Designing a network of Green Infrastructure to enhance the conservation value of protected areas and maintain ecosystem services

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Abstract

There is a growing demand for holistic landscape planning to enhance sustainable use of ecosystem services (ESS) and maintenance of the biodiversity that supports them. In this context, the EU is developing policy to regulate the maintenance of ESS and enhance connectivity among protected areas (PAs). This is known as the network of Green Infrastructure (GI). However, there is not a working framework defined to plan the spatial design of such network of GI.

Here, we use the software Marxan with Zones, to prioritize the spatial distribution of different management zones that accommodate the needs of a network of GI. These zones included a conservation zone, mainly devoted to protecting biodiversity, a GI zone, that aimed at connecting PAs and maintaining regulating and cultural ESS; and a management zone devoted to exploiting provisioning ESS. We performed four planning scenarios that distribute the targets for ESS and biodiversity in different ways across management zones. We also conducted a sensitivity analysis by increasing ESS targets to explore trade-offs that may occur when managing together biodiversity and ESS. We use Catalonia (northeastern Spain) as a case study.

We found that the representation of ESS could be achieved for intermediate targets in all scenarios. There was, however, a threshold on these targets over which trade-offs appeared between maintaining regulating and cultural ESS and biodiversity *versus* getting access to provisioning ESS. These “thresholds values” were displaced towards higher ESS targets when we moved from more strict to more flexible planning scenarios (i.e., scenarios that allowed mixing representation of objectives for biodiversity and ESS within the same zone).

This methodological approach could help design a framework to integrate biodiversity and ESS management in holistic plans and decision making and, at the same time, meeting European mandates concerning the design of GI networks, or similar needs elsewhere.

Keywords: co-benefits, connectivity, Marxan with Zones, multi-functionality, systematic conservation planning, trade-offs.

1. Introduction

The degradation of ecosystems and habitats is a widespread process worldwide (Ill *et al.*, 2000). Human impacts on ecosystems and biodiversity are cause of habitats loss and species extinctions (Didham *et al.*, 2007). This is not only a problem concerning nature conservation but also for human wellbeing, given the dependence of humans on the services provided by ecosystems (Mavrommati *et al.*, 2016; Bastian 2014). The more degraded ecosystems become, the more difficult it is to cover the increasing human demand for the services that they provide (Carpenter *et al.*, 2008; Tallis *et al.*, 2008). These ecosystem services (ESS), represent all the products and services that human obtain from ecosystems (Egoh *et al.*, 2007), directly benefiting people's wellbeing and contributing to economic development (Naido *et al.*, 2008). However, according to recent assessment, up to 60% of world's ESS have been degraded (MAES, 2015).

Despite the increasing efforts devoted to conservation in the last decades, little impact has been observed and biodiversity and ESS continue to decline (Butchart *et al.*, 2010; WWF, 2016) which claims for the need of more active ecosystem management, correct quantification and monitoring of ESS to preserve them and address societal needs (Tallis & Polasky, 2009). There is also urgent need for holistic landscape planning that integrate all these different objectives and values together (Martinez-Harms *et al.*, 2015). The consideration of both ESS and biodiversity in decision-making can help create new opportunities for sustainable use of ecosystems and biodiversity conservation (Egoh *et al.*, 2007; Schröter *et al.*, 2014; Mitchell *et al.*, 2015). Understanding the way ecosystems and human needs are related, offers the opportunity to develop new approaches in ecosystems management considering conservation and human needs as complementary (Balvanera *et al.*, 2001). This new paradigm changes the way conservation has been conceptualized so far, shifting away from traditional conservation schemes, focused on strict conservation goals, towards a new vision that combines conservation and other social demands. This has been defined by Mace (2014) as the "nature and people" concept which considers dynamic and resilient interactions between human and ecosystems.

However, planning for both biodiversity and ESS together, poses a challenge as there are not only co-benefits to be addressed (e.g., Venter *et al.*, 2009 a), but also trade-offs between conservation goals and granting access to particular ESS that might come at odds with the conservation of biodiversity and other ESS (e.g., Moran-Ordoñez *et al.*, 2016). A conservation plan that seeks to enhance sustainability should ideally try to maximize co-benefits from ESS and biodiversity conservation goals (Chan *et al.*, 2006) and, at the same time, to minimize trade-offs that could occur when managing together biodiversity and ESS. Therefore, specific planning strategies are necessary to manage all the factors that need to be included in holistic management plans to guarantee simultaneously the persistence of biodiversity and ESS as well as securing human well-being (Naidoo *et al.*, 2008). This is especially the case of highly humanized landscapes like in Europe where there is high competition for space for different purposes (e.g., conservation vs. development). This approach of integrated planning is receiving increasing support from international policies. The EU is currently working on designing a network of green infrastructure (GI) strategically planned to conserve and reconnect fragmented natural areas and, at the same time, to foster the maintenance of a wide range of ESS and their associated socio-economic benefits (Benedict & McMahon, 2002; European Commission, 2016). This GI aims to achieve multi-functionality and smart conservation, with special focus on areas that connect protected areas such as Natura 2000 sites (Mubareka *et al.*, 2013). In this way, including GI considerations in the planning and decision-making process can help maintaining ESS supply and biodiversity conservation goals, especially those threatened by land use changes, and to improve and restore soil and ecosystem functions (Liquete *et al.*, 2015).

The aim of this study was to develop an operational GI planning framework to achieve biodiversity conservation and maintenance of ESS by using a systematic conservation planning approach. Our goal was to prioritize the spatial allocation of different management zones to maximize co-benefits between important areas for biodiversity and ESS that are compatible with conservation priorities. At the same time, we tried to minimize the trade-offs between ESS that are not compatible with conservation, always ensuring the access to provisioning ESS, using

Catalonia region (NE Spain) as a case study area. We designed four planning scenarios to explore different landscape-level management options in the design of a GI network depending on how ESS are distributed between alternative management zones. We also performed a sensitivity analysis to illustrate thresholds over which trade-offs between ESS and biodiversity appear. To do so, we defined targets for every ES and biodiversity values, being targets the amount of each ES, or distribution of habitats and bird species that we wanted to be represented within our management zones.

2. Study area

The study focuses on Catalonia (NE Spain), which has a population of 7.5 million people and covers an area of 32,000 km². This region has wide diversity of habitats from coastal to alpine ecosystems structured in three main important geomorphological units: Coastal mountain range, Pyrenean mountain range and central depression. Catalonia mostly features a Mediterranean climate, although there are high temperature differences between the coastal areas (annual average temperature 16.5 °C) and the mountains with annual average of 9 °C (www.meteo.cat). The whole territory holds a rich biodiversity, with more than 3,000 plant species and 763 animal species (Banc de Dades de Biodiversitat de Catalunya, 2016). In addition, over 29% of its territory has diverse conservation status under the Natura 2000 network, which is a coordinated network of protected areas along Europe comprising more than 27,000 sites and covering 18% of the EU (European Commission, 2008). This network is formed by 115 spaces declared of Community Interest and by 73 spaces declared Areas of Birds Special Protection.

Catalonia is covered by approximately two million hectares of forest area (Corine Land Cover, 2012), representing 61% of the total area of the region, as well as by large crop areas (35% of the total area), also hosting high biodiversity values (Boada, 2003; Corine Land Cover, 2012). A land use map is included in Appendix B for further information. These large forest and agricultural lands are socioeconomically relevant and also of major importance as habitats for many species (Observatori forestal Català, 2015), so its preservation is crucial for achieving biodiversity conservation goals and meeting socioeconomic needs and demands. The economic activities

involving forestry and agriculture contribute to more than the 3 % of total Catalan GDP. Furthermore, forest ecosystems have other contributions in terms of ESS such as climate regulation and mitigation, erosion control and hydrological regulation (Luque *et al.*, 2017). For example, the economic impact of tourism related to natural sites in Catalonia is estimated at 160 million euro per year.

3. Material and methods

3.1. Conceptual framework

With the aim of designing a GI network for the maintenance of biodiversity and ESS we used a systematic planning approach considering multiple management zones that help address conflicting objectives (e.g., biodiversity conservation and granting access to provisioning services that might impact the former). In the particular case of a network of GI (i.e., to conserve and reconnect natural areas and maintain the delivery of ESS), at identifying i) core areas for conservation of biodiversity, ii) areas of connection between core areas that would also have an important value for the delivery of ESS (Fig 1), and iii) areas to grant access to provisioning ESS, that could impact the conservation of biodiversity or the maintenance of other ESS. The number of the management zones and their contribution to achieving the conservation objectives can be adapted to any specific context (e.g., types and number of ESS, relationship between ESS and ESS-biodiversity). However, the number and characteristic of these management zones should be based on pre-defined objectives that take into account local needs and the context of the planning exercise. The definition of the management zones would be also conditioned by the potential trade-offs between objectives that may arise and the data available to carry out the exercise (Fig. 2).

To optimize the spatial allocation of these different management zones, we used the software Marxan with Zones (Watts *et al.*, 2009), which is a decision support tool widely used for decision making when trying to harmonize biodiversity conservation and other human activities, such as the demand of ESS in our case (Klein *et al.*, 2008, Levin *et al.*, 2012). Marxan with Zones allows

prioritizing the spatial allocation of different management zones for conflicting uses, whenever possible, in a more flexible way than traditional planning, allowing the characterization of the management zone according to the special needs of each planning exercise (Hermoso *et al.*, 2018). For the prioritization of the spatial allocation of management zones, it is necessary to define the role that each management zone will play in the overall planning context, and the spatial relationship across zones (e.g., do we want them to be spatially clustered or disaggregated?). The former can be defined in Marxan with Zones through the file “zone target” that allows the distribution of the total amount of each feature (ESS and biodiversity) between the management zones, in this way one can decide, for example, which zones will contribute to the achievement of biodiversity targets. The file “zone boundary” in Marxan with Zones is used for defining the spatial relationship between management zones, which is also key to define connectivity aspects between zones.

3.2 Data compilation

All the data compiled was projected onto 1-km-resolution grid cells covering the whole study area that represented the minimum planning units of analysis. Given that the data available had different resolutions, information on all ESS, species and habitats distribution were translated into our network of 1-km-resolution grid cells.

We compiled data on bird biodiversity, habitats and ESS distribution as explained below. We selected bird data to represent fauna biodiversity because there is complete and reliable information available in the study region, which guarantees the quality and abundance of data. They are also good indicators of change due to its sensibility to environmental (Herrando *et al.*, 2014)

3.2.1. Biodiversity data

We sourced spatial distribution data of birds from the Atlas of the Breeding Birds of Catalonia (1999-2002, Estrada *et al.*, 2004) and the Atlas of the Winter Birds of Catalonia (2006-2009, Herrando *et al.*, 2011). These atlases represent the most complete source of bird species

distribution at 1-km cell resolution throughout the study area. We focused on the distribution of the bird species included in the European Bird Directive 2009/147/CE as species of Community Interest and the bird species considered as regionally threatened (Vulnerable, Endangered and Critically Endangered), (ICO, 2012).

We also sourced spatial distribution data of different habitat types from the Catalanian habitat cartography 1:50000, version 2 (ICGC, 2009.v2). This information reflects the distribution and extension of the different habitats throughout the study area. In the same way as for bird species, we retrieved the distribution of the most relevant habitats from a conservation perspective: the habitats considered of Community Interest included in the European Habitat Directive 92/43/CEE and the habitats considered as threatened at the regional scale (Carreras *et al.*, 2013).

3.2.2. *Ecosystem services data*

The Common International Classifications of Ecosystem Services (CICES) (Haines-Young and Potschin, 2013) structures ESS into three main types: regulating, cultural and provisioning. We selected a representative set of ESS in Catalonia, including four regulating ESS (i.e., avoidance of soil erosion, carbon storage, water retention and pollination potential), four provisioning ESS (i.e., biomass production, food crop production, mushroom production and available areas for extensive grazing) and two cultural ESS (i.e., recreation opportunity and hunting potential) (Table 1). We included mushroom production ESS not only for its economic and market value but also because edible mushroom picking is an important cultural activity traditionally developed in the region. Indeed, based on regional-level interviews, 23.5% (around 1.2 million) of adult people living in Catalonia region consider themselves as mushroom pickers (i.e. going to pick mushrooms at least once a year), and around half a million people are estimated to pick mushrooms more than three times a year (Górriz *et al.* 2014). Further explanation of the source and mapping process of ESS is included in Appendix A.

We classified the aforesaid ESS into three groups according to their degree of compatibility with biodiversity conservation (Table 1). This was then used to maximize co-benefits and minimize potential trade-offs between the ESS supply and biodiversity conservation goals.

- *Group A:* We included here ESS that are considered compatible with biodiversity conservation (mainly regulating ESS) and then those for which we would try to find co-benefits. This group comprised: *avoidance of soil erosion, carbon storage, water retention and recreation opportunity*. Recreation opportunity ESS was included in this group given the strong relationship between nature tourism/recreation with forests and natural areas despite potential impacts of this activity on some biodiversity elements.
- *Group B:* We grouped here the ecosystem services considered to have a low impact on biodiversity conservation, including: *pollination potential, mushroom production, potential areas for extensive grazing and hunting potential*.
- *Group C:* Includes all the provisioning ecosystem services that are considered non-compatible with conservation or that have a high impact on it. There are: *biomass production and food crop production*.

3.3. Analysis

3.3.1. Defining the role of each management zone

In this particular case study, we considered three different management zones for landscape-level planning. These management zones included i) a conservation zone, devoted mainly to biodiversity conservation and maintenance of ESS compatible with conservation; ii) a GI zone, to enhance the connectivity between conservation zones and maintain some ESS that are considered not highly impacting on habitats and species. With this two zones we also tried to identify potential co-benefits between ESS and biodiversity conservation; iii) and finally, we included a third management zone, called exploitation zone, that would be mainly devoted to granting access to provisioning ESS considered non-compatible with biodiversity conservation and maintenance of other ESS. This last management zone would help deal with potential trade-offs between ESS

supply and biodiversity conservation and to grant access to some ESS that could impair the achievement of conservation goals. Moreover, it also allows identifying areas where the access to these important ESS could be granted, and then avoiding impacts on the demand of these services whenever possible (e.g., access to water for agriculture). To minimize potential impacts of the exploitation zone on the conservation goals we also wanted them to be as spatially disconnected/isolated as possible from important areas for biodiversity conservation. In order to account for already existing conservation efforts on the ground, we incorporated the Natura 2000 network in the analyses by locking in all grid cells that fell within Natura 2000 under the conservation zone or the GI zone given the conservation focus of Natura 2000, created to protect threatened species and habitats but also for maintaining traditional human uses that enhance the protection and multi-functionality of this natural sites.

The representation target (i.e., target to be achieved across all management zones) for species and habitats was set according to their distribution ranges, so that we could cover it representation taking into account the relative rarity or commonness of each of them. We aimed to ensure a large coverage of the rarest species and habitats and avoid over representing the most common ones. Thus, we considered the rarest species and habitats as those having a distribution range covering less than 100 km² in the whole study area (i.e., 0.3% of the total area), and set a target of 75% of their distribution to be represented in the resulting landscape-level planning. For species and habitats with larger distribution ranges (between 100 and 1000 km²), we set a target of 25% of their distribution to be represented. Finally, for the most common species with distribution ranges over 1000 km², we set a target of 10% of their distribution. For the ESS, we set a constant target of 20% of the total amount of each service to be achieved. These targets were set for the demonstration exercise, while the implementation of this approach would benefit from further expert-based information on ecological needs of each species and habitats to better inform target setting.

We used the ability of Marxan with Zones (Watts *et al.*, 2009) software to deal with different targets per management zone to define the role that each zone would play in the overall planning

context (e.g., how and to what extent different management zones contribute to the achievement of representation targets for each ESS and biodiversity conservation goals). Therefore, these targets represent a measure of how much of the distribution of species and habitats or the amount of each ES that we wanted to allocate within management zones. By grouping the targets of each feature under different management zones, we also aimed at enhancing co-benefits (e.g., by assigning targets for biodiversity and compatible ESS under the same management zone) and minimize trade-offs (e.g., by allocating non-compatible ESS only under the exploitation zone) in different scenarios (see section 2.3.3. below).

3.3.2. *Optimizing the spatial allocation of management zones*

To prioritize the allocation of the different management zones, Marxan with Zones tries to minimize an objective function by means of a simulated annealing optimization algorithm (Watts *et al.*, 2009) that consists of three main terms:

$$\text{Objective function} = \sum_{PUs} \text{Cost} + BLM \sum_{PUs} \text{Boundary} + \sum_{Features} FPF \times \text{Feature Penalty}$$

The “Cost” parameter in the objective function is the sum of the cost of all 1-km² planning units (PUs) selected under each management zone. Marxan with Zones allows using different cost estimates for each PU, depending on the management zone under which each PU was allocated. In other words, different costs are allowed for each management zone, depending on the type of management required or constraint to uses that management would enquire (e.g., opportunity cost). We used the Global Human Footprint (Wildlife Conservation Society WCS, 2005) as a proxy for the cost of including a given PU under each management zone. This proxy reflects the degree of humanization of PUs and, thus, its suitability for conservation or exploitation purposes. We used the average value of the human footprint as a cost for the conservation and GI zones and 1 minus the average value for the exploitation zone. In this way, whenever possible, conservation and GI zones would be mainly allocated in areas with low human impact, whereas exploitation zones would be mainly allocated in areas with larger human impact. However, an area in good

condition with a high potential for provisioning services could still be selected under the exploitation zone if it was needed to achieve the targets for those services without impairing the achievement of biodiversity conservation and ESS targets (Hermoso *et al.*, 2018). In order to avoid the urban and industrial areas in the planning exercise, we removed all the PUs with more than 75% covered by these land use types.

The “Boundary” parameter in the objective function is used to ensure that the areas selected are spatially aggregated (Hermoso *et al.*, 2016; Watts *et al.*, 2009). The boundary penalty is calculated as the sum of all open boundaries in PUs in the solution weighted by a constant, called BLM (boundary length modifier) to control for the importance of connectivity in planning (higher BLM values result in higher aggregation and connectivity). We tested different BLM values and chose a BLM= 2.5 as it showed high aggregation within management zones. In addition to this global connectivity between PUs, the spatial relationship between management zones can also be specified through a “zone boundary” file in Marxan with Zones. We used this file to specify that i) the GI zone connects and buffers the conservation zone, protecting it from potential impacts, and ii) the exploitation zone is as spatially disconnected as possible from the conservation zone. To get to such spatial distribution of the management zones, we calibrated the zone boundary file as recommended in Watts *et al.*, (2008).

The “Feature Penalty” parameter is a penalty applied when a biodiversity conservation or ESS feature does not achieve the required target. This penalty is weighted by a species-specific factor, so-called “feature penalty factor” (FPF) that determines the importance of satisfying the target of each feature. We used FPF = 10 for all features to ensure that all of them (species, habitats and ESS) achieved the required target.

3.3.3. Testing the effect of target distribution across management zones

To demonstrate the effect of different management objectives and constraints imposed to each management zone we designed four alternative planning scenarios that distribute in different ways the targets for ESS and biodiversity across management zones. These scenarios included a

gradient ranging from low to high flexibility at mixing representation objectives for biodiversity and ESS within the same zone. Namely, from a strict scenario with a conservation zone exclusively devoted to the representation of biodiversity targets (i.e., conservation management), to more flexible scenarios where an increasing number of co-occurrence of biodiversity and ESS objectives were allowed within each management zone. This was used to assess the changes in the target achievement of ESS and biodiversity and to detect co-benefits from shared management of some ESS and biodiversity in a given management zone. In the first scenario (Scenario 1), the strictest one in terms of conservation measures, we placed 100% of each group of ESS in its more suitable management zone, according to the definition of the zones (group A ESS and biodiversity in the conservation zone, group B ESS in the GI zone and group C ESS in the exploitation zone); in the second scenario (Scenario 2), we allowed the co-occurrence of some group A ESS and biodiversity in the GI zone as well as of some group B ESS in the conservation one, maintaining the ESS of group C only in the exploitation zone. In the third scenario (Scenario 3), we let some target of group C ESS to occur in the GI zone in addition to the flexibility between group A ESS, biodiversity and group B ESS already included in the previous scenario. In the case of the fourth and last scenario (Scenario 4), we allowed the allocation of some ESS from all the groups in the conservation zone, increasing the flexibility of the Scenarios 2 and 3 by adding some ESS target of group C in the conservation zone as well (Table 2). We compared the four scenarios by computing the area devoted to each management zone and analyzing their spatial distribution in each final solution, as well as recording the target achievement of all biodiversity and ESS features in each scenario.

3.3.4. Sensitivity analysis on ESS targets

To explore the potential trade-offs that could arise between different ESS and biodiversity under increasing targets we carried out a sensibility analysis by changing the total targets associated to each ESS. We wanted to see how the target achievement of the ESS and biodiversity changes when we increased the total target on ESS. We also wanted to identify potential tipping points over which the achievement of targets representation could no longer be secured. (e.g., no more

access to provisioning ESS could be granted without compromising the maintenance of regulating ESS or biodiversity). To test this changes not only between management zones but also between scenarios, we ran the sensitivity analyses in the two opposite scenarios, the first one and the fourth one. We raised the target on all ESS gradually (same target variation for all the ESS) from 10 to 90% of the total amount of each ESS (5 % increments at a time).

4. Results

4.1. Spatial distribution of biodiversity values and ESS supply

The areas of highest priority/ threatened bird species richness were located along the coastal and the river network, given the high dependency of some of the species on aquatic habitats. The areas with the highest concentration of priority habitats were mainly located in the northern and northeastern parts of the study area. The ESS distribution is conditioned by the orography of the region. Thus, since in the central depression are located important areas devoted to agriculture, food crop production ESS has its highest values in that area, also characterized by high values of water retention and hunting potential ESS in these areas. In the northeast of the region, in the Pyrenean mountains, we found high values for ESS related to the presence of forest ecosystems (i.e. carbon retention and biomass production), and there are also high values for avoidance of soil erosion, water retention and grazing potential ESS related to the natural mountain pastures and the role of forests in the protection against erosion. Biodiversity and ESS distribution are mapped in Appendix B.

4.2. Testing the effect of target distribution across management zones

The solutions for the four alternative planning scenarios showed a pattern towards decreasing extent of the exploitation zone an increasing extent of the conservation and GI management zones from Scenario 1 to Scenario 4 (i.e., when moving from a strict planning scenario towards more flexible options where conservation and exploitation of some ESS were allowed to co-occur in the territory). There was also a reduction of the total area selected under the three management

zones as we move from Scenario 1 to Scenario 4, which indicates that, in the latter, 3,000 km² less area was needed to cover the same target demand of biodiversity and ESS comparing Scenario 4 with Scenario 1. On the other hand, the spatial allocation of all management zones remained quite stable across scenarios (Fig 3). Representation targets were achieved across all four scenarios.

The GI zone played a special role at buffering and connecting different conservation zones, including the Natura 2000 network. This zone also contributed to achieving the targets of the biodiversity features and ESS that were prioritized in this zone (i.e. mushroom production, pollination potential, available areas for extensive grazing and hunting potential). The representation of biodiversity (species and habitats) values in this zone increased as we moved from Scenario 1 to Scenario 4, the proportion of the GI zone being around 10% in Scenario 1, and more than 15% in Scenario 4. This implies that more than 1,500 PUs (1,500 km²) with high value for habitat and species conservation were added to this zone in Scenario 4 as compared to Scenario 1.

4.3. Sensitivity analysis on ESS targets

The area selected under each management zone changed non-linearly when we increased the target for ESS from 10 to 90%. In Scenario 1, we observed a tipping point beyond which it was not possible to allocate more area to the exploitation zone, with a maximum at approximately 40% of ESS target. The GI and exploitation zones followed a rather specular pattern, so that, in general, when the one increased the other decreased and vice versa. This pattern was not so marked under Scenario 4, where the area devoted to the exploitation zone reached its global maximum at around 90% of ESS target. Instead, was the conservation zone the one that showed a tipping point in Scenario 4, the maximum was around 70% of the ESS target (Fig. 4).

Regarding the effect of increasing targets on potential trade-offs between ESS, we found threshold values over which some ESS could not achieve the target. This happened for all management zones (Fig. 5). The trend in target achievement across the sensitivity analysis within each

management zone was similar across scenarios, which implied that there were always the same ESS that started to miss part of the targets requested (i.e., avoidance of soil erosion in the conservation zone, pollination potential in GI zone and biomass production in the case of the exploitation zone). The difference is that, in Scenario 4, this threshold was displaced towards higher values of targets for ESS. Thus, under Scenario 4, the appearance of trade-offs was delayed towards higher targets. For example, in the exploitation zone, we could no longer represent all the target for biomass production ESS when we reached targets > 40% in Scenario 1, whilst the same ESS only started to miss some of its representation target for targets > 50% in Scenario 4 (Fig 5c). The target achievement for biodiversity features was not sensitive to increasing targets for ESS, and remained practically constant along the range of percentages of ESS target (see Fig. 5). However, the total target achieved for species and habitats in the conservation zone was higher in Scenario 4 than in Scenario 1 (Fig. 5a).

5. Discussion

Here, we demonstrate how systematic planning with multiple management zones in large geographic units can assist decision-making when designing a network of GI and, at the same time, address potential trade-offs and co-benefits that may arise between biodiversity values and ESS exploitation. This approach integrates the distribution of ESS and biodiversity throughout the landscape, trying to enhance win-win situations (e.g., co-benefits of including some ESS in the same management zone) and minimize potential trade-offs between competing non-compatible objectives (e.g., allocating biomass extraction as far as possible from the conservation zone). This analytical framework could contribute to more holistic management planning by integrating both human development and biodiversity conservation simultaneously (Howe *et al.*, 2014) in the context of a GI strategy. Furthermore, the use of more flexible approaches where biodiversity and ESS coexist could help to enhance both biodiversity conservation and human wellbeing through synergetic relationships, so efforts implemented for the maintenance of ESS could also benefit the conservation of biodiversity (Morán-Ordóñez *et al.*, 2016; Hermoso *et al.*,

2018), e.g., some birds could benefit from some open spaces devoted to agriculture or pasture. Also the configuration of the GI zone plays a special role in connecting and buffering the conservation zone, not only granting ESS provision but also habitat connectivity functions (Mubareka *et al.*, 2013). The approach presented here could help to unlock new conservation opportunities in highly humanized landscapes, by enhancing the role of existing protected areas (e.g., by adding the value of the ESS that they provide), helping to minimize land use conflicts due to the high competition for space, and connecting protected areas and ecosystems.

The different planning scenarios that we tested, which represented alternative conceptual paradigms in the conception of management planning for biodiversity and ESS, led to a change in the extent of the different management zones. The progressive allocation of some provisioning and cultural ESS to the conservation zone came up with a diminution of the exploitation zone area and an increase of the other two management zones. This implied that the more flexible the scenarios were, the more increased the GI zone and, thus, the GI network value (i.e. connecting conservations zones and delivering ESS).

The sensitivity analysis on targets for ESS showed that trade-offs between ESS appear at some point beyond which it is not possible to further fulfil the targets for all of them at the same time (tipping point). These trade-offs appear even in the least strict scenario, which means that for high target demand on ESS, it was not possible to achieve the representation of all ESS even though the allocation of ESS to conservation and GI zones was more flexible. However, we demonstrate here that more flexible planning approaches that allowed some uses and exploitation of ESS in the conservation zone contribute to reduce trade-offs since these are displaced towards higher target levels. This flexible approach also suits the philosophy of Natura 2000 network that aims not to only preserve biodiversity, but also maintain traditional uses on the territory (Bastian *et al.*, 2014). Furthermore, the use of Marxan with Zones software allows for defining a spatial distribution of the management zones ensuring that conservation enclaves are not affected by anthropogenic impacts (e.g. exploitation of some ESS) within the framework of a GI strategy that connects natural sites. This is an approach never done before using the tool Marxan with Zones,

even though there are a few previous studies that have applied systematic planning strategies and others methodologies for designing GI networks in large territories (see Vallecillo *et al.*, 2018, Cannas *et al.*, 2018, Liqueste *et al.*, 2015).

The spatial distribution of the GI zone that resulted from the spatial prioritization exercise offers an important network of connection between natural areas. This is especially relevant given the actual limitations for many species to move between protected areas that are affecting the conservation of the biodiversity around the world (Benett & Saunders, 2010) and suits the objectives and characteristics required for the design of a GI network in Catalonia or elsewhere (i.e., representing some ESS and enhancing the ecosystem capacity to deliver services and to connect natural areas).

Further development of this analytical framework should pay special attention to the mapping of biodiversity features (considering the distribution of other species of flora and fauna that may represent even better the broad biodiversity of the study area). Moreover, the work presented here could also benefit from better and more representative mapping of ESS and/or consideration of more services (Schulp *et al.*, 2014). Additional key aspects that deserve further attention are, the consideration of social demand and existing policies on ESS (e.g., goals on bioenergy production) that would help set more realistic targets, the flow of ESS from where they are produced to the areas where they are demanded, and also the long-term temporal dynamics of ecosystems. Further research may also consider the potential trade-offs and co-benefits between ESS and biodiversity values based on systematic assessments of the relationships among them rather than on preconceived ideas on the compatibility between certain ESS supply and conservations goals (Roces-Díaz *et al.*, 2018a). In this sense, it is also important to take into account the spatial scale of the analysis, since this could also affect the relationship between ESS and biodiversity conservation (Roces-Díaz *et al.*, 2018b).

Moreover, the application of our approach needs careful consideration of the number of management zones and their associated management objectives to be adapted to the specific

planning problems faced in other areas. In our case, we considered three management zones to allow achieving conservation targets for biodiversity and different types of ESS and minimize potential conflicts between them. However, the number of management zones and their associated management objectives need to be designed on case-by-case basis according to local contexts and objectives. Some key aspects to consider when designing these management zones, are the assessment of the different objectives pursued (e.g., representation of biodiversity and ESS) and potential conflicts between them, and the definition of targets to cover demand- and/ or policy-driven quotas.

6. Conclusion

The use of integrated planning for ESS and biodiversity provides a holistic view of the opportunities and potential conflicts when managing landscapes for different, and often conflicting, objectives. We demonstrate how this integrated planning for multiple simultaneous objectives can be used to prioritize the spatial allocation of different management zones for achieving objectives of biodiversity conservation, maintenance of ESS and granting access to conflicting ESS. Moreover, we show that it is also possible to tackle spatial dependencies between different management zones (e.g., maximizing connectivity or disconnection between different zones). This latter feature makes this approach suitable for designing GI networks that enhance connectivity between biodiversity conservation areas and areas devoted to the maintenance of ESS. The integrated planning approach demonstrated here is flexible and could be used in other areas for optimizing and prioritizing the spatial allocation of management zones and in the case of European regions, meeting European mandates concerning the design of GI networks. In this regard, the aspects that require careful consideration are the definition of relevant management zones to be prioritized according to the specific needs (e.g., features to consider in the planning process) as well as a proper characterization of the potential conflicts and/or co-benefits between management objectives. This is a key issue when defining how many management zones would

be required and what it will be aimed at each of them. Finally, better data on biodiversity distribution and ESS would also enhance the reliability of the results that arise from the planning process.

Acknowledgments

This work was supported by the project *INMODES*, (CGL2017-89999-C2) founded by MINECO (Ministerio de Economía y Empresa, Spanish Government) and by the project *Strategies for adapting the Natura 2000 network to climate change* that have the support of the Ministerio para la Transición Ecológica (Spanish Government) through Fundación Biodiversidad (DOC20090050). V.H was supported by a Ramón y Cajal contract (RYC-2013-13979) funded by the Spanish Government

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648

649 Table 1: Summary of the ESS considered in this study.

Name	Source	Units	Resolution (m)	Ecosystem service type	Group type
Avoidance of soil erosion	MAES (Mapping and Assessment of Ecosystems and their Services, 2015)	dimensionless	100x100	Regulating and maintenance	A
Carbon storage	ICGC (Institute Cartogràfic i Geològic de Catalunya, 2016)	tons of C/ha	20 x20	Regulating and maintenance	A
Water retention	MAES (Mapping and Assessment of Ecosystems and their Services, 2015)	dimensionless	100x100	Regulating and maintenance	A
Pollination potential	MAES (Mapping and Assessment of Ecosystems and their Services, 2015)	dimensionless	100x100	Regulating and maintenance	B
Biomass production	ICGC (Institute Cartogràfic i Geològic de Catalunya, 2016)	tons of biomass/ha/year	20x20	Provisioning	C
Food crop production	MAES (Mapping and Assessment of Ecosystems and their Services, 2015)	1000 tons/year	10000x10000	Provisioning	C
Mushroom production	de-Miguel <i>et al.</i> 2014	kg/ha/year	1000x1000	Provisioning	B

Potential areas for extensive grazing	SIGPAC, 2011	% of grazing surface	1000x1000	Provisioning	B
Recreation opportunity	MAES (Mapping and Assessment of Ecosystems and their Services,2015)	9 categories	100x100	Cultural	A
Hunting potential	Herrando <i>et al.</i> , 2011	Presence/absence	1000x1000	Cultural	B

650

651 Table 2. Target distribution across management zones under each planning scenario.

		Conservation zone	GI zone	Exploitation zone
Scenario 1	<i>Biodiversity</i>	100	-	-
	<i>Group A</i>	100	-	-
	<i>Group B</i>	-	100	-
	<i>Group C</i>	-	-	100
Scenario 2	<i>Biodiversity</i>	75	25	-
	<i>Group A</i>	75	25	-
	<i>Group B</i>	25	75	-
	<i>Group C</i>	-	-	100
Scenario 3	<i>Biodiversity</i>	75	25	-
	<i>Group A</i>	75	25	-
	<i>Group B</i>	25	75	-
	<i>Group C</i>	-	25	75
Scenario 4	<i>Biodiversity</i>	75	25	-
	<i>Group A</i>	75	25	-
	<i>Group B</i>	25	75	-
	<i>Group C</i>	25	25	50

652

653

Figure 1. Conceptual framework for the design of a multifunctional GI network to conserve and reconnect natural areas and deliver ESS to society. To simplify this figure, this approach is presented by showing two management zones only (i.e., a core area devoted to biodiversity conservation and a green infrastructure zone also devoted to ESS supply), but the number of alternative management zones could vary depending on the context of each specific planning exercise and the objectives to be achieved. For instance, the core area, could also work as management zone for the maintenance of ESS and not only for biodiversity conservation, depending on the scenario being tested.

664

665 Figure 2. Elements to be considered and integrated in a network of GI approach.

Figure 3. Spatial distribution of the three management zones (conservation, GI network and exploitation) across the study area for the four different planning scenarios tested. These scenarios convey different ways of distributing representation targets for biodiversity and ESS across the three management zones, from a “strict” approach where management zones had exclusive objectives (e.g., no provisioning ESS were allowed within other management zones; Scenario 1), to a more flexible approach where management zones conveyed multiple uses simultaneously (e.g, the representation of a proportion of target for provisioning services was allowed across the three management zones; Scenario 4).

676

677 Figure 4. Area selected (km²) under each management zone for different targets of ESS. The
 678 upper figure corresponds to scenario 1 and the bottom figure depicts scenario 4.

680 Figure 5. Target achieved by biodiversity conservation and ESS supply features for different
681 targets on ESS in Scenarios 1 and 4: a) Conservation zone, b) GI network zone and c) Exploitation
682 zone. The black vertical line indicates the point where target achievement on ESS started to
683 decrease.