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Natura 2000 sites, public forests and riparian corridors: The connectivity backbone of forest green infrastructure

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ABSTRACT

The connectivity of protected areas, such as the Natura 2000 network, is crucial for maintaining healthy ecosystems and for the delivery of ecosystem services into the wider landscapes in which they are embedded.

We here present a novel combination of methods for connectivity analysis across heterogeneous landscapes, integrating graph-based analyses, least-cost path modelling and the Probability of Connectivity metric, and apply these methods to the network of Natura 2000 woodland sites in mainland Spain. We deliver key insights on the connectors between Natura 2000 sites: their location and width (including transboundary ones), their prioritization in conservation and restoration scenarios involving different land uses, and the bottlenecks (weak points due to land use pressures) found along them. Based on these results, we characterize the landscapes traversed by the connectors within and outside the protected sites to inform related land management decisions.

We show that forests of public utility play a key role in sustaining Natura 2000 connectivity in Spain. They may qualify as an effective area-based conservation measure significantly contributing to the connectivity element of Aichi Target 11.

Riparian forests were part of the identified connectors much more frequently than expected by their area. They stand out as a crucial green infrastructure safeguarding the connectivity of Natura 2000 woodland habitats, particularly when forest species need to traverse landscapes dominated by agricultural and artificial land uses.

Natura 2000 sites have good connectivity conditions compared to unprotected lands. First, the identified woodland connectors preferentially traversed Natura 2000 lands. Second, the large majority of bottlenecks occurred outside Natura 2000. Natura 2000 sites cannot, however, be considered free from connectivity limitations; they still contained a significant number of bottlenecks that would need to be addressed in the site-level management plans.

The priority connectors for conservation were preferentially found in the well-forested and well-protected landscapes in the main mountain ranges of Spain. On the contrary, the priority connectors for restoration traversed much more frequently landscapes dominated by agriculture. In these landscapes, connectivity improvements largely depend on the restoration of riparian forests and on measures that mitigate the intensification of agriculture by promoting landscape complexity and natural vegetation remnants. The remarkable spatial segregation found between the priority landscapes for connectivity conservation and those of priority for restoration highlights the need for an integrated perspective for land use planning and for the management of the Natura 2000 network in Europe.

1. Introduction

The connectivity of protected areas (PAs) refers to the possibility of animal species, and of the genes, seeds and pollen they carry, to move from one protected site to another. The connectivity of PA networks is essential for the preservation of healthy ecosystems with a high species richness and genetic diversity, for the delivery of ecosystem services into the wider landscapes, and for allowing the adaptation of species to climate and land use changes (Krosby et al., 2010; Laurance et al., 2012; Thomas et al., 2012; De Oliveira et al., 2017). The importance of

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PA connectivity is recognized in the Strategic Plan for Biodiversity for 2011–2020 adopted in 2010 by the parties to the United Nations Convention on Biological Diversity (CBD), which includes twenty Aichi Biodiversity Targets. Under Aichi Target 11, the international community agreed to increase by 2020 the terrestrial area under protection to at least 17% in ‘effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures´ (CBD, 2010). Recent global assessments have shown, however, that the connectivity element of Aichi Target 11 is far from being met; in 2016, only about one third of the world´s countries and ecoregions had 17% or more of their land covered by protected and connected areas (Saura et al., 2017, 2018). The main strategic priorities for sustaining or improving PA connectivity have been reported to considerably differ across countries (Saura et al., 2018). In many European countries, including Spain, ensuring the permeability of the unprotected landscapes in between PAs, rather than the designation of new PAs, has been highlighted as the main priority for well-connected PA systems (Saura et al., 2018). In this context, the role to be played by the wider (unprotected) landscapes and by other effective area-based conservation measures different from PAs (Jonas et al., 2014) stands out as crucial for sustaining and improving the connectivity of habitat networks.

One of the most important coordinated international actions for biodiversity conservation is the Natura 2000 network of protected areas in the European Union (EU). The aim of this network is to ensure the long-term persistence of Europe's most valuable and threatened species and habitats, listed under both the Birds Directive (79/409/EEC, amended as 2009/147/EC) and the Habitats Directive (92/43/EEC). Currently, the Natura 2000 network consists of more than 27,000 sites covering more than 18% of EU land (European Commission, 2016). This coverage is higher in some countries like Spain, where about 27% of the land is covered by Natura 2000 sites (European Commission, 2016). The importance of maintaining, or when possible improving, the connectivity of the Natura 2000 network is well recognized in the Habitats Directive: the EU member states are encouraged to conserve or restore the features of the landscape that increase the ecological coherence of the network and allow for the migration, dispersal and genetic exchange of wild species.

The amount of land that can be covered by fully-designated PAs is, however, limited (Bengtsson et al., 2003; Butchart et al., 2015), as well as the connectivity levels that can be achieved through PAs alone. For this reason, the functionality and long-term persistence of biodiversity relies on appropriate land use planning in the wider landscapes in which PAs are embedded; this includes the identification and management of key landscape elements in heterogeneous, multiple-use landscapes (Bengtsson et al., 2003; Garmendia et al., 2016; Tannier et al., 2016). In particular, sustainably managed forests and multifunctional forestry may play a key role in supporting the ability of species to move through unprotected lands (Laita et al., 2010; Bergsten et al., 2013), although such role has rarely been specifically evaluated in functional connectivity assessments. Riparian forests, on the other hand, are exceptionally rich in biodiversity, provide a wide range of ecosystem services, and can have a fundamental role in forest landscape functioning, acting as corridors between forest habitats and populations (Naiman et al., 1993; Gillies and StClair, 2008; Clerici and Vogt, 2013; Fremier et al., 2015). It is therefore advisable to consider the specific contribution of riparian forests in connectivity modelling and related landscape management recommendations. In this context, forests of different types should be conceived as part of the green infrastructure, which is defined as a strategically planned network of natural and semi-natural areas designed and managed to deliver a wide range of ecosystem services, including their ability to support connectivity (European Commission, 2013; Garmendia et al., 2016). In the EU, the Natura 2000 network constitutes the backbone of the green infrastructure, as explicitly recognized in the EU Green Infrastructure Strategy (European Commission, 2013). This strategy aims to ensure that the protection and restoration of green infrastructure become an integral part of land use planning and territorial development across multiple sectors.

Despite the importance of PA connectivity targets, there are very few comprehensive assessments that allow identifying which areas and landscape features, either within or outside protected lands, are most relevant to sustain the connectivity of protected forest sites and habitats over wide spatial scales. Many available studies have measured PA connectivity levels but have not mapped the functional connectors through which species movements and other ecological flows may be supported across the landscape (Laita et al., 2010; Minor and Lookingbill, 2010; Bergsten et al., 2013; Mazaris et al., 2013; Wegmann et al., 2014; Santini et al., 2016; Saura et al., 2017). Other studies that have mapped connectivity have not evaluated the specific contribution of forests or other specific green infrastructure elements to PA connectivity, but have rather considered other more generic landscape categories, such as wilderness areas, or the impacts of roads (Gurrutxaga et al., 2011; Gurrutxaga and Saura, 2014; Belote et al., 2016; Dickson et al., 2017). In addition, to our knowledge, none of these studies has assessed the connectivity performance of PAs compared to the unprotected landscapes, nor evaluated the degree to which connectivity restrictions may also be found within formally protected lands. Previous studies have either assumed PAs to be internally homogenous or have not separately disclosed the connectivity patterns within and outside PAs.

We here present a detailed analysis of the connectivity of the Natura 2000 sites covered by woodland habitats (forests and shrublands) in mainland Spain ($\approx$ 500,000 km^2) by applying a novel combination of methods and tools for functional connectivity modelling in heterogeneous landscapes. We first mapped the connectors between the central points of the Natura 2000 sites, thereby also accounting for potential connectivity limitations that might be imposed by the land uses within these sites. Second, we characterized the width of the permeable land strips along these connectors. Third, we prioritized the key connectors in which to concentrate conservation and restoration efforts. Fourth, we identified the bottlenecks (weak sectors) along these priority connectors. Fifth, and importantly, we assessed the degree to which different land cover and tenure types are a key part of the green infrastructure supporting the connectivity of the PA system. In this assessment, we payed particular attention to the role of riparian forests and of the public forest lands officially declared as of Public Utility in Spain. By doing so, we provide recommendations for the management and restoration of ecological functionality at wide planning scales, considering both protected sites and multiple-use landscapes, and demonstrate the considerable added value of a set of methods that also has potential of application in other countries in Europe or elsewhere.

2. Materials and methods

2.1. Woodland habitats: definition and spatial distribution

We defined three woodland habitat types with different forest canopy cover (FCC) and stage of development of the tree layer: (i) closed mature forest, with FCC $\geq$ 60% and tree diameter at breast height above 20 cm, (ii) open forest, with 10% $\leq$ FCC $<$ 60%, and (iii) shrublands, defined as areas covered by shrubs only or with a sparse tree layer (FCC $<$ 10%). These habitat types were considered for three reasons. First, they allowed evaluating how the results of the