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DIVERSITY

A roadmap for the conservation of freshwater mussels in Europe

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Article impact statement: Addressing knowledge gaps, threats, socioeconomics, conservation strategies, and governance and education needs is required for freshwater mussel conservation.

Abstract

Europe has a long history of human pressure on freshwater ecosystems. As pressure continues to grow and new threats emerge, there is an urgent need for conservation of freshwater biodiversity and its ecosystem services. However, whilst some taxonomic groups, mainly vertebrates, have received a disproportionate amount of attention and funds, other groups remain largely off the public and scientific radar. Freshwater mussels (Bivalvia, Unionida) are an alarming example of this conservation bias and here we point out six conceptual areas that need immediate and long-term attention: knowledge, threats, socioeconomics, conservation, governance and education. The proposed roadmap aims to advance research, policy and education by identifying the most pressing priorities for the short- and long-term conservation of freshwater mussels across Europe.

KEYWORDS
education, ecosystem services, freshwater ecosystems, governance, Unionida

INTRODUCTION

Freshwater ecosystems are under siege, with vertebrate populations declining consistently faster in freshwaters (3.0% annually since 1970) than on land (1.1%) (Dudgeon, 2019). This situation has put the freshwater biodiversity crisis in the news headlines and resulted in an urgent call to lessen species loss in these systems (Tickner et al., 2020). However, conservation is heavily biased toward charismatic vertebrate species; thus, other taxonomic groups threatened with extinction are largely overlooked (Mammola et al., 2020). Freshwater mussels (Bivalvia, Unionida) provide a pointed example of this conservation bias. These organisms are mostly sedentary during the adult phase, can live for decades, depend on a vertebrate host, usually a fish, to complete their life cycle and disperse (Modesto et al., 2018), and can provide fundamental ecosystem services (Zieritz et al., 2022). Despite their extraordinary ecological roles, freshwater mussels are highly imperiled (Lopes-Lima et al., 2018). In Europe, 20 species are considered valid (Lopes-Lima et al., 2017), of which 13 (65%) are classified as threatened or near threatened on the International Union for the Conservation of Nature (IUCN) Red List of species (www.iucnredlist.org). Given their precarious conservation status, there is a pressing need to provide a roadmap for the conservation of these organisms and their habitats in Europe. We contenplate six conceptual areas that we consider priorities in the short and long term: knowledge, threats, socioeconomics, conservation, governance, and education (Figure 1).

KNOWLEDGE GAPS AND DATA NEEDS

Several knowledge gaps exist regarding freshwater mussel conservation (Lopes-Lima et al., 2021). Urgent needs include revision of taxonomy; development of a publicly and easily accessible database that includes distribution information and taxonomic, functional, and genetic diversity data; ramping up the monitoring effort in specific regions (e.g., Balkans and Eastern Europe) and habitats (e.g., large and deep rivers and lakes); establishment of long-term ecological monitoring; and completion of IUCN conservation assessments for all European species. The study of their basic biological traits, such as ontogeny, dietary requirements, energy budget, fertilization, reproductive effort, fish hosts, behavior, growth, and survival, is still needed. There is also a pressing need for interdisciplinary cooperation, particularly with researchers working on hydrology, water chemistry, ichthyology, land management, and social and economic sciences.

THREATS TO FRESHWATER MUSSELS

Habitat loss and fragmentation, invasive species, pollution, and climate change are the major currently recognized threats to freshwater mussels in Europe (Lopes-Lima et al., 2017), but others may be overlooked. The European Union (EU) policy for alternative sources of energy will probably exert an additional incentive for dam construction. Negative impacts on freshwater mussels are expected to be particularly severe in the coming years in the Balkans, a global biodiversity hotspot, when considering the planned construction of hundreds of dams (Schwarz, 2015).

Great challenges will also be imposed by climate change due to alterations in temperature and precipitation regimes and to an increase in the number and intensity of extreme events. Particularly alarming is the prospect of water transfer projects (Shumilova et al., 2018) designed to cope with expected water shortages, mainly in southern countries. This would likely result in the introduction of non-native species and homogenization of freshwater mussel (and other biota, including fish) assemblages.

Emerging contaminants and recently discovered problems related to diseases and parasites may be responsible for localized mass die-offs (Richard et al., 2020), and need to be scrutinized. A dramatic and unexpected threat is the war in Ukraine. This conflict may directly affect freshwater biodiversity through the

FIGURE 1 Roadmap to freshwater mussel (FM) conservation in Europe encompassing six interrelated, major conceptual areas that need short- and long-term attention. For each conceptual area, the most pressing priorities are listed.

destruction of bridges and dams, malfunctioning of wastewater treatment plants, oil spills, and pollution (e.g., heavy metals and nuclear materials) (Richardson, 1994).

Europe is an excellent research arena in which to investigate the effects of improvement in water quality on biodiversity, which has been achieved in response to the EU Water Framework Directive (EU Directive 2000/60/EC). In addition, new legislative instruments (e.g., EU Regulation 2020/741 on minimum requirements for water reuse) and specific investment priorities (e.g., Cohesion Funds and investments in response to the EU Green Deal) will provide support to environmental projects. These initiatives have the potential to restore or increase the density of freshwater mussel populations in historically heavily disturbed systems (e.g., Vistula and Odra Rivers, Poland, and Lake Orta, Italy), and such comebacks can be highly informative for planning future restoration actions.

SOCIOECONOMIC EVALUATION

An economic evaluation of the ecosystem services mediated by freshwater mussels is crucial to inform conservation priorities. The use of sociological methodologies (e.g., questionnaires) to assess past, current, and future perceptions of freshwater mussel conservation status and value will be highly instructive. Special attention should be given to the role of freshwater mussels in water purification, given their high filtration capacity and ability to transfer particles and energy from the water column to sediments (Vaughn & Hoellein, 2018). Assessment of trade-offs between infrastructure development and freshwater mussel conservation and the offsetting of negative effects is also required. For example, in Portugal, the Boticas pearl mussel (*Margaritifera margaritifera*) breeding facility was constructed by the private company Iberdrola as compensation for the construction of dams in the Tâmega River basin. These offsetting measures should aim for no net loss of biodiversity, but they also need to account for density-dependent effects and aim to maintain the important functions mediated by freshwater mussels.

CONSERVATION STRATEGIES

Conservation of freshwater ecosystems and their biodiversity requires strategies for managing whole landscapes and differing connectivity dimensions (Abell et al., 2007). Southern European species with the relatively restricted spatial distribution and low population sizes, such as *Unio tumidiformis* (vulnerable), *Potomida littoralis* (endangered), and *Microcondylaea bonellii* (vulnerable), need urgent protection. Special attention should also be given to geographic areas that exhibit unique divergent genetic lineages or exceptional genetic diversity, and these features should be considered in prioritization exercises.

Moreover, due to their high sensitivity to human disturbance, freshwater mussels, in tandem with their fish hosts, have all the biological features of indicators of environmental quality and can be used as targets to increase and improve the cover of freshwater protected areas. In situ and ex situ

measures have been applied to some European freshwater mussel species, particularly *M. margaritifera*, but their effectiveness has been evaluated rarely, which points to the need for conservation evidence (i.e., assessment of the success or failure of the conservation interventions [Sutherland et al., 2019]). Future investments in the restoration of aquatic ecosystems also need to consider maintaining environmental flows crucial for both mussels and their hosts. These environmental flows need to be carefully assessed and managed because different taxonomic groups may have completely different flow requirements (Tonkin et al., 2021). The implementation of future conservation measures will need large financial investments, so alternative ways of funding, including private investors, will be necessary. Increased international and interdisciplinary collaboration is essential to share knowledge and build capacity, especially in countries where freshwater mussels are largely overlooked. Activities developed by ConFreMus (Conservation of Freshwater Mussels) (COST [European Cooperation in Science and Technology] Action funded by Horizon 2020 [https://www.cost.eu/actions/CA18239/]) through regular conferences of European malacological societies and collaboration among academic institutions and nongovernmental organizations have been crucial in facilitating these interactions.

GOVERNANCE NEEDS

In Europe, there is currently no comprehensive governmental framework strictly devoted to biodiversity conservation. However, the recent EU Biodiversity Strategy for 2030 aims to cover this shortfall by establishing a clear set of indicators against which progress will be regularly assessed. These assessments need to be more inclusive (i.e., consider gender equality and inclusion of currently poorly represented ethnic groups) and engage a diverse range of practitioners and stakeholders. Furthermore, biodiversity conservation needs to go beyond political borders, and this is absolutely pressing for the management of protected areas, which includes the maintenance of adequate river flows and connectivity across transboundary hydrological basins (Liu et al., 2020). After the failure to meet the targets proposed in the CBD's Strategic Plan for Biodiversity 2011–2020 (www.cbd.int), emerging agreements, such as the United Nations Post-2020 Global Biodiversity Framework, offer a new chance for global and unified efforts to achieve the Aichi targets. Europe should lead by example by implementing these agreements and making biodiversity conservation a priority for government leaders across the political spectrum.

EDUCATION NEEDS

Freshwater mussels are fascinating organisms whose peculiar life cycle provides a wonderful example of evolution. They can also be used as early warning systems for a myriad of human disturbances (e.g., several cities in Poland are using freshwater mussels to monitor the quality of the water consumed by 10 million people). Pearls and nacre of these organisms were in the past commonly used in jewelry and furniture. More recently, they are being used in cosmetics. These are just some examples of human uses of freshwater mussels that can be translated into education and outreach initiatives to raise public awareness for these animals. Such initiatives could include festivals and workshops (e.g., activities for children and teenagers); educational exhibits at museums, zoos, and aquariums; engagement on social media and wildlife websites; and production of videos, educational posters, banners, and cartoons. A nice example of an educational tool is the Pearl Mussel Game, which was produced in French, German, and Czech. These educational initiatives should target youth, but, if possible, take into account the experience of a growing of retired scientists and lay people eager to continue contributing to a sustainable and well-informed future.

CONCLUSION

This roadmap presents a practical framework composed of six conceptual areas that are fundamental pieces of the puzzle (Figure 1) and take into account national, regional, and local specificities. For example, although in some European countries, regions, or localities, current knowledge is sufficiently advanced to allow focusing on particular pieces of the puzzle, work in other European regions will have to start from scratch.

Actions should not be postponed until every knowledge gap has been filled. Because most causes of freshwater mussel decline in many European regions are already well understood, now is the time to find the best management solutions. This roadmap should go hand in hand with the recently launched EU Biodiversity Strategy for 2030 that proposes, among other targets, a 30% coverage of protected areas and restoration of 25,000 km of rivers. This opens an exciting opportunity for freshwater biodiversity conservation. Freshwater mussels cannot be ignored, and this may be the last chance for saving these organisms that, more than ever, deserve immediate conservation action.

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