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Sensitivity of river fishes to climate change: The role of hydrological stressors on habitat range shifts

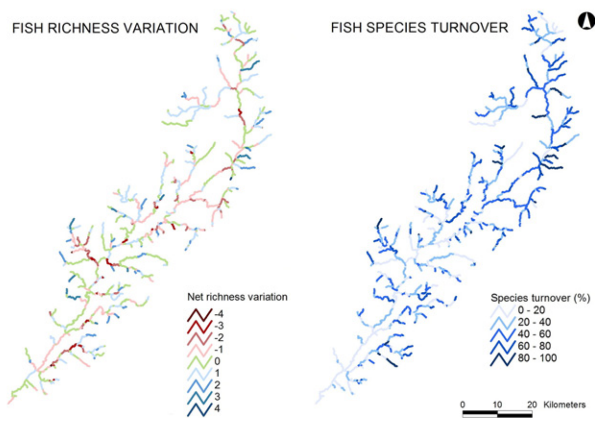
Pedro Segurado [a,*], Paulo Branco [a,b], Eduardo Jauch [c], Ramiro Neves [c], M. Teresa Ferreira [a]

[a] Universidade de Lisboa, Instituto Superior de Agronomia, Centro de Estudos Florestais (CEF), Tapada da Ajuda, 1349-017 Lisboa, Portugal
[b] CEris – Civil Engineering for Research and Innovation for Sustainability, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
[c] Universidade de Lisboa, Instituto Superior Técnico, MARETEC, Avenida Rovisco Pais, 1049-001 Lisboa, Portugal

HIGHLIGHTS

- Hydrological stressors were retained in habitat the models for most species
- Models using hydrology produce less severe predictions of fish habitat range shifts
- Hydrological stressors strongly influence projections of habitat range shifts.
- *Salmo trutta fario* was the most sensitive species to climate change

GRAPHICAL ABSTRACT



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ABSTRACT

Climate change will predictably change hydrological patterns and processes at the catchment scale, with impacts on habitat conditions for fish. The main goal of this study is to assess how shifts in fish habitat favourability under climate change scenarios are affected by hydrological stressors. The interplay between climate and hydrological stressors has important implications in river management under climate change because management actions to control hydrological parameters are more feasible than controlling climate. This study was carried out in the Tamega catchment of the Douro basin. A set of hydrological stressor variables were generated through a process-based modelling based on current climate data (2008–2014) and also considering a high-end future climate change scenario. The resulting parameters, along with climatic and site-descriptor variables were used as explanatory variables in empirical habitat models for nine fish species using boosted regression trees. Models were calibrated for the whole Douro basin using 254 fish sampling sites and predictions under future climate change scenarios were made for the Tamega catchment. Results show that models using climatic variables but not hydrological stressors produce more stringent predictions of future favourability, predicting more distribution contractions or stronger range shifts. The use of hydrological stressors strongly influences projections of habitat favourability shifts; the integration of these stressors in the models thinned shifts in range due to climate change. Hydrological stressors were retained in the models for most species and had a high importance, demonstrating that it is important to integrate hydrology in studies of impacts of climate change on freshwater fishes.

* Corresponding author.
E-mail address: psegurado@isa.ulisboa.pt (P. Segurado).

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This is a relevant result because it means that management actions to control hydrological parameters in rivers will have an impact on the effects of climate change and may potentially be helpful to mitigate its negative effects on fish populations and assemblages.

1. Introduction

Since 1976 the rate of global warming has been the steepest of the last 1000 years. This increase in average temperature has predictable impacts on species. Nevertheless, organisms, populations and communities tend to respond not to global averages but to more regional changes (Walther et al., 2002). Climate change and additional human-induced impacts on rivers have led freshwater biodiversity to plunge at a pace faster than that of terrestrial or marine biodiversity (Vörösmarty et al., 2000; Alcamo et al., 2003; Jenkins, 2003; Dudgeon et al., 2006). Several species have specific temperature thresholds and precipitation tolerances (Woodward, 1987; Hoffman and Parsons, 1997) by which species distributions are shaped in different climatic regimes. Additionally, with climate alterations these specific combinations of temperature and hydrology tend to shift due to changes in precipitation, water temperatures, evaporation and hydrological patterns (Filipe et al., 2013). These changes ultimately alter habitat conditions for freshwater species (Regier and Meisner, 1990; Schindler, 2001; Wenger et al., 2011), and species often follow this environmental shift by accordingly shifting their distribution ranges. In fact, during the last century it became clear that poleward and upward shifts of species ranges were occurring all around the world and for a vast variety of taxa (Easterling et al., 2000; Hughes, 2000; McCarty, 2001; Walther et al., 2001). Freshwater species are severely affected by habitat alterations but their dispersal is strongly constrained by the river network configuration (Grant et al., 2007), e.g. even adjacent basins may show very low fish dispersal rates between them. Hence, river fish ranges have a limited ability to trace the geographical shifts of favourable environments.

Freshwater communities are additionally impacted by multiple stressors that act upon the systems (Ficke et al., 2007; Palmer et al., 2008; Olden et al., 2010; Comte et al., 2013) and are sometimes composed by species of limited dispersion capability which seriously hamper their ability to handle habitat and environmental alterations (Woodward et al., 2010). Xenopoulos et al. (2005) estimated that the predicted reduction in river discharge caused by climate change and water abstraction may lead 75% of local fish diversity to extinction by 2070. Although difficult to assess, due to complex abiotic and biotic interactions (Clavero et al., 2010), the impacts of discharge reduction are even more relevant in southern Europe rivers (Maceda-Veiga, 2013). Climate change may also affect fish by operating indirectly on properties that are specific to river networks, such as the hydrological regime and water quality (Palmer et al., 2009). Most studies so far did not evaluate how these factors may operate simultaneously on fish occurrence (e.g. Buisson et al., 2008; Filipe et al., 2013). Planning conservation actions for freshwater fish species is challenging (Beatty et al., 2014) because of their different life cycles, some of which involving the use of different habitats at different life stages (Magoulick and Kobza, 2003), and the inherent longitudinal gradient of rivers, where upstream always influences downstream sections (Gorman and Karr, 1978; Allan et al., 1997).

Climate is accepted to have a major control over the natural distribution of most species (Pearson and Dawson, 2003) and, consequently, the change in climate will most likely influence species range shifts (contractions and expansions) (Hughes, 2000; McCarty, 2001; Walther et al., 2002). In fact, modelling the ecological consequences of climate change has become a very prolific field of research in the last decade (Bellard et al., 2012). Although few predictions have been confirmed empirically, there is growing evidence that many species are shifting their range boundaries to track recent climate change in a consistent way both across terrestrial and aquatic environments (Comte and Grenouillet, 2013). There are strong evidences that anthropogenic climate change is accelerating declines of many freshwater fish species, particularly in regions with arid or Mediterranean climates (Moyle et al., 2013). Freshwater fish are considered especially vulnerable to environmental changes, because their dispersal ability besides being greatly constrained by the river network structure (Grant et al., 2007), it is further limited by artificial barriers (Branco et al., 2014). Factors that are intrinsic to species, such as physiological traits, may also interfere on the potential effects of climate change on fish. Climate alterations can lead to changes in growth, survival, reproduction, or responses to changes at other trophic levels (Beaugrand et al., 2002, 2003). In fact, recent studies have demonstrated a significant effect of species traits on the variability of the observed range shifting trends on stream fishes under climate change (e.g. Alofs et al., 2014). This has important implications on the biotic integrity assessment of rivers that most often rely on indicators based on functional guilds of species. It is important to understand which functional guilds will be more or less resilient to adapt the bioassessment methods to climate change.

The majority of work that tries to determine climate change impacts on freshwater fish species has been focused on cold water species (Keleher and Rahel, 1996; Nakano et al., 1996; Rahel et al., 1996) of the Northern hemisphere (Comte et al., 2013) and usually focusing on thermal suitability under climate change, neglecting the influence of other variables on fish species distribution (Eaton and Sheller, 1996; Rahel et al., 1996; Mohseni et al., 2003; Sharma et al., 2007). Widening this knowledge to other species types of different regions and encompassing several variables that are interconnected with climate change would grant us a more comprehensive understanding of the susceptibility of freshwater fish species to climate change (Beatty et al., 2014). For example, hydrology has been shown to play an important role on determining the life-history strategies of freshwater fish species (Mims and Olden, 2012; Chessman, 2013; Sternberg and Kennard, 2013). Nevertheless, and although climate change directly promote hydrological changes, approximately 80% of the studies that aim at determining the impacts of climate changes on distributional ranges of freshwater fish species do not consider the direct effect of hydrology and focus solely on climatic and habitat variables (Comte et al., 2013).

Here, we calibrated empirical fish habitat favourability models in the Douro basin, NW Iberian Peninsula, and assessed the importance of considering hydrological stressors in the future fish habitat shift projections within a pilot sub-basin, under a high-end scenario of climate change. We assessed the shifts of habitat favourability for a range of fish species with distinct life-history traits and also the changes in species richness and species turnover. We expect an important impact of hydrological stressors in the distribution shifts of favourable fish habitats, which we hypothesize to be more evident for species that use habitats less prone to hydrological stressors. We also expect that non-native species will benefit from the climate and hydrological projected changes. The interplay between climate and hydrological stressors in the projected geographical shifts of habitat favourability has important implications in river management under climate change because while the implementation of actions to control hydrological parameters may be feasible and with immediate effects, climate mediation actions are harder to implement and their response is more dilated in time. The relative contribution of hydrological changes to fish habitat regression under future climate changes is also relevant to select species that are more vulnerable to hydrological alterations under climate change and hence be used as indicators of water scarcity and drought.