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 7-46%, 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.

Keywords: Fish, amphibians, reptiles, Marxan, connectivity, endemic.

1. Introduction

Freshwater ecosystems and biodiversity are among the most diverse and threatened systems in the world (Strayer and Dudgeon, 2010), 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 *et al.*, 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 km², across 28 countries (European Commission 2013, <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 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 km² (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 (Allan *et al.*, 2007; 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 km² 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 km² (Duero/Douro, Tajo/Tagus, Guadiana - shared by Spain and Portugal - and Guadalquivir and Ebro, flowing only in Spain), medium-size basins (> 10,000 km²; 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 5,938 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 km²; Average $\pm$ SD). Subcatchments were delineated from

a 90-m digital elevation model (sourced from the SRTM 90m 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 7,300 km² or 2,000 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 was the sum of penalties for missed connections (Hermoso *et al.*, 2011, 2012).

$$Objective\ function = \sum_{planning\ units} Cost + SPF \sum_{features} Feature\ Penalty + CSM \sum Connectivity\ Penalty \quad (1)$$

We used a high species penalty (SPF=100) to ensure that all species achieved the three conservation targets. We also evaluated the use of five connectivity levels (CSM = 0, 0.12, 0.25, 0.37 or 0.5; Table 1) to determine the effect of increasing connectivity on the spatial distribution of selected subcatchments. Increasing CSM increases connectivity among subcatchments, but this is achieved at expenses of selecting a larger number subcatchments (Hermoso *et al.*, 2011). We accounted for both longitudinal and lateral connectivity, because longitudinal connectivity is key to strictly aquatic species such as fish, while some amphibians and reptiles can also move overland across hydrological boundaries. To do this, we set the connectivity penalty proportional to the distance between each pair of subcatchments (penalty=distance (km)^{-1/2}), either longitudinally, following the river network topology, or laterally, measured as Euclidean distances between the centroids of subcatchments (Hermoso *et al.*, 2012).

Given the lack of reliable information on conservation costs, we assumed cost was directly proportional to the degradation status of each subcatchment, as estimated from the proportion of land devoted to urban, industrial or intensive agriculture (Corine Land Cover dataset <http://www.eea.europa.eu>; Table A1). We thus tried to avoid areas devoted to intensive uses whenever possible (*sensu* Linke *et al.*, 2012). We accounted for existing protected areas by locking in solutions those subcatchments that had greater than 75% of the area protected within Natura 2000. In this way we aimed to find the minimum set of additional subcatchments to those already protected that would be required to represent freshwater species at each target level.

We ran the optimisation algorithm 100 times (2 million iterations each) and retained the best solution within all runs for subsequent analyses. We ran independent analyses for each combination of target level and connectivity scenario (3 targets x 5 CSM values).

2.4 Surrogacy of species listed in Habitats Directive

Considering that Natura 2000 was specifically designed to offer protection to species listed in the Annexes II and IV of the Habitats Directive, we ran the analyses for two different groups of species: i) only fish, amphibian and reptile species listed in the Annexes (n=23 species), and ii) all species for which we had data (Table A1). This resulted in 30 different scenarios (3 targets x 5 CSM x 2 species groups; Table 1). The analyses using the reduced set of species listed in Habitats Directive aims to explore the minimum set of subcatchments required to at least fulfil the immediate exigencies of the Directive. Given the incomplete coverage of endangered species in the Habitats Directive (Regnery *et al.*, 2013), we assessed the surrogacy value of the species included in the Annexes at representing the others not included. We measured the representation (number of subcatchments) of species not considered in the analyses within each best solution, and assessed surrogacy as the proportion of species that would achieve the conservation targets. We would expect all non-listed species to achieve the conservation target if listed species were optimal surrogates of freshwater biodiversity. The second analyses with all the species was used to demonstrate the area that would be required to adequately represent all the species in case they were not adequately represented in the surrogacy analysis.

2.5 Efficiency and connectivity

We evaluated efficiency (1-proportion of all subcatchments selected) of 15 different scenarios (3 targets x 5 CSM), assuming that the most efficient solutions would represent all species and achieve high connectivity with a low number of subcatchments needed (Hermoso *et al.* 2011). On the other extreme, inefficient solutions would require high number of subcatchments to achieve high connectivity and represent all species. We used 1-Connectivity Penalty (CP) from the objective function as an indication of the degree of connectivity achieved. High CP values indicate poor spatial connection between subcatchments included in the solution, as it misses many subcatchments in-

between selected ones. We divided CP by 100,000 to make it range between 0-1. In order to further evaluate the effect of locking in Natura 2000 in the prioritisation process, we compared the efficiency of solutions described above against two alternative planning scenarios: (i) locking no subcatchment as if no protected areas existed; and (ii) locking subcatchments already included in pre-Natura 2000 network. These analyses were run for the same target levels and connectivity scenarios, and efficiency was calculated likewise (Table 1).

Figure 1. Extent of planning solutions measured as the proportion of all subcatchments included for each conservation scenario (15 scenarios, comparing 3 target levels and 5 CSM values). Bars represent values for solutions accounting for all species (N=91). Dotted lines represent the proportion of subcatchments including only species listed in the Annexes II and IV of the Habitats Directive. The solid grey line shows the proportion of subcatchments already protected by Natura 2000.

2.6 Protection against threats

To explore the capacity of priority areas for protecting freshwater species from potential threats, we assessed the average threat intensity within best solutions. To account for the propagation of threats into protected areas from upstream reaches, we also measured the average threat intensity in

subcatchments located up to 150 km upstream protected ones. We also compared the results from our prioritization exercise with the average threat intensity within subcatchments protected by Natura 2000, and upstream Natura 2000 using the above distance threshold.

3. Results

3.1 Priority areas and surrogacy of species listed in Habitats Directive

A total of 3,100 subcatchments (15.7% of the Iberian Peninsula) had >75% of their area within Natura 2000. In order to fulfil the conservation targets for species listed in the Annexes II and IV of the Habitats Directive, an additional 800-4,300 subcatchments would be needed (extremes for lowest and highest connectivity and target levels respectively). This represents up to 32% of the Iberian Peninsula, adding 4-17% more subcatchments to current Natura 2000 (Fig. 2 a-c). The new subcatchments are mainly along the Mediterranean coast in Eastern Spain, and the Atlantic coast in Portugal and Northern Spain (Fig. 2). Despite the significant increase in the number of protected subcatchments, only 35-60% of species would be adequately represented depending on the target level (Fig. 3a-b). This shows the poor surrogacy value of species listed in the Annexes, especially for highly endangered species (Fig. 3c-d). When focusing on the overall species set, conservation targets could be achieved with the addition of 700-5,000 more subcatchments, or an increase in total number of subcatchments between 3-25% (for lowest and highest connectivity and target levels respectively; Fig. 1) in relation to previous solutions when using just species listed in the Habitats Directive (1,500-9,000 or 7-47% more subcatchments to be added to Natura 2000; Fig. 2 d-f). The analysis identified additional subcatchments of high priority in the South West corner of the Iberian Peninsula, the central portion of the Guadiana and Tagus Rivers, and coastal Cantabria (northern Spain) and Catalonia (NE Spain) regions (Fig. 2).

Figure 2. Gap analysis of Natura 2000 for freshwater fish, amphibians and semi-aquatic reptiles, considering either the species listed in the Habitats Directive (a-c) or all the 91 species (e-f), for three representation targets (100, 250, and 500 subcatchments). Colour intensity represents the range from low (light yellow) to high (red) connectivity levels (CSM) used to get the solution. Natura 2000 is represented in grey.

Figure 3. Summary of the surrogacy value of species listed in the Habitats Directive (N=30) at representing either all species studied (a-b; N=91) or the unlisted species (c-d; N=61), in relation to the five connectivity levels tested (a, c; CSM), and five IUCN threat categories (c, d) for the intermediate CSM value (dotted box in panels a-b). Surrogacy was measured as the proportion of species that would achieve the different target levels in solutions identified using just the species listed in the Habitats Directive.

3.2 Efficiency and connectivity

As expected, more ambitious conservation targets demanded more subcatchments to achieve similar connectivity within priority areas (Fig. 2, 4). However, to achieve the same increase in connectivity it was necessary to incorporate more subcatchments at low than high targets. Regardless of the target level, efficiency was significantly lower for all scenarios when subcatchments protected by Natura

2000 were locked in, than when no subcatchments were forced into the solution or when only pre-Natura 2000 were locked in (Fig. 4).

Figure 4. Efficiency (measured as 1- proportion of total subcatchments selected) at achieving connectivity for three conservation planning scenarios (not locking any reserves, locking pre-Natura 2000, and locking Natura 2000) and target levels (black=100, grey=250 and white=500 subcatchments), in relation to the target connectivity level.

3.3 Protection against threats

Except for the highest target and connectivity scenarios, selected subcatchments displayed significantly lower threat intensity than unselected subcatchments (Fig. 5). In all scenarios the threat intensity was higher in selected subcatchments than within Natura 2000, with differences increasing for more ambitious targets and connectivity levels. (Fig. 5). The threat intensity upstream of selected subcatchments was generally lower than upstream of Natura 2000, except for high conservation target scenarios where the requirement for a large amount of new subcatchments forced the selection of more degraded areas (Fig. 5).

Figure 5. Summary of threat intensity in subcatchments selected for three conservation targets and five connectivity levels. Bars show the average ($\pm$ SD) threat intensity within selected subcatchments (black), upstream selected subcatchments (up to 150 km; grey), and in unselected subcatchments (white). Dotted and solid lines represent the average threat intensity in subcatchments within and upstream of Natura 2000, respectively. Threat intensity is measured as the percentage of subcatchments under intensive land uses (see Table in Appendix A3 for details).

4. Discussion

Using systematic conservation approaches, we have identified a minimum set of additional subcatchments that would be needed for enhancing the conservation value of the Natura 2000 network for freshwater biodiversity in the Iberian Peninsula, thereby filling the gap reported in previous studies (Abellán *et al.*, 2007; Sánchez-Fernández *et al.*, 2008; 2013; Hermoso *et al.*, 2015). These subcatchments could contribute to the existing Natura 2000 network to ensure: i) adequate

representation of freshwater species, ii) protection of key ecological processes related to spatial connectivity (e.g., migrations or fluxes of material and energy along river networks), and iii) minimisation of impacts from human disturbances to freshwater biodiversity. Species listed in Annexes II and IV of the Habitats Directive were found to have low value as biodiversity surrogates, especially for other endangered species with restricted distribution ranges. Overall, our results point out the need for expanding Natura 2000 to effectively protect European's freshwater biodiversity, and to extend planning and conservation efforts to all species rather than focusing on just a few listed species.

We found that ensuring adequate representation of freshwater biodiversity and ecological processes would require adding 7-46% of subcatchments to the ones already covered by Natura 2000.

Depending on connectivity requirement, implementing protection of the additional subcatchments needed to achieve the 250 subcatchment target would require an increase in the area managed under Natura 2000 to include 32-47% of the Iberian Peninsula. The selected subcatchments are mainly located along the Mediterranean coast in Eastern Spain, and the Atlantic coast in Portugal and Northern Spain. These subcatchments ensure the protection of some species with very restricted ranges that are currently poorly covered by Natura 2000. For example, the Critically Endangered *Valencia hispanica* has only 7% of its extremely reduced distribution along the Mediterranean coast within Natura 2000, while the Endangered *Achondrostoma occidentale* is restricted to a few coastal catchments in Portugal that are not included within any Natura 2000 area (Rogado *et al.*, 2005).

Apart from increasing species coverage, the additional subcatchments selected in our analyses also improve the spatial design of Natura 2000. This is the case of areas in the South West corner of the Iberian Peninsula and the central portion of the Guadiana, Tagus and Douro Rivers. These subcatchments were selected by Marxan to enhance longitudinal and lateral connectivity, and to address common problems related to terrestrial focused designs, such as using rivers to delineate the boundaries of reserves or narrow terrestrial corridors along the river network (Roux *et al.*, 2002; Nel *et al.*, 2007, 2009). Additional subcatchments in the Cantabric region (northern Spain) were also selected to enhance the connectivity between already existing protected areas and the Atlantic Ocean.

Including all these spatial needs resulted in large areas selected, especially when trying to ensure high connectivity. The large extent of solutions like the ones proposed here could compromise the implementation of conservation recommendations under traditional conservation practice schedules (e.g., all of them required strict reservation). However, this might not be a major drawback of large solutions under the philosophy of Natura 2000, which does not require the declaration of traditional protected areas exclusively designated for conservation purposes. Instead, Natura 2000 aims to enhance harmonization of biodiversity conservation with other legitimate land uses by implementing best management practices. This is important as it makes the implementation of conservation in highly humanised environments like most of Europe more flexible. Therefore, the subcatchments selected could be incorporated in a multi-zoning structure of different management regimes (Abell *et al.*, 2007), where subcatchments that sustain populations of rare and/or threatened species could be allocated to strict conservation, while other subcatchments could be managed for sustainable use and continue contributing to maintain connectivity and other important ecological processes. However, further effort would be needed to identify these different management zones. Accounting for the additional values that areas under Natura 2000 provide such as essential ecosystem services (e.g., clean water provision, flood protection, or recreational value, among others) might also help increase the strategic value of these areas for humans and create new conservation opportunities.

One of the challenges for Natura 2000 will be to ensure sustainable management in the future, both ecologically and economically (Cabeza 2013; Kati *et al.*, 2014). Given the high degree of humanization of Europe and the large extent of Natura 2000, future additions will certainly need the consideration of areas that are affected to some degree by human intervention (Cortina *et al.*, 2014). These areas might be essential for protecting some species that are present only in highly humanised landscapes (Hermoso *et al.*, 2015), such as a newly described nase species (*Iberochondrostoma olissiponensis*) that is confined to lowland watercourses around Lisbon (Gante *et al.*, 2010). This is the case of the Iberian Peninsula as our results demonstrate. Although we accounted for threat intensity during the prioritization process to try to avoid disturbed areas, this was not always possible due to the lack of undisturbed areas remaining unprotected and the need to protect some species that

only occur in degraded ones. This translated into an overall increase in average threat intensity within priority areas. Given the conservation value of degraded areas, management plans are needed to ensure the effectiveness of conservation efforts (Game *et al.*, 2013), especially given that most Natura 2000 sites will remain in private hands and submitted to forestry and agricultural land uses (Tsiafouli *et al.*, 2013).

Finally, the low performance reported for other terrestrial taxa in the Iberian Peninsula (Araújo *et al.*, 2007) raises questions about the true effectiveness of the world's largest network of protected areas, and highlights the need to consider additional areas (Araújo *et al.*, 2007). We would recommend extending the analyses performed here by integrating other taxonomic groups to get a global view of the effectiveness of Natura 2000, and further fill potential gaps as we did for freshwater biodiversity. This would provide a complete, updated and accurate conservation strategy required to address the conservation needs of threaten species and ecosystems in Europe. In particular, it might make a valuable contribution to EU biodiversity strategy to 2020, helping to achieve the overall goal of halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020 (<http://ec.europa.eu/environment/nature/biodiversity/comm2006/2020.htm>).

5. Conclusions

In summary, our study underlined major limitations of Natura 2000, showing that the restricted set of freshwater species listed under the Habitats Directive provide a poor surrogate for freshwater biodiversity in general, and identifying several new areas that need to be included in the network of protected areas for achieving adequate representation of such biodiversity. The new areas are required because highly endangered and range-restricted species were largely left out or are poorly represented in Natura 2000, and because no consideration was given to the maintenance of ecological processes requiring habitat connectivity and to the need for avoiding threat propagation across riverscapes. These results, together with the poor performance of Natura 2000 reported for other areas and taxa in Europe, suggests there is a need to evaluate the overall effectiveness of the network to protect European's biodiversity. The framework presented here should provide a useful tool to undertake

such an evaluation, especially by integrating the specific needs of freshwater biodiversity that have been poorly considered in the design of reserve networks. Finally the conservation planning approach presented here could be extended to other taxa and ecosystems in Europe, and also applied to other regions worldwide to enhance the adequacy of protected areas for freshwater biodiversity.

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Table 1. Parameters configuration for the different planning scenarios tested in this study. The four parameters modified for planning scenarios were: a) conservation features (two different sets of species data), b) targets to be achieved (three targets considered), c) connectivity strength (CSM; five different strengths considered) and d) protected area considerations. Our assessment of surrogacy resulted in 30 scenarios tested, and was based on all possible combinations of three parameters (15 scenarios = 2 conservation feature datasets x 3 targets x 5 CSM). Our assessment of plan efficiency when locking existing protected areas into the Marxan solution or not resulted in 45 scenarios tested (3 targets x 5 CSM x 3 protected area considerations).

Conservation features	Target (# of subcatchments)	Connectivity (CSM)	Protected area consideration
EU Habitats species (n = 22)	100	0	No protected areas
All freshwater dependent species (n = 91)	250	0.12	Pre-Natura protected areas
	500	0.25	Natura 2000 protected areas
		0.37	
		0.5	