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Research article

Filling gaps in a large reserve network to address freshwater conservation needs

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ABSTRACT

Freshwater ecosystems and biodiversity are among the most threatened at global scale, but efforts for their conservation have been mostly peripheral to terrestrial conservation. For example, Natura 2000, the world's largest network of protected areas, fails to cover adequately the distribution of rare and endangered aquatic species, and lacks of appropriate spatial design to make conservation for freshwater biodiversity effective. Here, we develop a framework to identify a complementary set of priority areas and enhance the conservation opportunities of Natura 2000 for freshwater biodiversity, using the Iberian Peninsula as a case study. We use a systematic planning approach to identify a minimum set of additional areas that would help i) adequately represent all freshwater fish, amphibians and aquatic reptiles at three different target levels, ii) account for key ecological processes derived from riverscape connectivity, and iii) minimize the impact of threats, both within protected areas and propagated from upstream unprotected areas. Addressing all these goals would need an increase in area between 7 and 46%, depending on the conservation target used and strength of connectivity required. These new priority areas correspond to subcatchments inhabited by endangered and range restricted species, as well as additional subcatchments required to improve connectivity among existing protected areas and to increase protection against upstream threats. Our study should help guide future revisions of the design of Natura 2000, while providing a framework to address deficiencies in reserve networks for adequately protecting freshwater biodiversity elsewhere.

1. Introduction

Freshwater ecosystems and biodiversity are among the most diverse and threatened systems in the world, and are commonly exposed to higher pressures than adjacent terrestrial or marine ecosystems (Nel et al., 2007). However, there has been little emphasis on declaring protected areas for the primary purpose of conserving freshwater biodiversity (Nel et al., 2009). Because of their terrestrial focus, existing protected areas often fail to address key ecological processes, such as the upstream-downstream propagation of impacts along rivers or the migration of freshwater-dependent species between spawning and growing areas (Pringle, 2001). These limitations underline the urgent need to improve the poor performance of protected areas to address specific needs of freshwater ecosystems and biodiversity.

The European Natura 2000 is the world's largest network of protected areas, encompassing over 25,500 sites, with a joint area of nearly 800,000 km^2, across 28 countries (http://ec.europa.eu/environment/nature/natura2000/). Natura 2000 was established under the European Union's Habitats Directive (Council Directive 92/43/EEC), and comprises Special Areas of Conservation (SACs) designated under the Habitats Directive, and Special Protection Areas (SPAs) designated under the 1979 Birds Directive (Council Directive 79/409/EEC). This network includes protected areas exclusively designated for conservation purposes, but also other

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areas where conservation is expected to be harmonized with human uses. Despite its large extent, the representativeness and capacity of Natura 2000 to protect freshwater biodiversity and key ecological processes have been questioned (e.g., Dimitrakopoulos et al., 2004; Hermoso et al., 2015). For example, in the Iberian Peninsula, Natura 2000 covers about 150,000 km^2 (25.8% of land surface) and encompasses 28,440 km of rivers and streams (approximately 25% of all watercourses). However, several taxa are poorly or moderately represented within Nature 2000, including reptiles and birds (Araújo et al., 2007), lichens (Rubio-Salcedo et al., 2013), and bats (Lisón et al., 2013) (but see Abellán et al., 2011 for an exception regarding raptors). This situation is especially worrying in freshwater ecosystems, with Hermoso et al. (2015) reporting that only a small percentage of fish, amphibians and aquatic reptile species (15% of 91 species) have at least 25% of their distribution protected or even less for higher targets. Although there is no consensus on the most appropriate target for conservation, these poor representation questions the conservation effectiveness of Natura 2000 for freshwater biodiversity. Similar results have been found for other aquatic taxa in the Iberian Peninsula (e.g., aquatic beetles; Abellán et al., 2007; Sánchez-Fernández et al., 2008, 2013), which warns for more attention to adequately protect the highly endangered and endemic Iberian freshwater biodiversity (Smith and Darwall, 2006).

The effectiveness of Natura 2000 could also be compromised by deficiencies in safeguarding key ecological processes (Hermoso et al., 2015). As in many other regions of the world, rivers in Natura 2000 are commonly used to define boundaries of protected areas or just simply as connecting corridors for terrestrial biodiversity (Hermoso et al., 2015). Consequently, it is common to find poor spatial overlap between protected areas and hydrological units such as subcatchments, which are more appropriate management units for freshwater ecosystems than rivers themselves (Hermoso et al., 2011). Given that Natura 2000 is now well established (although see Kati et al., 2014), there is a need to evaluate what additional areas could improve representation of freshwater biodiversity and include related key ecological processes.

Here, we use a systematic conservation approach to identify a minimum set of areas that complement Natura 2000 to i) adequately represent freshwater fish, amphibians and reptiles in the Iberian Peninsula, ii) account for key ecological processes affecting freshwater biodiversity related with spatial connectivity (Pringle, 2001; Fagan, 2002), and iii) mitigate the propagation of human disturbances along the river network. We use subcatchments as planning units, include connectivity between these units to improve the spatial design of priority areas, and account for land use intensity within subcatchments to avoid highly disturbed areas where the cost-effectiveness of conservation could be compromised. We also evaluate the surrogacy value of freshwater-dependent species listed in the Annexes II and IV of the European Union's Habitats Directive to adequately represent all freshwater-dependent species. Based on our results, we offer recommendations to improve the efficiency of protected area networks for conserving freshwater biodiversity and related ecological processes.

2. Methods

2.1. Study area

Our study area was the Iberian Peninsula (Spain and Portugal, excluding islands), covering approximately 583,000 km^2 and spanning four freshwater ecoregions (Abell et al., 2008). The majority of freshwater vertebrates are endemic to this region, making it a specific biogeographic unit for which to address conservation planning problems. The Iberian Peninsula comprises five major rivers systems with a drainage area >50,000 km^2 (Duero/Douro, Tajo/Tagus, Guadiana - shared by Spain and Portugal - and Guadalquivir and Ebro, flowing only in Spain), medium-size basins (>10,000 km^2; Jucar, Segura, and Minho rivers, among others), smaller basins (e.g., Tinto, Odiel, and Mondego Rivers), and small coastal basins. These hydrological units cover a wide range of orographic and climatic conditions, from Mediterranean to temperate (Hermoso et al., 2015).

2.2. Species distribution and protected areas

We compiled information on the spatial distribution for 91 freshwater-dependent species, including 62 fish species, 24 amphibians and 5 semi-aquatic reptiles (See Table in Appendix A1). Data on amphibians and reptiles were sourced from recent atlases at a 10-km grid cell resolution (Spain: Pleguezuelos et al., 2002; Portugal: Loureiro et al., 2010). Fish data for Portugal were based on the database built in Filipe et al. (2009) and in the Carta Piscícola (http://www.cartapiscicola.org/), whereas data for Spain was derived from the most recent atlas (Doadrio, 2002). We also updated these databases with species records from our own sampling carried out in the region. Our final database was the most comprehensive available for the Iberian Peninsula, with 49,463 occurrence records within 5938 10-km grid cells.

For our conservation planning assessment, we delineated 19,854 subcatchments, each including the portion of river length between two consecutive nodes or a river connection and its contributing area (Length = 7.7 ± 4.8 km, Area = 29.1 ± 23.5 km^2; Average ± SD). Subcatchments were delineated from a 90-m digital elevation model (sourced from the SRTM 90 m Digital Elevation Database v4.1; Jarvis et al., 2008) in ArcGIS 10.1 (ESRI, 2011). We then intersected the 10-km grid cells and subcatchments, and assumed that a species was present in a subcatchment whenever the grid cell occupied more than 50% of the subcatchment. Species distributions were then visually inspected to ensure that occurrences had not been assigned to the wrong hydrological catchment from grid cells overlapping two neighbour catchments.

We sourced the most up-to-date network of protected areas in the Iberian Peninsula, including Natura 2000, from the World Database of Protected Areas (UNEP, 2014). We considered all areas protected under IUCN categories II–VI as the pre-Natura network, as most of them had already been declared when Natura 2000 was created (Hermoso et al., 2015).

2.3. Priority areas for freshwater biodiversity

We used the software Marxan (Ball et al., 2009) to find an optimal set of subcatchments (our planning units) to represent each species' within 100, 250 and 500 subcatchments (target levels), respectively, under different connectivity requirements (see below and Table 1). For example, a conservation target of 250 subcatchments is roughly equivalent to 7300 km^2 or 2000 km of stream length. Our conservation targets ensured that we represented the entire distributions of the rarest and most threatened species, and a significant proportion of common species' distributions (see Supplementary figure in Appendix A2).

Marxan uses a heuristic optimisation algorithm to minimise an objective function (Equation (1)) that includes the cost of selecting subcatchments in the solution, with additional penalties for not achieving the conservation target for all species (Feature Penalty, weighted by Species' Penalty Factor, SPF) and spatial constraints that influence the connectivity of subcatchments in the solution (weighted by a Connectivity Strength Modifier, CSM). The overall connectivity penalty for a set of subcatchments in a given solution