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An European Tale of Diadromous Fish – From history to what lies in the future

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Abstract

Climate change and water impoundment cause decline of diadromous fish. In our study, we determine their European distribution using historical data and assess their probability of occurrence considering climate and longitudinal connectivity modifications for the 20th and 22nd century. Macro-scale bioclimatic models will yield adequate predictions of climate change impacts on species distribution, improving the knowledge about these species` past, present and future distributions.

Keywords: *Diadromous species, historical distribution, climate change, ecological modelling, longitudinal connectivity*

Introduction

Diadromous fish species migrate between fresh water and the sea at a certain phase of their life cycle (McDowall 1992). Despite being relatively primitive fish they have a highly specialised life cycle (McDowall 1992) and a relevant role in terms of ecosystem services (Limburg and Waldman 2009), e.g. providing an important protein source for humans, contributing to the energy flow link between fresh and marine environments and representing a relevant component of marine and freshwater food chains (Limburg and Waldman 2009). At a global scale, diadromous species are not only relevant at an economic perspective (Lassalle et al. 2009a) but also at cultural and social levels (Limburg and Waldman 2009). Moreover, in terms of conservation, planning to protect these species could translate into protection for the majority of the freshwater systems as these are species that occupy several habitats in numerous freshwater systems often in 100 or even 1000 kilometres distance from each other (Abell 2002). Additionally, their migratory habits often translate into greater risk of extinction when compared with other fish species (Jonsson et al. 1999, McDowall 1992). During these movements they are not only more exposed to threats from predation and/or fishing exploitation, but have also an increased probability of being affected by habitat degradation, particularly because both residential and passage habitats have to be considered (McDowall 1992). Diadromous fish populations have been declining or going extinct at least since the beginning of the 20th century (Béguer et al. 2007, Limburg and Waldman 2009). Habitat destruction and degradation, loss of longitudinal connectivity, overfishing, pollution, introduction of alien and/or invasive species and climate change are the most relevant causes for this decline (Limburg and Waldman 2009). Dam construction can expose these fish species to nearly all of the mentioned treats. Damming leads to blocked or delayed migration, direct mortality when fish pass through turbines or over spillways, profound discharge modifications, severe habitat loss, destruction and alteration, water quality degradation, modification of the thermal and chemical characteristics of river water, loss of migration routes and spawning grounds and inevitably lower reproduction success (Larinier 2001). In several basins, throughout the globe, dam construction is the main reason for the decline of stocks from several diadromous species (Larinier 2001, Nicola et al. 1996). Some dams have solutions (eg ladders, lifts) engineered to enable fish to pass the physical barrier but generally with low effectiveness (Larinier 2001, Limburg and Waldman 2009). These structures tend to be species specific or generally inadequate for most of the migratory species (Larinier 2001) and only mitigate the problem because the number of individuals passing the barrier is far less than would be without the dam (Limburg and Waldman 2009).

Climate change is not only a direct cause of decline of diadromous species abundance and distribution range, but it can also enhance other threats. The expected changes in flood and drought frequency and magnitude, in precipitation and temperature can aggravate the problems caused by water impoundment (Abell 2002, Vörösmarty et al. 2000). Also, as freshwater species have limited options to escape water scarcity, extreme flows and flooding, water temperature rise and water competition with humans, consequences of climate change are likely to be more severe for these organisms (Abell 2002). It is known that climate change is driving shifts in species distributions, altering species interactions and de-stabilising communities (Chen et al. 2011, Parmesan and Yohe 2003, Thomas et al. 2006). Because certain populations of some species have adaptations to natal spawning and incubation sites (e.g., Dittman and Quinn 1996), climate induced changes in distribution could contribute to the extinction of some populations (Lassalle et al. 2009a).

Large-scale models not only allow us to capture the entire environmental range of a species and to improve our understanding on their ecology but also provide data for adequate conservation planning (Béguer et al. 2007). The impact of climate change on diadromous fish species has been addressed in other studies, although generally at the basin level (Béguer et al. 2007, Lassalle et al. 2009a, Lassalle and Rochard 2009) or finer resolutions but at more restricted geographical extents (Leathwick et al. 2005, Trinko Lake et al. 2012). Modelling at a finer resolution such as river segment enables the acquisition of detailed information about intra-basin variations (e.g., Branco et al. 2013, Leathwick et al. 2005), without losing the perspective at the species distribution level, when performed for the entire environmental range of the species.

Studies on diadromous species distributions have used historical data to avoid the multiple impacts that occurred during the last century on riverine habitats and fish species distribution, such has climate changes, deterioration of habitat and water quality, unsustainable fisheries and the damming spree that occurred in Europe (Lassalle et al. 2009a, Lassalle and Rochard 2009). The use of historical sources raises questions about data accuracy, sampling and interpretation biases (Lassalle et al. 2009a, Swetnam et al. 1999), though its value for ecological studies and the utility of historical insight cannot be underestimated (Swetnam et al. 1999). In fact, the explanatory value of modelling fish historical presence is relevant and has been demonstrated in several studies (e.g., Lassalle and Rochard 2009, Logez et al. 2012). Authors agree that merging different methods (Swetnam et al. 1999), combining information from several independent spatial and temporal sources (Hayashida 2005, Rackham 1998, Swetnam et al. 1999, Szabó 2010) and using independent datasets to cross-check information (Crumley 2007) can help mitigate the limitations and lead to more accurate knowledge about past ecosystem conditions.

Objectives

We aim to study the distribution of European diadromous fish species using historical data and also assess changes in the probability of occurrence of these species in European rivers taking into consideration the hampering of longitudinal connectivity and climate change scenarios. The specific objective are: assess the historical distribution of 9 diadromous species in Europe using the historical data from the EFI+ project (http://efi-plus.boku.ac.at/); compare the distribution of the diadromous species based on historical data with the potential and current distribution and also, predict their distribution for the beginning of the 22nd century under several climate change scenarios; estimate the European eel historical distribution for the beginning of the 20th century using historical data from the New European Fish Index (EFI+) project, compare it with the current distribution and make predictions for the beginning of the 22nd century under several climate change scenarios; assess the individual and combined effect of climate changes and longitudinal connectivity loss on the probability of occurrence of diadromous species in large European rivers along the 20th century and for the beginning of the 22nd century.

River segment will be the unit of resolution allowing not only to perceive global changes but also changes at the intra basin level. Modelling and making predictions for the distribution of European diadromous species using such a small resolution, covering the whole European continent and starting from a detailed historical dataset is what makes this study innovative and different from previous works.

Proposed Materials and Methodology

The New European Fish Index (EFI+) historical database (http://efi-plus.boku.ac.at/) and the version 2.1 of the River and Catchment Database from the Catchment Characterisation and Modelling (CCM2) (Vogt et al. 2007) will be used in all tasks. The CCM2 is the first comprehensive database of river networks and catchments boundaries, establishing a hierarchical structure from small river catchment to large rivers basins, for the entire European continent and including the Atlantic islands, Iceland and

Turkey (Vogt et al. 2007). This database established a fully connected network for every European river and corresponding basin, composed of hierarchically nested river segments and respective drainage basin for which there is a set of characteristics (Vogt et al. 2007). The historical data were collected using the CCM2 framework, providing information on the presence or pseudo-absence of several diadromous species for the European rivers segments until the beginning of the 20th century. Adding to the impossibility of considering real absence, presence in a river segment was considered true if an upstream segment had a confirmed historical presence. Climate data for the 20th and 21st century will be downloaded from the Climatic Research Unit (CRU) of the University of East Anglia database. The climate data predictions for the beginning of the 22nd century will be obtained through the Intergovernmental Panel on Climate Change (IPCC) data distribution centre and also from other sources with relevant and/or distinct predictions (e.g., Mora et al. 2013).

To accomplish the first specific objective, each species will be modelled individually using the EFI+ project historical database (http://efi-plus.boku.ac.at/), the CCM2 database of river physical variables (Vogt et al. 2007) and the CRU climate data (Mitchell et al. 2004) for the beginning of the 20th century. Climate data will report only to the first decade of the 20th century because the IPCC has identified the 1910-1945 period as the first when temperature rising has occurred (Solomon 2007). Historical data fits the Bernoulli distribution and has an inherent spatial autocorrelation that has to be taken into consideration for statistical purposes. The spatial autocorrelation is likely to occur because in the historical database the species were considered to be present throughout all river segments located downstream from each presence record. Different modelling techniques will be performed (e.g., Generalised linear mixed models (GLMM) with Bayesian approach, multivariate adaptive regression splines (MARS), boosted regression trees (BRT), random forest) in order to assess the consistency of the distribution models. Models uncertainty will also be evaluated.

To assess the species probability of occurrence under several climate change scenarios we will first perform predictions for what should be the current distribution of diadromous species if it was only affected by climate alterations. This will allow not only to understand which additional threats may have contributed to the current species distribution, but also will enable the establishment of a baseline to compare with the predictions for the beginning of the 22nd century. Models performed for the first specific objective will be used to produce the predictions using current climate date and climate data scenarios for the beginning of the next century.

European eel will be the focus of a specific analysis due to its scientific, economic and social prominence expressed in recent European Union measures to recover population stocks. Moreover, because it has a very wide distribution, this has led to some consequences in the data collection (e.g., in France there is only information for large rivers). To obtain the distribution of the European eel for three different centuries we will start to model for the beginning of the 20th century using the historical data. With this model we can, predict the probability of occurrence for the present and for the beginning of the 22nd century. I this way, we have two baseline situations from distinct centuries to compare with the scenarios of climate change for the next century. Statistical procedure for this species will use the aforementioned databases and similar modelling techniques mentioned previously.

To assess the combined effect of climatic changes with the loss of longitudinal connectivity on the probability of occurrence of diadromous species in large European rivers, besides historical data, information about the existing dams in European large rivers is also required. This information will be obtained using several existing databases such as: International Commission on Large Dams (ICOLD) database, the Food and Agriculture organisation's (FAO) global water information system (AQUASTAT), Global Reservoir and Dam Database (GRanD) from the Global Water System Project (GWSP) and the European Lakes, Dams and Reservoirs Database (ELDRED) from the European Environment Agency (EEA). Considering these two sources of disruption (climate changes and loss of longitudinal connectivity) for diadromous species, their probability of occurrence will be modelled for the beginning and middle of the 20th century, for the present conditions and also for the beginning of the 22nd century.

Expected Results

Several studies working to establish models about diadromous species distributions have obtained species specific models, either using historical data (Béguer et al. 2007, Lassalle et al. 2009a, Lassalle and Rochard 2009) or contemporaneous data (Lassalle et al. 2009b, Logez et al. 2012). Except for the study of Logez et al. (2012), all the other were performed at the basin level. Temperature related variables have assumed great relevance in all of the aforementioned studies. In two of them (Lassalle et al. 2009a, Lassalle and Rochard 2009) variables related to precipitation have also proved to be relevant. In this work, and particularly for the first specific objective, by using a smaller resolution (segment level), climatic variables are not only expected to be relevant but also the information about species distribution thresholds to be more accurate. Considering the large dataset that will be used, the predicted distribution of diadromous fish species for the beginning of the 20th century obtained by the different modelling approaches should point to the same set of variables for most of the species.

Studies performed at the basin level have shown that due to future climate changes some basins will become unsuitable for some of their native diadromous species (Lassalle et al. 2009a, Limburg and Waldman 2009). Taking into consideration these studies temperature will probably be one of the primary constraints on the distribution of diadromous fish at the European scale. Results of this objective are thus expected to closely follow the Lassalle and Rochard (2009) findings by predicting a distribution reduction in southern distribution limits for species less tolerant to temperature changes. Additionally, because modelling will be performed at river segment level, it will be possible to go beyond large scale results and dwell into intra-basin changes. These results will also indicate which species will be the most threatened by climate changes.

Predictions for European eel distribution at the basin level have come to different conclusions: non-relevance of climatic variables (Lassalle et al. 2009a), relevance of these type of variables (Lassalle et al. 2009b, Lassalle and Rochard 2009) and impossibility to achieve valid models due to the species wide distribution (Béguer et al. 2007). Considering the large dataset to be used, that modelling will be done at the segment level and that we are encompassing the species full environmental range it is most probable that climatic variables will be relevant for this species distribution. If so, it will also be interesting to verify if the Lassalle and Rochard (2009) predictions of a distribution expansion for this species is confirmed.

It is expected that a dam closer to the mouth of the river will be more detrimental than one that is closer to the source of the river, especially for anadromous species. The former dam will became a constraint right at the beginning of the migration, when animals have entered the river. Contrary to the construction of a dam or weir, climate changes effects over diadromous species distribution occur in a wider time frame (Larinier 2001). We thus expect dams and weirs to have a more rapid and direct effect than climate variation over one or two decades, or even half a century. On the other hand, climate change effects over centuries could not only aggravate the problems caused by water impoundment (Abell 2002, Vörösmarty et al. 2000) but also become more relevant than these (Larinier 2001).

Final Considerations

Species distribution models are a common tool in biological and ecological studies and deeply imbedded in Hutchinson's (1957) ecological niche concept (Araújo and Guisan 2006). The correlative approach relates species distribution data with environmental data through space and time (Pearson and Dawson 2003), allowing an understanding of the realised niche for the considered species and providing an indication of relevant environmental variables.

Continental-scale distributions tend to be primarily determined by climate, consequently the use of bioclimatic models may potentially yield valid predictions of climate change impacts on species distribution at this scale (Pearson and Dawson 2003). Data for this study is compiled at the continental scale, and for most species encompasses their global distribution or at minimum their complete European distribution range. Thus, a modelling approach is adequate. Considering also the large size of the database, it is reasonable to argue that model results and outputs are not biased *a priori*, and that this work will improve existing knowledge and information about European diadromous fish species´ past, present and future distributions.

Given the high complexity of natural systems, limitations to model prediction accuracy should not be disregarded (Pearson and Dawson 2003). However this is, nevertheless, a tool that helps managing species against the face of global change (Austin 2007).

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