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Impacts of climate change and land-use scenarios on *Margaritifera margaritifera*, an environmental indicator and endangered species

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HIGHLIGHTS

- Develop a verification scheme to check stress on *M. margaritifera* based on thresholds
- Assess the impact of future climate change in conservation status of *M. margaritifera*
- Assess the impact of land-use in habitat requirements of *M. margaritifera*
- Propose conservation measures to prevent extinction of *M. margaritifera* in Portugal

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ABSTRACT

In this study, we assess the impacts of future climate and land-use in the Beça River (northern Portugal) under different scenarios and how this will translate into the conservation status of the endangered pearl mussel *Margaritifera margaritifera* (Linnaeus, 1758). This species is currently present in several stretches of the Beça River that still hold adequate ecological conditions. However, the species is threatened by projected declines in precipitation for the 21st century, with implication on the river flows and water depths that might decrease below the species requisites. This situation could be especially critical during summer conditions since the ecological flows may not be assured and several river stretches may be converted into stagnant isolated pools. The habitat connectivity will also be affected with reverberating effects on the mobility of *Salmo trutta*, the host of *M. margaritifera*, with consequences in the reproduction and recruitment of pearl mussels. In addition, human-related threats mostly associated with the presence of dams and an predicted increases in wildfires in the future. While the presence of dams may decrease even further the connectivity and river flow, with wildfires the major threat will be related to the wash out of burned areas during storms, eventually causing the disappearance of the mussels, especially the juveniles. In view of future climate and land-use change scenarios, conservation strategies are proposed, including the negotiation of ecological flows with the dam promoters, the replanting of riparian vegetation along the water course and the reintroduction of native tree species throughout the catchment.

1. Introduction

The occurrence of droughts in the early 1990s has resulted in very poor harvests and water shortages in Mediterranean regions, exposing the susceptibility of these areas to climatic extremes (Karas, 1997). The effects of the ongoing global warming can be observed in many terrestrial, freshwater and marine species that have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions, namely: freshwater fishes (Regier and Meisner, 1990), plants (Araujo et al., 2004; Lemieux and Scott, 2005), mammals (Burns et al., 2003), small birds (Wilby and Perry, 2006), and macroinvertebrates (Bonada et al., 2007). According to McLaughlin et al. (2002) as well as to Pounds et al. (2006), these changes in climate may have already caused several species extinctions. The IPCC (2014)

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corroborates this idea, stating, with high confidence that under projected climate change during and beyond the 21st century many terrestrial and freshwater species faces increased extinction risk once this phenomenon interacts with other stressors, such as habitat modification, over-exploitation, pollution, and invasive species.

In general, studies on climate or land-use impacts on the conservation of aquatic biota are focused on a few vertebrate species selected on the basis of their geographical range, ecological relevance or current conservation status. Freshwater invertebrates received much less attention but inside this group freshwater mussels are among the species frequently used in those studies or programs, because they play an important role in the ecosystem, with some species being classified as indicator or umbrella species, and are one of the most endangered groups of animals on the planet (Bogan, 2008; Galbraith et al., 2010; Geist, 2010; Howard and Cuffey, 2006; Lopes-Lima et al., 2014; Skinner et al., 2003; Sousa et al., 2013). Due to its large size, sedentary, long life span and variable sensitivity to environmental contaminants, freshwater bivalves can also be very useful as indicators of ecological integrity and as sentinels of environmental perturbation (Farris and Van Hassel, 2006). This is also the case of the freshwater pearl mussel *Margaritifera margaritifera* (Linnaeus, 1758) which only occurs in pristine oligotrophic waters, being very sensible to human perturbation. In fact, the poor conservation status attained by freshwater mussels are related to human activities that include habitat loss and fragmentation (e.g. river channelization and presence of dams), pollution (e.g. nutrients, heavy metals, endocrine disruptors), overexploitation (e.g. use of shells and pearls), introduction of invasive species and climate change (Lydeard et al., 2004; Strayer et al., 2004). In addition, freshwater mussels have a specialized larva, the glochidium, that needs fish as hosts in order to complete their life cycle, which further complicates the conservation of these species.

The freshwater pearl mussel (*M. margaritifera*) is one of the most threatened freshwater bivalves worldwide (Geist, 2010). This species is a long-lived bivalve mostly occurring in cool running waters of the Holarctic region. Since the 1900s, this species declined by more than 90% in Europe and became rare or even disappeared in many European countries, including Portugal (Bauer, 1988; Buddensiek, 1995; Frank and Gerstmann, 2007; Reis, 2003). This situation triggered a conservational response and the freshwater pearl mussel is currently protected internationally by the Bern Convention (Annex III) and the European Commission Habitats Directive (Annex II and V), being listed as "Endangered" globally and as "Critically Endangered" in Europe by the IUCN Red List of Threatened Species (Cuttelod et al., 2011; http://www.iucnredlist.org).

In Portugal, the freshwater pearl mussel is present in several rivers, namely: Beça, Cávado, Mente, Neiva, Paiva, Rabaçal, Terva and Tuela (Reis, 2003; Varandas et al., 2013). In all rivers the freshwater pearl mussels were found in unspoiled stretches, located away from the major human settlements. The evidence of recent juvenile recruitment in the Rabaçal, Tuela, Paiva, Mente and Beça Rivers, make these water courses extremely important for the conservation of *M. margaritifera* in the south of Europe. However, irrespective of being well preserved in some stretches the habitat requirements for the species are currently being threatened by global climate change and various local anthropogenic pressures (Varandas et al., 2013). In the Iberian Peninsula, the species is already at the southern edge of its distribution and any changes in the temperature may become problematic (Sousa et al., in press). On the other hand, when subject to extreme climatic events, such as large return-period droughts or floods, high mortalities may occur (Hastie et al., 2003; Sousa et al., 2012). Future climatic scenarios for the Mediterranean basin over the next 50–100 years predict an increase in the mean air temperature (between 1–5 °C) and extreme events frequency accompanied by a decrease in the annual precipitation (IPCC, 2014). According to this Report (IPCC, 2014) the regional risks from climate change particularly in southern Europe include: 1) "increasing water restrictions"; 2) "significant reduction in water availability from river abstraction and from groundwater resources, combined with increased water demand (e.g., for irrigation, energy and industry, domestic use) and with reduced water drainage and runoff as a result of increased evaporative demand"; and 3) "… increasing risk of wildfires".

In addition to climate change, Portuguese *M. margaritifera* populations (in the Beça, Terva, Rabaçal, Mente, Tuela, Neiva and Paiva Rivers) are also subject, at present, to other human threats such as the construction of dams for irrigation or hydroelectric power generation, changes in the river channel, water abstraction, disappearance or reduction of *Salmo trutta* populations that function as host for the larva, organic pollution by domestic effluents and the changes in river water quality during the period of the first rains after the occurrence of forest fires (Reis, 2003; Sousa et al., in press; Varandas et al., 2013).

A review of the literature disclosed a great number of studies on the *M. margaritifera* focused on the analysis of distribution, abundance and structure of the populations, as well as on habitat and water quality characterization (Geist, 2010). It also revealed that impact studies are much scarcer and that studies projecting future scenarios are even rarer. This study brings first elements to fill this gap by investigating the future impacts that global climate change and local anthropogenic pressures will exert in one *M. margaritifera* population located at the southern edge of the species distribution (the Beça River in Portugal). In short, the impacts are evaluated using a verification scheme based on a comparison among actual/future water quality/river flow conditions and corresponding environmental thresholds required for *M. margaritifera*. Given the scenarios of temperature increase (between 1–5 ° C) for the region under consideration in the relatively near future, it is intended with this study to predict the future environmental conditions in Beça River by using several modeling approaches. For this, we use as target species *M. margaritifera* not only because it is a flagship species, lying in danger of extinction, but also because it has a very peculiar life cycle since it requires a host species. Thus, starting from the worst scenario of temperature increase it is expected that both species (parasite and host) may disappear in the Iberian Peninsula because the ecological requirements of the species cannot become satisfied. Results will be discussed in light of the current knowledge on the biology and ecology of *M. margaritifera*. This information will be essential to design future management measures devoted to the conservation of an important endangered and indicator species at the southern edge of its distribution range.

2. Materials and methods

2.1. Study area

The Beça River, a tributary of the Tâmega River (Fig. 1), is located in northern Portugal, a humid Mediterranean region (Temperate Mediterranean with continental influences). With a total length of 55.2 km and a catchment of 345 km^2 it drains a mountainous area where the altitudes vary within 190–1270 m and the average hillside inclinations reach 11.7 ± 7.6°. Land use and occupation assessed by the 2006 Corine Land Cover inventory (Caetano et al., 2009; http://www.eea.europa.eu), available at http://www.dgterritorio.pt, showed that the region is dominated by semi-natural areas (45%), agricultural areas that include non-irrigated arable land, pastures and heterogeneous agriculture areas (32%), and forests (23%). The occupation in the headwaters and middle sector of the basin is characterized by shrubs where the relief is craggy and by dry farming areas, pastures and natural grasslands in the valleys surrounding the local villages. The downstream sector is used for wood production, being occupied by large and continuous spots of *Pinus pinaster* forests. A significant portion of these woodlands was destroyed by fire in the last decade. According to the Institute for the Conservation of Nature and Forests (http://www.icnf.pt), within the period 2000–