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Catchment zoning to unlock freshwater conservation opportunities in the Iberian Peninsula

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ABSTRACT

Aim Conservation management in freshwater systems requires addressing some key ecological processes to warrant functional and effective protected areas. There are systematic planning methods available to address these needs, but they often result in large areas identified as priority for strict protection, which might constrain their implementation. Considering multiple zones with different management regimes might provide a more flexible and practical solution to this problem, though this approach remains poorly used in freshwater systems. We evaluate the use of a multizone approach to enhance protection of freshwater biodiversity and ecological processes in a large reserve network, Natura 2000.

Location Iberian Peninsula.

Methods We tested three scenarios of freshwater conservation planning: (1) a protection-only approach based on areas identified using Marxan; (2) a more flexible approach where multiple management zones are considered using Marxan with Zones, both accounting for Natura 2000; and (3) a third one similar to (2) but ignoring Natura 2000. The three scenarios were compared considering their effectiveness in representing all species. We also evaluated the role of Natura 2000 within the management zones identified and the effect of these areas.

Results We found that although there was only an 8% reduction in total area required to complement Natura 2000 under the multizone approach compared to the protection-only approach, the refinement of conservation recommendations under different management zones can reduce the area needed for strict protection by 62%. Considering Natura 2000 compromised the efficiency of solutions while only one-third of its extent was selected under the strict protection zone.

Main conclusions The refinement in management recommendations and resulting improvement in efficiency achieved by using the multizone approach could help unlock the needed expansion of Natura 2000 to adequately cover freshwater conservation needs in the Iberian Peninsula and other areas where similar issues have been highlighted.

Keywords

amphibians, freshwater fish, management zones, Marxan with Zones, Natura 2000, reptiles, systematic conservation planning.

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INTRODUCTION

Conservation planning has experienced significant advances in the last decade, including the development of new methods and tools addressing the specific needs of freshwater ecosystems (Collier, 2011; Linke *et al.*, 2011). These advances have been necessary in view of the concerning conservation status of freshwater ecosystems and biodiversity worldwide (Vörösmarty *et al.*, 2010), and the insufficient attention they had received (Nel *et al.*, 2007). To be effective, conservation planning for freshwater biodiversity must incorporate key aspects of freshwater ecology such as longitudinal connectivity (Pringle, 2001) and the propagation of threats along dendritic river networks (e.g. Moilanen *et al.*, 2008; Hermoso *et al.*, 2011, 2012). This is necessary to ensure maintenance of ecosystem processes, such as migrations or the flux of nutrients and energy, and to minimize the negative effect of threats within protected areas that might undermine conservation efforts (Nel *et al.*, 2007; Roux *et al.*, 2008). The consideration of these processes results in more effective conservation for freshwater biodiversity (Linke *et al.*, 2011).

Despite the significant contributions made in the last decade, systematic conservation planning for freshwater systems still needs further advances to make conservation recommendations more flexible and implementable (Abell *et al.*, 2007; Hermoso *et al.*, 2015a). A key problem to be solved is that the application of planning methods often highlights very large portions of hydrological catchments needed for securing connectivity and other ecosystem processes (Linke *et al.*, 2007; Thieme *et al.*, 2007; Moilanen *et al.*, 2008). These recommendations may be unfeasible in practice because of the potential conflict between conservation and other human activities, and thus very difficult to implement. To make conservation planning more informative and feasible for decision-making, Abell *et al.* (2007) proposed a multizone approach to help fulfil the spatial needs and ensure effective protection of fresh waters in a more flexible way. This approach is composed of three different zones with different management regimes (Abell *et al.*, 2007), including: (1) 'freshwater focal areas', vital for the protection of freshwater biodiversity, and similar to current protected areas in terrestrial or marine realms; (2) 'critical management zones', which need to be managed to maintain the ecological functionality of focal zones (e.g. connectivity to allow movement of individuals and gene exchange) and where human uses compatible with this conservation purpose are allowed; and (3) 'catchment management zones', linking the entire upstream catchment to a critical management zone, where human uses are not constrained, but best practices are required (e.g. treatment of wastewater disposal, maintenance of riparian buffers in good condition or by restricting the use of pesticides). This approach is increasingly accepted as an appropriate freshwater conservation framework (e.g. Linke *et al.*, 2011; Nel *et al.*, 2011; Esselman *et al.*, 2013), but it has rarely been applied in practice. However, Hermoso *et al.* (2015a) demonstrated how to incorporate this multizone structure in systematic conservation planning by using Marxan with Zones (Watts *et al.*, 2009), a common planning tool in marine (e.g. Klein *et al.*, 2009) and terrestrial planning (e.g. Schröter *et al.*, 2014). The use of this novel approach reduced the catchment area recommended under strict protection by 42% in freshwater ecosystems of Northern Australia (Hermoso *et al.*, 2015a), which translates into increased cost-effectiveness, less potential conflict with other uses and more implementable recommendations.

Freshwater ecosystems in the Iberian Peninsula hold a large proportion of endemic and threatened species, with half the freshwater fishes, amphibians and reptiles assessed for conservation status considered under threat of extinction (Doadrio, 2002; Pleguezuelos *et al.*, 2002; Oliveira *et al.*, 2005; Rogado *et al.*, 2005). Therefore, conservation of this endangered biota needs more attention, particularly because the main network of protection areas established in Europe, the Natura 2000 network, performs poorly for aquatic biodiversity. Recent studies have reported insufficient representation of freshwater biodiversity within Natura 2000 (Abellán *et al.*, 2007; Sánchez-Fernández *et al.*, 2008, 2013; Hermoso *et al.*, 2015b) and unsatisfactory spatial design for freshwater conservation purposes, with poor alignment with hydrological units and limited consideration of ecological processes (Hermoso *et al.*, 2015b). There are estimates that an expansion in the area covered by Natura 2000 of up to 47% would be needed to represent all freshwater vertebrates and enhance connectivity within protected areas (Hermoso *et al.*, 2015c). However, this large increase in land devoted to conservation would be troublesome in a region where Natura 2000 already covers 25.8% of land surface (150,000 km^2), and a similar proportion of all watercourses (Hermoso *et al.*, 2015b). Conservation recommendations like these could be difficult to implement under traditional conservation regimes, where other land uses need to be restricted within protected areas. In these circumstances, innovative planning models are particularly needed, to provide conservation recommendations that are both feasible and effective.

To develop more flexible and feasible conservation recommendations for the Iberian's freshwater biodiversity, here we use Marxan with Zones to implement Abell *et al.* (2007) conservation planning framework. We prioritized the spatial allocation and extent of freshwater focal, critical and catchment management zones to represent freshwater fish, amphibians and aquatic reptiles, and account for longitudinal connectivity. To evaluate the gains and losses in efficiency of a multiple management zone approach, and its capacity to address the propagation of threats, we compared three alternative scenarios: (1) using Marxan, where binary solutions are identified (e.g. protection-only) locking in areas within Natura 2000; (2) Marxan with Zones, where the multizone, non-binary approach is used, also including all areas in Natura 2000; and (3) Marxan with Zones similar to scenario (2) but without Natura 2000 as if no protected areas existed (Fig. 1). Priority areas were selected to ensure (1) adequate representation of freshwater species; (2) protection

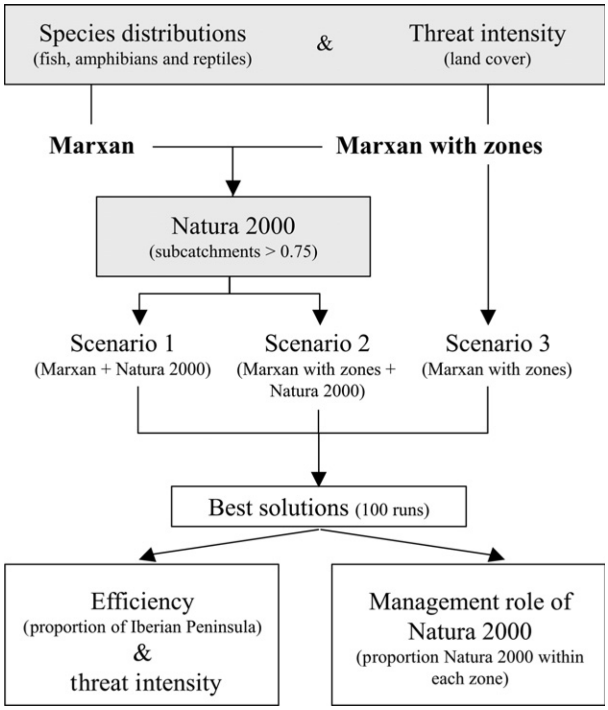

Figure 1 Flow diagram of analyses carried out in this study.

of key ecological processes related to spatial connectivity (e.g. migrations or fluxes of material and energy along river networks); and (3) minimization of impacts from human disturbances to freshwater biodiversity. We would expect the multizone approach to provide more efficient solutions, with less area under strict protection than the traditional binary approach. Given the limited value of Natura 2000 for freshwater conservation referred to previously, we would also expect further gains in efficiency and threat prevention when not considering such current protected areas in conservation planning. The methodology demonstrated here may be used for enhancing conservation opportunities in other regions of Europe and elsewhere, where similar problems to the Iberian Peninsula have been highlighted (Nel *et al.*, 2007).

METHODS

Study area

The study focused on the entire Iberian Peninsula (Spain and Portugal, excluding islands), which covers about 583,000 km^2 and spans across four freshwater ecoregions (Abell *et al.* 2008). The Iberian Peninsula comprises five major river catchments with drainage area > 50,000 km^2 (Duero/Douro, Tajo/Tagus, Guadiana – shared by Spain and Portugal – and Guadalquivir and Ebro, flowing completely in Spain), medium-size basins (> 10,000 km^2; Jucar, Segura, Minho rivers among others), smaller basins (e.g. Tinto, Odiel or Mondego Rivers) and small coastal basins. These catchments cover a wide range of orographic and climatic conditions, from Mediterranean to temperate (Hermoso *et al.*, 2015b), and host a unique biodiversity. Most catchments in the Iberian Peninsula are isolated from those in neighbouring Europe by the Pyrenees, and most of its freshwater vertebrate fauna is endemic, which makes it a distinctive biogeographic unit particularly suitable to address conservation planning problems.

Species distribution and Natura 2000

We compiled information on the spatial distribution of 91 freshwater-dependent species, including 62 fish, 24 amphibians and five semi-aquatic reptiles (Appendix S1). We compiled occurrence data of aquatic amphibians and reptiles 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 were derived from the most recent atlas (Doadrio, 2002). Recent surveys made by the authors were used to update datasets. The final database comprises the most comprehensive information on the present occurrence of these taxa in the Iberian Peninsula, with 49,463 occurrence records within 5938 10-km grid cells.

To make the analyses sounder for freshwater ecosystems, we translated the information originally reported in 10-km grid cells into subcatchments. We delineated 19,854 subcatchments, each including the portion of river stretch between two consecutive nodes or watercourse connections and its contributing drainage area (Length = 7.7 ± 4.8 km, Area = 29.12 ± 23.5 km^2; Average ± SD) from a 90-m resolution digital elevation model (sourced from the SRTM 90 m DIGITAL ELEVATION DATABASE 4.1; Jarvis *et al.* 2008) in ARCGIS 10.1 (ESRI 2011). We then intersected grid cells and subcatchments and assumed a species to be present in a subcatchment whenever the grid cell occupied more than 50% of the subcatchment. The spatial distribution of each species was then visually inspected to ensure that occurrences had not been assigned to the wrong hydrological catchment from grid cells overlapping two neighbour catchments (examples in Appendix S2). The extent of Natura 2000 was sourced from the World Database of Protected Areas (UNEP, 2014), which contains the most up-to-date representation of the protected area system in the Iberian Peninsula. Given the lack of overlap in boundaries of Natura 2000 and subcatchments, we considered that a subcatchment was adequately protected when > 75% of its extent was within Natura 2000.

Catchment zoning for freshwater conservation

Our multizone planning approach was based on Abell *et al.* (2007), which considers three management zones with increasing restrictions to human activities: ‘catchment management zones’, ‘critical management zones’ and ‘freshwater focal areas’. We used the software Marxan with Zones (Watts *et al.*, 2009) to prioritize the spatial allocation of a minimum set of subcatchments to each management zone, aiming to achieve the conservation targets and the function of each zone. Marxan with Zones uses a simulated annealing algorithm similar to the conventional Marxan, which minimizes an objective function that conveys three different parameters: cost of reserve, connectivity and species' representation shortfall (Watts *et al.*, 2009).

The cost of reserve is the sum of all the partial costs of subcatchments included in any of the zones. In order to account for feasibility of conservation, we included estimates of threat intensity across the Iberian Peninsula as an alternative estimate of cost. Areas under high threat are less suitable for conservation because they would need additional conservation actions (e.g. eradication of invasive species or restoration of habitat quality) to ensure the threat to biodiversity is adequately addressed. We used the proportion of each subcatchment under intensive human uses (Appendix S3) as an estimate of threat intensity. This estimate was used as a penalty in the prioritization process similar to Linke *et al.* (2012), where we tried to avoid the allocation of any zone in highly degraded areas whenever possible.

The connectivity penalty accounts for all connections along the river network (longitudinal connectivity) that are missed in the solution. This is used to foster longitudinally connected reserve networks (e.g. Hermoso *et al.*, 2011) and inform Marxan with Zones on how zones should be spatially arranged within the catchment (e.g. Hermoso *et al.*, 2015a). Following the network topology of the drainage system, a penalty would apply every time an upstream subcatchment to any given subcatchment selected is not included in the solution. This information is provided to Marxan and Marxan with Zones by a boundary file that contains all pairwise upstream connections to any given subcatchment, and a penalty value associated. This file differs from terrestrial and marine boundary files as it is made of all longitudinal connections between subcatchments. Penalties in the boundary file are distance weighted according to the distance between subcatchments along the river network (penalty = distance $(\text{km})^{-1/2}$; see Hermoso *et al.*, 2011 for details) rather than exposed, non-protected, boundaries as normally done in marine and terrestrial applications. The overall weight of the connectivity component in the objective function can be controlled by a Connectivity Strength Modifier (CSM). The value used here (CSM = 0.5, constant across all scenarios) was calibrated following recommendations by Hermoso *et al.* (2011) as the best trade-off value between ecological connectivity and area needed using Marxan. Higher connectivity could only be achieved at expenses of including larger areas, up to full catchments in some cases. In Marxan with Zones, we can also foster connectivity not only within zones (e.g. longitudinal connectivity within reserves as in Marxan) but also across different zones. Here, we used this capability to specify the spatial arrangement of different management zones to fulfil the recommendation by Abell *et al.* (2007). We sought to identify core conservation areas or freshwater focal zones connected through critical management zones and buffered upstream by catchment management zones. To do this, we used the boundary zone (Watts *et al.*, 2008) to guide Marxan with Zones on how the different zones should be arranged spatially and where conservation targets could be achieved according to the role each zone plays (Abell *et al.*, 2007). This was done by calibrating the zone boundary file following recommendations in Hermoso *et al.* (2015b) to specify the desired spatial relationship between zones.

Finally, we set a constant target of 250 subcatchments across all species, which roughly represents 2000 km of stream length or 7300 km^2 of the spatial distribution of each species whenever possible. This is a conservative target that is used here for the sake of demonstration, but that it would ensure the full coverage of the spatial distribution of all Critically Endangered and most Endangered aquatic vertebrates in the Iberian Peninsula, as well as significant proportions of the ranges of Vulnerable species (Appendix S1; Hermoso *et al.*, 2015b). Better informed targets driven by ecological and conservation needs of each species should be used to enhance conservation recommendations, but this is beyond the demonstration purpose of this study. We set a high Species Penalty Factor (SPF = 10) to ensure conservation targets were achieved for all species. SPF is a weight that can be applied in the objective function of Marxan and Marxan with Zones to control for the importance of achieving targets for species. If SPF is set low, targets for some species could be missed due to trade-offs with costs, in case some species were very expensive to fully represent for example. Marxan with Zones allows specifying the contribution of each zone to the achievement of targets by using a zone target file. To be conservative, we wanted targets to be achieved mostly in freshwater focal areas (90%), while the additional two zones would mainly contribute 5% to the achievement of representation of targets each, apart from ensuring adequate connectivity and minimizing the downstream propagation of threats into freshwater focal areas and.

Conservation planning scenarios

We used three planning scenarios (Fig. 1) to compare conservation recommendations derived from Marxan (Ball *et al.*, 2009) and Marxan with Zones (Watts *et al.*, 2009), and the effect of including Natura 2000 in the solutions. We kept all conservation constraints constant, such as cost and connectivity, to make results comparable across scenarios. In scenario 1, we identified priority areas for conservation using Marxan as demonstrated in previous studies (e.g. Hermoso *et al.*, 2011, 2015c). We locked in all subcatchments adequately covered by Natura 2000 (> 75% of subcatchment covered under Natura 2000), so our objective was to find a minimum set of areas to fill the representation gaps for freshwater biodiversity in Natura 2000 reported in Hermoso *et al.* (2015a). In scenario 2, we explored the same conservation planning problem but using Marxan with Zones under the three protection zones structure detailed above. Finally, in scenario 3, we used Marxan with Zones as in scenario 2, but did not lock in subcatchments covered by Natura 2000. All scenarios were run 100 times (2.5 million iterations each) and the best solution was retained for further analyses.

Efficiency and threat intensity of best solutions

As targets were set constant across scenarios, we used the extent of the solution as a surrogate for the relative efficiency of each scenario, measuring the proportion of the Iberian Peninsula included in each best solution. We also recorded the proportion of all selected areas coincident across scenarios as an estimate of spatial overlap, and the proportion of Natura 2000 included in each zone (only for scenarios 2 and 3). The later would help evaluate the role of Natura 2000 in protecting freshwater biodiversity under the multizone approach. We would expect to find a large proportion of Natura 2000 selected as freshwater focal areas if already protected subcatchments were critical for achieving the conservation targets, regardless of the scenario used. We also recorded the average threat intensity within subcatchments selected under the three different scenarios to compare the capacity of these planning approaches to deal with the spatial distribution of threats and evaluate how threats were distributed across management zones.

RESULTS

We found that some priority areas for conservation of Iberian freshwater biodiversity were consistent across conservation planning scenarios. These were mainly distributed along the upstream reaches of the Ebro River, Jucar River and Miño catchments, low reaches of the Tagus River and the Guadiana catchments, and small coastal catchments along the Portuguese, Northern Spain and Eastern Mediterranean coasts (Fig. 2a,b).

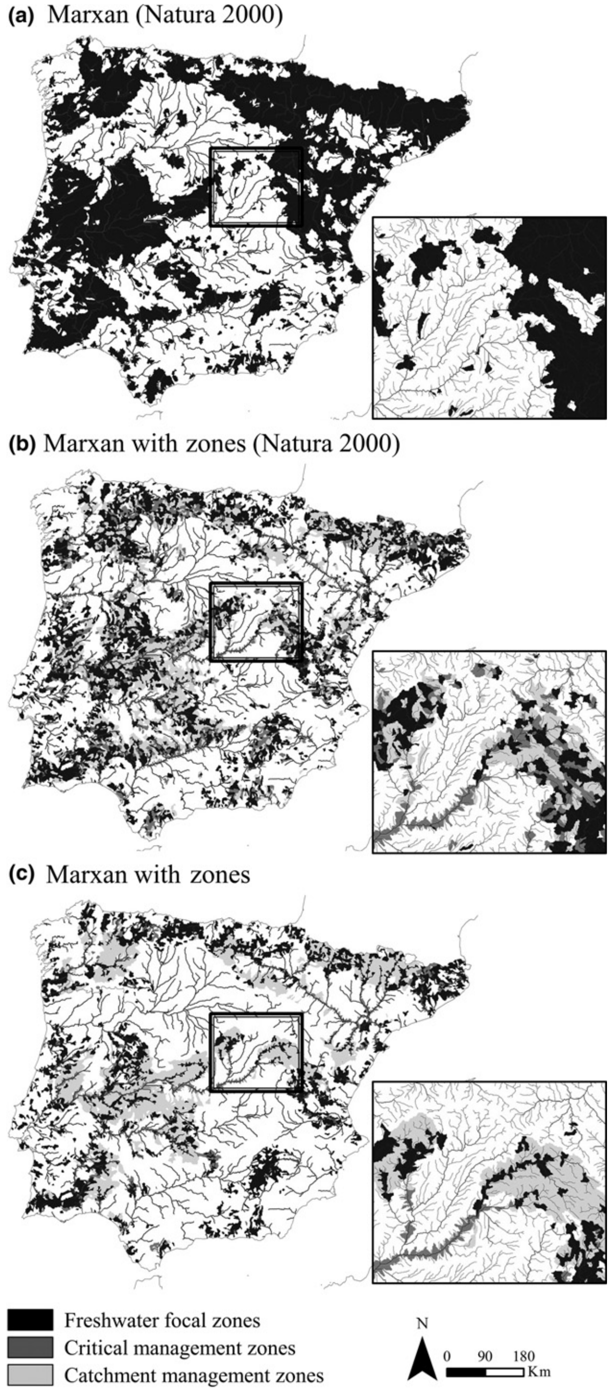

Figure 2 Best solutions obtained after 100 runs (2.5 million iterations each) in Marxan (scenario 1) and Marxan with Zones (scenarios 2 and 3). Best solution obtained from Marxan is only composed by freshwater focal zones (black subcatchments), while solutions from Marxan with Zones also had Critical management zones (dark grey) and Catchment management zones (light grey).

Efficiency of best solutions

The adequate representation of all freshwater species and connectivity objectives would require an additional 67.2% of area to that already included in Natura 2000 (i.e. up to 48% of the Iberian Peninsula) if using conventional Marxan conservation planning (scenario 1; Fig. 2a). The total area required for strict conservation would be reduced, however, if using multizone planning approach. Under scenario 2, Marxan with Zones selected 8% less area than conventional Marxan to achieve the same objectives (Fig. 2a,b). However, the improvement in efficiency was especially significant when considering only freshwater focal areas under scenario 2, which represented a 62% increase in efficiency compared to scenario 1 (Fig. 3). Only one-third of the area already protected under Natura 2000 was selected as freshwater focal zones, while the remaining 2/3 was distributed equally within critical and catchment management zones (Fig. 4). Results from scenario 3 showed that efficiency could be further improved by planning as if no reserves already existed, as the extent of focal zones was 41.8% lower than the area currently protected under Natura 2000. Likewise, the extent of these focal zones was 68.7% smaller than the protection areas

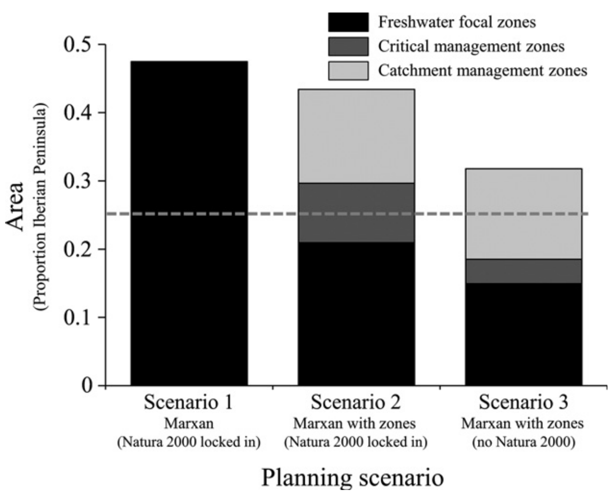

Figure 3 Efficiency, measured as the proportion of the Iberian Peninsula selected under different scenarios shown in Fig. 2. The dotted line indicates the area already covered by Natura 2000.

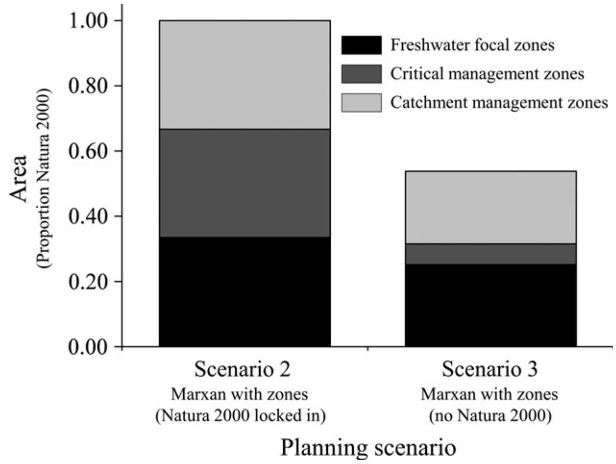

Figure 4 Proportion of subcatchments in Natura 2000 included under each management zone for two planning scenarios, where Natura 2000 was locked in solutions and not locked in (scenarios 2 and 3 respectively).

selected under scenario 1, and 28.7% lower than the focal zones selected under scenario 2 (Figs 2c & 3). The reduction in area needed in relation to scenario 2 was especially significant in critical management zones (58.8% less area; Fig. 3). Only 55% of the area selected in scenario 3 was in Natura 2000, mostly under critical and catchment management zones (Fig. 4). Moreover, most of freshwater focal zones were allocated outside the current extent of Natura 2000 (74% and 71% under scenarios 2 and 3 respectively), giving an indication of the limited value of currently protected areas for representing freshwater biodiversity.

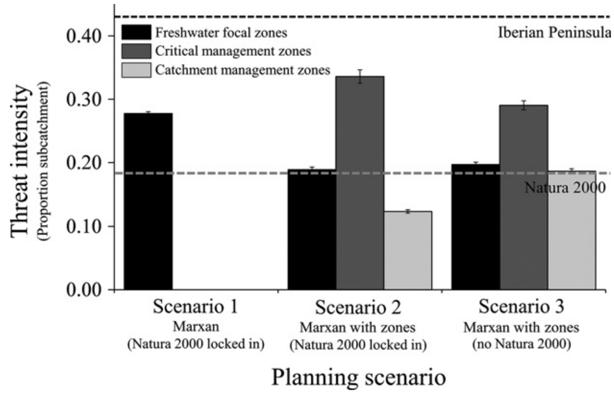

Figure 5 Threat intensity (average ± SE) within subcatchments included in best solution of each planning scenario shown in Fig. 2. The dotted grey line represents the threat intensity in subcatchments included in Natura 2000 and the dotted black line represents the average threat intensity in the Iberian Peninsula.

Threat intensity

The average threat intensity within subcatchments selected by Marxan in scenario 1 was higher than the average within Natura 2000, but significantly lower than the Iberian's average (Fig. 5). Threat intensity was significantly lower within freshwater focal zones selected by Marxan with Zones under both Scenarios 2 and 3, and very similar to threat intensity within Natura 2000 (Fig. 5). Catchment management zones showed similar or lower threat intensity values than focal zones and Natura 2000. Threat intensity was, however, higher in critical management zones than in the other two management zones and in Natura 2000.

DISCUSSION

Here, we show that using a multiple management zone approach in conservation planning for freshwater biodiversity can significantly enhance the efficiency of conservation planning outcomes. This approach also helps refine management recommendations from simple binary solutions, where only an indication on conservation priority areas is provided (e.g. Hermoso *et al.*, 2011; Linke *et al.*, 2012), to more specific information on the particular contribution to conservation objectives of each zone and the type of management it should receive. In combination, this increase in efficiency and refinement in recommendations could help unlock the necessary expansion of Natura 2000 to adequately cover freshwater conservation needs in the Iberian Peninsula (Hermoso *et al.*, 2015c). Given the generally limited value for freshwater biodiversity of protected areas identified for terrestrial purposes (Nel *et al.*, 2007), this approach could also be valuable elsewhere.

Under the traditional binary conservation planning approach, we found that up to 48% of the Iberian Peninsula would be considered a high priority for conservation of freshwater biodiversity, corresponding to the area needed to overcome the deficiencies of Natura 2000 reported previously (Abellán *et al.*, 2007; Sánchez-Fernández *et al.*, 2008;

Hermoso *et al.*, 2015b). This would require a significant increase in the extent of protection areas on a region where more than 25% of land is already protected, with the additional difficulty of strictly protecting the rest of the territory, which tends to be highly humanized (Hermoso *et al.*, 2015b). Solutions from scenario 1 included large portions of catchments needed for improving representation of freshwater vertebrates and enhance longitudinal connectivity within protected areas. However, the large extension of new areas needed could hinder the practical implementation of recommendations, due to high costs and potential conflicts with other uses. Although the extent of priority areas did not change significantly when using the multizone approach (only 8% less area selected) and their spatial allocation was similar (63.8% of subcatchments coincident in scenarios 1 and 2), by refining management recommendations we could reduce the area needed under strict protection and then enhance efficiency. We found that the recommendations on total area requiring strict protection could be reduced threefold compared to the binary approach. This improvement in efficiency was, however, constrained by the need to incorporate all subcatchments under Natura 2000. The area needed for all three management zones together could be further reduced by 26% when not locking in Natura 2000 in solutions in scenario 3. The effect of including Natura 2000 in the multizone approach was more significant on critical management zones, responsible for ensuring connectivity among freshwater focal areas with near 60% more area needed when including Natura 2000. The reason for the significant decline in efficiency for this zone is related to the need to connect more areas forced in the prioritization under scenario 2. Overall, the comparison across the different scenarios indicates that the significant gain in efficiency achieved by the multizone approach that we demonstrate here is compromised by the spatial configuration of Natura 2000. This is a consequence of the poor consideration of freshwater criteria when the network was designed (Hermoso *et al.*, 2015b), but that has to be integrated in freshwater conservation planning, to acknowledge the value of Natura 2000 for other taxonomic groups (although see Araújo *et al.*, 2007; Rubio-Salcedo *et al.*, 2013; Lisón *et al.*, 2013).

Although we forced the selection of Natura 2000 in scenario 2, we did not constrain the inclusion of these areas under freshwater focal zones directly and left the spatial allocation of management zones open during the optimization process. This helped us to provide management recommendations not restricted to new additions only, but span also to existing protected areas. For example, we found that only a third of Natura 2000 was identified as freshwater focal zones, while the remaining extent could be managed under critical management zones or catchment management zones. This approach could fit better the stakeholders' needs given that the network is already well established. This network of protected areas aims to enhance harmonization of biodiversity conservation and other legitimate land uses by implementing best management practices, and avoiding strict protection whenever possible. Therefore, after pointing an area as part of Natura 2000 there is a need for identification of management plans where both conservation goals and the sustainable socioeconomic development are considered (Cortina & Boggia, 2014). Our approach and solutions could help guiding the development of management plans that allow for the maintenance of sustainable land uses, while achieving conservation goals in an efficient way. Here, we provide specific recommendations for areas within Natura 2000 by identifying zones in need of strict protection that sustain populations of rare and/or threatened species, and other areas that could be managed for sustainable use and continue contributing to maintain connectivity and other important ecological processes.

Natura 2000 covers predominantly the least disturbed areas in the Iberian Peninsula (e.g. mountains and uninhabited regions; Hermoso *et al.*, 2015b), so any expansion of the protected area network will necessarily have to incorporate land under some sort of human impact (Cortina & Boggia, 2014). These areas might also be essential for protecting some species that are present only in highly humanized landscapes (Hermoso *et al.*, 2015b), such as Lisbon's arched-mouth nase (*Iberochondrostoma olisiponensis*; Gante, Santos & Alves 2007) that is confined to lowland watercourses around Lisbon (Gante *et al.*, 2010) or the Endangered Spanish toothcarp (*Aphanius iberus;* Valenciennes 1846) that only occurs in small coastal wetlands along the Eastern Mediterranean coast of Spain (Verdiell-Cubedo *et al.*, 2014). For these reasons, it was difficult to avoid degraded areas from the selection of new priority areas under all scenarios, and thus additions of new subcatchments increased the average threat intensity within of priority areas for conservation. However, subcatchments selected under the binary approach showed on average higher disturbance compared to focal and catchment management zones identified under the multizone approach. This would help reduce potential threats to the conservation of biodiversity both within protected areas and propagated into protected areas from upstream. Critical management zones were located, however, in areas more intensively used on average, especially under scenario 2. The conservation of these areas is challenging, given the conflict with other land uses such as urban development and intensive agriculture. It would be important to ensure the maintenance of the key function these zones play at connecting freshwater focal areas through adequate management plans, such as ensuring adequate ecological flows during low flow seasons, or the remediation of critical barriers to movement. An additional feature of Marxan with Zones is the ability to specify representation targets within each management zone (Hermoso *et al.*, 2015a). This could help to further refine the analyses by integrating information on species' sensitivity to threats, whenever available, so species that are not sensitive could be also represented in management zones under higher threat.

The implementation of management actions to reinforce the effectiveness of the network of protected areas (Game *et al.* 2013) should ideally apply to all management zones and not be restricted to focal areas. Given the broad range of threats affecting the Iberian freshwater biodiversity (Clavero *et al.*, 2010; Hermoso & Clavero, 2011), there are multiple management alternatives that will need further consideration in future planning. Some of these could be, for example, habitat protection by retaining buffer zones around core aquatic habitats, creation of artificial ponds and restoration of wetlands, translocation of populations or release captive-bred individuals to reinforce existing populations, removal or control of invasive species (e.g. aquatic plants, fish and crayfish), and implementation of education and awareness programs (Sutherland *et al.*, 2015). In order to be effective, cross-country collaborations will be needed to ensure the effectiveness of conservation management in trans-boundary rivers (Dolezsai *et al.*, 2015). For example, the conservation program of *Anaecrypris hispanica* (Steindachner, 1866), a critical endangered species in the Guadiana River catchment, could be greatly enhanced if management actions being implemented in the Portuguese section of the catchment were coordinated with stakeholders on the Spanish section of the catchment. Recommendations on management zones that we provide here span across both countries, which might help reduce current poor consideration of trans-boundary issues. However, further effort is required to adequately plan the implementation of management actions that were not explicitly considered in this study, using systematic methods to ensure cost-effectiveness of allocation of management efforts (Cattarino *et al.*, 2015).

In summary, here we show that by shifting the perspective from a binary protection of landscapes to a multiple management zone approach we can provide flexible and realistic planning solutions easier to adopt by land planners and policy makers of strongly humanized regions with concerning protection status of species and ecosystems. It is the case Iberian Peninsula, where we were able to provide conservation planning solutions that enhance representation of freshwater biodiversity and ecological processes involved and improve efficiency by refining conservation recommendations.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1 List of species, taxonomic group and distribution area in the Iberian Peninsula.

Appendix S2 Examples of translation of spatial distribution data in 10 × 10 km grid cells into subcatchments for two species [*Rana temporaria* (Linnaeus, 1758) and *Luciobarbus sclateri* (Günther, 1868)].

Appendix S3 Corine Land cover classes as categorised in intensive uses and natural uses for this study.

BIOSKETCHES

Virgilio Hermoso is a Ramon y Cajal Research Fellow at the Forest Science Centre of Catalonia. His research interests focus on developing new approaches to guide decision-making for conservation and restoration of freshwater ecosystems and biodiversity. He is also interested in the study of threats to freshwater biodiversity, especially on the interactive effects of habitat degradation and introduced species.

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