



Review

Non-native freshwater fauna in Portugal: A review



Pedro M. Anastácio ^{a,*}, Filipe Ribeiro ^b, César Capinha ^{c,d}, Filipe Banha ^a, Mafalda Gama ^a, Ana F. Filipe ^{c,d}, Rui Rebelo ^e, Ronaldo Sousa ^f

^a MARE – Marine and Environmental Sciences Centre, Departamento de Paisagem Ambiente e Ordenamento, Escola de Ciências e Tecnologia, Universidade de Évora, Évora, Portugal

^b MARE – Marine and Environmental Sciences Centre, Faculdade de Ciências da Universidade de Lisboa, Lisbon, Portugal

^c CIBIO/InBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos da Universidade do Porto, Campus Agrário de Vairão, R. Padre Armando Quintas, 4485-661 Vairão, Portugal

^d CEABN/InBIO, Centro de Ecologia Aplicada, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal

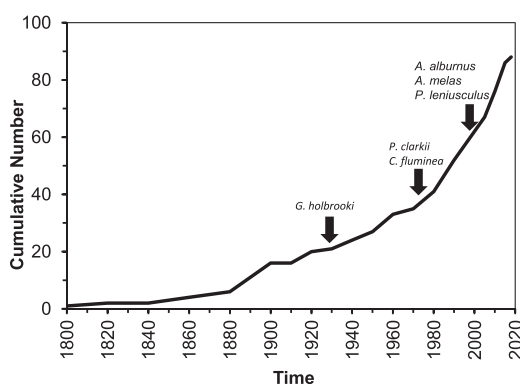
^e Department of Animal Biology and Centre for Ecology, Evolution and Environmental Changes, Faculdade de Ciências, Universidade de Lisboa (cE3c-FCUL), Lisbon, Portugal

^f CBMA – Centre of Molecular and Environmental Biology, Department of Biology, University of Minho, Braga, Portugal

HIGHLIGHTS

- We reviewed information on non-native freshwater fauna in Portugal.
- Fish and mollusks are the taxonomic groups with more established species.
- Most species are native from other regions of Europe and North America.
- The Portuguese and EU legislation showed large discrepancies in its invasive species.
- We identified invaders for which legislation and actions are needed.

GRAPHICAL ABSTRACT



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ABSTRACT

We present the most updated list of non-native freshwater fauna established in Portugal, including the Azores and Madeira archipelagos. This list includes 67 species at national level but corresponds to 84 species records, of which 53 are in the mainland, 23 in the Azores and 8 in Madeira archipelagos. We also discuss the progression of the cumulative number of introductions since 1800 and identify the most probable vectors of introduction, main taxonomic groups and their regions of origin. Furthermore, we review the existing knowledge about ecological and economic impacts, invasion risk and potential distribution of invaders, under present and future climatic conditions, and the applied management actions, including the production of legislation. Along the 20th century the number of successful introductions increased at an approximate rate of two new species per decade until the beginning of 1970s. Since then, this rate increased to about 14 new species per decade. These introductions were mainly a result of fisheries, as contaminants or for ornamental purposes. Fish and mollusks are the taxonomic groups with more established species, representing more than half of the total. Most species (>70%) are native from other regions of Europe and North America. Studies about ecological or socioeconomic impacts are more common for fish, crustaceans and mollusks. Impacts for most amphibians, reptiles and mammals are not thoroughly studied. A few studies on the impacts and management actions of health-threatening mosquitoes are also available. The potential distribution in the Portuguese territory was modelled for 26 species. Only a minority of these models provides projections of distributions under scenarios of future climate change. A comparison of the Portuguese and EU legislation shows large discrepancies in the invasive species lists. Using the EU list

* Corresponding author.

E-mail address: anast@uevora.pt (P.M. Anastácio).

and a ranking procedure for the national context, we identify freshwater species of high national concern for which actions are urgently needed.

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1. Introduction

The growing use of inland waters for recreation, food provisioning or navigation led to an increase in connectivity between aquatic systems and to the introduction of numerous non-native species. As a consequence, we now witness a growing homogenization of aquatic communities (Rahel, 2007; Villéger et al., 2011). Freshwater ecosystems present great declines in their biodiversity worldwide (Dudgeon et al., 2006; Millennium Ecosystem Assessment, 2005) and biological invasions are considered a major cause for those declines (Sala et al., 2000; Strayer and Dudgeon, 2010). The relative isolation of most freshwater ecosystems allowed the evolution of numerous endemisms and this is also the case in Portuguese freshwaters. The Pyrenean desman (*Galemys pyrenaicus*), fishes such as the saramugo (*Anaecypris hispanica*), or the unionid mussel (*Unio tumidiformis*) are iconic examples of endemic Iberian freshwater fauna occurring in Portugal, which are vulnerable to biological invasions (Barbosa et al., 2009; Cabral et al., 2005; Reis and Araujo, 2009). The Portuguese mainland shares most of its large river basins with Spain, and policies, laws and management actions are mostly implemented at a national level without full cooperation between the two countries. This may be problematic because the behaviour associated with the introduction of non-native freshwater fauna is distinct between these Iberian countries. Therefore, the adoption or voting of international conventions such as European Union (EU) regulations, needs to be framed within the context of each nation.

In Portugal, most studies about biological invasions in freshwater ecosystems have been directed to single species or specific groups (mainly fish, bivalves and crayfish). There is currently no full revision updating the list of non-native species and summarizing vectors of introduction, ecological and economic impacts and possible management actions to mitigate these impacts. This review summarizes the current knowledge about the history and introduction rates, main pathways, original locations, and ecological and socioeconomic impacts of non-native freshwater fauna in Portugal (mainland, Azores and Madeira archipelagos). In addition, the invasion risk and potential distribution of these species under present and future climatic conditions, plus the management actions applied so far in Portugal are also discussed. This

knowledge is vital for the design of an effective national invasive species monitoring plan and the future implementation of management actions and legislation.

2. Methods

Information on successful introduction records (i.e. non-native species that have established in the wild) for the Portuguese continental area (i.e. mainland), Madeira and the Azores archipelagos, from the 17th century to the present date, was compiled. We included species capable of living in freshwater at least during a part of its life-cycle and excluded cryptogenic, casual, or euryhaline species occurring only occasionally in freshwater. The following taxonomic groups of organisms were considered: “Mollusks”, “Crustaceans”, “Other Invertebrates”, “Fish” and “Amphibians, Reptiles and Mammals”. Other invertebrates included insects and non-arthropod species such as Cnidarians, Platyhelminthes, Nematodes and Annelids. Because of their great mobility and difficulty to distinguish accidental from established species, non-native aquatic birds were excluded from our analyses, except in the case of risk assessment of invasive species included in European Union legislation (see below for further details).

The native range of the species was divided into Europe, Africa, Asia, North America, South America and Oceania. Whenever a native distribution included more than one region (e.g. Europe and Asia), the closest region to Portugal was considered (e.g. Europe). The identification of the main pathway of introduction was primarily based on the published literature for Portugal or, when absent, on author's own knowledge. When information was not available from neither of these sources, we used the information available on the European Alien Species Information Network (EASIN) database (Katsanevakis et al., 2015). Nine EASIN categories were considered: “Fisheries”, “Contaminant”, “Stowaway”, “Ornamental”, “Biological Control and Research”, “Aquaculture”, “Animal Production”, “Others” and “Unknown”.

We reviewed the main ecological and economic impacts and distribution data for the above-mentioned fauna, as well as predictions from species distribution models (SDMs) for the current environmental conditions and under scenarios of future climates. National and international legislation was also reviewed, as well as management actions

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