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Influence of macrohabitat preferences on the distribution of European brook and river lampreys: Implications for conservation and management

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ABSTRACT

The European river lamprey, *Lampetra fluviatilis* (L.), and the European brook lamprey, *Lampetra planeri* (Bloch, 1784), are considered highly threatened in Portugal. However, the lack of information about the ecology and distribution of these species poses difficulties to the identification of concrete actions directed to their conservation. A total of 401 sampling sites, randomly distributed throughout the entire Portuguese mainland territory were selected, and *Lampetra* sp. ammocoetes presence or absence checked with electrofishing. These data, together with 11 macrohabitat predictors, were analyzed using Boosted Regression Trees (BRTs). The BRT models consistently identified five environmental variables as the most important for predicting the distribution of European brook and river lamprey ammocoetes: altitude, distance to coast, sand, maximum temperature of the warmest month and precipitation of the driest month. The relationships of these variables with the species probability of occurrence suggest that lampreys occur in low altitude river stretches (<170 m), relatively close to the coast (<150 km) and with a sandy substrate (>70% sand). In addition, intermediate values of temperature and precipitation were also found to have a positive correlation with the species occurrence. A map with the probability of occurrence of *Lampetra* sp. in Portugal was generated and stretches of rivers were delimited with different conservation priorities. Rivers classified with the highest level of conservation priority were considered to be proposed as Special Areas of Conservation, under the Natura 2000 Networking Programme.

1. Introduction

There are three species of lampreys in Portugal: the sea lamprey (*Petromyzon marinus* L.), the European river lamprey (*Lampetra fluviatilis* L.) and the European brook lamprey (*Lampetra planeri* Bloch, 1784) (Baldaque da Silva, 1891). While *P. marinus* and *L. fluviatilis* are parasitic and anadromous, *L. planeri* is non-parasitic and resident, inhabiting strictly freshwater environments (Hardisty, 1986a, 1986b, 1986c). Although being considered of "Least Concern" in Europe (IUCN, 2010), the genus *Lampetra* is considered highly threatened on the Iberian Peninsula, the southern limit of its distribution (Cabral et al., 2005; Doadrio, 2001; Mateus et al., 2012). In Spain, the European river lamprey is considered "Regionally Extinct" and the European brook lamprey is considered "Critically Endangered" (Doadrio, 2001). In Portugal, both species are classified as "Critically Endangered" mainly due to the high population fragmentation, declining number of subpopulations and habitat degradation (Cabral et al., 2005). The high population fragmentation of *Lampetra* sp. populations in Portugal is mainly caused by the construction of obstacles to migration (dams, weirs and other man-made barriers) that prevent the anadromous species from reaching the spawning grounds and the gene flow between some resident populations within the same watershed. Habitat degradation may also limit the area available for these species and be responsible for the isolation of some subpopulation nucleus within the same watershed. The main causes of the habitat degradation are water pollution, dredging and habitat destruction through channel and bank regulation (Mateus et al., 2012).

During the larval and metamorphosis stages (where lampreys are known as ammocoetes and transformers, respectively), the

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morphological distinction of lampreys is often difficult (Hardisty and Potter, 1971). In addition, ammocoetes of all three species may sometimes be found at the same sites (Hardisty, 1979), which makes even more difficult the distinction between them. It is possible to distinguish between *P. marinus* and *Lampetra* sp. ammocoetes by the presence of different patterns of pigmentation in the head and tail (Potter and Osborne, 1975). However, in the larval and transformer phases, the two *Lampetra* species are morphologically similar, and neither taxonomic (Hardisty and Potter, 1971; Zanandrea, 1959) nor genetic criteria (Espanhol et al., 2007; Schreiber and Engelhorn, 1998) can separate them in the present state of knowledge. In fact, the taxonomic status of river and brook lampreys is still under debate (Blank et al., 2008; Espanhol et al., 2007; Schreiber and Engelhorn, 1998). The hypothesis of the existence of a single species with two distinct ecotypes that evolve according to the environmental pressures has been proposed by several authors (e.g. Docker, 2009; Eneqvist, 1937; Espanhol et al., 2007).

L. planeri and *L. fluviatilis* are confined to European watersheds, occurring from Norway in the north to the Iberian Peninsula in the south (Hubbs and Potter, 1971; Mateus et al., 2012). Unlike in the rest of its geographic range, in the Iberian Peninsula *L. fluviatilis* and *L. planeri* have distinct distributions. In Spain, *L. fluviatilis* is extinct and only two populations of *L. planeri* are known, one of which only recently described (Mateus et al., 2011a; Perea et al., 2011). In Portugal, while *L. fluviatilis* is only found in the Tejo river basin, *L. planeri* has a wider distribution (Almaça and Collares-Pereira, 1988; Espanhol et al., 2007; Mateus et al., 2012). Considering the restricted distribution of *L. fluviatilis* in Portugal (already extinct in Spain), as well as the highly fragmented Portuguese populations of *L. planeri* (with restricted distribution in Spain), in addiction to all the threats that both species are subject (see next paragraph), it is of great importance the effective conservation of the Portuguese populations of this genus, with the risk of, otherwise, losing the southern populations of both species. In addition, genetic diversity attained for the Iberian glacial refugia is higher than that found for the rest of the distribution area of both species (Espanhol et al., 2007; Mateus et al., 2011b), thus, failure in conservation strategies would result in the loss of genetic diversity and unique evolutionary lineages of the Iberian Peninsula.

The conservation of both *Lampetra* species in the Iberian Peninsula is dependent on the effective habitat preservation and rehabilitation measures. However, the lack of general information concerning these species, particularly the ones related to habitat preferences and the identification of the environmental conditions responsible for their distribution, has been delaying the effective designation of special sites for the genus protection under the scope of the Natura 2000 Networking Program. According to the Habitats Directive (92/43/EEC), European Union member states are required to identify Special Areas of Conservation (SAC) for species considered to be under threat and listed under Annex II of this Directive. The designation and protection of these habitats is important for the preservation of species more susceptible to the numerous anthropogenic threats (Primack, 1995). The identification of the environmental factors that constrain the presence of *Lampetra* sp. is an important tool in the selection of suitable sites for designation (Goodwin et al., 2008). This information is particularly important to predict species distribution.

The main objective of this study was to gather the necessary information to properly designate SAC for the genus *Lampetra* in Portugal. To achieve this objective we first performed a comprehensive sampling survey to identify presence or absence of ammocoetes belonging to the genus *Lampetra* throughout Portuguese watersheds. Secondly, the presence/absence information was statistically analyzed, together with several environmental predictors selected a priori, generating a model that tries to explain the distribution of *Lampetra* sp. in Portugal. Using the distribution model output, a map of probability of occurrence of *Lampetra* sp. for the entire Portuguese territory was generated. Finally, priority conservation criteria were defined to classify watersheds according to their importance to *Lampetra* species. Water stretches included in the highest priority conservation level were set to be proposed as SAC under the European Natura 2000 ecological network of protected areas.

2. Materials and methods

2.1. Study area and sampling

This study was performed in mainland Portugal, south-western Europe. It comprises an area of approximately 89 060 km^2 with a relatively high climatic, geomorphologic and hydrologic heterogeneity. Portuguese climate is characterized by wet winters and dry summers that are temperate in almost the entire west coast, and hot on the majority of the southern central plateau region (ICA, 2011). Current environmental conditions produce several types of watercourses, ranging from perennial streams with continuous flow in the northern region to typical Mediterranean temporary streams with clearly marked cycles of floods and droughts in the south (Gasith and Resh, 1999).

The *Lampetra* sp. presence and absence database included data from two main sources: the field campaigns developed in 2002 for the Portuguese Red List of Threatened Vertebrates (Cabral et al., 2005), and the National Conservation Plan for Brook and River lampreys (Almeida et al., 2011), collected in 2009 and 2010. The same sampling procedure was used for both field surveys to maximize the probability of ammocoetes capture and reduce sampling costs due to the large size of the study area. Prior to the selection of sampling sites, a number of preliminary sampling stations were marked, proportionally to the total drainage area of each river basin with a minimum of one sampling station per 17.5 × 17.5 km squares of catchment area. However, during the field surveys, if the sampling sites did not present the minimum conditions to sustain a population of ammocoetes (i.e. presence of sandy substrate), these points were whenever possible randomly replaced by others located in the same grid. There were effectively sampled 401 stations. Ammocoetes were collected by electro fishing (Hans Grassl ELT 60 II-HI 500 V-DC) from May to September. The stretch of the river sampled was 20 times the average width of the flooded area of the river, for rivers up to 30 m wide, and 10 times the average width of the river, for rivers more than 30 m wide. Geographic coordinates of sampling stations were recorded with a handheld GPS (Magellan SportTrak).

2.2. Environmental predictors

The environmental variables used for modeling the distribution of *Lampetra* sp. were selected by their a priori potential relevance to the studied lamprey species and conditioned by the availability of high quality data for the entire study area. Seventeen environmental variables were selected within the following parameters typology: geomorphology, climate, environmental stressors and hydrology (Table 1). This information was derived from previous databases and Geographic Information System (GIS) (ESRI, 2009).

The variables used in the analysis belonging to the geomorphology features were: altitude, river slope, distance to coast, and the type of substrate through the percentage of silt and sand in the soil. Altitude (*altitude*) was obtained from the Shuttle Radar Topography Mission (resolution of 1 km^2; SRTM, 2010). Elevation is an indicator of local topographically driven variation in river flux, which in turn influences the development of local habitat differentiation (Leathwick et al., 2008), such as water velocity, depth and substrate coarseness (Lassalle et al., 2008). The variable slope