# Green infrastructure spatial planning considering ecosystem services assessment and trade-off analysis. Application at landscape scale in Galicia region (NW Spain).

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## Abstract

Green Infrastructure (GI) is increasingly being adopted in land management as a way of ensuring provision of the ecosystem services (ESS) required for human well-being. As GI is a spatial concept, spatial planning methods must be applied in designing GI. Many studies have focused on designing certain GI zones or on planning a GI specifically considering one or a few ESS. However, studies on GI planning considering all types of ESS and different GI zones are scarce. This paper describes a methodology that addresses the holistic spatial planning of GI by considering the potential capacity of areas to provide all of the ESS assessed. Buffer zones and multifunctional zones were delineated by using a specific procedure for each zone at landscape scale. The spatial planning of buffer areas and multifunctional zones was based on the analysis of trade-offs between ESS and on the integration of synergic ESS by means of a multicriteria evaluation technique. The methodology was validated by application to the spatial planning of a GI in the region of Galicia at landscape level. Integration of the results of ESS assessment in a multifunctional GI makes land planning and management easier and ensures provision of all types of ESS.

*Keywords: green infrastructure delineation; green infrastructure zoning; multicriteria evaluation; multifunctional green infrastructure.*

## 1. Introduction

Green Infrastructure (GI) is defined in the European Commission (EC)'s communication *"Green Infrastructure (GI) — Enhancing Europe's Natural Capital"* 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 (ESS). The GI approach is increasingly being adopted in land management policies and strategies as a way of ensuring provision of the ESS required for human well-being and quality of life. As GI is inherently a spatial concept (Snäll et al., 2016), spatial planning methods must be applied in designing GI networks.

The spatial planning of GI requires, first of all, information about the spatial pattern of the ESS provision potential across the landscape. This aspect has been addressed in a large number of studies. Several published reviews outline the main methods used for ESS modelling, assessment (de Groot et al., 2010) and mapping (Martínez-Harms & Balvanera, 2012; Schägner et al., 2013) and describe decision support tools for ESS evaluation (Bagstad et al., 2013).

The results of ESS assessment are often used as a basis for spatial planning decisions (Arkema et al., 2015; Ruckelshaus et al., 2015). However, such results have not been widely used for the spatial planning of GI, and implementation is challenging (de Groot et al., 2010; Ruckelshaus et al., 2015). For instance, Portman (2013) highlights the difficulty of simplifying complexities between ESS so that planning processes can incorporate this approach. Some studies have achieved a step forward in GI planning by delineating hotspots, understood both as areas that provide a large proportion of a particular service or as areas providing more than one ES (Schröter & Remme, 2016). However, usually the spatial delineation of such hotspots does not either distinguish zones according to the type of ESS provided or delineate clearly the spatial area of GI. On the contrary, hotspots are frequently referred to administrative units such as municipalities (Queiroz et al., 2015).

Many studies have focused on the design of part of a GI, especially ecological corridors (e.g. Chang et al., 2012), or on planning a GI specifically aimed at one or a few ESS, such as those related to the water cycle (Liu et al., 2016). However, studies on GI planning considering all types of ESS are scarce (Kopperoinen et al., 2014). Estreguil et al. (2019) compiled outstanding case studies of GI planning, most of which focused on connectivity analysis and delimitation of ecological corridors, but did not delimit buffer zones or multifunctional areas. The method used in the EU Green Infrastructure Strategy and described by the EEA (2014) and Liquete et al. (2015) is particularly striking and identify zones with the maximum combined capacity to provide regulating and maintenance ecosystem services, which form part of GI network for conservation, and zones with a moderate capacity to provide those ESS, which are included in GI network for restoration.

Multi-criteria evaluation of the results of the ESS assessment is the most common technique used for the spatial delineation of GI. This method usually uses a weighted linear combination to aggregate criteria corresponding to the different ESS assessed. Meerow and Newell (2017) applied a GIS-based multi-criteria approach to the spatial planning of a multi-functional urban GI by using the weighted linear summation for a combination of six ESS maps and incorporating stakeholder priorities via allocation of the map weights. In a similar way, Gret-Regamey et al. (2017) developed a GIS-based multi-criteria decision analysis (MCDA) approach integrated in a web platform to enable interactive exploration of the consequences and trade-offs. The linear combination of multiple standardised ESS values is also call “intensity method” in other studies (Schröter & Remme, 2016). Kopperoinen et al. (2014) also aggregated ESS provision potential raster layers, in this case allocating the same weight to each ESS, into a total ESS provision potential raster layer from which multifunctional areas of GI can be identified.

Heuristic optimisation techniques represent a further step in developing the spatial planning of GI, although, in most cases, algorithms designed for different purposes are applied. These include spatial conservation prioritization techniques for planning natural spaces (Snäll et al., 2016; Vallecillo et al., 2018) and land use optimisation algorithms for regional planning (Hu et al., 2014). Marxan software for conservation planning implements reserve selection algorithms and was used by Schröter & Remme (2016) and Vallecillo et al. (2018) to plan GI based on multiple ESS.

None of the methods described in either of the cited studies deals with the delineation of different buffer or multi-functional zones of the GI. However, the method described by Liquete et al. (2015) distinguishes two GI zones (conservation and restoration), but does not delineate different areas according to the type of ESS provided.

Here we propose a methodology for the spatial planning of GI that delineates different GI zones according to the ESS provided in each area: a buffer zone, determined by the regulating and maintenance services; and three multi-functional zones, identified by expert evaluation of ESS and by analysis of synergies and trade-offs. The conclusions of the EEA (2014) regarding the spatial analysis of synergies and trade-offs between the selected ESS were therefore taken into account.

For future developments, Liquete et al. (2015) also propose considering provisioning and cultural services and integration of the demand for ESS, i.e. the relationship between where ESS are produced and where they are consumed. Both aspects are included in the methodology proposed in this paper, which takes the results of the provisioning and cultural services assessment into account and considers the demand for cultural services in delineating one of the multi-functional zones.

Here, we present a methodology that addresses the holistic spatial planning of GI by taking the potential of areas to provide all of the ESS assessed into account and delineating buffer zones and three types of multifunctional zones via the use of a specific procedure for each zone at regional or landscape scale. This methodology is described in the following section and applied in the subsequent section for GI planning in the region of Galicia.

## 2. Methodology

In order to plan a multifunctional GI that meets the objectives of biodiversity preservation and supply of ESS required for human well-being, two issues must be considered: the connectivity of spaces with natural values and land potential for providing ESS (Liquete et al., 2015); and the scale of analysis for the identification of GI elements and their capacity to supply ESS (Grêt-Regamey et al., 2014; Raudsepp-Hearne et al., 2010). The EEA (2011) distinguishes between GI at urban scale and at landscape scale (regional, national or transnational), as these are constituted by different land elements and managed with specific instruments and procedures for each scale. In this paper, a methodology for the spatial design of a multifunctional GI at landscape level was developed on the basis of information about the spatial distribution of the provision potential of multiple ESS and considering the connectivity of the GI elements and the proximity to demanding areas of certain ESS.

### *2.1. Ecosystem services assessment*

The ESS provision potential is the capacity of an area to produce an ES, which depends on the land qualities required to produce a specific ESS and on the actual provision (Kopperoinenn et al., 2014). Ecosystems can provide multiple services, which vary depending on their uses and ecological functions and even on the scale. The ESS were identified on the basis of the almost hundred ESS included in the Common International Classification of Ecosystem Services (CICES 5.1; Haines-Young & Potschin, 2018), from which the ESS evaluable with the available data for the study region were selected. The remaining ESS were weighted in a multi-disciplinary approach by five research groups: three biologists specialised in biodiversity; five forestry and agricultural engineers specialised in rural land use planning; three architects and urban planners; and two civil engineers specialised in hydrological analysis. Each group assigned a score of between 1 and 10 to each ES according to its relative importance for the regional GI of Galicia, distributing a maximum of 200 points between the different ESS. The following ESS were selected from the resulting scores (Table 1). The remaining ESS obtained a score lower than 10 or were discarded because the data required for their assessment were not available.

Table 1. Selected ESS from CICES 5.1

| Type of ES | Code | Class | Score |
|---|---|---|---|
| **Provision** | 1.1.1.1 | Cultivated terrestrial plants for nutritional purposes | 33 |
| | 1.1.1.2 | Fibres and other materials from cultivated plants | 24 |
| | 1.1.1.3 | Cultivated plants grown as a source of energy | 26 |
| | 1.1.3.1 | Animals reared for nutritional purposes | 26 |
| | 1.1.3.2 | Fibres and other materials from reared animals for direct use or processing | 24 |
| | 4.2.1.1 | Surface water for drinking | 47 |
| | 4.2.1.2 | Surface water used as a material | 35 |
| | 4.2.2.1 | Ground water for drinking | 40 |
| **Regulation** | 2.1.1.2 | Filtration, sequestration, storage, accumulation by microorganisms, algae, plants and animals | 25 |
| | 2.2.1.1 | Control of erosion rates | 34 |
| | 2.2.1.3a | Hydrological cycle regulation | 30 |
| | 2.2.1.3b | Flood control | 34 |
| | 2.2.1.5 | Fire protection | 34 |
| | 2.2.2.3 | Maintaining nursery populations and habitats (including gene pool protection) | 43 |
| | 2.2.5.1 | Regulation of the chemical condition of freshwaters by living processes | 29 |
| | 2.2.6.1 | Regulation of chemical composition of atmosphere and oceans | 45 |
| **Cultural** | 3.1.1.2 | Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions | 24 |
| | 3.1.2.3 | Characteristics of living systems that are resonant in terms of culture or heritage | 39 |

Some closely related ESS were grouped together as insufficient information was available to evaluate each ES distinctively. This applied to ESS 1.1.3.1 and 1.1.3.2, which were grouped as ES "Animals reared for nutritional purposes or fibre production", and to ESS 4.2.1.1, 4.2.1.2 and 4.2.2.1, which were grouped into ES "Water for drinking or used as a material". The most recent version of CICES (5.1) considers ESS related to hydrological cycle regulation and to flood prevention as a single group, although they were considered separate services in the previous version (4). However, in this case, we carried out independent evaluation of each ESS because different types of analysis are required.

The models used for ESS assessment are described below, with the exception of ESS 4.2.1.1, 4.2.1.2, 4.2.2.1, 2.2.1.3, 2.2.1.5, 2.2.2.3 and 2.2.5.1, whose provision potential was obtained from unpublished studies carried out by researchers specialised in the hydrological cycle and biodiversity.

### 2.1.1. Provisioning ESS

All the provisioning ESS assessed depend directly or indirectly on land suitability for producing plant biomass. Thus, the potential provision of these services was calculated as the weighted summation of the land suitability for biomass production and the capacity of current land covers to supply the ES in question, on the basis of the approach described by Burkhard et al. (2009) for determining the capacity of different land covers to generate ESS.

Land suitability for biomass production was determined from precipitation and temperature (Kandziora et al., 2013), land aspect and slope (Grêt-Regamey et al., 2014), soil texture (Porta i Casanellas et al., 1994) and geomorphology (analysed from TPI index; Weiss, 2001), as in Equation 1:

$$\text{Biomass production} = \text{Temperature} \times 0.3 + \text{Precipitation} \times 0.1 + \text{Aspect} \times 0.1 + \text{Slope} \times 0.2 + \text{Geomorphology} \times 0.2 + \text{Soil} \times 0.1 \qquad \text{(Equation 1)}$$

This model was used to evaluate ESS 1.1.1.1, 1.1.1.2, 1.1.1.3 and 1.1.3.1 with a weighting factor of between 0 and 5 (as in Burkhard et al., 2009), for each land cover in the *Land Use Information System of Spain* (https://www.siose.es/SIOSEtheme-theme/documentos/pdf/Doc_tec_SIOSE2005_v2.3.pdf) according to its capacity to produce plants for food (ES 1.1.1.1), wood and biomass for energy (ES 1.1.1.3), vegetal fodder (ES 1.1.3.1) and vegetal fibre from wood and from herbaceous plants (hemp and flax; ES 1.1.1.2). In the latter case, the productivity of forest and agricultural species with the highest potential to produce vegetal fibre (i.e. eucalyptus and hemp in the study region), was used for reference purposes. The weights for different agricultural land covers were divided by 5, as hemp productivity (3 tn/ha.year; Höppner & Menge-Hartmann, 2007) is five times lower than that of *Eucalyptus nitens* (16 tn/ha.year; Pérez Cruzado, 2011). The weights allocated to each land cover for each ES shown in Table 2 were subsequently normalised between 0 and 1.

Table 2. Weights allocated to current land covers for each ES

| **Land cover** | **Weights for different ESS** | | | |
|---|---|---|---|---|
| | **ESS 1.1.1.1** | **ESS 1.1.1.2** | **ESS 1.1.1.3** | **ESS 1.1.3.1, 1.1.3.2** |
| Rock, water, beaches, mines, cliffs | 0 | 0 | 0 | 0 |
| Artificial land cover | 0 | 0 | 0 | 0 |
| Conifer trees | 0 | 5 | 5 | 0 |
| Crop and meadow | 5 | 1 | 1 | 4 |
| Crop | 5 | 1 | 1 | 4 |

|  |  |  |  |  |
|---|---|---|---|---|
| Deciduous trees | 2 | 5 | 5 | 1 |
| Eucalyptus | 0 | 5 | 5 | 0 |
| Eucalyptus and conifer trees | 0 | 5 | 5 | 0 |
| Wetland | 0 | 0 | 1 | 0 |
| Scrubland | 0 | 0 | 2 | 2 |
| Scrubland and trees | 1 | 5 | 2 | 2 |
| Scrubland and rock | 0 | 0 | 0 | 0 |
| Mix of tree species | 2 | 5 | 5 | 0 |
| Mosaic or agricultural and scrub land | 3 | 1 | 3 | 3 |
| Mosaic of agricultural and urban land | 1 | 0 | 0 | 1 |
| Mosaic of crops and tree species | 3 | 3 | 0 | 3 |
| Meadow | 0 | 0 | 0 | 5 |
| New forest plantations | 0 | 4 | 4 | 0 |
| Vineyard and woody crops | 4 | 0 | 2 | 0 |
| Urban | 0 | 0 | 0 | 0 |
| Urban green areas | 1 | 0 | 1 | 0 |

### 2.1.2. Regulating ESS

ES 2.1.1.2, related to water purification, was assessed as the average of pollution emission potential and pollution filtering capacity, by considering nitrogen as reference pollutant (Liquete et al., 2015). On one hand, the main anthropogenic sources of nitrogen pollution are households, industrial spills and gases generated by car traffic or application of fertilizer to farmland (Sutton, 2011); according to this, weights between 0 and 1 were allocated to each land cover (Table 3). The resulting map was used as input weight raster to calculate a pollution flow accumulation map with the “Flow accumulation” tool in Arcgis. This map provides the pollution emission potential.

On the other hand, the filtering capacity of rivers depends on the residence time of pollutants in water, so that the nitrogen filtering capacity increases with distance from the source of the river (Grizzetti et al., 2008). Nonetheless, the nitrogen levels tend to be maintained when the volume of the river reaches a certain level (Alexander et al., 2000). The filtering capacity of watercourses was therefore determined on the basis of the distance from the source, by allocating a value of 0 to stretches at distances less than 2 km and greater than 30 km from the source and a linearly normalised value for corresponding distances of between 0 (30 km) and 1 (2 km).

The filtering capacity of land is determined by the capacity of the vegetation to hold water and absorb nitrogen from the water, as well as by the capacity of soil organisms to break down water pollutants. This was estimated by assigning the weights indicated in Table 3 to each land cover and using the weights proposed by Burkhard et al. (2009) as reference weights. The resulting map was combined with the map of filtering capacity of rivers, by assigning the value of the latter map to the cells corresponding to rivers, to estimate the final pollution filtering capacity.

Table 3. Weights allocated to land covers according to their capacity to produce nitrogen, to filter pollution and to prevent soil erosion

| Land cover | Weight according to N production | Weight according to capacity of filtering | Weight according to soil erosion prevention capacity |
|---|---|---|---|
| Rock, water, beaches, cliffs | 0 | 0 (excluding water) | 0 |

| | | | |
|---|---|---|---|
| Artificial land cover | 1 | 0 | 0 |
| Mines and extraction areas | 1 | 0 | 0 |
| Conifer trees | 0 | 4 | 4 |
| Crop and meadow | 0.7 | 0 | 0 |
| Crop | 0.8 | 0 | 0 |
| Deciduous trees | 0 | 5 | 5 |
| Eucalyptus | 0.2 | 4 | 4 |
| Eucalyptus and conifer trees | 0.2 | 4 | 4 |
| Wetland | 0 | 3 | 0 |
| Scrubland | 0 | 4 | 3 |
| Scrubland and trees | 0 | 4 | 3 |
| Scrubland and rock | 0 | 3 | 0 |
| Mix of tree species | 0 | 5 | 5 |
| Mosaic or agricultural and scrub land | 0.5 | 0 | 2 |
| Mosaic of agricultural and urban land | 1 | 0 | 0 |
| Mosaic of crops and tree species | 0.5 | 1 | 2 |
| Meadow | 0.3 | 0 | 0 |
| New forest plantations | 0.2 | 3 | 3 |
| Vineyard and woody crops | 0.8 | 1 | 1 |
| Urban | 1 | 0 | 0 |
| Urban green areas | 0.2 | 1 | 2 |

The provision potential for ES 2.2.1.1, related to erosion control, was calculated as the average of the erosion potential and the soil retention capacity of each land cover type. The erosion potential was obtained from the National Soil Erosion Inventory, which applies the RUSLE method. The soil retention capacity was estimated by allocating the weights indicated in Table 3 to the current land covers and using those applied by Burkhard et al. (2009) as reference weights and normalising them between 0 and 1.

One of the most important ESS from the point of view of the contribution of GI to climate change mitigation and adaptation is ES 2.2.6.1, related to the regulation of chemical composition of atmosphere. Three cases were considered in order to evaluate the carbon capture and storage potential of ecosystems. These cases represent different points of the carbon cycle and distinguish the capacity of carbon capture by biomass, the carbon transfer from biomass to soil and the carbon storage in soil.  Each case can be assimilated to a different residence time of carbon in the ecosystem:

*1. Carbon capture* (ES 2.2.6.1a) represents the capacity of atmospheric carbon capture by biomass, with carbon becoming an integral part of biomass through metabolic processes. The period evaluated varies from 0 to 20 years, since this is the residence time of carbon in the ecosystem for short term forest species in the region. The carbon capture potential was obtained from current land covers, which were each allocated a weight (Table 4) based on those proposed by Janssens et al. (2003) and on data of carbon capture obtained by Macías et al. (2005).

*2. Short-term carbon storage* (ES 2.2.6.1b) is an indicator of the degree of carbon transfer from biomass to soil, as well as of the storage capacity in the biomass itself that is not used intensively by humans in a period from 20 to 150 years (period established from short and long-term forest species). The short-term carbon storage potential was obtained from current land covers, allocating them a weight (Table 4) based on those reported by Pérez-Cruzado et al. (2012), Balboa-Murias et al. (2006) and Janssens et al. (2003).

3. *Long-term carbon storage* (ES 2.2.6.1c) evaluates the carbon storage potential of soil; this is the carbon that potentially remains longest in an ecosystem. The main factors that influence the carbon storage capacity of soils include lithological substrate, relief, climate (temperature and precipitation), hydromorphology and chemical soil stabilization (Macias et al., 2004; Rodríguez-Lado & Martínez-Cortizas, 2015). Considering the available information, a weighted summation of temperature (weight 0.1), precipitation (weight 0.2), lithology (weight 0.6) and geomorphology (weight 0.1) was calculated. Precipitation was scored according to the relationship between carbon content and precipitation ranges reported by Macías et al. (2004); temperature was evaluated according to its inverse influence on carbon storage (Rodríguez-Lado & Martínez-Cortizas, 2015); and lithology was assessed according to data reported by Macías et al. (2004), which relates lithological categories to carbon content. Regarding the geomorphology, determined by the TPI index, the different areas were awarded scores, as follows: flat areas, 1; low sloping areas, 0.8; medium sloping areas, 0.6; embedded valleys, 0.4; and highly sloping areas and summits, 0.2.

Table 4. Weights allocated to land covers for calculation of carbon capture and storage potential

| **Land cover** | **Weight according to C capture** | **Weight according to C storage** |
|---|---|---|
| Rock, water, beaches, cliffs | 0 | 0 |
| Artificial land cover | 0 | 0 |
| Mines and extraction areas | 0 | 0 |

| | | |
|---|---|---|
| Conifer trees | 0.31 | 0.44 |
| Crop and meadow | 0 | 0 |
| Crop | 0 | 0 |
| Deciduous trees | 0.13 | 0.88 |
| Eucalyptus | 1 | 0 |
| Eucalyptus and conifer trees | 0.65 | 0.22 |
| Wetland | 0.06 | 0.50 |
| Scrubland | 0.05 | 0.47 |
| Scrubland and trees | 0.05 | 0.47 |
| Scrubland and rock | 0.05 | 0.47 |
| Mix of tree species | 0.48 | 0.44 |
| Mosaic or agricultural and scrub land | 0 | 0 |
| Mosaic of agricultural and urban land | 0 | 0 |
| Mosaic of crops and tree species | 0 | 0 |
| Meadow | 0.13 | 1 |
| New forest plantations | 0.65 | 0.22 |
| Vineyard and woody crops | 0 | 0 |
| Urban | 0 | 0 |
| Urban green areas | 0 | 0 |

### 2.1.3. Cultural ESS

Cultural ES 3.1.1.2, which is related to the influence of landscape quality of ecosystems on outdoor activities that improve societal well-being and health, was evaluated. For this purpose, both the landscape quality of each land cover type and the degree of visibility from the most suitable sites for outdoor activities (cliffs, rocks, beaches, rivers, river mouths, lakes, reservoirs, cycling and hiking trails and St. James

Way) were considered. Land cover types were grouped according to their aesthetic quality, on the basis of the studies of Di Giulio et al. (2009) and Uuema et al. (2013), and were scored (Table 5) according to the degree of public satisfaction with each landscape type obtained in a previous study (https://cmatv.xunta.gal/seccion-organizacion/c/CMAOT_Instituto_Estudos_Territorio?content=Direccion_Xeral_Sostibilidade_Paisaxe/directrices_paisaxe/seccion.html&std=memoria_proceso_participacion_publica.html). The degree of visibility was calculated as the number of the previously mentioned sites (subsequently normalised between 0 and 1) that are visible from each cell of a raster map.

Table 5. Scores for aesthetic quality of types of land cover

| **Land cover type** | **Weight according to the aesthetic quality** |
|---|---|
| Water | 0.87 |
| Scrubland and rock | 0.68 |
| Forest | 0.91 |
| Intensive agricultural land | 0.71 |
| Extensive agricultural land | 0.87 |
| Vineyard | 0.87 |
| Urban and artificial areas | 0.34 |
| Rururban areas | 0.62 |
| Mines and extraction areas | 0.23 |
| Singular elements | 0.9 |
| Historic places | 0.9 |

Cultural ES 3.1.2.3, in which the ecosystem capacity to maintain historic records is evaluated through the soil potential for preservation of archaeological remains, was assessed. The soil capacity to preserve organic, bone, metallic and stratigraphic remains was determined from lithological and geomorphology data, as well as from the location of peatlands and wetlands, following Kibblewhite et al. (2015). Hydromorphic soils, ecosystems with high water retention and calcareous Leptosols were assigned a score of 5 in plains or summits and of 4 in low sloping hillsides, other calcareous soils and non-calcareous Leptosols were awarded a score of 3, and the remaining soils in medium or low sloping areas and plains were given a score of 2 and sealed soils,  a score of 1.

### 2.2. Ecosystem services trade-off analysis

Both synergies and trade-offs occur between ESS; the former imply compatibility or even an increase in the supply of two or more ESS, whereas the latter involve a decrease in the supply of one ES in favour of another (Lee & Lautenbach, 2016). Trade-off analysis provides information that can be used to establish criteria for GI delineation as it enables identification of areas with high provision potential for several ESS (Baró et al., 2017). The correlations between the ESS provision potential maps were determined with the Spearman's rank correlation coefficient (Spearman, 1904). This test was used because it is robust in the face of differences in data distribution.  The correlation coefficient (ρ) for each pair of ESS was calculated using all the values of the variables (maps) and varied between 1 (positive correlation) and -1 (negative correlation). The thresholds established by Raudsepp-Hearne et al. (2010) were used to indicate the level of correlation:

| | |
|---|---|
| $\rho \leq 0.3$ | No correlation |
| $0.3 < \rho < 0.5$ | Moderate correlation |
| $\rho \geq 0.5$ | Strong correlation |

### 2.3. Spatial planning of GI

The proposed GI design comprises the following: core areas, which include areas with high levels of biodiversity; corridors, which ensure ecological connectivity among core areas; buffer zones, aimed at preserving ecological functionality and maintaining corridors and core areas; and multifunctional zones, aimed at supplying ESS by ensuring compatible land uses.

### *2.3.1. Buffer zones*

The average provision potential of regulating ESS was used to delineate buffer zones. The average potential was calculated by summing the provision potential maps of each regulating ES normalised between 0 and 1, and subsequently divided by the number of ESS. The 20 % of the cells in the resulting map with the highest values were selected and the groups of these cells that entailed more than 100 ha and that were adjacent to core areas or ecological corridors were established as buffer zones.

### *2.3.2. Multi-functional zones*

The different types of multifunctional zones were defined on the basis of the most valued ESS by the aforementioned groups of researchers, with the exception of the ESS related to biodiversity, which is the priority service in core areas and corridors, and of regulating ESS, already used to delimit buffer zones.

For delineation of multifunctional zones, in addition to the potential provision of ESS, the proximity to potentially demanding areas was considered. This was one of the main challenges identified by Liquete et al. (2015) and addressed by Vallecillo et al. (2018). Areas where the population potentially places high demands on natural resources and functions were considered demanding areas, which also included core areas and corridors.

The ESS considered in each multifunctional zone were classified into two groups: (i) primary ESS, which are directly related to the main function of the multifunctional zone in question; and (ii) secondary ESS, which does not show trade-off with primary ESS. Land potential for multifunctional zones was calculated by means of Equation 2:

Potential = 0.6 x primary ESS provision potential + 0.4 x secondary ESS provision potential (Equation 2)

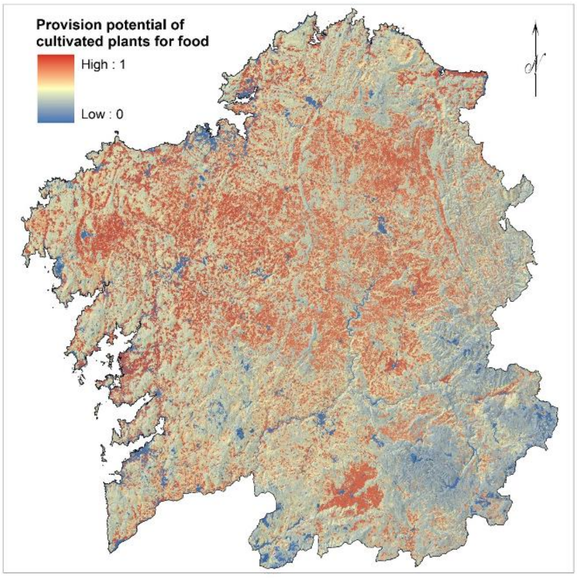
Both primary and secondary ESS provision potentials were calculated by summing the provision potential maps of each ES normalised between 0 and 1 and dividing the result by the number of ESS considered. Core areas, corridors and buffer zones, as well as areas of artificial land cover, were removed from this calculation.

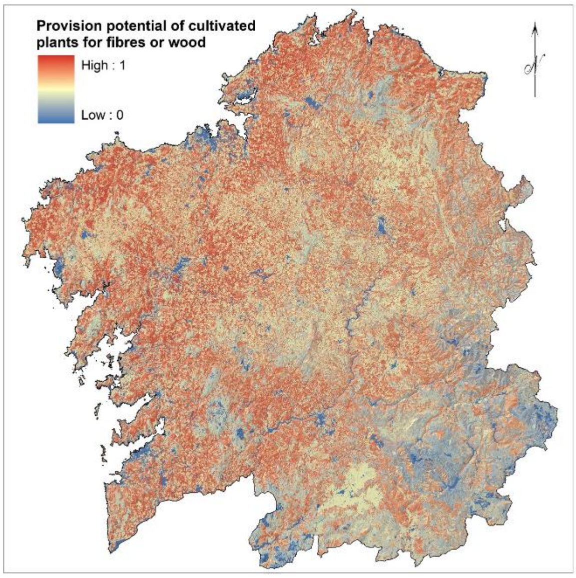
The 20 % of the cells with the highest potential values for each multifunctional area were selected, and those included in patches of less than 100 ha were subsequently removed. This ensured that multifunctional zones were large enough to be able to establish effective guidelines and management strategies that contribute to preserving biodiversity and ESS provision. Finally, patches that met the criterion of a certain proximity to demanding zones were selected.

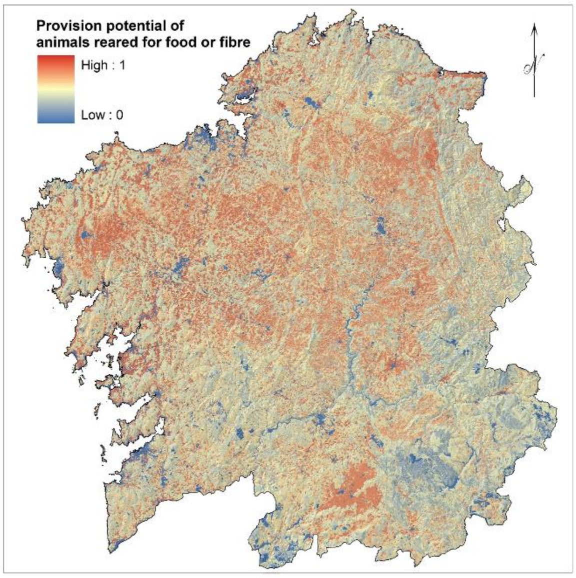
## 3. Application to spatial planning of GI in Galicia

### *3.1. ESS evaluation*

The autonomous region of Galicia (NW Spain) comprises an area of 29 000 km$^2$ and has a population of almost three million people. Maps obtained by applying the ESS evaluation methodologies described in section 2.1 are shown in Figure 1. These maps enabled us to calculate the average provision potential for all ESS of each land cover (Table 6) as the average of the cell values corresponding to each land cover in the map of average provision potential for all ESS. Globally, forest is the land cover with the highest provision potential. This type of land cover has a high potential capacity for regulating ESS related to pollution filtering, regulation of the hydrological cycle, biodiversity, erosion and forest fire prevention and carbon capture and storage, as well as for provisioning ESS such as production of vegetal fibre or biomass for energy. Among the different types of forest land covers, autochthonous deciduous trees stand out as the highest suppliers of ESS related to the hydrological cycle and short-term carbon storage. In general, fast growing forest species display the highest provision potential for ESS related to growing plants, such as carbon capture and vegetal fibre production. The second place in ESS provision corresponds to scrubland, which also plays an important role in ESS supply, although not as much as forest land cover, due to the lower volume of biomass. The last place is occupied by agricultural land cover, as despite having a high potential for provisioning ESS, this type of land use can cause erosion, pollution by agrochemicals and loss of biodiversity. Wetland stands out as the land cover with the highest potential for ESS related to the hydrological cycle, long-term carbon storage, biodiversity and preservation of archaeological remains.


Provision potential of cultivated plants for food
High : 1
Low : 0


Provision potential of cultivated plants for fibres or wood
High : 1
Low : 0


Provision potential of animals reared for food or fibre
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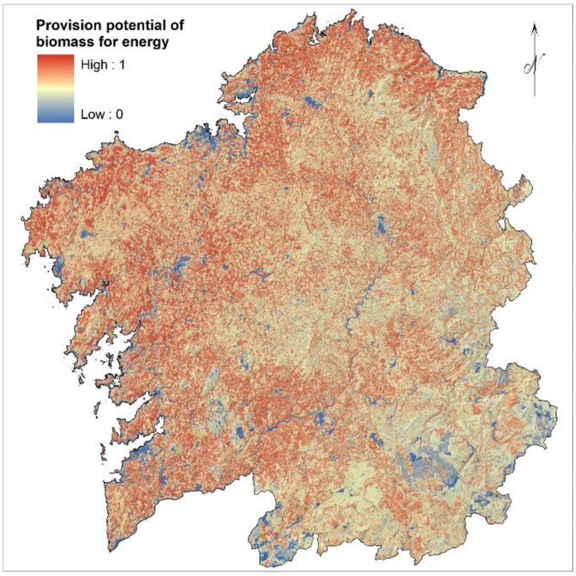
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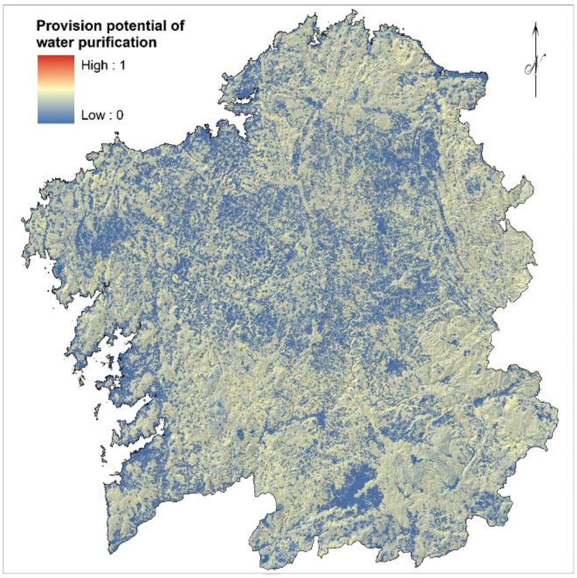
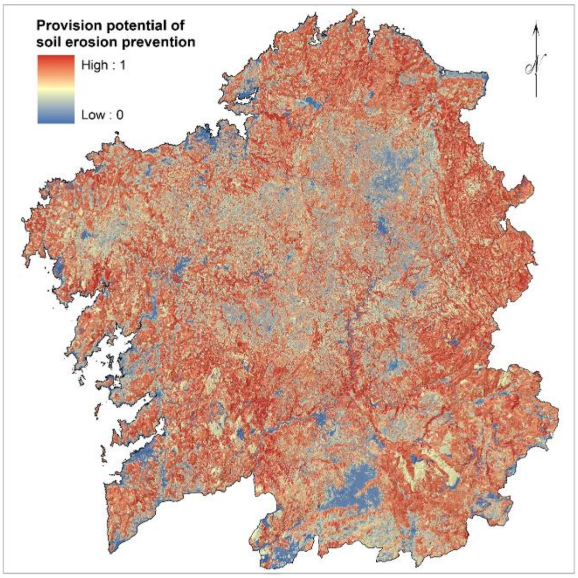
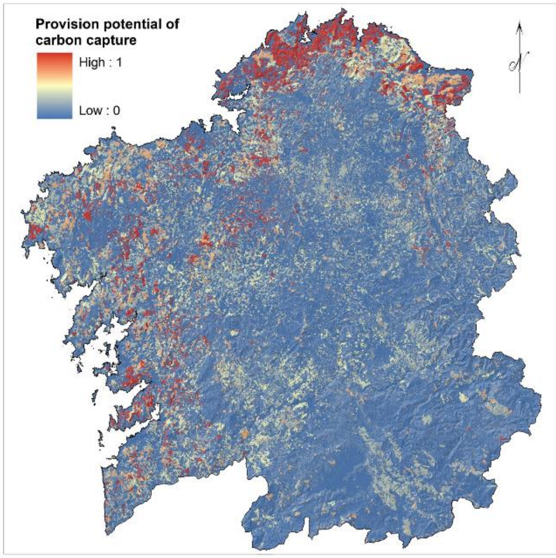
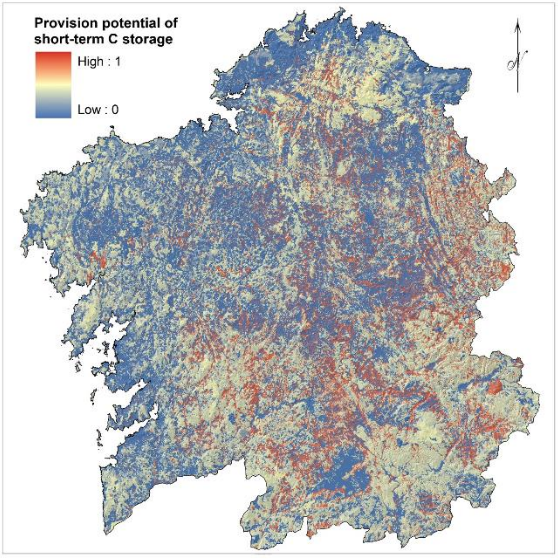
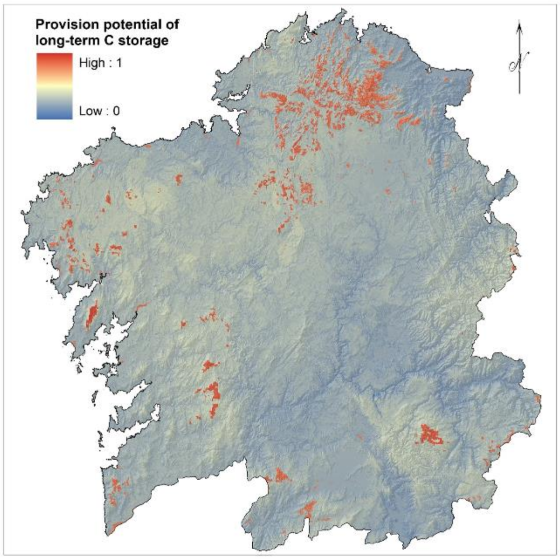
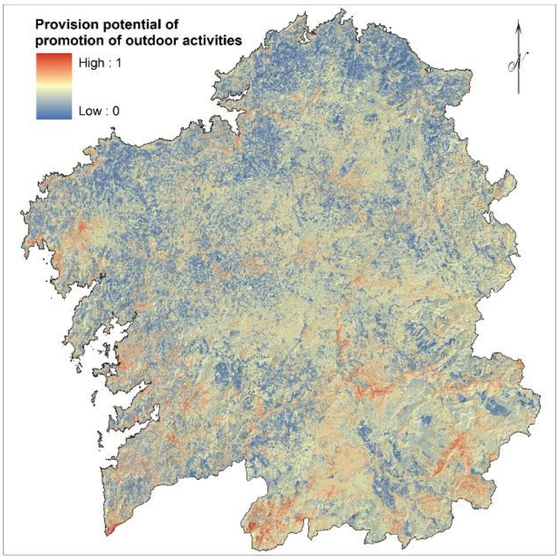

Provision potential of water purification
High : 1
Low : 0


Provision potential of soil erosion prevention
High : 1
Low : 0


Provision potential of
carbon capture
High : 1
Low : 0
N


Provision potential of
short-term C storage
High : 1
Low : 0
N


Provision potential of
long-term C storage
High : 1
Low : 0
N


Provision potential of
promotion of outdoor activities
High : 1
Low : 0
N

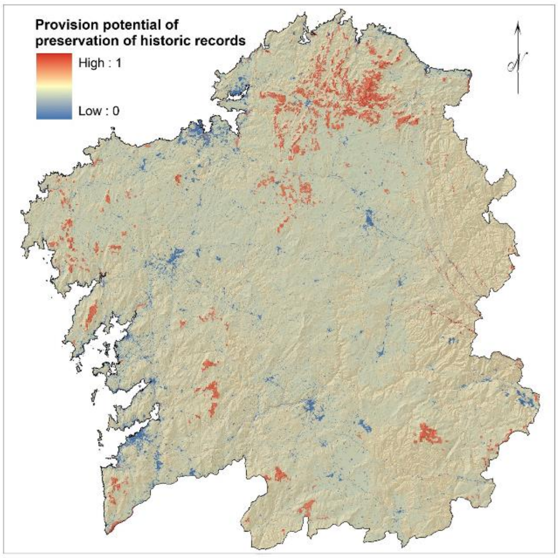

Provision potential of
preservation of historic records
High : 1
Low : 0
N

Figure 1. Maps of ESS provision potential

Table 6. Average provision potential for all ESS

| Land cover | Average provision potential for all ESS |
|---|---|
| Deciduous trees | 0.75 |
| Mix of tree species | 0.69 |
| Eucalyptus | 0.67 |
| Eucalyptus and conifer trees | 0.66 |
| Conifer trees | 0.64 |
| Scrubland and trees | 0.64 |
| Scrubland | 0.61 |
| Mosaic of crops and tree species | 0.60 |
| New forest plantations | 0.59 |
| Mosaic of agricultural and scrub land | 0.57 |
| Crop | 0.56 |
| Crop and meadow | 0.56 |
| Wetland | 0.53 |
| Scrubland and rock | 0.52 |
| Meadow | 0.52 |
| Vineyard and woody crops | 0.51 |

The results of the correlation analysis of ESS provision maps shown in Table 7 were used for spatial delineation of the GI by taking the trade-offs between groups of ESS into account. The following main trade-offs were identified: the long-term carbon storage vs. cultivated terrestrial plants for nutritional purposes; pollution filtering and erosion prevention vs. cultivated plants for nutritional purposes; carbon capture vs. cultivated plants for livestock; biodiversity vs. vegetal fibre production, biomass production for energy and carbon capture; and biodiversity vs. plants cultivated for human consumption.

Table 7. Correlation matrix

| | 4.2.1.1 | 2.2.2.3 | 1.1.1.3 | 2.2.5.1 | 2.2.6.1a | 2.2.6.1b | 2.2.6.1c | 2.2.1.5 | 1.1.1.1 | 3.1.2.3 | 2.2.1.1 | 1.1.1.2 | 2.1.1.2 | 1.1.3.1 | 3.1.1.2 | 2.2.1.3b | 2.2.1.3a |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **4.2.1.1** | 1 | | | | | | | | | | | | | | | | |
| **2.2.2.3** | -0.1 | 1 | | | | | | | | | | | | | | | |
| **1.1.1.3** | 0.1 | *-0.3* | 1 | | | | | | | | | | | | | | |
| **2.2.5.1** | **0.1** | 0.1 | 0.0 | 1 | | | | | | | | | | | | | |
| **2.2.6.1a** | 0.1 | *-0.3* | **0.8** | 0.0 | 1 | | | | | | | | | | | | |
| **2.2.6.1b** | 0.0 | *0.3* | 0.2 | 0.2 | 0.1 | 1 | | | | | | | | | | | |
| **2.2.6.1c** | *0.4*[*] | 0.0 | 0.0 | 0.1 | 0.0 | -0.1 | 1 | | | | | | | | | | |
| **2.2.1.5** | -0.1 | **0.5** | 0.0 | 0.0 | -0.1 | 0.1 | 0.0 | 1 | | | | | | | | | |
| **1.1.1.1** | 0.0 | *-0.3* | 0.2 | -0.1 | -0.2 | *-0.4* | 0.1 | 0.2 | 1 | | | | | | | | |
| **3.1.2.3** | 0.0 | *0.3* | -0.1 | 0.1 | 0.0 | 0.2 | 0.2 | 0.1 | -0.2 | 1 | | | | | | | |
| **2.2.1.1** | 0.1 | 0.0 | **0.6** | 0.1 | **0.5** | **0.6** | -0.1 | -0.1 | *-0.4* | 0.1 | 1 | | | | | | |
| **1.1.1.2** | 0.1 | *-0.4* | **0.9** | 0.0 | **0.7** | 0.1 | 0.0 | 0.0 | *0.3* | -0.2 | *0.4* | 1 | | | | | |
| **2.1.1.2** | 0.1 | 0.1 | **0.5** | 0.1 | **0.5** | **0.8** | -0.1 | -0.1 | **-0.5** | 0.1 | **0.9** | *0.4* | 1 | | | | |
| **1.1.3.1** | 0.0 | -0.2 | -0.1 | 0.0 | *-0.4* | **-0.5** | 0.2 | 0.1 | **0.8** | -0.1 | **-0.5** | 0.0 | **-0.6** | 1 | | | |
| **3.1.1.2** | -0.1 | *0.3* | *-0.4* | -0.1 | **-0.6** | 0.1 | -0.1 | 0.2 | 0.1 | 0.0 | -0.2 | *-0.4* | -0.2 | 0.2 | 1 | | |
| **2.2.1.3b** | 0.1 | 0.1 | *0.3* | 0.1 | 0.2 | *0.3* | *0.3* | 0.1 | -0.1 | 0.1 | *0.4* | 0.2 | *0.4* | 0.0 | -0.1 | 1 | |
| **2.2.1.3a** | 0.1 | 0.0 | *0.3* | 0.2 | 0.2 | *0.3* | *0.4* | 0.0 | -0.1 | 0.1 | **0.5** | *0.3* | **0.5** | 0.0 | -0.1 | **0.9** | 1 |

[*] *Strong positive correlation and strong negative correlation in bold* ($\rho \geq 0.5$)*; moderate positive correlation and moderate negative correlation in italics* ($\rho \geq 0.3$-$0.5$)

### *3.2 Delineation of GI*

The core areas of the proposed GI correspond directly to the Nature Network 2000 spaces. The ecological corridors were spatially delineated by direct interpretation of aerial photographs by experts from the Institute of Agrarian Biodiversity and Rural Development (www.ibader.gal). The core areas, corridors and buffer zones, delineated according to the methodology described in the previous section, are shown in Figure 2. The buffer zones comprise an area of 136.227 ha (Table 8), which represents 13 % of the total GI and 4.6 % of the total area occupied by the region and which, according to the methodology used, are located in areas adjacent to core areas and corridors with the aim of reducing possible impacts on these zones.

Table 8. Core areas, ecological corridors and buffer zones

| Type of zone | Area (ha) | Percentage of IV |
|---|---|---|
| Core area | 358.895 | 34.14 % |
| Ecological corridor | 263.254 | 25.04 % |
| Buffer zone | 136.227 | 12.96 % |

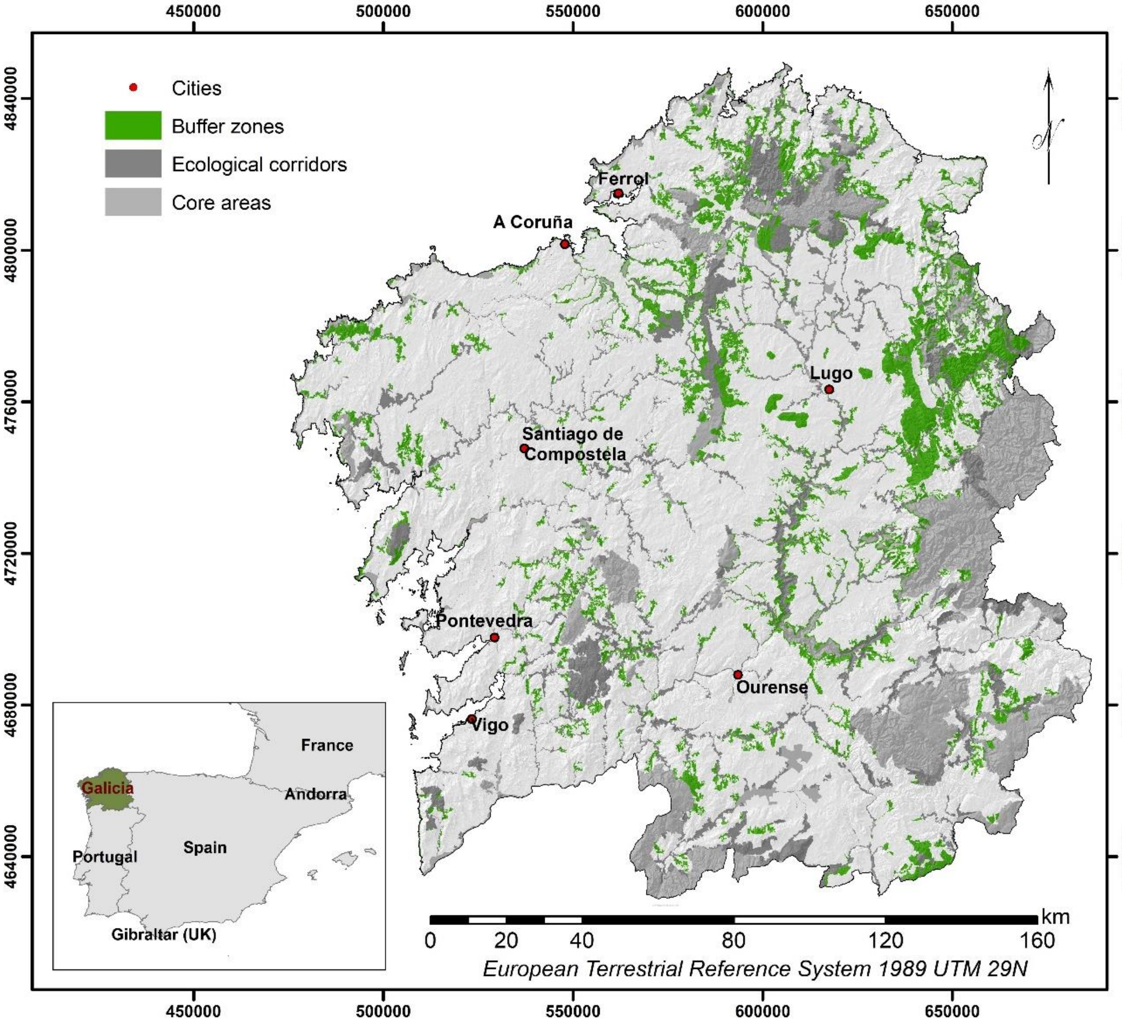


Figure 2. Map of core areas, corridors and buffer zones

With the exception of ESS related to biodiversity and regulating ESS, those prioritised by experts were related to food production, and a "multifunctional area for sustainable food production" was thus defined; this was followed by cultural ESS, which led to a "multifunctional area for well-being of urban population"; and finally those ESS related to production of wood and other forest products, thus defining a "multifunctional area for sustainable exploitation of forest resources".

In zones delimited for sustainable food production, the primary ESS were 1.1.1.1 and 1.1.3.1 and the secondary ESS were all remaining services, except ESS 2.2.6.1, 2.1.1.2, 2.2.1.1 and 2.2.2.3, because of their trade-offs with the primary ESS. Once cells corresponding to the 20% of the highest values were selected and the patches of cells with less than 100 ha were removed, patches adjacent to core areas, corridors and buffer zones were included in this type of multifunctional zone.

In zones delimited for well-being of the urban population, the primary ESS was 3.1.1.2 and the secondary ESS were the remaining services, with the exception of 1.1.1.3, 2.2.6.1 and 1.1.1.2 because of their trade-offs with the primary ESS. In this case, an additional factor “proximity to human demand” was taken into account as closeness to population increases the real flow of the primary ESS in this type of multifunctional zone (Vallecillo et al., 2018). For this reason, patches located close to population settlements with 1000 or more inhabitants were selected by means of the following criteria about patch size and distance to settlements: patches higher than 2 ha and located less than 200 m from settlements, patches higher than 20 ha and located less than 2 km from settlements and patches higher than 100 ha and located less than 5 km from settlements were selected.

Finally, the definition of multifunctional areas for sustainable exploitation of forest resources was based on the primary ESS 1.1.1.2 and 1.1.1.3, and on the remaining ESS as secondary ESS, with the exception of ESS 2.2.2.3 and 3.1.1.2 because of trade-offs with the primary ESS. Once the 20 % of cells with the highest values were selected and the patches of cells with less than 100 ha were removed, patches adjacent to core areas, corridors and buffer zones were included in this type of multifunctional zone.

The cells selected to be part of several multifunctional zones were allocated to a specific type of multifunctional zone by adopting the following priority criterion derived from expert ranking of the ESS:  cells were first allocated to the multifunctional area for sustainable food production, secondly to the multifunctional area for well-being of urban population and  thirdly to the muntifunctional area for sustainable exploitation of forest products. Resulting multifunctional zones are shown in Figure 3.

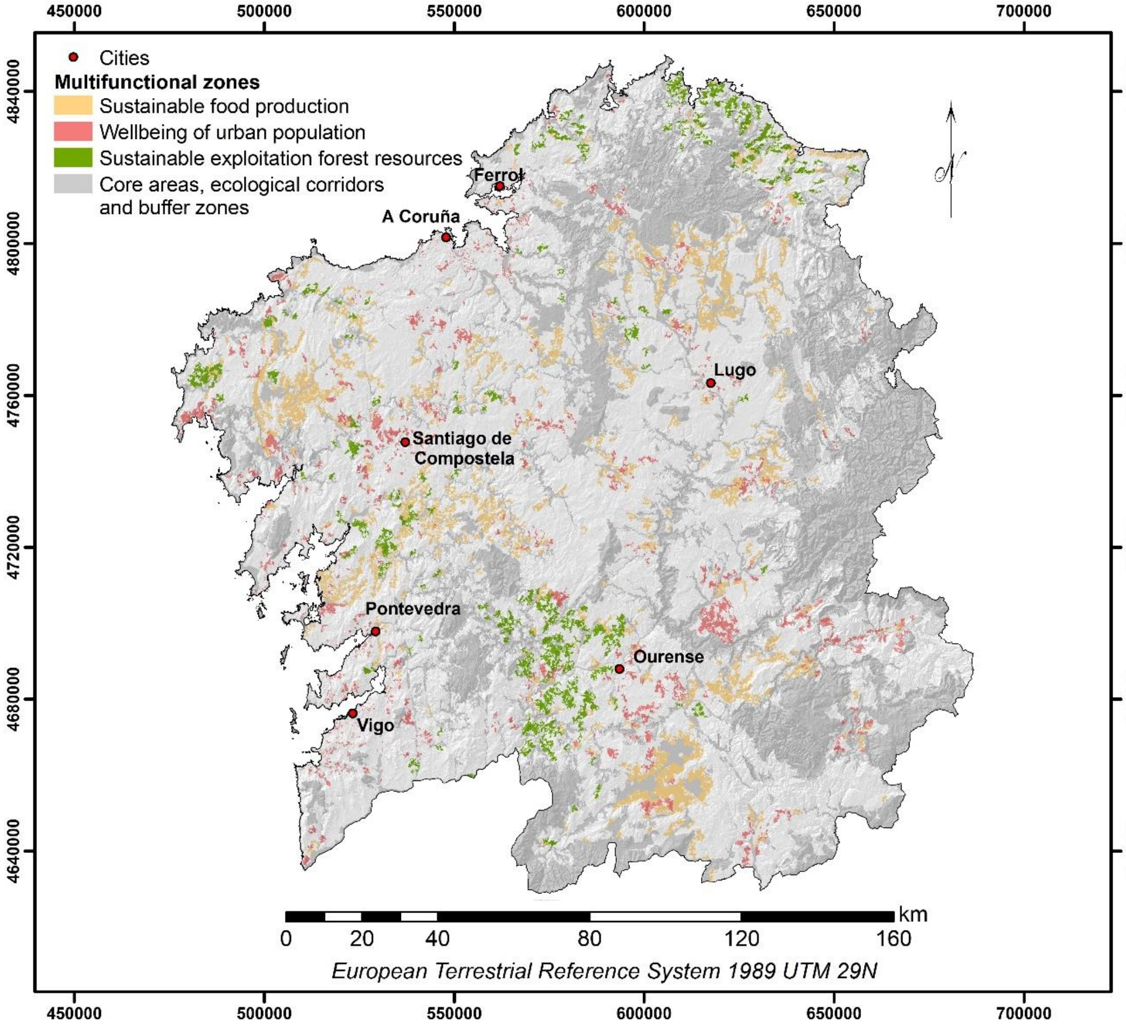


Figure 3. Map of multifunctional zones

Multifunctional zones cover an area of 292.836 ha, which represents 28 % of the total GI (Table 9) and 9.9 % of the regional area (Table 10). The largest area occupied by multifunctional zones for sustainable food production is due to the priority criterion established for overlaps between multifunctional zones. The resulting GI covers 35.5 % of the area of Galicia.

Table 9. Area of different multifunctional zones

| **Multifunctional zone** | **Area (ha)** | **Percentage of multifunctional zone** | **Percentage of GI** |
|---|---|---|---|
| Sustainable food production | 154.997 | 52.93 % | 14.74 % |
| Wellbeing of urban population | 74.049 | 25.29 % | 7.04 % |
| Sustainable exploitation of forest resources | 63.790 | 21.78 % | 6.07 % |
| Total multifunctional zone | 292.836 | 100 % | 27.85 % |

Table 10. GI areas in Galicia

| **Zone** | **Area (ha)** | **Area (%)** |
|---|---|---|
| Core areas | 358.895 | 12,14 |
| Ecological corridors | 263.254 | 8,90 |
| Buffer zones | 136.227 | 4,61 |
| Multifunctional zones | 292.836 | 9,90 |
| Total GI | 1.051.212 | 35,55 |
| Galicia | 2.957.127 | 100 |

## 4. Discussion

As mentioned in the Introduction, spatial planning of GI requires information about the spatial patterns of ESS provision across the landscape, i.e. planners must know the extent to which each part of a region provides each service. Among the numerous methods that can be used for ESS assessment (Martínez-Harms & Balvanera, 2012; Schägner et al., 2013), those based on causal relationships between environmental variables were applied in the present study. Although land use/cover is one of the most important variables in many of the methods, this type of data was not used directly as a proxy for ESS supply but also other variables that influence provision potential of ESS were considered. The design of a specific evaluation method for each ES allowed individualized assessment. The individual evaluation of each ES facilitates possible improvement of the global methodology, and consequently better results, by means of partial improvements, i.e. by the improvement or further development of the currently most imprecise methods of evaluating ESS, for example, by validating them against primary data (Schägner et al., 2013).

The results of ESS assessment can be used directly by decision and policy makers for land management (Ruckelshaus et al., 2015). The maps of ESS provision potential obtained in the present study enable identification of the areas in the region with the highest potential capacity to supply ESS and also enables identification of the types of ESS provided in each area. Forest areas have been shown to have the highest potential for ESS provision, especially for regulating services. Of the different types of forest areas, autochthonous deciduous forests stand out as providers of regulating ESS. After forest ecosystems, scrubland is the second highest supplier of ESS.

The selection of ESS and the assessment methods used in this approach can be modified in order to adapt the results of ESS assessment to the specific objectives of the plan, instrument or regulation supported by them. By way of examples, in the case of a climate action plan, more relevance should be attached to ESS related to mitigation (2.2.6.1) or adaptation (2.2.1.3a or 2.2.1.5) of climate change and more climatic variables could be included in the ESS assessment methods; or in the case of a sustainable tourism plan, other cultural ESS could be evaluated, for example by dividing the results of the ES 3.1.1.3 assessment into two maps of provision potential of landscape quality and of suitability for outdoor activities, or by including ESS related to tourism activities such as ecosystem characteristics enjoined by people or recognised by their cultural or historical character.

Integration of the results of ESS assessment into a multifunctional GI makes land planning and management easier and ensures the provision of all types of ESS. Previously identified difficulties in such integration (Portman, 2013) were overcome by distinguishing different zones in the GI. In addition to well-known core areas, corridors and buffer zones, several types of multifunctional zones were identified and delineated.

Many studies aimed at spatial planning of GI focus on a specific area of the infrastructure, usually ecological corridors, or on one or a few ESS; however, studies concerning the spatial delineation of GI made up of different zones are scarce. Some of the existing methods distinguish different GI areas (Chang et al., 2012; Liquete et al., 2015) or different scenarios (Vallecillo et al., 2018), but none of these methods delineate different types of multifunctional zones according to the bundle of ESS provided. This paper proposes a method for the spatial planning of buffer areas and several types of multifunctional zones based on the analysis of trade-offs between ESS and on the integration of synergic ESS by means of a multicriteria evaluation technique. The resulting GI comprises 35 % of the total area occupied by the region of Galicia and is divided into core areas (34 % of the GI area), corridors (25 %), buffer zones (13 %) and multifunctional zones (28 %). These three types of multifunctional zones were identified by expert ranking of the ESS in order to ensure that the GI will supply all the required services. More than half of the multifunctional area (53 %) was allocated to sustainable food production and the remaining area was almost equally assigned to zones for wellbeing of urban population (25 %) and for sustainable exploitation of forest resources (22 %). This distribution can be explained by the priority criterion used to delineate multifunctional zones on the basis of scores assigned to ESS by the expert groups.

The identification of multifunctional zones enabled the whole range of ESS in the spatial design of the GI to be considered, thus achieving an integrative GI. Most existing studies on spatial planning of GI at landscape level do not consider provisioning ESS, although with some exceptions (Grêt-Regamey et al., 2017; Hu et al., 2014), and few cultural ESS are usually evaluated. Liquete et al (2015) propose the delivery of provisioning and cultural services in a GI as one of the main challenges, in which trade-offs between different ecosystems services must be considered. The GI designed in the present study incorporated the three types of ESS included by CICES (provisioning, regulating and cultural services). Thus, the following various benefits of GI are ensured, and multiple objectives are met (EEA, 2014): ecological benefits (e.g. biodiversity preservation or climate change adaptation), economic benefits (e.g. food or wood production) and social benefits (e.g. health and wellbeing).

In this study three types of multifunctional zones were identified by expert evaluation and by analysis of trade-offs. However, different multifunctional zones could be identified according to the specific objectives of each plan. Taking as reference the previous examples, in a climate action plan, multifunctional zones for risk prevention or carbon storage could be delineated; in a sustainable tourism plan, multifunctional zones for rural tourism linked to traditional agriculture or for life watchers could be identified.

Liquete et al. (2015) point out the integration of human demand for ecosystem services as another important challenge. This issue has been addressed in multifunctional zones for wellbeing of urban population, by considering the proximity of suitable areas for outdoor activities and other cultural services to population settlements, since proximity to people contributes to the most evident increase in the service benefit in the case of the ES related to outdoor recreation (Vallecillo et al., 2018). By contrast, the demand for food and forest products was considered at a regional level. In addition, core areas and corridors were considered as proxies for the demand for certain ecological services, and the distance between these zones and urban settlements was used as a spatial constraint in the GI design.

Division of the GI into several zones enables different management criteria or guidelines, or even regulations, to be established for each zone. These can then be adapted to the specific characteristics and the bundle of ESS provided by each area. The delineation of different zones also facilitates integration of the GI in land use zoning or spatial plans as different land planning categories. The grouping and weighting of ESS can be modified in order to achieve different planning objectives and provide different land categories, so that supporting diverse types of plans or instruments, such as landscape conservation plans, rural development plans, comprehensive land use plans, biodiversity conservation strategies, etc.

The methodological approach described in this paper can be applied in other regions at different scales, from municipal to national or international level, and for multiple purposes, because it is based on several key issues potentially replicable in any case: (i) spatial delineation of different buffer and multifunctional zones of the GI, (ii) definition of multifunctional zones on the basis of a ESS trade-off analysis, (iii) consideration of different groups of ESS in each multifunctional zone, including provisioning and cultural services and according to the planning objectives, and (iv) spatial planning of the different areas of the GI by means of multicriteria evaluation of the results of ESS assessment.

## 5. Conclusions

The methodology proposed in this paper for spatial planning of GI is based on the results of ESS assessment and mapping. The ESS provision potential maps give basic information for decision-making on spatial planning and land management by locating the areas that provide each ES and quantifying these services. The results of ESS assessment can be applied in multiple land management or planning processes, from protection of core areas of GI to ecosystem restoration, identification of compatible land use options, evaluation of current or future land policies, allocation of resources for environmental protection or restoration, analysis of alternative locations for projects or activities, etc.

The incorporation of the results of ESS assessment both in spatial planning of GI and in land management faces numerous challenges due to the complexity of the ES concept and of the relationships among ESS. Therefore, new global methodologies and approaches must be developed to facilitate these processes. The proposed methodology incorporates some aspects recommended as future improvements in previous studies, such as the consideration of cultural ESS assessment and of the location of demanding areas for spatial delineation of the GI. In addition, the main contribution of this methodology is the zoning of different areas of GI. Buffer zones were delineated from the average provision potential for regulating ESS and defined as being adjacent to core areas and corridors. The Natura 2000 Network sites were considered core areas and corridors were identified by experts.  Different types of multifunctional zones were then identified and delineated from the provision potential of diverse groups of ESS. Different types of multifunctional zones were defined in order to include the remaining most important ESS and delineated from the maps of provision potential of some primary ESS (those most closely related to the functions of each type of multifunctional zone) and secondary ESS (the remaining ESS without trade-offs with the principal ESS).

The methodology was validated by applying it to the spatial planning of GI in the region of Galicia at a landscape level. Outcomes of ESS assessment not only provided the basis for the spatial planning of GI, but also for identifying land cover and consequently areas with the highest global ESS provision potential. The resulting GI includes different zones: core areas, corridors, buffer zones and three types of multifunctional zones (“sustainable food production”, “well-being of urban population” and “sustainable exploitation of forest resources”). GI zoning in different areas with specific, known characteristics enables different guidelines or regulations to be established for the management of each zone. As each zone supplies different ESS, the optimal or compatible land uses or activities vary, and specific strategies, plans or regulations should therefore be designed for the management of each area. In short, GI zoning enables better, more precise management adapted to the characteristics of each area and ESS supply.

In the case study, the land use/cover data source (SIOSE) had a great influence on the results of ESS assessment because of the high incidence of mixed land use categories in Galicia. The mixed categories had to be reclassified to be used as a proxy of ecosystems, which implied an increase on the land use/cover classification error. The Spanish National Geographic Institute is currently working on a new version of SIOSE with higher spatial resolution and without mixed categories, which will probably allow to improve the results of ESS assessment. Moreover, future research could develop new heuristic optimisation techniques specific to GI spatial planning for delineation of GI as well as to the zoning of different GI areas. This would enable maximization of the provision of synergic ESS and of the total number of ESS provided by each area.

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## References

Alexander, R.B., Smith, R.A., Schwarz, G.E., 2000. Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico. *Nature*, 403 (6771), 758-61.https://doi.org/10.1038/35001562

Arkema, K.K., Verutes, G., Wood, S.A., Clarke-Samuels, C., Rosado, S., Canto, M., Rosenthal, A., Ruckelshaus, M., Guannel, G., Toft, J., Faries, J., Silver, J. M., Griffin, R., Guerry, A.D., 2015. Embedding ecosystem services in coastal planning leads to better outcomes for people and nature. *Proceedings of the National Academy of Sciences of the United States of America*, 112(24), 7390-7395.

Bagstad, K.J., Semmens, D.J., Waage, S., Winthrop, R., 2013. A comparative assessment of decision-support tools for ecosystem services quantification and valuation. *Ecosystem Services*, 5, e27-e39.https://doi.org/10.1016/j.ecoser.2013.07.004

Balboa-Murias M.A., Rojo A., Álvarez J.G., Merino A., 2006. Carbon and nutrient stocks in mature Quercus robur L. stands in NW Spain. *Annals of Forest Science*, 63, 557-565.https://doi.org/10.1051/forest:2006038

Baró, F., Gómez-Baggethun, E., Haase, D., 2017. Ecosystem service bundles along the urban-rural gradient: insights for landscape planning and Management. *Ecosystem Services*, 24, 147-59.https://doi.org/10.1016/j.ecoser.2017.02.021

Burkhard, B., Froll, F., Müller, F., Windhorst, W., 2009. Landscapes‘ capacities to provide ecosystem services – A concept for land-cover based assessments. *Landscape Online*, 15, 1-22. https://doi.org/10.3097/LO.200915

Chang, Q., Li, X., Huang, X., Wu, J., 2012. A GIS-based green infrastructure planning for sustainable urban land use and spatial development. *Procedia Environmental Sciences*, 12, 491-498.https://doi.org/10.1016/j.proenv.2012.01.308

de Groot, R.S., Alkemade, R., Braat, L., Hein,, L., Willemen, L., 2010. Challenges in integrating the concepto of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, 7, 260-272.https://doi.org/10.1016/j.ecocom.2009.10.006

Di Giulio, M., Holderegger, R., Tobias, S., 2009. Effects of habitat and landscape fragmentation on humans and biodiversity in densely populated landscapes. *Journal of Environmental Management,* 90(10), 2959-68. https://doi.org/10.1016/j.jenvman.2009.05.002

Estreguil, C., Dige, G., Kleeschulte, S., Carrao, H., Raynal, J., Teller, A., 2019. *Strategic Green Infrastructure and Ecosystem Restoration: geospatial methods, data and tools, EUR 29449 EN*. Luxembourg: Publications Office of the European Union. https://doi.org/10.2760/06072

EEA, 2011. *Green Infrastructure and Territorial Cohesion. The Concept of Green Infrastructure and its Integration into Policies Using Monitoring Systems. EEA Technical Report nº 18/2011*. Luxembourg: Publications Office of the European Union.

EEA, 2014. *Spatial Analysis of Green Infrastructure in Europe. EEA Technical Report, nº 2*. Luxembourg: Publications Office of the European Union.

Grêt-Regamey, A., Weibel, B., Bagstad, K.J., Ferrari, M., Geneletti, D., Klug, H., Schirpke, U., Tappeiner, U., 2014. On the effects of scale for ecosystem services mapping. *PLoS ONE*, 9 (12): e112601.https://doi.org/10.1371/journal.pone.0112601

Grêt-Regamey, A., Altwegg, J., Sirén, E.A., van Strien, M.J., Weibel, B., 2017. Integrating ecosystem services into spatial-planning – A spatial decision support tool. *Landscape and Urban Planning*, 165, 206-219. http://dx.doi.org/10.1016/j.landurbplan.2016.05.003

Grizzetti, B., Bouraoui, F., De Marsily, G., 2008. Assessing nitrogen pressures on European surface water: nitrogen pressures on European water. *Global Biogeochemical Cycles*, 22 (4), GB4023.https://doi.org/10.1029/2007GB003085

Haines-Young, R., Potschin, M.B., 2018. *Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure*.https://cices.eu/content/uploads/sites/8/2018/01/Guidance-V51-01012018.pdf

Höppner, F., Menge-Hartmann, U., 2007. Yield and quality of fibre and oil of fourteenn hemp cultivar in Northern Germany at two harvest dates. *Landbauforschung Völkenrode*, 3(57), 219-232.

Hu, H., Fu, B., Lü, Y., Zheng, Z., 2014. SAORES: a spatially explicit assessment and optimization tool for regional ecosystem services. *Landscape Ecology*, 30(3), 547-560. https://doi.org/10.1007/s10980-014-0126-8

Janssens I.A., Freibauer A., Ciais P., Smith P., Nabuurs G., Folberth G., Schlamadinger B., Hutjes R.W.A., Ceulemans R., Schulze E.D., Valentini R., Dolman A.J., 2003. Europe’s terrestrial biosphere absorbs 7 to 12% of European anthropogenic CO2 emissions. *Science*, 300, 1538-1542.https://doi.org/10.1126/science.1083592

Kandziora, M., Burkhard, B., Müller, F., 2013. Mapping provisioning ecosystem services at the local scale using data of varying spatial and temporal resolution. *Ecosystem Services*, 4, 47-59.https://doi.org/10.1016/j.ecoser.2013.04.001

Kibblewhite, M., Gergely, T., Hermann, T., 2015. Predicting the preservation of cultural artefacts and buried materials in soil. *Science of the Total Environment*, 529, 249-263. https://doi.org/10.1016/j.scitotenv.2015.04.036

Kopperoinen, L., Itkonen, P., Niemelä, J., 2014. Using expert knowledge in combining green infrastructure and ecosystem services in land use planning: an insight into a new place-based methodology. *Landscape Ecology*, 29, 1361-1375. https://doi.org/10.1007/s10980-014-0014-2

Lee, H., Lautenbach, S., 2016. A Quantitative Review of Relationships between Ecosystem Services. *Ecological Indicators*, 66, 340-51.https://doi.org/10.1016/j.ecolind.2016.02.004

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.https://doi.org/10.1016/j.envsci.2015.07.009

Liu, Y., Theller, L.O., Pijanowski, B.C., Engel, B.A., 2016. Optimal selection and placement of green infrastructure to reduce impacts of land use change and climate change on hydrology and water quality: An application to the Trail Creek Watershed, Indiana. *Science of the Total Environment*, 553, 149-163. https://doi.org/10.1016/j.scitotenv.2016.02.116

Macías, F., Calvo de Anta, R., Rodríguez-Lado, L., Verde, R., Pena Pérez, X., Camps Arbestain, M., 2004. El sumidero de carbono de los suelos de Galicia. *Edafología*, 11(3), 341-376

Macías F., Camps M., Rodríguez-Lado L., 2005. Alternativas de secuestro de carbono orgánico en suelos y biomasa de Galicia. *Recursos Rurais*, 1, 71-85.

Martínez-Harms, M.J., Balvanera, P., 2012. Methods for mapping ecosystem service supply: a review. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 8(1-2), 17-25. http://dx.doi.org/10.1080/21513732.2012.663792

Meerow, S., Newell, J.P., 2017. Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. Landscape and Urban Planning, 159, 62-75. http://dx.doi.org/10.1016/j.landurbplan.2016.10.005

Pérez Cruzado, C., 2011. *Models for Estimating Biomass and Carbon in Biomass and Soils in Pinus radiata (D. Don), Eucalyptus globulus (Labill) and Eucalyptus nitens (Deane & Maiden) Maiden Plantations Established in Former Agricultural Lands in Northwestern Spain*. PhD Thesis. University of Santiago de Compostela.

Pérez-Cruzado, C., Mansilla-Salinero, P., Rodríguez-Soalleiro, R., Merino, A., 2012. Influence of tree species on carbon sequestration in afforested pastures in a humid temperate region. *Plant Soil*, 353, 333-353. https://doi.org/10.1007/s11104-011-1035-0

Porta i Casanellas, J., López-Acevedo, M., Roquero de Laburu, C., 1994. *Edafología: para la Agricultura y el Medio Ambiente*. Madrid: Mundi-Prensa.

Portman, M.E., 2013. Ecosystem services in practice: Challenges to real world implementation of ecosystem services across multiple landscapes – A critical review. *Applied Geography*, 45, 185-192.https://doi.org/10.1016/j.apgeog.2013.09.011

Queiroz, C., Meacham, M., Richter, K., Norström, A.V., Andersson, E., Norberg, J., Peterson, G. (2015). Mapping bundles of ecosystem services reveals distinct types of multifunctionality within a Swedish landscape. *Ambio,* 44, S89-S101.https://doi.org/10.1007/s13280-014-0601-0

Raudsepp-Hearne, C., Peterson, G.D., Bennett, E.M., 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences*, 107(11), 5242-47.

Rodríguez-Lado, L., Martínez-Cortizas, A., 2015. Modelling and mapping organic carbon content of topsoils in an Atlantic area of southwestern Europe (Galicia, NW-Spain). *Geoderma*, 245-246, 65-73.https://doi.org/10.1016/j.geoderma.2015.01.015

Ruckelshaus, M., McKenzie, E., Tallis, H., Guerry, A., Daily, G., Kareiva, P., Polasky, S., Ricketts, T., Bhagabati, N., Wood, S.A., Bernhardt, J., 2015. Notes from the field: Lessons learned from using ecosystem service approaches to inform real-world decisions. *Ecological Economics*, 115, 11-21.https://doi.org/10.1016/j.ecolecon.2013.07.009

Schägner, J.P., Brander, L., Maes, J., Hartje, V., 2013. Mapping ecosystem service's values: Current practice and future prospects. *Ecosystem Services*, 4, 33-46.https://doi.org/10.1016/j.ecoser.2013.02.003

Schröter, M., Remme, R.P., 2016. Spatial prioritisation for conserving ecosystem services: comparing hotspots with heuristic optimisation. *Landscape Ecology*, 31(2), 431-450.https://doi.org/10.1007/s10980-015-0258-5

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.https://doi.org/10.1007/s00267-015-0613-y

Spearman, C., 1904. The proof and measurement of association between two things. *American Journal of Psychology*, 15, 72-101.https://doi.org/10.2307/1422689

Sutton, M.A., 2011. *The European Nitrogen Assessment: Sources, Effects, and Policy Perspectives*. Cambridge: Cambridge University Press.

Uuemaa, E., Mander, U., Riho, M., 2013. Trends in the use of landscape spatial metrics as landscape indicators: a review. *Ecological Indicators*, 28, 100-106. https://doi.org/10.1016/j.ecolind.2012.07.018

Vallecillo, S., Polce, C., Barbosa, A., Castillo, C.P., Vandecasteele, I., Rusch, G.M., Maes, J., 2018. Spatial alternatives for Green Infrastructure planning across the EU: An ecosystem service perspective. *Landscape and Urban Planning*, 174, 41-54. https://doi.org/10.1016/j.landurbplan.2018.03.001

Weiss, A.D. 2001. Topographic position and landforms analysis. *ESRI Users Conference*, San Diego (CA). http://www.jennessent.com/downloads/tpi-poster-tnc_18x22.pdf