Klinkenberg, B. (2011) Ecosystem services in conservation planning: Targeted benefits vs. co-benefits or costs? *PLoS One*, 6. doi - 10.1371/journal.pone.0024378

Chan, K.M.A., Shaw, M.R., Cameron, D.R., Underwood, E.C. & Daily, G.C. (2006) Conservation Planning for Ecosystem Services. *PLoS Biol*, 4, e379. doi - 10.1371/journal.pbio.0040379

Chan, K.M.A., Pringle, R.M., Ranganathan, J.A.I., Boggs, C.L., Chan, Y.L., Ehrlich, P.R., Haff, P.K., Heller, N.E., Al-Khafaji, K. & Macmynowski, D.P. (2007) When Agendas Collide: Human Welfare and Biological Conservation. *Conservation Biology*, 21, 59-68. doi - 10.1111/j.1523-1739.2006.00570.x

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

Cimon-Morin, J., Darveau, M. & Poulin, M. (2013) Fostering synergies between ecosystem services and biodiversity in conservation planning: A review. *Biological Conservation*, 166, 144-154. doi - http://dx.doi.org/10.1016/j.biocon.2013.06.023

de Groot, R.S., Blignaut, J., Van Der Ploeg, S., Aronson, J., Elmqvist, T. & Farley, J. (2013) Benefits of Investing in Ecosystem Restoration. *Conservation Biology*, 27, 1286-1293. doi - 10.1111/cobi.12158

DG Environment (2012) *The Multifunctionality of Green Infrastructure. Science for Environment Policy. In-depth Reports* European Commission. Retrieved from - http://ec.europa.eu/environment/nature/ecosystems/docs/Green_Infrastructure.pdf

Dickie, I.A., Bennett, B.M., Burrows, L.E., Nuñez, M.A., Peltzer, D.A., Porté, A., Richardson, D.M., Rejmánek, M., Rundel, P.W. & van Wilgen, B.W. (2014) Conflicting values: Ecosystem services and invasive tree management. *Biological Invasions*, 16, 705-719. doi - 10.1007/s10530-013-0609-6

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

Egoh, B.N., Paracchini, M.L., Zulian, G., Schägner, J.P. & Bidoglio, G. (2014) Exploring restoration options for habitats, species and ecosystem services in the European Union. *Journal of Applied Ecology*, 51, 899-908. doi - 10.1111/1365-2664.12251

Epanchin-Niell, R.S. & Hastings, A. (2010) Controlling established invaders: Integrating economics and spread dynamics to determine optimal management. *Ecology Letters*, 13, 528-541. doi - 10.1111/j.1461-0248.2010.01440.x

European Commission (2008) *Towards an EU Strategy on Invasive Species. COM(2008) 789 final* Retrieved from - http://ec.europa.eu/environment/nature/invasivealien/docs/1_EN_ACT_part1_v6.pdf

European Commission (2010) *EU energy trends to 2030*, Publications office of the European Union, Luxembourg. Retrieved from - https://ec.europa.eu/energy/sites/ener/files/documents/trends_to_2030_update_2009.pdf

European Commission (2011) *Our life insurance, our natural capital: an EU biodiversity strategy to 2020. COM(2011)244*, Brussels. Retrieved from - http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0244:FIN:EN:PDF

European Commission (2013a) *Green infrastructure (GI) - enhancing Europe's Natural Capital. COM(2013)249*, Brussels. Retrieved from - http://eur-lex.europa.eu/resource.html?uri=cellar:d41348f2-01d5-4abe-b817-4c73e6f1b2df.0014.03/DOC_1&format=PDF

European Commission (2013b) *Mapping and Assessment of Ecosystems and their Services: An analytical framework for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020* (Discussion paper. Technical Report). Retrieved from - http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/MAESWorkingPaper2013.pdf

European Environment Agency (2014) *Spatial analysis of green infrastructure in Europe*. (EEA Technical report). European Environment Agency. Retrieved from - http://www.eea.europa.eu/publications/spatial-analysis-of-green-infrastructure/at_download/file

European Environment Agency (2015) *Exploring nature-based solutions: The role of green infrastructure in mitigating the impacts of weather- and climate change-related natural hazards*. (Technical report No 12/2015). Retrieved from - http://www.eea.europa.eu/publications/exploring-nature-based-solutions-2014/at_download/file

Frélichová, J. & Fanta, J. (2015) Ecosystem service availability in view of long-term land-use changes: a regional case study in the Czech Republic. *Ecosystem Health and Sustainability*, 1, 1-15. doi - 10.1890/ehs15-0024.1

Hermoso, V., Clavero, M., Villero, D. & Brotons, L. (2016) EU's conservation efforts need more strategic investment to meet continental conservation needs. *Conservation Letters*, n/a-n/a. doi - http://dx.doi.org/10.1111/conl.12248

Higgins, S.I., Richardson, D.M. & Cowling, R.M. (2000) Using a dynamic landscape model for planning the management of alien plant invasions. *Ecological Applications*, 10, 1833-1848. doi - http://dx.doi.org/10.1890/1051-0761(2000)010[1833:UADLMF]2.0.CO;2

IUCN (2008) The IUCN Red List of Threatened Species. Version 2011.

Liquete, C., Kleeschulte, S., Dige, G., Maes, J., Grizzetti, B., Olah, B. & Zulian, G. (2015) Mapping green infrastructure based on ecosystem services and ecological networks: A Pan-European case study. *Environmental Science & Policy*, 54, 268-280. doi - http://dx.doi.org/10.1016/j.envsci.2015.07.009

Louette, G., Maes, D., Alkemade, J.R.M., Boitani, L., de Knegt, B., Eggers, J., Falcucci, A., Framstad, E., Hagemeijer, W., Hennekens, S.M., Maiorano, L., Nagy, S., Serradilla, A.N., Ozinga, W.A., Schaminée, J.H.J., Tsiaousi, V., van Tol, S. & Delbaere, B. (2010) BioScore–Cost-effective assessment of policy impact on biodiversity using species sensitivity scores. *Journal for Nature Conservation*, 18, 142-148. doi - http://dx.doi.org/10.1016/j.jnc.2009.08.002

Lung, T., Meller, L., van Teeffelen, A.J.A., Thuiller, W. & Cabeza, M. (2014) Biodiversity Funds and Conservation Needs in the EU Under Climate Change. *Conservation Letters*, 7, 390-400. doi - 10.1111/conl.12096

Madureira, H. & Andresen, T. (2014) Planning for multifunctional urban green infrastructures: Promises and challenges. *URBAN DESIGN International*, 19, 38-49. doi - 10.1057/udi.2013.11

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

Maes, J., 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. doi - http://dx.doi.org/10.1016/j.biocon.2012.06.016

Maes, J., Barbosa, A., Baranzelli, C., Zulian, G., Batista e Silva, F., Vandecasteele, I., Hiederer, R., Liquete, C., Paracchini, M., Mubareka, S., Jacobs-Crisioni, C., Castillo, C. & Lavalle, C. (2014) More green infrastructure is required to maintain ecosystem services under current trends in land-use change in Europe. *Landscape Ecology*, 1-18. doi - 10.1007/s10980-014-0083-2

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

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

Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-being: Synthesis*, Island Press, Washington, DC. Retrieved from - http://www.millenniumassessment.org/documents/document.356.aspx.pdf

Norton, B.A., Coutts, A.M., Livesley, S.J., Harris, R.J., Hunter, A.M. & Williams, N.S.G. (2015) Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning*, 134, 127-138. doi - 10.1016/j.landurbplan.2014.10.018

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, 1121-1124. doi - 10.1126/science.1172460

Schneiders, A., Van Daele, T., Van Landuyt, W. & Van Reeth, W. (2012) Biodiversity and ecosystem services: Complementary approaches for ecosystem management? *Ecological Indicators*, 21, 123-133. doi - http://dx.doi.org/10.1016/j.ecolind.2011.06.021

Schröter, M., Rusch, G.M., Barton, D.N., Blumentrath, S. & Nordén, B. (2014) Ecosystem Services and Opportunity Costs Shift Spatial Priorities for Conserving Forest Biodiversity. *PLoS One*, 9, e112557. doi - 10.1371/journal.pone.0112557

Snäll, T., Lehtomäki, J., Arponen, A., Elith, J. & Moilanen, A. (2016) Green Infrastructure Design Based on Spatial Conservation Prioritization and Modeling of Biodiversity Features and Ecosystem Services. *Environmental Management*, 57, 251-256. doi - 10.1007/s00267-015-0613-y

TEEB (2012) *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations.* Routledge, Abingdon and New York.

Tucker, G., Underwood, E., Farmer, A., Scalera, R., Dickie, I., McConville, A. & van Vliet, W. (2013) *Estimation of the financing needs to implement Target 2 of the EU Biodiversity Strategy. Report to the European Commission*. Institute for European Environmental Policy, London. Retrieved from - http://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/2020/Fin%20Target%202.pdf

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

Venter, O., Fuller, R.A., Segan, D.B., Carwardine, J., Brooks, T., Butchart, S.H.M., Di Marco, M., Iwamura, T., Joseph, L., O'Grady, D., Possingham, H.P., Rondinini, C., Smith, R.J., Venter, M. & Watson, J.E.M. (2014) Targeting Global Protected Area Expansion for Imperiled Biodiversity. *PLoS Biology*, 12. doi - 10.1371/journal.pbio.1001891

Zorrilla-Miras, P., Palomo, I., Gómez-Baggethun, E., Martín-López, B., Lomas, P.L. & Montes, C. (2014) Effects of land-use change on wetland ecosystem services: A case study in the Doñana marshes (SW Spain). *Landscape and Urban Planning*, 122, 160-174. doi - 10.1016/j.landurbplan.2013.09.013

8. Appendices

Appendix 1. Land use categories of the EU 'Reference Scenario' used to assess the supply of ecosystem services and suitability for threatened and vulnerable species. Correspondence with the Bioscore data based on Corine Land Cover classification is also shown

'Reference Scenario'	**Bioscore - Corine Land Cover**
Urban fabric	Continuous urban fabric
	Discontinuous urban fabric
Industry and related uses	Industrial or commercial units
Infrastructure	Road and rail networks and associated land
	Port areas
	Airports
	Mineral extraction sites
	Dump sites

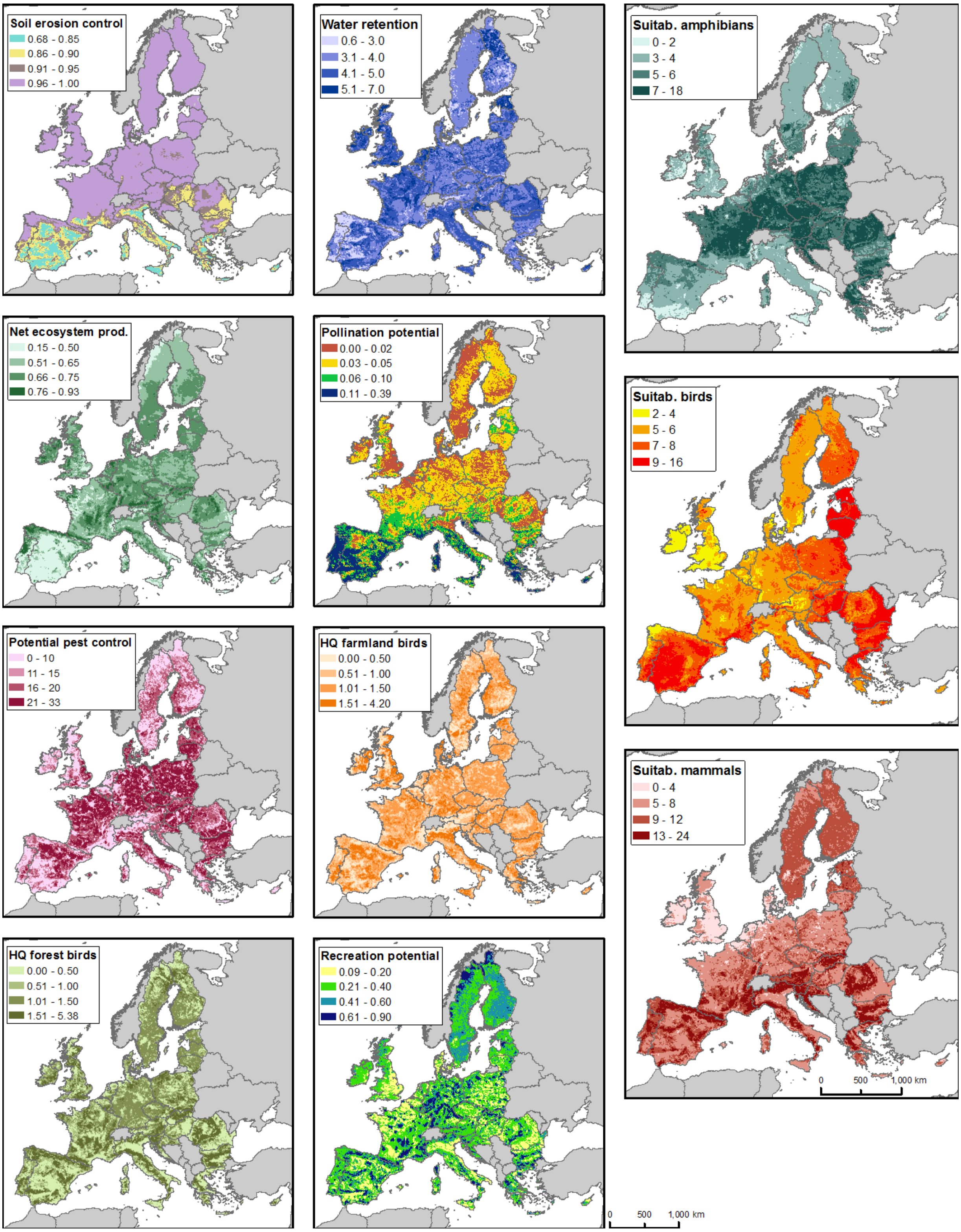
Appendix 1. Land use categories of the EU 'Reference Scenario' used to assess the supply of ecosystem services and suitability for threatened and vulnerable species. Correspondence with the Bioscore data based on Corine Land Cover classification is also shown

'Reference Scenario'	**Bioscore - Corine Land Cover**
	Construction sites
Urban green leisure	Green urban areas
	Sport and leisure facilities
Arable	Non-irrigated arable land
	Permanently irrigated land
	Rice fields
	Annual crops associated with permanent crops
	Complex cultivation patterns
	Land principally occupied by agriculture, with significant areas of natural vegetation
Permanent crops	Vineyards
	Fruit trees and berry plantations
	Olive groves
	Agro-forestry areas
Pastures	Pastures
Forests	Broad-leaved forest
	Coniferous forest
	Mixed forest
Natural land	Natural grasslands
	Moors and heathland
	Sclerophyllous vegetation
Transitional woodland-shrub	Transitional woodland-shrub
Other nature	Beaches, dunes, sands
	Bare rocks
	Sparsely vegetated areas
	Burnt areas
	Glaciers and perpetual snow
Wetlands	Inland marshes
	Peat bogs
	Salt marshes
	Salines

Appendix 1. Land use categories of the EU 'Reference Scenario' used to assess the supply of ecosystem services and suitability for threatened and vulnerable species. Correspondence with the Bioscore data based on Corine Land Cover classification is also shown

'Reference Scenario'	Bioscore - Corine Land Cover
	Intertidal flats
Water bodies	Water courses
	Water bodies
	Coastal lagoons
	Estuaries
	Sea and ocean

Appendix 2. Maps of the prioritization features: ecosystem services and suitable land uses for threatened and vulnerable species (amphibians, birds and mammals)



Appendix 3. Overlay of the 'best solution' of the three scenarios used for the spatial selection of the GI network: 'Nature for nature' (N4N), 'Nature for people' (N4P) and 'Nature to restore' (N2R). The scenarios overlay is given for all possible combinations.