European Freshwater Bivalves: moving from assessment to conservation planning

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CONSERVATION PLANNING SPECIALIST GROUP
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CONFREMUS
IUCN SSC MOLLUSC SPECIALIST GROUP

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Cover photo species (from top left to bottom right): *Sphaerium lacustre, Unio crassus, Dreissena stankovici, Margaritifera margaritifera*

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IUCN: is a membership union uniquely composed of both government and civil society organisations. It provides public, private, and non-governmental organisations with the knowledge and tools that enable human progress, economic development, and nature conservation to take place together.

IUCN Species Survival Commission (SSC): The IUCN Species Survival Commission (SSC) is a science-based network with over 8,500 members in 186 countries. Being the largest of the seven expert commissions of IUCN, the SSC members work independently and with the different IUCN Units to build knowledge on the status of species and threats to them and to provide advice, develop policies and guidelines and facilitate conservation planning. Through this work, SSC catalyses conservation action and enables IUCN to influence policy and assist societies in biodiversity conservation.

IUCN SSC Mollusc Specialist Group (MSG): The Mollusc Specialist Group's mission is to contribute to molluscan biodiversity conservation, to promote an understanding of their intrinsic value, and to promote the role of molluscs in ecosystem health, ecosystem services, and human livelihoods.

IUCN SSC Conservation Planning Specialist Group (CPSG): was established in 1979. Its mission is to increase the effectiveness of conservation efforts worldwide through scientifically sound, collaborative planning processes that bring together people with diverse perspectives and knowledge to catalyse positive change for species. CPSG provides species conservation planning expertise to governments, other SSC Specialist Groups, zoos and aquariums, and other wildlife organisations.

Contents

Acronyms & Abbreviations

A2P	Assess to Plan, a multi-species conservation planning approach developed by CPSG
AMBER LIFE project	Adaptive Management of Barriers in European Rivers
BEWS	Mussel-based Biological Early Warning Systems
CBD	Convention on Biological Diversity
CEN	European Committee for Standardization (CEN from French: Comité Européen de Normalisation)
CONFREMU	'Conservation of freshwater mussels: a pan-European approach', an EU COST action involving a network of 129 scientists from 31 European countries (CONFREMU CA18239)
COST	European Cooperation in Science and Technology
CPSG	Conservation Planning Specialist Group of the IUCN SSC
DDT	Dichlorodiphenyltrichloroethane (insecticide)
EC	European Commission
eDNA	Environmental DNA
EFBEN	European Freshwater Bivalve Expert Network
EIP	European Innovation Partnership
ERL	European Red List, a regional IUCN Red List initiative supported by the EC
ERL Pulse	A European Red List project to reassess out of date assessments and produce a Red List Index
ESFRI	European Strategy Forum on Research Infrastructure
EU	European Union
EUROMAL	European Congress of Malacological Societies
FMCS	Freshwater Mollusk Conservation Society
FPM	Freshwater Pearl Mussel
GAP	Good Agricultural Practice
IAS	Invasive Alien Species (see Terms Defined table below for definition)
INNS	Invasive Non-Native Species
IUCN	International Union for Conservation of Nature
LIFE+/LIFE Project	An EU funding instrument for the environment and climate action.
MMEs	Mass Mortality Events. These refer to significant die-offs of freshwater bivalves.
MSG	IUCN SSC Mollusc Specialist Group
MolluscaBase	A taxonomic database supported by LifeWatch and part of the European Strategy Forum on Research Infrastructure (ESFRI)
MUSSELp	MUSSEL Project – an online database of all freshwater bivalve species described to date.
N2000	Natura 2000: Network of protected areas covering Europe's most vulnerable threatened species and habitats
PA	Protected Area. Includes the EU Natura 2000 network and the Bern Convention Emerald Network of protected areas, as well as local or regional protected areas that are not part of the Natura 2000 or Emerald networks.
PAF	Priority Action Frameworks
SDM	Species Distribution Model
SSC	The Species Survival Commission of IUCN
WFD	Water Framework Directive

Terms Defined

Catchment	The catchment of a water body is an area of land that collects rainwater and moves it by gravity downslope into that water body.
Bivalve	An aquatic mollusc, class *Bivalvia,* which has a compressed body enclosed within a hinged shell.
Competent Authority/ Authorities	Any government department, national agency or local government agency with legal obligations to comply with environmental law.
Encysted	When bivalve larvae (glochidia) become attached to their host fish and the host encloses them in a cell capsule or cyst.
Invasive Alien Species	An alien species whose introduction and/or spread threaten biological diversity. An 'alien species' is any species, subspecies or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce. i.e., not all alien or non-native species threaten native biodiversity. The term 'invasive non-native species' (INNS) is used in some countries but has the same meaning.
Lentic	Standing water such as: ponds, lakes, marshes.
Levee	An embankment built to prevent the overflow of a river.
Lotic	Fast flowing freshwater such as: rivers, springs, streams.
Minoritised language	A language that is marginalised, persecuted, or banned.
Minority language	A language spoken by a minority of the population of a territory.
Mussel	A bivalve mollusc.
Scouring	Abrasive action of swift-flowing water on the riverbed and banks.
Trochophore	Primary short-lived free-swimming larval stage that develops into a veliger.
Veliger	Free swimming secondary larval stage that feeds and moves using cilia.
Wetlands	An area of land that is either covered by water or saturated with water.

Executive summary

Authors: David Aldridge, David Allen, Manuel Lopes-Lima

What are freshwater bivalves

Bivalves are a class of molluscs characterised by two hinged shells that can be opened and closed for breeding, feeding, and burrowing. They are generally sessile filter-feeders that spend most of their lives half-buried in soft sediments, such as sand and mud, or attached to harder substrates, such as rocks and stones. Although most bivalve groups are marine, some inhabit brackish water, and others are strictly freshwater.

In Europe, there are 66 species of native freshwater bivalves that can be divided into three main groups: the unionids, the sphaeriids and the dreissenids. All of them follow the same general body plan of bivalves with two shells covering a soft body which includes a central body with most internal organs, a mantle consisting of a sheet of tissue to secrete both shells, two pairs of gills and one muscular foot which can be used for local movements or for selecting and guiding fibres (byssus threads) for attachment to hard substrates.

UNIONIDS

The first group includes 25 species of the order Unionida, which consists of two families with European representatives: Unionidae, with 23 species, and Margaritiferidae, with only two species. These species are commonly known as freshwater mussels or naiads. Until the taxonomic change of the order Unionoida to Unionida, unionids were only considered as species belonging to the family Unionidae, but in this document all species belonging to both families Unionidae and Margaritiferidae are referred to as unionids. Unionids are typically larger than those in the other two freshwater bivalve groups in Europe. They can be found in burrowing substrates of a wide range of habitats, including stagnant waters such as ponds, lakes, and reservoirs, as well as flowing watercourses like rivers, streams, channels, and ditches. Unionids have a unique life cycle that enables them to survive in flowing environments. Unlike marine bivalves, they undergo internal fertilisation and produce specialised larvae known as glochidia. Once mature, glochidia are released from their parents into the water. They use specialised structures, such as teeth and a larval thread, to attach themselves to a host, which is typically a fish. After attaching, they encyst for a variable period of time to complete their metamorphosis before shedding and beginning a free life in the sediments. While some species of unionids can complete their life cycle in a wide range of fish hosts, others are restricted to very few species. This obligatory dependency on fish, coupled with high sensitivity to habitat disturbance, makes unionids one of the most threatened groups in the world.

SPHAERIIDS

The second group comprises 35 species from the Sphaeriida order, which includes a single family, the Sphaeriidae. These species are commonly known as pea and orb mussels, or pea and fingernail clams, due to their small size and shape, typically ranging from 2-15 millimetres. However, in this document, they will be referred to as sphaeriids. Sphaeriids also have internal fertilisation but retain their embryos until they complete their full development without undergoing a larval stage. Once they reach adulthood, individuals are expelled from their parents and begin their independent lives in the sediment. They inhabit burrowing substrates in a wide variety of habitats, including standing and flowing waters, as well as man-made habitats such as water fountains, concrete channels, and ditches. They can also occur in raised pit bogs or soil, as long as the substrate contains enough moisture. Sphaeriids have a high dispersal capability as they can attach to a variety of aquatic, terrestrial, and even aerial animals, including water beetles, amphibians, mammals, and birds. These bivalves are poorly understood and studied due to their small size and the challenges of identifying them without causing harm. Most sphaeriids are generally considered to be widespread and common, and therefore not of conservation concern. However, recent evidence suggests that some species are in decline, indicating that inadequate attention and monitoring may obscure the true conservation status of many species previously thought to be common, stable, and widespread.

DREISSENIDS

The third and final group only includes six species all belonging to the Dreissenidae family included in the Myida order. Adult dreissenids live attached to hard substrates such as rocks and stones by byssus threads, often in large colonies of many individuals. Unlike the other two groups, they reproduce by external fertilisation in the water column, where microscopic larvae develop as part of the plankton. The larvae (trochophores that metamorphose into veligers) can swim actively or be transported by currents, eventually attaching to any type of solid substrate where they begin to grow into adults.

European dreissenids can be divided into two genera, *Dreissena* and *Congeria*, each with three species. The genus *Dreissena* is notorious for containing two species, the Zebra Mussel (*Dreissena polymorpha)* and the Quagga Mussel (*Dreissena bugensis)*, which are among the world's worst invasive species, causing ecological and economic damage. Both species are native to a small area of Europe but have now invaded much of Europe's freshwaters. The third European species in this genus, *D. carinata*, occurs in the Balkans and is not known to be invasive. The three species in the genus *Congeria* are all endemic to aquatic environments of a few cave systems in the western Balkans and therefore have very restricted distributions. Due to threats to the cave systems where they occur all *Congeria* species have a higher risk of extinction than the more widespread *Dreissena* species.

Why bivalves need their own plan

Freshwater ecosystems are under extensive pressure from anthropogenic threats and freshwater bivalves are considered one of the most imperilled taxonomic groups on the planet. More than 1,300 species of freshwater bivalves have been described globally, and only just over half of these species have been assessed for the IUCN Red List to date. Globally, nearly 38% of the 754 extant freshwater bivalve species for which sufficient data are available are considered threatened. It is important to note that this figure of 754 species refers to the species that have been assessed globally (i.e. assessing their global population status as opposed to assessing only the population that occurs within Europe, as is done for the European Red List for species that are not endemic to the European region). A significant 20% (151 species) are listed as Data Deficient, reflecting how much further research is still required, particularly in terms of population sizes and trends. Work is underway by IUCN to assess the remaining species of freshwater bivalve that have not yet been assessed for the IUCN Red List.

In Europe, many populations of freshwater bivalves have undergone recent rapid declines. In some cases, the drivers of decline that cause this high level of threat are clear and pervasive across all taxa (e.g. habitat loss, pollution events and, more recently, drought). However, the cause of many of the declines remain enigmatic with some mass mortality events happening to a single bivalve species within a multi-species assemblage.

The conservation status of the European unionids is especially acute, with 92% of the 16 described species considered threatened (with none assessed as Data Deficient). Ongoing molecular studies are identifying new species and revealing additional conservation concerns. For the sphaeriids, the level of threat is believed to be lower (17% of extant species for which sufficient data are available are threatened). However, we have insufficient knowledge of the distribution and ecology across Europe to evaluate the risk for the other 83% of species, with six species remaining Data Deficient.

Bivalves play an important role in the functioning of freshwater ecosystems, supporting a rich and diverse aquatic community. Their shells can be used to reconstruct pollution histories and their response to changing environmental conditions is making them an increasingly important tool for monitoring water quality. The filtration of water provided by some species can facilitate recreational activities and enhance water destined for potable or industrial supply. Given the wide importance of freshwater bivalves it is especially concerning that they are at such risk. Without more effective conservation action, more species will be lost and their ecosystem services will continue to diminish.

The Assess to Plan (A2P) process is a methodology developed by the Conservation Planning Group (CPSG) of the IUCN Species Survival Commission (SSC). In producing this report, the A2P methodology was employed by European experts working on freshwater bivalves as part of the EU COST Action 'CONFREMU CA18239'. In doing so we present a workflow that can help to address the challenges associated with the conservation of Europe's freshwater bivalves.

Challenges to freshwater bivalve conservation in Europe

Challenges to freshwater bivalve conservation in Europe are complex and interconnected and converge on major themes:

- the loss, degradation and disturbance of critical habitats and the wider catchment-level habitats;
- the loss or decline of freshwater bivalve hosts (most commonly fish and lamprey);
- invasive alien species;
- the level of knowledge on freshwater bivalve biology, distributions and life history traits;
- a general lack of awareness and understanding among policy makers and the general public;
- gaps in knowledge, tools and expertise which prevent some of these issues from being addressed;
- and ineffective or conflicting management actions in freshwater habitats.

The planning approach

The core of this document was drafted during virtual and in-person planning workshops held in January 2023, February 2024 and March 2024. The workshops followed the completion of the European Red List reassessment of the European freshwater bivalves, which was a collaboration between COST CONFREMU CA18239 and IUCN as part of the European Red List 'ERL Pulse' project. IUCN SSC CPSG contributed to conservation planning for taxa with the EU Pulse project in the role of neutral planning facilitator. Following the workshops, both workshop participants and additional experts were consulted on successive drafts (see inside cover for details).

Planning scope

The planning workshops focused on the 66 species of native freshwater bivalves that occur in the European region. Of these, 31 have been assessed as threatened i.e. Critically Endangered (seven species), Endangered (16 species) or Vulnerable (eight species). A further 35 species were assessed as Near Threatened (two species), Least Concern (27 Least Concern), and Data Deficient (six species). 73 experts were involved in this initiative representing 61 organisations and spanning 28 countries.

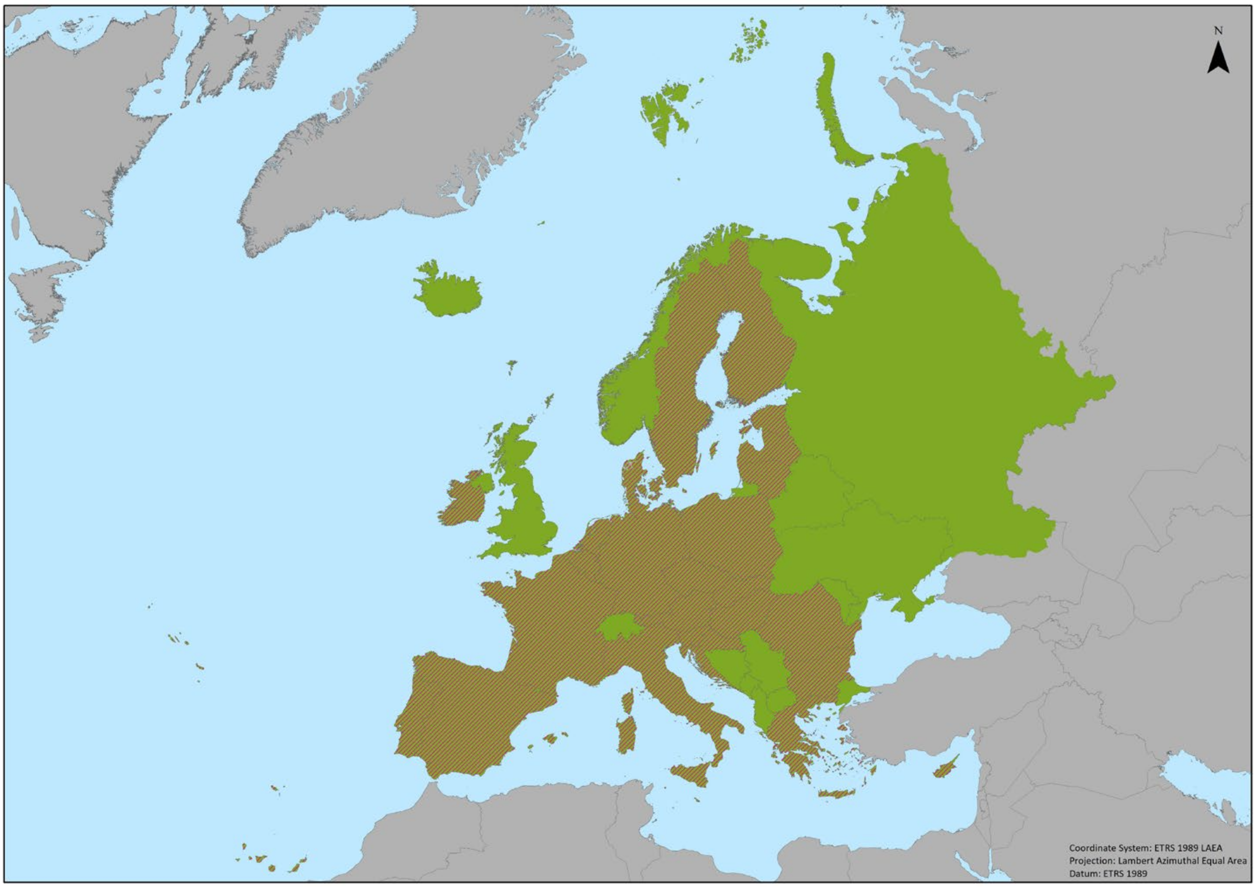


Figure 1*: The 'Pan Europe' European Red List assessment area followed for the reassessment of the European freshwater bivalves. The area includes the European Macaronesian archipelagos (Canaries, Azores and Madeira) and the Spanish North Africa territories, and extends east to Cyprus and the Ural Mountains in Russia. Species are assessed for both this Pan Europe region and for the EU27 Member States.*

1
PROVIDE IDENTIFICATION TOOLS, DATABASES & EXPERTS FOR BIVALVE MONITORING AND CONSERVATION

Priorities:
- A complete set of identification tools for European freshwater bivalves at EU and country level, including training.
- Baseline surveys, harmonised monitoring and reporting as a decision basis for conservation.
- Networking, knowledge transfer and certification to ensure long-term expertise.
- Identification of ecological requirements.
- Designation of priority sites and protected areas for freshwater bivalves.

2
ADEQUATE IDENTIFICATION, UNDERSTANDING AND MANGEMENT OF KEY THREATS TO FRESWATER BIVALVES

Priorities
- Habitat loss is reduced and catchment connectivity is restored.
- The impacts of climate change and natural disasters are understood and mitigated where possible.
- The effects of pollutants are quantified and their sources controlled.
- The role of diseases and parasites in freshwater bivalves are better understood and appropriate measures are identified to manage them.
- High risk invasive non-native species are identified, prioritised and managed.
- Suitable populations of host fishes are maintained.

3
INCREASED AWARENESS AND ENGAGEMENT IN BIVALVE CONSERVATION

Priorities:
- Increased recognition of the importance and beneficial roles of freshwater bivalves.
- Increased involvement in local and regional conservation efforts.
- Improved cooperation between all key sectors.
- Development and use of existing tools for guidance and training for a wide audience, at multiple levels.

4
SUFFICIENT POLICIES PROTECTING FRESHWATER BIVALVES AND THEIR EFFECTIVE ENFORCEMENT

Priorities:
- Assessment, legal protection, and planning for threatened species.
- Review of national legislation to ensure that there is no conflict with freshwater bivalve conservation. Ensure existing laws are effectively implemented and enforced with better outcomes for freshwater bivalves.
- Ensure EU legislation supports ecological gains for freshwater bivalves.
- Promote and provide sufficient guidance for project assessment, that is fit for purpose and fulfils all legal requirements for freshwater bivalves.
- Ensure compliance with best practice guidelines.
- Revision of water quality status thresholds to comply with freshwater bivalve requirements.

Figure 2: *Summary of Recommended Goals and Priorities*

Audience

The target audience for this work is the diverse array of decision-makers, managers, practitioners and scientists required to implement recommended actions. Key audiences include:

- European and national government nature conservation and environmental agencies and Competent Authorities;
- catchment managers;
- policy makers (local, national and regional);
- the scientific community and places of learning (universities, institutes, schools, local ecology education centres);
- Natura 2000 site and other protected area managers;
- groups with similar conservation interests (e.g. working with fishes, catchments, rivers, lakes, habitat restoration), and local communities in areas where action is most needed.
- water resource managers and regulators;
- non-governmental organisations (NGOs);
- developers (and their ecologists);
- the main land-user groups (agriculture, grasslands, forestry);
- nature conservation area management bodies;
- relevant business sectors, such as the extractive industries, pharmaceutical and agrochemical sectors.

Implementation

This plan is European in scope following the Pan Europe assessment region of the IUCN European Red List. Though many of the outlined actions can be implemented at the European level, most of the work identified will need to be implemented, supported, and enabled at regional (for example, European Union), national, sub-national and local levels and would benefit from dialogue and collaboration among the diverse stakeholder groups working there. National or sub-national planning workshops aimed at customising and operationalising this preliminary plan for the local context could speed uptake and progress. Implementation of this preliminary plan will be monitored and encouraged through IUCN SSC Mollusc Specialist Group.

Introduction to European freshwater bivalves and their conservation

Authors: David Aldridge, Manuel Lopes-Lima, Evelyn Moorkens, Katarzyna Zając, Tadeusz Zając

Why freshwater bivalves are important

Freshwater bivalves can be found in almost any water body, from small stagnant ponds to large flowing rivers. Unionids can dominate the benthic biomass of rivers and lakes and their creation of bio-deposits alongside their filtration of the water means that they are recognised as important ecosystem engineers. A single unionid can filter over 40 litres of water a day, leading to increased light penetration which in turn can encourage growth of bottom-rooting macrophytes. The parts of shells exposed into the water column can provide refuge for invertebrates and fishes and provide an attachment substrate for other organisms, which may monopolise on the incurrent flow of food-rich water being drawn to the unionid's inhalant siphon. The burrowing of freshwater bivalves through sediments can create important mixing and facilitate biogeochemical cycles. The importance of these organisms in engineering the environment around them is demonstrated by the regular finding that greater densities of freshwater bivalves are associated with greater taxonomic richness of other invertebrates.

Freshwater bivalves can also make an important contribution to freshwater food webs. Small individuals, including sphaeriids and juvenile unionids, can be a major dietary component of benthic foraging fish, such as Bream (*Abramis brama*) and Tench (*Tinca tinca*), while larger mussels are eaten by Otters (*Lutra lutra*), Wild Boars (*Sus scrofa*), Brown Rats (*Rattus norvegicus*) and birds such as Coot (*Fulica atra*).

The filtration of water by freshwater bivalves has been found not only to clear water but also to remove chemical contaminants and water-borne pathogens. Consequently, there is growing interest in the use of mussels as biological filters to improve water quality. In addition, predictable changes in valve opening, heart rates and locomotion are being harnessed in the development of bivalve-based biological early warning systems (BEWS) in the management of water destined for potable supply. Growth rings on the shell of some European freshwater bivalves have been shown to serve as indicators of annual variation in growth rates and can be used to infer temporal environmental change, while combining shell annuli with quantitative measures of heavy metals that are sequestered into the shell can allow the reconstruction of the pollution history of a waterbody.

Historically, the European population of the Freshwater Pearl Mussel (*Margaritifera margaritifera*) was prized for its pearls, which were included in regal headwear. However, overfishing of this species for pearls is recognised as one of the drivers of decline in some populations and has led to the legal protection of the species.

The life history of freshwater bivalves

The gills of many freshwater bivalves serve not only as a respiratory structure but also play a role in reproduction, providing marsupial brood chambers for developing eggs and larvae. Most sphaeriids are hermaphroditic and are capable of self-fertilisation (Fig. 4). Their fertilised eggs develop in the protected environment of the marsupium of the inner gill and are provided with a supply of oxygenated water, becoming extra-marsupial larvae and then juveniles as they grow and develop. The live juveniles are released into the water, with some species producing no more than a dozen in a lifetime. Sphaeriids rarely live for more than a year or two.

The life history of the unionids is especially unusual (Fig. 3). Females brood eggs within marsupia and males release sperm into the water. The sperm is drawn into the brooding females via their inhalant water currents with fertilisation taking place within the gill. Fertilised eggs develop into bivalved larvae called glochidia, which are typically armed with hooks and spines. When mature, the glochidia are released through the exhalant siphon, often on long mucus threads. In the case of some members of the *Unio crassus* complex, the glochidia are ejected within water jets which the females spurt from the edge of the river. The released glochidia attach to the gills, fins or scales of host fishes (and occasionally lamprey), where they become encysted and metamorphose into juveniles. Some unionids are generalists, using a wide range of host species, while others such as the Freshwater Pearl Mussels have a much narrower host range. Using host fishes greatly facilitates dispersal for unionids which are largely sedentary as adults. In the case of the Freshwater Pearl Mussel, the glochidia derive nutrients from their host and grow considerably whilst on the host.

The glochidia may remain on the host for a few weeks or many months (depending on the species) before excysting from the host and falling to the river or lakebed as a juvenile unioinid. The juvenile unionids spend the first part of their life deposit feeding while buried within the sediments. When their siphons develop (after a few months in some species and after a few years in others) the juveniles move to the surface of the substrate and begin to suspension feed. Many unionids, such as *Unio* spp. and *Anodonta* spp., can reach maturity in a few years and may live for 8-30 years. The Freshwater Pearl Mussel may take decades to reach reproductive maturity and can live for over 200 years.

The dreissenids are the only freshwater bivalves to release both their male and female gametes directly into the water column. The eggs from female dreissenids are fertilised in the open water by sperm released by males and develop into free-swimming veliger larvae. The veligers remain in the water for approximately three weeks where they grow and pass through a number of developmental stages before settling onto a suitable substrate with byssus threads. Dreissenids can reach reproductive maturity within a year and live typically for three to five years.

Geographic distribution

Of the 66 species of native freshwater bivalves assessed for the European Red List, 27 species are endemic to Europe and six are endemic to the European Mediterranean region. Data on the distribution of freshwater bivalves is uneven within Europe and many regions lack surveys or data on population trends. Some species are over- or under-represented in survey data; for example, the Freshwater Pearl Mussel and the Thick-shelled River Mussel (*Unio crassus*) are well studied, whereas much less is known for example about the Depressed River Mussel (*Pseudanodonta complanata*) and most of the sphaeriids.

The highest bivalve species richness per basin is found in central, northern, and eastern Europe (Fig. 5). However, although southern Europe is characterised by lower species richness per basin, it contains a higher number of range-restricted species.

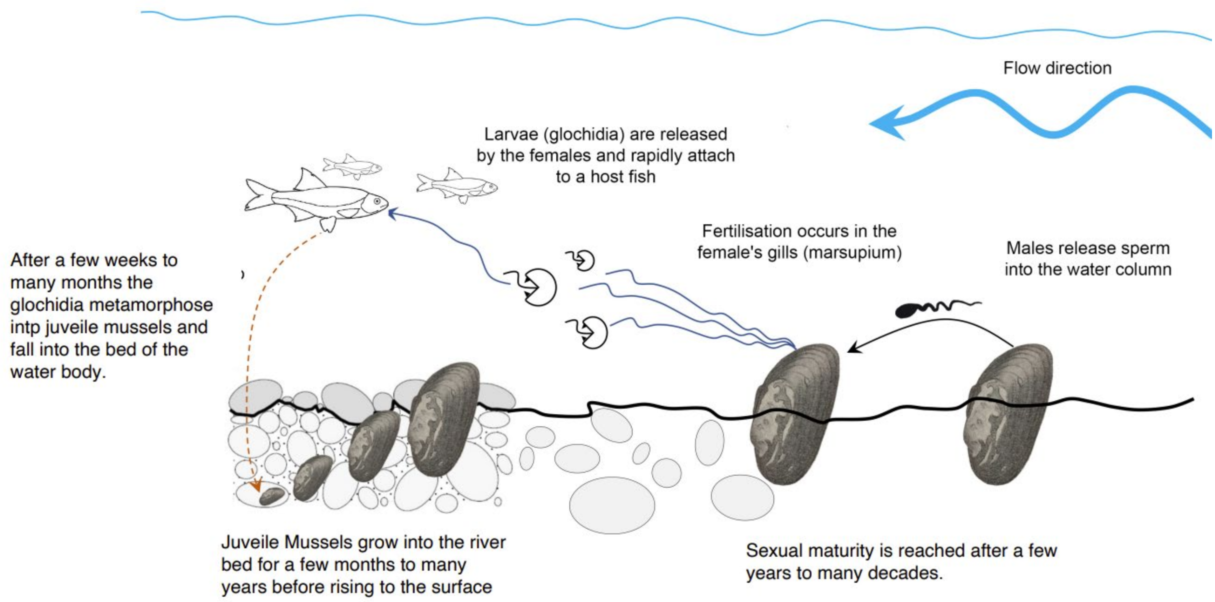


Figure 3*: Lifecycle of unionid species. Source: Vincent Prié*

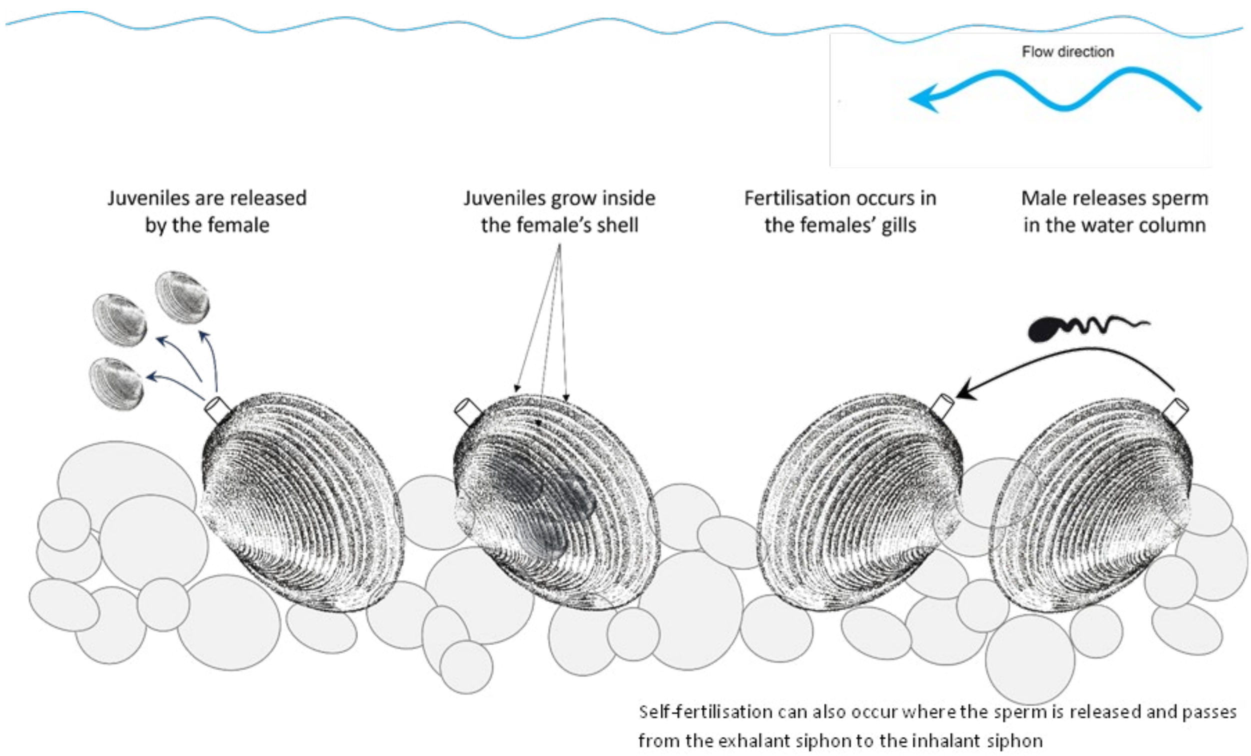


Figure 4*: Lifecycle of sphaeriid species. Source: Vincent Prié*

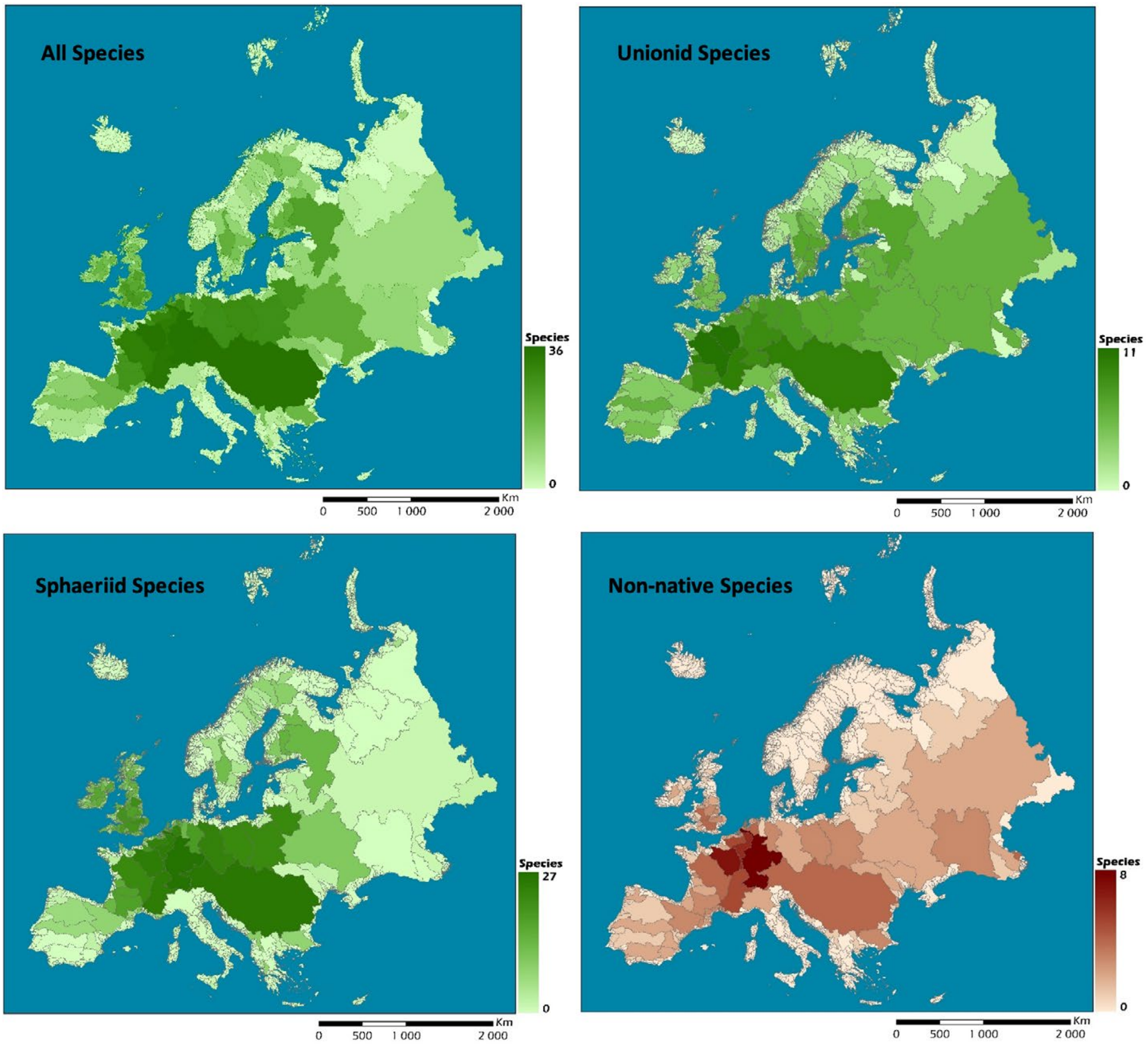


Figure 5: *Distribution maps for different groups of European freshwater bivalve species. Source: European Red List.*

Macro- and micro-habitat preferences

Once developed, juvenile and adult bivalves burrow, bore, or attach to the substrate with thin fibres. Important macro habitats for freshwater bivalves according to the 2023 Red List Assessment are permanent freshwater lakes, permanent freshwater marshes and pools, permanent rivers, streams and creeks, and artificial canals, drainage channels and ditches. However, microhabitat features such as type and size of substrate, nutrient level, alkalinity, and water temperature are significant in determining bivalve suitability. Some species are particularly adapted to fast flowing waters with little fine sediment, whereas others prefer muddy substrates; the same differentiation also holds true for other factors such as nutrients etc. Certain bivalves are also more or less tolerant to habitat characteristics such as water hardiness (calcium) and siltation. See tables below for species specific habitats.

***Table 1.** Principal habitats occupied by European unionids (table structure adapted from Lopes-Lima et al 2017). Dark grey, often present; light grey, occasionally present; white, no data.*

Species	Lentic					Lotic				Other habitats	
	Upland lakes & tarns	Lowland lakes & reservoirs	Ponds	Swamps	Marsh drains	Trickles & ditches	Large, slowflowing lowland rivers	Streams & small flowing rivers	Upland rivers & streams	Mediterranean temporary rivers	Canals
Margaritifera margaritifera	Light grey	Light grey					Light grey	Dark grey	Dark grey		Light grey
Pseudunio auricularius							Dark grey				Dark grey
Anodonta anatina	Light grey	Dark grey	Dark grey	Light grey	Light grey	Light grey	Dark grey	Dark grey	Light grey	Dark grey	Dark grey
Anodonta cygnea		Dark grey	Dark grey		Light grey		Light grey	Light grey			Dark grey
Anodonta exulcerata		Dark grey	Dark grey		Light grey	Light grey	Light grey	Light grey			Light grey
Pseudanodonta complanata	Light grey	Light grey	Light grey				Dark grey	Dark grey			
Unio bruguierianus		Light grey	Light grey		Light grey	Light grey	Dark grey	Dark grey	Dark grey		Dark grey
Unio carneus		Dark grey			Light grey	Light grey	Light grey	Dark grey	Dark grey		Dark grey
Unio crassus		Light grey			Light grey	Light grey	Dark grey	Dark grey	Dark grey		Dark grey
Unio delphinus		Light grey					Dark grey	Dark grey	Light grey	Dark grey	
Unio desectus						Light grey	Dark grey	Dark grey			Dark grey
Unio elongatulus		Dark grey	Dark grey	Light grey	Light grey	Light grey	Dark grey	Light grey	Light grey		Dark grey
Unio gibbus										Dark grey	
Unio gontierii		Light grey			Light grey	Light grey	Dark grey	Dark grey	Dark grey		Dark grey
Unio ionicus		Light grey			Light grey	Light grey	Dark grey	Dark grey	Dark grey		Dark grey
Unio mancus		Dark grey				Dark grey	Dark grey	Dark grey		Dark grey	Dark grey
Unio nanus		Light grey	Light grey		Light grey	Light grey	Dark grey	Dark grey	Dark grey		Dark grey
Unio pictorum		Dark grey	Dark grey		Light grey	Light grey	Dark grey	Dark grey	Light grey		Dark grey
Unio ravoisieri		Dark grey						Dark grey		Dark grey	
Unio tumidiformis								Dark grey		Dark grey	
Unio tumidus		Dark grey	Light grey		Light grey	Light grey	Dark grey	Dark grey			Dark grey
Unio vicarius		Light grey					Light grey	Dark grey	Dark grey		Dark grey
Microcondylaea bonellii		Light grey					Dark grey	Dark grey		Light grey	Light grey
Potomida acarnanica		Light grey					Dark grey	Light grey			Light grey
Potomida littoralis		Light grey					Dark grey	Dark grey		Dark grey	Dark grey

Table 2. *Principal habitats occupied by European sphaeriids (table structure adapted from Killeen, Aldridge & Oliver 2004). Dark grey, often present; light grey, occasionally present; white, no data.*

Species	Lentic					Lotic				Other habitats	
	Upland lakes & tarns	Lowland lakes & reservoirs	Ponds	Swamps	Marsh drains	Trickles & ditches	Large, slowflowing lowland rivers	Streams & small flowing rivers	Upland rivers & streams	Mediterranean temporary rivers	Canals
Euglesa casertana	Dark grey	Light grey	Light grey	Light grey	Light grey	Light grey	Dark grey	Dark grey	Dark grey		Dark grey
Euglesa compressa							Dark grey				Light grey
Euglesa edlaueri		Light grey									
Euglesa globularis			Dark grey	Dark grey							
Euglesa henslowana		Light grey					Dark grey	Dark grey			Dark grey
Euglesa hibernica	Dark grey	Light grey	Light grey		Light grey		Light grey	Light grey	Light grey		Light grey
Euglesa hinzi	Light grey										
Euglesa lilljeborgii	Dark grey								Light grey		
Euglesa maaseni		Light grey									
Euglesa milium	Light grey	Light grey	Dark grey	Dark grey	Dark grey		Light grey	Dark grey			Light grey
Euglesa nitida	Dark grey	Dark grey	Dark grey	Light grey	Light grey		Dark grey	Dark grey	Light grey		Dark grey
Euglesa obtusalis	Light grey		Light grey	Dark grey	Dark grey	Light grey					
Euglesa parvula											
Euglesa personata	Light grey		Light grey	Light grey	Light grey	Dark grey		Light grey			
Euglesa ponderosa							Dark grey				Light grey
Euglesa pseudosphaerium			Light grey	Light grey	Dark grey						Light grey
Euglesa pulchella	Dark grey	Light grey	Light grey	Light grey	Light grey		Light grey	Dark grey			
Euglesa subtruncata	Light grey	Light grey	Light grey				Dark grey	Dark grey	Light grey		Light grey
Euglesa supina							Dark grey				Dark grey
Euglesa waldeni	Light grey										
Eupera viridans											

Odhneripisidium annandalei											
Odhneripisidium conventus											
Odhneripisidium moitessierianum											
Odhneripisidium tenuilineatum											
Pisidium amnicum											
Pisidium dilatatum											
Pisidium punctiferum											
Sphaerium corneum											
Sphaerium lacustre											
Sphaerium mamillanum											
Sphaerium nitidum											
Sphaerium nucleus											
Sphaerium ovale											
Sphaerium rivicola											
Sphaerium solidum											

Freshwater bivalve declines

There are many factors leading to the decline and loss of freshwater bivalve populations (see Box 1 below), which vary not only from species to species but also within species across their ranges. Globally, the well-established major threats to freshwater biodiversity include loss, fragmentation and degradation of habitat, overexploitation, pollution, introduction of non-native invasive species, and climate change. Freshwater bivalves are vulnerable to all these threats. In the 2023 EU revised list of Habitats Directive Article 17 pressures and threats, 176 threats are listed, all of which have the potential to impact freshwater bivalves (https://cdr.eionet.europa.eu/help/habitats_art17). Many of these relate well to the 99 subdivisions within the 12 categories of threats used by IUCN (https://www.iucnredlist.org/resources/threat-classification-scheme). Each individual pressure can be the main cause of decline in a bivalve population, but more often it is the combined pressure from multiple stressors that have resulted in freshwater bivalves being very vulnerable to ongoing declines, with very little possibility for natural recovery.

Box 1: Declines in Unionids - Evidence from EU Habitat's Directive Article 17 Reporting

Author: Evelyn Moorkens

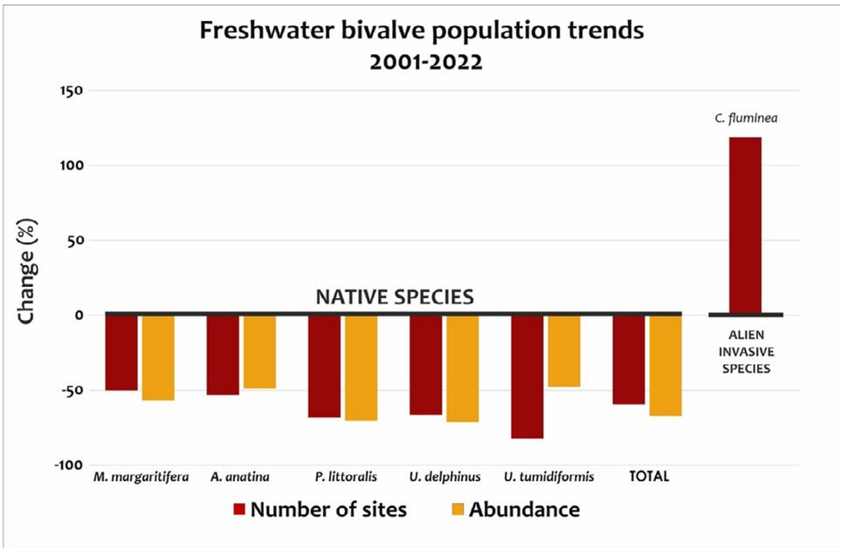
Article 17 of the Habitat's Directive requires that Member States monitor each protected habitat and species and report every 6 years on the status of the range, population, habitat and future prospects of each habitat or species.

As an example, the critically endangered Freshwater Pearl Mussel in Ireland has been reported Under Article 17 in 2007, 2013, and 2019.

In 2013, the national population had declined by 8% from the 2007 value.

In 2019, the national population had declined by between 12.6 and 32.7% from the 2013 value, or 20-40% decline since the first Article 17 report in 2007 and is likely to be closer to the higher value of 40%.

Agreed, harmonised monitoring of all freshwater bivalves is important to our understanding of the very sharp and rapid declines that are occurring in this group.



Left: A specimen of *Unio delphinus* in its natural habitat; Right: Changes (%) in the overall presence in the number of sites and abundance of native and alien invasive freshwater bivalves in Portugal from 2001 to 2022.
Photo and table credit: Manuel Lopes Lima.

Preliminary Red List process for freshwater bivalves

Since 2005, the European Red List has served as a critical tool for assessing the conservation status of Europe's species, while raising awareness about their vulnerability, and informing and influencing decision-making. Funded by the European Commission, more than 16,000 taxa (species, subspecies and varieties) have been assessed for the European Red List to date, including all vertebrate species (mammals, amphibians, reptiles, birds and fishes), terrestrial and aquatic molluscs, dragonflies, butterflies, bees, grasshoppers, crickets and bush-crickets, trees, medicinal plants, bryophytes (mosses, liverworts and hornworts), hoverflies, and pteridophytes (ferns and lycopods), and a selection of saproxylic beetles, endemic shrubs, and further selected vascular plants.

The European freshwater bivalves were first assessed in 2010-2011[1], with 48 species assessed and 22% (10 species) of extant species for which sufficient data are available found to be threatened; 42.8% of the Unionida species for which sufficient data are available were assessed as threatened, whilst for the Sphaeriida this figure was just 7.4%.

In 2020, the European Commission supported the European Red List 'Pulse' project - *Measuring the Pulse of European Biodiversity*. This four-year project reassessed 11 of the out-of-date European Red Lists (Red List assessments become formally out of date after ten years), including the freshwater bivalves.

The European bivalve reassessment considered 72 species that occur in Europe, of which six species are introduced and therefore placed as Not Applicable for the European Red List. Of the 66 species assessed, 31 species were placed into one of the IUCN threatened categories (CR, EN, or VU), resulting in nearly 52% of extant species for which sufficient data are available considered threatened. Two species (3%) were assessed as Near Threatened (NT), 27 species (41%) as Least Concern (LC) and six species (9%) as Data Deficient (DD).

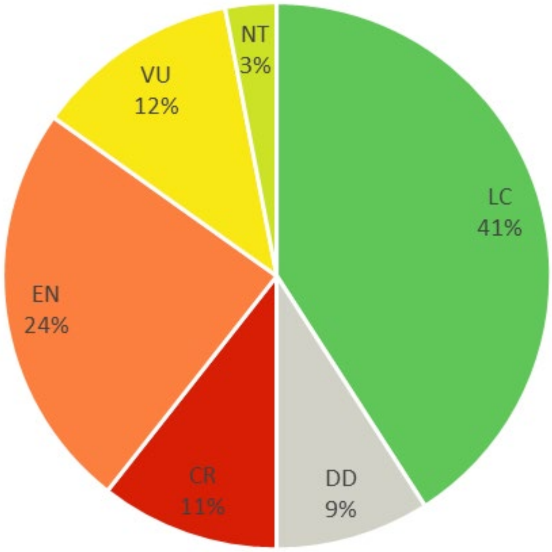


Figure 6: *The proportion of European freshwater bivalves in each Red List Category at the European scale. Source: European Red List.*

However, this overall value of threat (approaching 52%) for all freshwater bivalves hides significance differences between the two main taxonomic groups. Within the Unionida (two Margaritiferidae and 23 Unionidae species), 92% of species are threatened, with no Data Deficient (DD) species. For the Sphaeriida (five threatened and six DD species), 17% of species for which sufficient data are available are considered threatened (rising to 31% if all DD species were found to be threatened).

1 Cuttelod, A., Seddon, M. and Neubert, E. 2011. *European Red List of Non-marine Molluscs*. Luxembourg: Publications Office of the European Union.

1. Tools, databases and experts

Lead Author: *Jürgen Geist*
Co-authors: *Ian Killeen, Vincent Prié, Evelyn Moorkens, Tadeusz Zając*

1.1 Introduction

One of the major challenges to the conservation of threatened freshwater bivalves arises from the lack of knowledge, expertise in identification and survey, and gaps in understanding basic biology and distribution of freshwater bivalves. Data coverage is uneven between species and regions and a lack of standardised monitoring methods and training to identify many freshwater bivalve species both in the field and the lab contribute to these gaps in knowledge. The causes of the significant European-wide population declines seen in freshwater bivalves have not been well documented and publicised, and large die-offs of freshwater bivalves are not always understood, nor well researched. Improved networking and training opportunities will facilitate the development of tools and consequently improve the conservation and restoration of European freshwater bivalves (including currently overlooked species) and their habitats.

1.2 Challenges relating to tools, databases and experts

1.2.1 Identification tools for European freshwater bivalves at the European and country level, including training

Although some identification tools exist for freshwater bivalve species and/or regions, many species are not included in existing taxonomical identification guides at all. A concise and complete identification guide for all currently known European freshwater bivalve species should include illustrations, taxonomy, expected phenotypic variability and distribution and be made available online and as a field guide, at both a European and country level, with appropriate language translations. Existing freshwater bivalve databases (such as e-mussels.eu) are not homogeneously used or known across Europe and should be better disseminated.

Another challenge to providing accurate tools comes from cryptic species (such as *Anodonta* species) whose taxonomic identity is not reflected by their morphology, or newly described species for which morphological identification features might exist but are not yet described (e.g. the *U. crassus* complex).

Compared to the unionids, the sphaeriids are much less studied, partly because they can be difficult to identify in the field. Therefore, very few malacologists, let alone freshwater biologists, study this group of freshwater bivalves. With so little knowledge, particularly on ecology and distribution, the threat status of many species is difficult to assess, and declines and local extinctions go unnoticed. The lack of taxonomic expertise is unlikely to be overcome in the coming years without specialist training. Environmental DNA (eDNA) analysis (see section 1.3) offers an opportunity to acquire new information as sphaeriid species are well detected by this technique, but this must be undertaken in conjunction with taxonomic expertise.

1.2.2 Baseline surveys, harmonised monitoring and reporting as a decision baseline for conservation

Conservation and monitoring of freshwater bivalves depend largely upon having good baseline data. Implementing baseline surveys, developing and implementing basic standards (e.g. the Comité Européen de Normalisation (CEN) standard) can provide reliable quantitative information which provides a basis for measuring change.

Monitoring methods for European freshwater bivalves have been developed for some countries or regions but are not widely tested, comparable or available. The exception is for an existing CEN standard for the Freshwater Pearl Mussel which was put together by an international team comprising the entire European distribution range of this species. Monitoring is usually carried out only for species protected on the EU Habitats Directive, or for species on individual country Red Lists. Invertebrate analysis for the Water Framework Directive (WFD) monitoring rarely includes identification of freshwater bivalves to species level.

The non-inclusion of bivalves in most invertebrate scoring systems for water quality analysis provides no incentive for general aquatic biologists to learn to identify freshwater bivalves. Better use could be made of invertebrate samples collected by environmental agencies for water quality monitoring if the sphaeriids in particular were passed on to specialists.

It is important to stress that the same survey and monitoring methods may not be valid for all geographic regions, habitats and species. However, some level of harmonisation is needed to allow comparisons of data, e.g. for the same species within one region. This refers also to the determination of favourable conservation values (desired level of a species population integrity) for particular countries. A lack of information sharing between countries and freshwater bivalve experts has led to differing approaches and a more cohesive, collaborative effort should focus on harmonising monitoring methods and developing standardised protocols for taxa across Europe. This is necessary to facilitate analyses of population trends over time and comparisons among different regions.

Given the high level of threat across this species group, it is important that baseline surveys and monitoring should address all freshwater bivalves, not just those traditionally considered threatened or that appear in, for example, the EU Habitats Directive Annexes.

1.2.3 Networking, knowledge transfer and certification to ensure long-term expertise

For the two bivalve species listed on Annex II of the EU Habitats Directive (*M. margaritifera* and *U. crassus*) a Europe-wide network of expertise has been built up through e.g. academic research, national monitoring programmes and EU Life programmes. However, for most other species and especially the sphaeriids, there is a significant lack of expertise regarding identification and surveying. This is an especially serious issue in southern Europe, where many of the threatened species occur.

To some extent the lack of taxonomic expertise is a relatively recent phenomenon. In the latter part of the 20th century, many countries, particularly in northwest Europe, had a national expert who identified and validated specimens collected (mostly by members of amateur societies) for national species distribution recording schemes. Following closure of projects and the retirement of experts, much of this skill set was lost. Recruitment of students to study freshwater bivalves, both in academia and in natural history societies is difficult and in part, as a result of a preference for species groups with better funding opportunities and career paths. There is a perception that working in deep, turbid waters with bivalves buried in sediment presents health and safety issues.

Provision of a comprehensive set of identification tools is not in itself sufficient to raise interest in freshwater bivalves or to encourage academic and amateur study, or to raise their importance in invertebrate analysis. Traditionally the interest in freshwater bivalves has come from members of the several European malacological societies, and effort must be made by the conservation and research community to ensure that this source of important data is not lost. Developing interest in freshwater bivalves and their identification and ecology to provide a new generation of experts is best provided through training. A range of appropriate courses designed and provided (through in-house workshops, webinars, online learning etc.) by the current group of experts needs to be provided to a wide group of conservation agencies, universities, aquatic consultancies, national malacological societies, natural history groups and NGOs. Mechanisms such as online databases need to be available for uploading and sharing records and other data, at the same time ensuring protection of endangered species. In addition to new data, knowledge transfer can be improved by databasing information that is yet to be made widely available from sources such as grey literature, museum collections, and monographs written in national languages.

A useful accompaniment to training would be certification levels based upon the complexity of the course undertaken. This is likely to be particularly important for aquatic consultancies.

Freshwater bivalve experts must take responsibility for ensuring that rare or threatened species are brought to the attention of conservation authorities, including national Red List coordinators.

1.2.4 Identification of ecological requirements and life history traits

Understanding of the basic biology of many freshwater bivalve species is still needed and details on ontogeny (development and life history traits), dietary requirements, energy budget, fertilisation, reproductive effort, fish hosts (for unionids), behaviour, growth, survival, as well as on threat response and parasites are lacking for many important taxa. Biological factors that influence distribution and tolerance levels of species to certain threats such as chemicals and pollutants are also important for effective conservation.

1.2.5 Designation of priority sites and protected areas for freshwater bivalves

Sites that include rare, threatened, or range-restricted species or have high species richness or a high percentage of the global population have not yet been identified for most freshwater bivalves. Many current protected sites have been identified for terrestrial vertebrates (e.g. Important Bird Areas) and plants (Important Plant Areas) but freshwater bivalves may not be well represented in these sites. Many of the sites and habitats that are important for threatened freshwater bivalves may exist outside protected area networks. Wide-scale exploration, especially in southern and eastern Europe, should be used to identify the actual distribution of species throughout Europe and priority sites of conservation concern, such as Key Biodiversity Areas, should be identified to create an evolving list accepted by experts, ready to be presented for environmental authorities to use, especially in environmental impact assessments. That becomes increasingly important in southern Europe, which is highly impacted by climate change and many extinctions may otherwise remain unnoticed.

These priority site assessments should also consider future climate scenarios because current sites may be not suitable in the future. Exercises using species distribution models (SDMs) and systematic conservation planning should be pursued and consider not only bivalves' requirements, but in the case of unionids also their fish hosts. These assessments can guide countries and the EU towards meeting their CBD target of conserving and restoring 30% all degraded ecosystems by 2030. The EU Biodiversity Strategy, for example, specifically mentions the expansion of protected areas networks to meet the CBD targets. Assessments could also be useful in identifying and proposing sites for protection under the Emerald Network of Areas of Special

Conservation Interest and assist countries with meeting their obligations under the Bern Convention.

The taxonomic, functional, and genetic diversity of freshwater bivalves are still being explored and are not well understood for some species, especially the sphaeriids. Such information can be used to determine priority populations for conservation, to inform captive breeding programmes, and aid in understanding local adaptation and informing strategic management decisions for specific populations.

1.3 Opportunities for filling gaps relating to tools, databases and expertise

1.3.1 Monitoring

At present, national monitoring within the EU focuses on those species protected by the EU Habitats Directive (the Freshwater Pearl Mussel and the 10 Thick-shelled River Mussel species complex). Outside of the EU, the Bern Convention acts to protect some species. However, the monitoring effort is not evenly distributed. As a result, many of the other species are neglected in monitoring schemes.

The criteria used by the European Commission for reporting under Article 17 of the Habitats Directive are too general and do not allow for any evaluation of the quality of monitoring and assessing the actual situation of a population and its perspectives in larger geographical scale, and the very general system does not allow for any study of factors causing decline. These data are hidden in state systems or are not collected at all if the monitoring by "the best expert judgement" is still allowed. Provided that in some countries using this system there are no experienced malacologists or they are not employed in monitoring, the results are frequently questioned. The reproduction of unionids is totally dependent on the availability of fish hosts and yet only in few countries is the fish monitoring linked with unionid monitoring.

Many freshwater bivalve species that are not listed in Annex II of the Habitats Directive but are an important component of wider Natura 2000 sites, should be monitored and used as a means of assessing the condition of protected sites. An important body of work that should be prioritised is a detailed freshwater bivalve survey of all aquatic Natura 2000 sites. This would place many important freshwater bivalve populations within a monitoring and conservation structure.

Most of the monitoring of freshwater ecosystems is designed with drinking water quality in mind, and so concentrates on chemical and biological pollution, rather than the hydrology and catchment land cover. These catchment issues impact negatively on freshwater bivalves through hydraulic and chemical factors. The Water Framework Directive requires an assessment of hydro-morphological and groundwater quality. The assessments made are unsuitable in many cases for threatened freshwater bivalve species. The discrepancy between the hydro-morphological assessments and the groundwater assessments regarding the restoration of catchment wetness levels to provide adequate near bed velocity and protect against sediment and nutrient concentrations during low flows is extreme in some cases. For example, in Ireland over three million Freshwater Pearl Mussels are at risk of impact from inadequate groundwater and other hydro-morphological pressures in catchments that have been passed as "good" in Water Framework Directive assessments. This could be addressed by adequately linking freshwater bivalve status evaluation or perspective of protection to the results of monitoring according to the Water Framework Directive, and this is considered to be a policy change priority.

A further solution might be provided by incorporating unionids and fish monitoring into wider systems of water quality monitoring, with the possibility of analysing all data together. It is also important that all collected data should be regularly analysed and conclusions implemented in freshwater management. It is recommended that data collected using public funding is made available for analysis to answer ongoing research questions and conservation measure value assessments, with strict conditions for information on exact locations of vulnerable species, such as the Freshwater Pearl Mussel, which may be targeted for pearl fishing.

The recent development of eDNA procedures allows the use of eDNA as a common tool for species detection (including cryptic species) and facilitates our understanding of species ranges – both for unionids and their fish hosts and the overlap of these two groups. However, this does not resolve the problem of abundance assessment, the monitoring of unionid habitats and the identification of environmental factors threatening this group.

1.3.2 Freshwater bivalve-specific databases

IUCN European Red List of Freshwater Bivalves

The European Red List is a long-term project of IUCN and the EU and covers a number of different species groups. It includes all freshwater bivalves native to or naturalised in Europe (66 species in total). Its geographic scope is continent-wide, extending from Iceland in the west to the Urals in the east, and from Franz Josef Land in the north to the Canary Islands in the south. It excludes the Caucasus region including the Russian Northern Caucasus. Importantly, for each species, Red List assessments capture the key information on the known range and distribution, habitat and ecology, population status and major threats, as well as recommendations for conservation action. Red List information provides valuable evidence to support conservation initiatives throughout Europe.

All assessments are published to The IUCN Red List of Threatened Species (iucnredlist.org), and the European freshwater bivalve assessments are available to download from the Red List website using this query.

On-line resources, databases and tools

There are several online resources that play a crucial role in supporting and advancing the field of freshwater bivalve research and conservation, providing invaluable resources for scientists, researchers, conservation managers and environmental agents.

The MUSSEL Project (MUSSELp) is a comprehensive online database of all freshwater bivalve species described to date. This database includes an updated taxonomic backbone and georeferenced images of each species from museum specimens around the world, including many types. All nomenclature is referenced with online links to the respective bibliographic source. It also includes brief distributions, conservation status and information on the availability of genetic information.

The MolluscaBase initiative is a taxonomic database supported by LifeWatch and part of the European Strategy Forum on Research Infrastructure (ESFRI). It is curated by a group of editors with extensive expertise in malacology. MolluscaBase serves as a reference point for the accurate classification and naming of all molluscs, including freshwater bivalves. The taxonomic landscape of these organisms can be complex, with subtle morphological differences requiring accurate identification. Having a central repository of taxonomic information streamlines the classification process, reduces errors and ensures consistency across studies. This is particularly important in the context of biodiversity assessments, ecological monitoring, conservation planning and invasive species identification, where accurate taxonomy is the foundation of reliable research. MolluscaBase is the taxonomic backbone followed by the IUCN Red List for molluscs.

Box 2: The importance of networks in finding and connecting those working in countries where there are few people focusing on bivalves - European Freshwater Bivalve Expert Network (EFBEN)

Authors: Tadeusz Zając, Manuel Lopes-Lima

The conservation of freshwater bivalves has become increasingly important since the listing of four species in the Habitats Directive in 1992. Since then, more researchers have become interested in studying these threatened species and have formed small research groups, particularly for the Freshwater Pearl Mussel. Large conferences can be useful tools for exchanging information. Therefore, the international freshwater bivalve congress series was initiated in Bragança, Portugal in 2012. It was then repeated in Buffalo, USA in 2015 and in Verbania-Pallanza, Italy in 2018. Together with the more traditional malacological meetings, such as the Unitas Malacologica - world congress of malacology and the European Malacological Societies Congress series, all these events brought together a group of scientists and conservationists interested in these animals.

During the discussions of this group, a common need was identified for a project that could enhance our understanding of freshwater bivalves and improve their conservation in Europe. This idea resulted in multiple collaborative research projects across Europe and the preparation of a major review publication analysing the status of freshwater mussels in Europe. The team of authors subsequently devised a pan-European networking project centred on the study and conservation of freshwater bivalves. The project 'CONFREMU CA18239, Conservation of Freshwater Mussels: A Pan-European Approach' was submitted to the COST Association, which agreed to fund it.

The CONFREMU network accomplished several significant tasks, including building an open database of distribution records covering all of Europe, characterising the genetic structure of European mussels, and producing a CEN standard for mussel monitoring and conservation. The network will continue after the end of the CONFREMU project (2024) as the European Freshwater Bivalve Expert Network (EFBEN). The network, composed of 138 scientists from 31 countries, also became a natural partner for the USA Freshwater Mussel Conservation Society (FMCS), and potential coordination and/or integration among the two is being discussed. This offers an opportunity to set up a worldwide organization focused on the conservation of freshwater mussels.

Closing meeting for the project CONFREMU, Conservation of Freshwater Mussels: A Pan-European Approach in Mértola, Portugal, 2024. Photo credit: Manuel Lopes-Lima.

The current knowledge of the spatial distribution and population trends of freshwater bivalves within Europe is poor, preventing a comprehensive understanding of the biogeography and conservation status of this faunal group in the continent. Filling the knowledge gap on population trends and distribution of European freshwater bivalves was one of the main priorities of a European Union funded networking project, COST Action CA18239 - Conservation of freshwater mussels: a pan-European approach (CONFREMU CA18239). This project aimed to increase knowledge for the conservation of unionids in Europe and adjacent regions.

The concerted efforts of this network of scientists has resulted in the most complete taxonomically and geographically accurate distribution records of freshwater bivalve species for Europe and adjacent regions. The database, which includes 94 native and seven non-native freshwater bivalve species and 260,184 (to date) georeferenced records, is the result of an extensive species distribution survey involving private records from 70 specialists and multiple sources (e.g. published articles, grey literature, online biodiversity databases and scientific collections from museums, research institutions and universities). All individual records were then curated by a large team of experts, and records of dubious origin and identification were eliminated. This database, available online (https://e-mussels.eu) as georeferenced point records or grids of various sizes (from 10×10 km to 100×100 km, more detailed data available on request), is a key source of information for future studies on the biodiversity, biogeography, and conservation of these imperilled organisms.

1.4 Goals and recommendations

The following section identifies a pathway to addressing the challenges discussed above over the next 5-10 years. It describes a major goal with associated sub-goals and recommended actions, with examples of organisations that could lead or support the implementation of those actions in Europe.

GOAL 1: PROVIDE IDENTIFICATION TOOLS, DATABASES & EXPERTS FOR BIVALVE MONITORING AND CONSERVATION

Including:
- A complete set of identification tools for European freshwater bivalves at EU and country level, including training.
- Baseline surveys, harmonised monitoring and reporting as a decision basis for conservation.
- Networking, knowledge transfer and certification to ensure long-term expertise.
- Identification of ecological requirements.
- Designation of priority sites and protected areas for freshwater bivalves.

GOAL 1: RECOMMENDATIONS		
1.1	**Provide a complete set of identification tools for European freshwater bivalves at European and country level, including training.**	
Recommended action		**Current or potential leads and collaborators**
1.1.1	Provide a complete set of identification and informative tools (e.g. CONFREMU CA18239 Freshwater Bivalve database (https://e-mussels.eu)).	CONFREMU, EFBEN, MSG

GOAL 1: RECOMMENDATIONS		
1.1.2	Facilitate easily accessible training methods for the identification of all freshwater bivalves of Europe.	EFBEN, FMCS, national malacological societies, museums, national environmental ministries
1.2	**Baseline surveys, harmonised monitoring and reporting as a decision basis for conservation.**	
Recommended action		**Current or potential leads and collaborators**
1.2.1	Undertake surveys to characterise the distribution and habitat of all freshwater bivalve species by 2030 across all Europe (in alignment with CBD targets).	National Natural Environment Agencies, Universities, Researchers, experts, national malacological societies, EFBEN
1.2.2	Develop, implement, and promote harmonisation of monitoring protocols (including eDNA) for all freshwater bivalves (EU standards for mussels in progress via CEN).	National Natural Environment Agencies, FMCS, universities, researchers, experts, CEN, EFBEN, EC
1.2.3	Promote harmonised reporting of key data to data repositories and ensure open access (e.g. population status and trends). National biological database centres should be implemented where they are not already existing.	National Environment Agencies, National Biological Record Centres, EFBEN, EC
1.2.4	Include freshwater bivalves to species level in water quality monitoring scoring systems.	WFD, National Environment Agencies, EFBEN, Competent Authorities for water bodies
1.2.5	Any freshwater bivalves collected in water quality invertebrate samples should be kept and made available to freshwater bivalve experts.	EFBEN, WFD, National Environment Agencies, Competent Authorities for water bodies
1.3	**Networking, knowledge transfer and certification to ensure long-term expertise.**	
Recommended action		**Current or potential leads and collaborators**
1.3.1	Promote and sustain extensive freshwater bivalve expert networks across Europe.	EFBNEN, CONFREMU, FMCS, Euromal, conferences, international projects (e.g. COST)
1.3.2	Promote and standardise certification and recognition of necessary skills/expertise to perform identification and/or monitoring.	CEN, CONFREMU, FMCS, Euromal, National Certification Bodies
1.3.3	Promote liaison and engagement between experts and skilled amateurs.	EFBEN, FMCS, National Malacological Societies, Natural History Societies, Wildlife Trusts, Field Clubs

GOAL 1: RECOMMENDATIONS		
1.4	**Identification of ecological requirements.**	
Recommended action		**Current or potential leads and collaborators**
1.4.1	Increase knowledge of ecological requirements (e.g. temperature tolerance, water quality, substrate, flow, nutrition).	Universities, NGOs, EFBEN, FMCS, National Malacological Societies, international researcher collaboration.
1.4.2	Identify unionid host suitability across environmental and geographical gradients.	Universities, NGOs, EFBEN, FMCS, national malacological societies.
1.4.3	Harmonise approaches to identifying the significance of stressors and threats.	Universities, EFBEN, FMCS
1.5	**Identification of Priority Sites for conservation.**	
Recommended action		**Current or potential leads and collaborators**
1.5.1	Use systematic conservation planning to identify priority sites for freshwater bivalves. Include these priority sites in protected area networks and management (e.g. Natura 2000 and the Emerald Network) to assist European Biodiversity Strategy in meeting CBD 2030 targets.	IUCN, Universities, NGOs, EFBEN, FMCS, National Malacological Societies, National Nature Conservation Agencies,

2. Identification and management of threats

Lead Authors: David Aldridge, Karel Douda, Evelyn Moorkens
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2.1 Introduction

Freshwater bivalves are exposed to a range of well-known threats that include aquatic habitat loss, wider catchment changes resulting in loss of ecological function, pollution, effects of climate change and natural disasters, and invasive non-native species. Other threats are less clear, with increasing reports of mass mortality events whose causes remain enigmatic. There is growing recognition of the role of parasites and diseases in driving declines and die-offs, while the dependence of unionids upon host fishes means that they are also impacted by threats to fish populations. An understanding of the threats to the sphaeriids is even poorer than that of the unionids.

The European Union's drive towards alternative energy is likely to result in increased dam construction which can harm bivalves through changes to hydrology and can prevent movement of host fishes. Water transfer projects to bolster water shortages, especially in southern Europe, risk an increase in suboptimal flows and drought. The effects of emerging pollutants, such as microplastics and nanomaterials, on freshwater bivalves remains poorly understood and there is an urgent need to understand how the interaction of different stressors may impact upon bivalve populations. The war in Ukraine brings additional threats to aquatic ecosystems in the east of Europe, with destruction of habitat, removal of dams, pollution associated with damage to infrastructure, and neglected biosecurity measures.

Europe has a number of legislative instruments that can help protect freshwater bivalves from these threats, including the EU Water Framework Directive (EU Directive 2000/60/EC) and the EU Regulation on Minimal Requirements for Water Use (EU Regulation 2020/741) (see Section 4 on policy). In addition, several successful catchment management and habitat restoration projects have enhanced bivalve numbers at the local scale while captive breeding and reintroduction of some of the most endangered species have helped to restore declining and extirpated populations.

Box 3: Mass Mortality Events

Author: David Aldridge

While long-term monitoring studies have demonstrated that many populations of freshwater bivalves are declining across Europe, recent attention has been paid to episodic mass mortality events (MMEs) in unionid mussels, sometimes including catastrophic mortalities where >90% of individuals are lost in a subpopulation over a very short timeframe. In some cases, the cause of MMEs is all too clear: droughts (see picture) driven by climate change, poor dam management and over-abstraction can result in complete extirpation of freshwater bivalves alongside mortality in many other taxa. However, in a number of growing reports across Europe, the cause of MMEs remains enigmatic with die-offs occurring within only small localities or within a single bivalve species within a broad ecological community. Possible drivers of these MMEs include virus outbreaks, introduction of novel pathogens and diseases, or the release of unknown pollutants into the environment. Research is needed to develop protocols for rapid responses to MME events in freshwater bivalves so that drivers can be identified, and appropriate remedial measures can be implemented.

Dead shells of the Swan Mussel (Anodonta cygnea) along the banks of the Bude Canal, Cornwall, UK, in summer 2022 after a prolonged period of drought. Photo credit: David Aldridge.

2.2 Threats to freshwater bivalves

2.2.1 Loss and disturbance from damage to the aquatic habitat or terrestrial catchment areas

Freshwater bivalves are largely sedentary and require habitats that remain stable both in physical structure and in condition. While some species and populations may have adapted to naturally variable habitats, such as sporadic short-term droughts or occasional saline incursions, dramatic or long-term deviations from historical norms can lead to widespread mortalities.

Habitat modification due to flood management, dam creation, riparian development, land-use change and abstraction for agriculture and industry greatly threaten the long-term survival of bivalves in most rivers. In our most remote and sensitive catchments, very small changes in land use, drainage and intensification can be enough to cause population extinctions (see Box 4).

The effects of pollution from chronic siltation are the single biggest cause of bivalve death and can account for the functional extinction of longer-lived species, where older individuals survive but are no longer replaced by a younger generation. Accumulation of fine sediment reduces oxygen exchange within the river or lake bottom substrate, which sphaeriids and juvenile unionids rely on. Adult unionids of some species (with the notable exception of the very sensitive Freshwater Pearl Mussel) can be more tolerant of siltation if their siphons remain exposed to the water column. Change in food quality for unionids may also be a problem when fine sediments increase. Sedimentation arises from disturbance or damage to the wider catchment, where there is direct connectivity from the catchment to the aquatic zone.

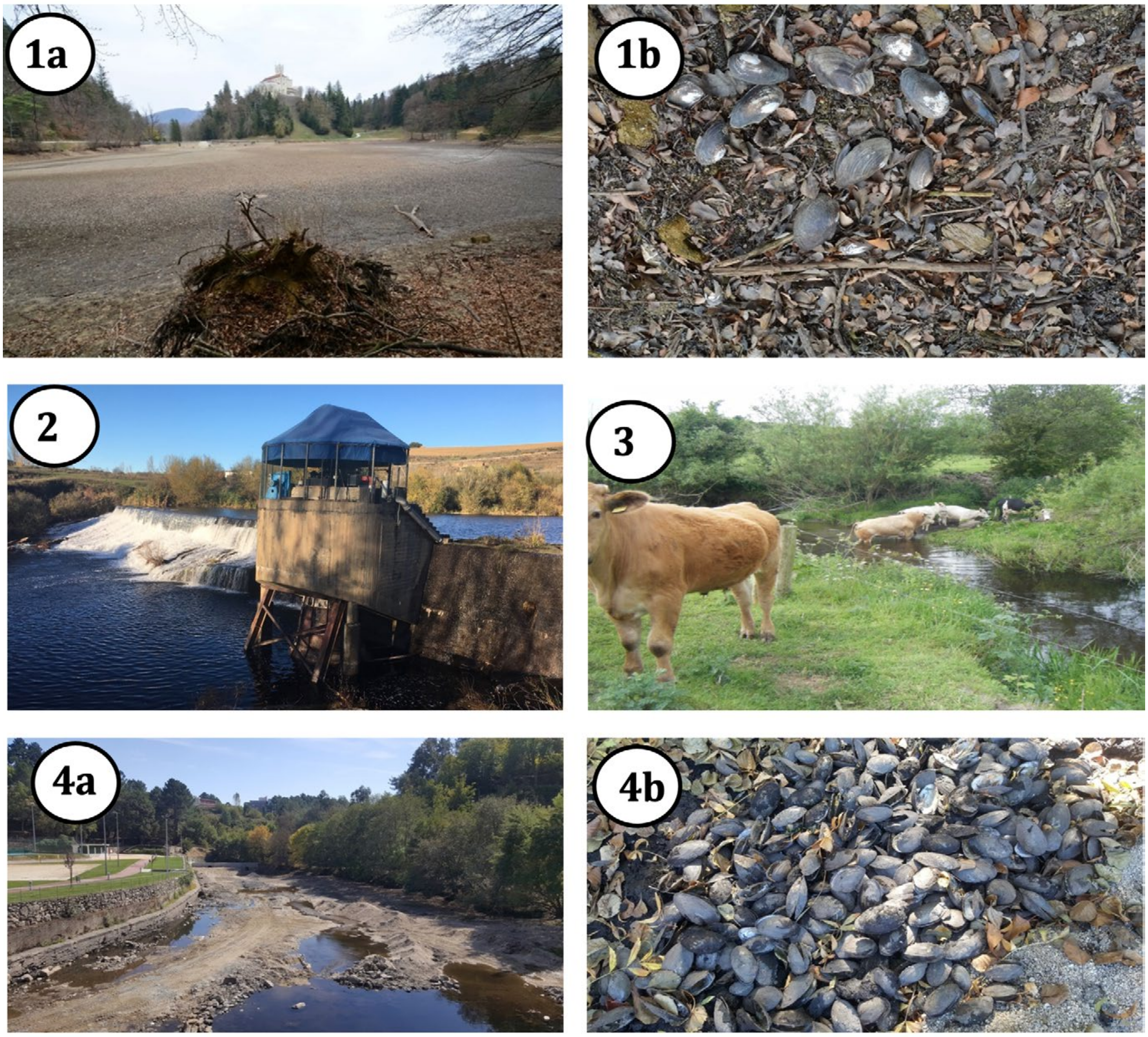
Existing dams and levees can frequently discharge large amounts of water, increasing scour of the riverbed and significantly altering water temperature, flow patterns, and siltation rates. Inappropriate peatland drainage for forestry can lower groundwater levels and reduce summer flows below ecologically sustainable levels. Deforestation of naturally forested headwaters can similarly lead to sudden increases in discharge and elevated siltation. Management of waterbodies, including certain conservation actions targeted at non-molluscan taxa, can have negative effects on freshwater bivalves through actions such as changes to vegetation, dredging of sediments, and dam removal that creates large shifts in microhabitats, changes to siltation patterns or alteration of hydrological regimes. Channelisation for flood defence and enhanced navigation can remove marginal habitats and reduce habitat heterogeneity.

Mining and extraction of sand, gravel, and raw materials from the channel or lake not only threaten freshwater bivalves directly with excavation and removal from their habitat, but also indirectly through the increase of siltation, altered sediment structure and changed flow patterns. Mining may also relay waste from the crushing of bedrock from quarries and deep mines into riverbeds and lakes, causing smothering.

Catchment drainage, abstraction, and diversion can reduce flows, increase siltation and risk desiccation. Lowering the water table can result in the release of toxic iron ochre or other pollutants from subsoils. Reduced flows can also exacerbate other stressors, such as by reducing the dilution of pollutants or facilitating the establishment of invasive non-native species.

Box 4: Examples of threats to freshwater bivalves and their habitats

Authors: David Aldridge, Mary Seddon



1a. To remove accumulated sediments and halt eutrophication events, Lake Trakošćan, Croatia was drained. Before the draining operations took place all fish that inhabited the lake (carp, catfish, perch, pike) were transferred to other nearby lakes. However, no provision was made for protection of any invertebrate fauna including the unionids, which experienced a mass mortality (1b). Once the lake was refilled with water, fish were returned, but three species of unionids were extirpated. Photo credits: Jasna Lajtner.

2. Weirs on the River Sabor, Portugal, prevent movements of host fishes, and harm bivalves through increased scour of the riverbed and alterations to water temperature, flow patterns, and siltation rates. Photo credit: Simone Varandas.

3. Cattle grazing along river margins in Ireland leads to trampling of bivalves and disturbance of the riverbed, while erosion of riverbanks results in increased sedimentation. Photo credit: Evelyn Moorkens.

4a. Management to improve the riverbed of the River Corgo, Portugal, using large excavators removed many invertebrates, and led to a mass mortality of two unionid species (*Unio delphinus* and *Anodonta anatina*; 4b. Photo credit: Simone Varandas.

2.2.2 Climate change and natural disasters

Climate change is resulting in dramatic changes to Europe's freshwater ecosystems. Flooding events are becoming more regular in many streams and rivers, and this risks displacement of freshwater bivalves, especially during the winter when bivalves become less active. Summertime droughts, especially in ponds and streams, have become a major concern, resulting in numerous reports of mass die-offs of unionids. While many freshwater bivalves can tolerate short periods of drying by burrowing or by moving with the receding waters, recent droughts in Europe have been more extreme and prolonged, leaving no refugia for these organisms. The associated loss of host fish populations during droughts means that future recruitment of unionids may be reduced or impossible.

Extreme cold in the winter has also been reported to lead to mass die-offs of unionids. When coupled with low flows, riverbeds can freeze resulting in entire assemblages of these freshwater bivalves dying *in situ*.

2.2.3 Pollution

River and lake systems across Europe are exposed to various types of inorganic and organic water pollution. Point-source contamination (especially sewage and industrial discharge) can be highly detrimental to freshwater bivalves, but diffuse sources (such as from atmospheric deposition and agricultural run-off) appear even more important. Diffuse sources are especially challenging for management as they often have no legally prescribed environmental quality standards.

Pollutants can have a range of modes of toxic action upon the physiology and behaviour of freshwater bivalves, although the mechanisms by which many pollutants act upon these animals are poorly understood. The large volumes of water filtered by freshwater bivalves can elevate their exposure to environmental contaminants and genotypic or phenotypic responses can lead to elevated tolerance within localities with long-term sublethal exposures. Freshwater bivalves can respond to acute exposure to some toxins by protein binding and detoxification, excretion, or storage within the shell.

The introduction of nutrients from agriculture, forestry run-off or sewage outfalls is a major threat for European freshwater bivalves. Nitrogen and phosphorus concentrations are elevated in most European regions, despite long-term mitigation efforts, and can act directly on freshwater bivalves or indirectly through the effects of eutrophication. Elevated orthophosphate in the water has been associated with release of premature eggs and under-developed glochidia. Eutrophication can result in hypoxic conditions which are particularly detrimental to highly specialised species, whereas habitat generalist species may tolerate or even benefit from eutrophication.

Pesticides used in agriculture, heavy metals released from industrial discharges, and salts used for de-icing roads are all recognised as being harmful to European freshwater bivalves. Heavy metals such as lead and copper can affect the formation of shells, and while at low levels can be tolerated, they may bioaccumulate to lethal levels under continuous exposure. Road salt, which enters freshwaters as a seasonal pollutant, alters filtration behaviour in certain unionid species and reduces the attachment success of larvae to their host fishes. The negative effects of acid rain have been a particular problem in northern Europe, where reduced riverine pH has been associated with lack of recruitment of Freshwater Pearl Mussels, likely due to the difficulty of laying down calcareous shell material (see Box 10).

There are a number of emerging environmental contaminants that deserve greater attention in the context of freshwater bivalve conservation. Microplastics and nanoplastics have been shown to harm marine bivalves at the molecular, cellular, and organismal level but their effect on freshwater bivalves, especially in natural systems, is poorly known. Release of pharmaceutical and personal care products are increasing within Europe's freshwaters, and it has been shown that fluoxetine, a drug used to treat depression, can induce spawning and disrupt reproduction in unionids.

Although there are relatively robust monitoring networks for the quality of European surface waters, they will have limited applicability for the protection of freshwater bivalves because of the scarcity of acute and especially chronic toxicity data. We have little understanding of the toxicity to freshwater bivalves of combinations of pollutants or how sensitivity changes through the year, at different stages of life history, or across different species.

2.2.4 Parasites and disease

There is growing evidence that pathogenic organisms, including viruses, bacteria, fungi, and protozoa, may play a significant role in the decline of populations and the disappearance of freshwater bivalves. Yet parasites and disease are not listed as a threat in any current IUCN assessment of freshwater bivalves. Trematodes have been shown to sterilise females in several European unionids and can sometimes affect the majority of individuals. Unionicolid mites can also have deleterious impacts on unionid fecundity. To date, no parasites have been described within juvenile unionids nor within the sphaeriids. As evidence accumulates on the role of parasites and disease in driving enigmatic mass die-offs in freshwater bivalves, and the role of invasive bivalves in introducing and mediating parasite populations, the importance of understanding this form of threat is likely to gain more attention.

2.2.5 Invasive non-native species

Invasive non-native species can harm European freshwater bivalves directly through competition for resources, displacement and predation and indirectly through transmission of novel parasites and disease, habitat alteration, and driving changes to host fish availability. Invasive species may be introduced purposefully such as through stocking or for ornamental purposes, or unintentionally such as through contaminants of the aquarium and aquaculture trade, or through movement of boat traffic, water sports equipment or angling activities. Increased connectivity of major rivers in Europe during the 20th century as a result of canal construction has facilitated a westward spread of harmful invasive species from the Ponto-Caspian region.

Invasive freshwater bivalves have proven to be especially harmful to native European unionids. Some effects are clear (see Box 5) while other impacts are less certain. For example, the invasion of the Asian Clam (*Corbicula fluminea*) into Europe has been associated with many declines of native bivalves but the drivers of the decline remain enigmatic. The arrival of the Chinese Pond Mussel (*Sinanodonta woodiana*) into Europe has affected native unionids not only through competition for resources but also through increased host immunity to glochidia of native mussels because of previous attachment from glochidia of the Chinese Pond Mussel.

It is not only invasive freshwater bivalves that threaten Europe's native freshwater bivalves. The establishment of non-native freshwater fish can reduce populations of key host fish species for some mussel species while some non-native fish may be incompatible hosts for the glochidia of European unionids, leading to reduced recruitment success. Introduced molluscivorous mink, muskrats, fishes, and crayfish have been shown to be important predators of European freshwater bivalves and may have disproportionately large effects on smaller species and juveniles. Deterioration of water quality, such as through smothering of watercourses by invasive plants, can have knock-on impacts on native freshwater bivalves.

Box 5: Invasive non-native species

Author: David Aldridge

Invasive non-native species are recognised as one of the major drivers of biodiversity declines in freshwater ecosystems. They can impact bivalves in both direct and indirect ways. Zebra Mussels (*Dreissena polymorpha*) can be especially harmful to unionid mussels through their smothering of the shell (see photo), resulting in reduced food intake and lower body condition of the underlying unionid. Zebra Mussels are native to the Ponto-Caspian region of Eastern Europe but spread into Western Europe from the 18th century onwards as a result of increased shipping and greater interconnectivity of waterways. They have been found attached to the shells of many of European mussel species, but particularly favour species with large shell areas exposed into the water column, such as the Duck Mussel (*Anodonta anatina*). During the late 20th century, a congener of the Zebra Mussel, the Quagga Mussel (*Dreissena rostriformis bugensis*) began a westward spread across Europe and appears to be completely replacing Zebra Mussels where they co-occur. The impact of Quagga Mussels on unionids in Europe is still largely unknown.

A Duck Mussel (*Anodonta anatina*), smothered by invasive Zebra Mussels (*Dreissena polymorpha*) in the River Stour, Suffolk, UK. Photo credit: David Aldridge.

2.2.6 Loss of host species

The reliance of unionids on host fishes to complete their life cycle places an additional threat on them. Some threatened unionids, such as the Freshwater Pearl Mussel and Spengler's Freshwater Mussel (*Pseudunio auricularius*), have a relatively narrow range of viable host species and this can make them even more vulnerable to the indirect effects of changes in fish populations. While many of the threats to Europe's fish populations are shared with unionids, some are not and this means that conservation efforts require protection of additional components of the ecosystem, including the facilitation of fish movements (especially of anadromous species), the protection of spawning grounds, the management of fish parasites and disease, protection from competition arising from non-host fish stocking activities, disturbance from noise pollution, recreation and boat traffic, and protection from overfishing.

2.2.7 Combined impacts of multiple threats

All of the above pressures can act in combination, resulting in exacerbation and prolonging of stress events. For example, catchment drainage resulting in lower summer flows can act in combination with climate change-induced droughts to further reduce flow velocities, which in turn can lead to concentration of fine sediment and chemical pollutants.

2.3 Opportunities for improved understanding and management of threats

2.3.1 Protecting habitats for freshwater bivalves

Protected Area (PA) networks, including and especially the Natura 2000 and Emerald networks, should be some of the most readily mobilised vehicles for the conservation of freshwater bivalves. Priority habitats that overlap with existing PA networks and that are important for freshwater bivalves should be highlighted, and newly identified, biodiversity rich sites outside existing PAs should be protected and added to the national network.

Starting with the larger PAs with their own management bodies, and using existing databases, Red List databases as well as other tools and resources, bivalve species inventories can be established, priority species confirmed, their conservation needs identified and addressed, and population trends monitored. As part of this effort, planned management measures to enhance or maintain the conservation status of catchments within existing PAs could be systematically screened, optimised, and reviewed for bivalve conservation.

Focus should be placed on catchment-based management, which should ensure that connectivity of rivers is maintained or enhanced and that the requirements of host fish are integrated with the requirements of freshwater bivalves (see Box 6). Future climate scenarios should be modelled with projected distributions of freshwater bivalves mapped using tools such as species distribution models. Such models should be used to identify suitable refuge areas for bivalves where protection and restoration of habitats should focus. Thankfully, there are many examples of successful restoration of freshwater mussel habitats (See Boxes 6, 7, 9 and 10).

Box 6: Benefits Of Catchment-Level Management

Author: Evelyn Moorkens

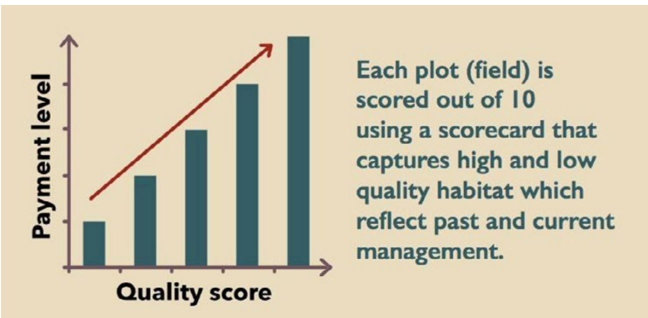
The Pearl Mussel Project in Ireland is an example of an initiative specifically targeting the restoration of this species.

It aims to restore wet open peat bog and sustainable flows, to support the survival of juvenile mussels. Areas of marginal land that were drained for farming now support landowners by paying them for providing these ecosystem services.

It employs a **results-based approach** in which landowners are paid on a scale that relates to the quality of catchment restoration achieved (see below).

This is proven to be a great way to incentivise catchment restoration.

Left: Drained peatland (before) does not store water; Right: Wet peatland (after) stores water in saturated soil and drains and slowly releases it during dry periods to sustain mussels in the river below. Photo credit: Pearl Mussel Project.



Box 7: Habitat Restoration

Authors: Tadeusz Zając, Nicoletta Riccardi

With its long and well documented history of pollution, Lake Orta offers a unique opportunity to document the recovery of freshwater unionid mussels after local extinction. In 1926, Lake Orta in Italy underwent a catastrophic industrial pollution event which destroyed the biotic community. However, in the 1980's lake restoration began by treatment of discharges and liming intervention, and this resulted in a relatively rapid recovery of the aquatic community and lake conditions.

Live individuals of *Unio elongatulus* had not been recorded in the lake for over one century, but in 2012 they were found to be present. Since Lake Orta lacks a direct connection with known source populations, re-appearing mussels were likely to have been transported by fish carrying glochidia that were used for lake restocking after liming.

This case is evidence that recovery/recolonization is possible despite a high degradation of the habitat in the past. But not only improvements in the water and sediment quality are needed for mussel's recovery; the fact that it was nearly ten years after the reappearance of fish that mussels were found again reflects the need of the whole trophic chain to be reestablished to allow for the survival of host-fish populations necessary for mussel's reproduction.

Left: 1989-1990 Liming efforts in the lake to restore natural PH levels; Right: Mussels recolonize in 2000, discovered in 2012. Photo credit: Nicoletta Riccardi

2.3.2 Restoration of local populations using assisted augmentation and management methods

Although this document identifies conservation actions such as habitat protection and management, for some threatened taxa this approach may not be enough or may not act swiftly enough to reverse declines and drive recovery. For these taxa, more intensive interventions may be needed (see Box 8 below). The IUCN's *Guidelines on the Use of Ex situ Management for Species Conservation* consider these and other intensive management interventions a valuable resource for identifying instances where more intensive population management methods may be required. Currently, more data are needed to first identify which species may need this intensive approach and to create set guidelines to successfully translocate, breed, or reintroduce them, and to mitigate for possible transmission of disease or parasites. Current barriers to this process include time and funding limitations, lack of expertise, and incentives and legislation.

Habitat restoration measures must always be undertaken to complement any artificial augmentation programme in order to ensure that in the long term the population can maintain itself as a viable component of its natural habitat.

Box 8: Assisted augmentation and management

Author: Frankie Thielen

The complex nature of freshwater ecosystems, the extent of degradation, the slow recovery of biodiversity, natural processes of succession, stakeholder involvement, and ongoing monitoring and management all contribute to the time and effort required for the long-lasting restoration of freshwater habitats. This process might last too long for some highly threatened freshwater mussel populations.

Therefore, assisted augmentation and management strategies are used to support mussel populations such as:

- creating refuge areas;
- transferring (translocations) adult mussels from healthy recruiting rivers to rivers with poor populations, whist taking precautions to avoid transfer of parasites and disease;
- releasing artificially encysted host fish;
- captive breeding of freshwater mussels.

Captive breeding of freshwater mussels has attracted more attention in Europe in recent years for several reasons:

- Conservation of threatened species: Many freshwater mussel species are threatened or at risk of extinction. Captive breeding programmes help preserve and increase their populations, ensuring their long-term survival.
- Ecological balance: Freshwater mussels play a crucial role in aquatic ecosystems. They filter water, removing sediments and pollutants, and provide habitat and food for other organisms. By breeding and reintroducing mussels into their natural habitats, we help maintain a healthy and balanced ecosystem.
- Restoration of mussel populations: Captive breeding allows for the production of a large number of juvenile mussels that can be released into their native habitats, helping to restore populations in areas where they have declined or disappeared, and helping to retain genetic identity.
- Scientific research: Captive breeding programmes provide opportunities for scientists to study the life cycle, behaviour, and biology of freshwater mussels in a controlled environment. This research contributes to our understanding of these species and aids in developing effective conservation strategies. Genomic approaches also offer great potential to understand the biological and ecological features and behaviours.

In summary, captive breeding of freshwater mussels is crucial for conserving threatened species, restoring populations, maintaining ecological balance, and advancing scientific knowledge. However captive breeding and the other intensive management strategies can or should never replace the restoration of aquatic habitats for freshwater mussels and promoting natural recolonisation.

Inside captive breeding facilities and captive bred individuals ready to be released. Photo credit: Frankie Thielen

Box 9: The River Lutter and the Freshwater Pearl Mussel, a success story

Author: Frankie Thielen

Together with its tributaries, the Lutter forms a widely ramified watercourse system in the districts of Celle and Gifhorn in northern Germany, which together with the stream valleys has been designated as the "Lutter Nature Reserve" - covering a total area of approx. 2,450 hectares. Due to its outstanding ecological importance, the new nature reserve is also part of the Natura 2000 European protected area network.

The River Lutter and its adjacent habitats support a high biodiversity with many threatened plant and animal species, including the Freshwater Pearl Mussel. In the 15th century, the Lutter River system likely supported millions of individuals. However, by 1994 there were only around 1,800 aged mussels left. Other plants and animals in the heath streams had suffered a similar fate.

The low human population density, the large forests and the lack of industry offered the opportunity for developing a natural stream system typical of the heathland and protecting it for future generations.

The Lutter conservation project commenced in 1989 under the direction of Reinhard Altmüller, with the Freshwater Pearl Mussel as its main focus. The project organisers, the districts of Celle and Gifhorn, purchased approx. 1,150 hectares of land and acquired the right to use a further approx. 570 hectares. As part of this project, which was subsidised by the Federal Ministry for the Environment and the state of Lower Saxony in close cooperation with the agricultural and forestry sectors, restored sections of stream to their natural state. Agricultural land was taken out of use and left to develop into forest, the spring moors from which the streams originate were rewetted, coniferous forest stands were converted into deciduous forest, and facilities were built to keep nutrients, sand, and silt loads out of the Lutter, and targeted measures were taken to augment the remaining population of Freshwater Pearl Mussels.

Many successes have already been achieved: the sand and mud loads in the Lutter have decreased, the fish community is increasing, and over 10,000 juvenile mussels have been counted. This means that the conservation project and special species protection measures have succeeded in preventing the extinction of this species in this region. Similarly, many other species have also benefited from the protection and restoration of the habitat for the Freshwater Pearl Mussel.


Left: An area of the River Lutter with mussels; Right: Dr. Reinhard Altmüller demonstrating the clean stream gravels. Photo credit: Evelyn Moorkens.

2.3.3 Enhancing knowledge and legislation about pollutants

Knowledge on the impact different types of pollutants have in freshwater habitats and on freshwater bivalves still needs more investigation, and sustainable levels of substances for bivalve survival should be identified. Studies of North American species suggest that juvenile freshwater bivalves are more sensitive to pollutants than are adults, and so environmental limits should be set to protect the most sensitive life history stages.

Ensuring the protection of freshwater bivalves from water pollution necessitates decisive national environmental regulations, stimulated and enforced by clear and robust legislation at the international level, and should include knowledge based on the tolerances of freshwater bivalves. Existing legislative instruments should be used as much as possible to consider the requirements of freshwater bivalves. For example, by the revision of substances on the lists of pollutants that need to be controlled and adjusting the limits (Water Environmental Quality Standards Directive - 2008/105/EC; Priority Substances Directive – 2013/39/EU).

2.3.4 Developing a better understanding of the effects of parasites and disease

The role and identity of parasites and disease in driving declines and mass mortality events in freshwater bivalves requires urgent attention. Protocols need to be developed for rapid responses to mass mortality events so that appropriate samples of affected and unaffected (control) material can be collected and preserved for subsequent diagnostic investigations. Experiments are required to understand how parasites and disease are transmitted within and between freshwater bivalve species, including consideration of non-native bivalves as possible vectors. The role of fish hosts in the transmission of parasites and disease also requires consideration as they can serve as vectors of important freshwater bivalve parasites such as trematodes.

Biochemical and behavioural markers need to be identified that can provide early warnings of stressed populations. Biosecurity protocols and best practices must be developed so that parasites and disease are not transmitted during well-intentioned translocations of bivalves. Similarly, more consideration to avoid the transmission of parasites and disease are required within captive breeding facilities, especially where animals from multiple catchments are held within the same facility. While we know little about the parasites and diseases of unionids and dreissenids, we know even less about those affecting sphaeriids.

2.3.5 Invasive alien species impacts and control

While the impacts of some invasive alien species (IAS) on European freshwater bivalves are well understood, the effects of other invaders are poorly known. Particular attention should be paid to invasives that are spreading rapidly and occurring at high densities in European systems, such as Quagga Mussels (*D. bugensis*) and Asian clams (*Corbicula* spp.).

Although there are invasive species already known to be spreading and impacting European freshwater bivalves, none are listed as Species of Special Concern under the EU IAS Directive (Regulation (EU) 1143/2014). This list is revisable and conservation actions should focus on identifying harmful invasives and submitting them for addition. Such a listing can help to drive effective control programmes towards the IAS species that are most harmful to freshwater bivalves.

Box 10: Reversing the Effects of Pollution: The negative impact of acidification on the Freshwater Pearl Mussel in Norway and Sweden and its recovery after liming

Author: Jon H. Mageroy, Co-author: Bjørn Mejdell Larsen

Acid rain had significant negative impacts on freshwater systems throughout large parts of Europe. The impact reached its peak in 1980, but the aftereffects are still impacting ecosystems[1].

In Norway and Sweden, acid rain continues to have a negative impact on freshwater systems, especially in the southwestern regions of both countries[2,3]. This has resulted in a strong negative impact on the Freshwater Pearl Mussel (FPM), both by impacting the mussels directly and their host fish[4-6]. In Agder County on the southern coast of Norway, ca. 90 % of the populations were lost[7], primarily due to acidification[4]. In Rogaland County on the southwestern coast, ca. 30 % of the populations were lost[8], due to agricultural impacts and acidification[9]. In southern Sweden, 43 % of the populations were lost. pH was significantly higher in watercourses with than without mussels in the most acidified counties, but not in less impacted counties[5].

To limit the negative effects of acidification, Norway and Sweden are currently spending ca. 6.5[10] and 14[3] million EUR annually on liming, respectively. In Norway, the FPM has been rediscovered in six limed rivers, where it was thought to have gone extinct. In these rivers, but also in less damaged rivers, recruitment is now occurring and the populations are increasing[7,11-18]. In the best studied population, the Ogna River, the population has recovered from ca. 500 mussels in 1997, upon rediscovery, to ca. 10,000 mussels in 2018. However, recruitment levels have varied greatly during the recovery period[16]. In Sweden, mussel survival has been higher in limed sections than non-limed sections of watercourses[5], annual growth increased after liming[19] and densities increased significantly in 5 out of 14 limed populations, but methodological limitations might explain why they found no significant impact on recruitment[6].

Although many FPM populations have been permanently lost due to acidification in Norway and Sweden, these findings show that it is possible to counteract pollution effects and aid the recovery of mussel populations.

Freshwater Pearl Mussel from the Storelva River in the Vegårvassdraget Watercourse, one of the rivers where mussels were rediscovered after liming. Photo credit: Bjørn Mejdell Larsen.

See appendix 1 for references.

2.3.6 Freshwater fish conservation to support unionid populations

Due to the dependence of unionid larval development on suitable host fish, the conservation of unionids is closely related to the conservation of freshwater fish. Even if host fishes are known for some taxa, there is generally a lack of knowledge of fish host suitability for many unionid species, and thus there is an urgent need to perform host fish mapping at global and local scales. There are cases where the same unionid species may use, and depend on, different hosts in different regions, and metamorphosis success and development times of unionid larvae on different fish hosts can differ, which needs to be considered in the management of fish stocks. For some species, hosts may have been identified only from laboratory infestations and this may not reflect incidences of host use in natural populations. As a starting point, it is necessary to comprehensively collate what is known about host compatibility and incompatibility from published and grey literature across Europe.

In a second step, fisheries management strategies in Europe must also take into consideration their impacts upon unionid populations. For example, in Germany, the European Minnow (*Phoxinus phoxinus*) was removed from streams as an undesired species without considering its important role as a host to the Thick-shelled River Mussel. After the impacts to mussels were highlighted, this practice was changed, with population recoveries of both host fishes and unionid populations in some areas. Fish stocking into lakes and rivers should also be better integrated with unionid conservation. For example, stocking of foreign genetic lineages can change the host function, and thereby the status of unionid populations, even for host specialists such as the freshwater pearl mussel. Stocking of predatory fish to enhance angling risks reducing the populations of host fishes for unionids.

In the future, fisheries management should be integrated with unionid management strategies, especially in systems with especially important or vulnerable species of mussel. Particular attention should be given to maintaining or restoring connectivity of river systems through the appropriate removal of barriers such as dams and weirs.

2.4 Goals and recommendations

The following section identifies a pathway to addressing the challenges discussed above over the next 5-10 years. It describes a major goal with associated sub-goals and recommended actions, with examples of organisations that could lead or support the implementation of those actions in Europe.

GOAL 2: ADEQUATE IDENTIFICATION, UNDERSTANDING AND MANGEMENT OF KEY THREATS TO FRESWATER BIVALVES.

Ensuring:

- Habitat loss is reduced and catchment connectivity is restored.
- The impacts of climate change and natural disasters are understood and mitigated where possible.
- The effects of pollutants are quantified and their sources controlled.
- The role of diseases and parasites in freshwater bivalves are better understood and appropriate measures are identified to manage them.

- High risk invasive non-native species are identified, prioritised and managed.
- Suitable populations of host fishes are maintained.

GOAL 2: RECOMMENDATIONS		
2.1	**Habitat loss is reduced and catchment connectivity is restored.**	
Recommended action		**Current or potential leads and collaborators**
2.1.1	Identify priority catchments across Europe focusing on the most threatened species (considering unique genetics) and by identifying what can be realistically protected.	NGOs, Academia, Catchment level bodies (transboundary and national), EFBEN
2.1.2	Increase connectivity of freshwater habitats through catchment management (e.g. through removal of dams).	National Nature Conservation Authorities, relevant Competent Authorities, advice from EFBEN, Transboundary Authorities, Environmental Agencies
2.1.3	Ensure waterbodies are maintained above established minimal environmental flows/flow velocities/water levels.	National Nature Conservation Authorities, relevant Competent Authorities, advice from EFBEN, Environmental Agencies
2.1.4	Promote hydromorphological and other habitat features that are important to freshwater bivalves.	National Nature Conservation Authorities, relevant Competent Authorities, advice from EFBEN, Environmental Agencies
2.2	**The impacts of climate change and natural disasters are understood and mitigated where possible.**	
Recommended action		**Current or potential leads and collaborators**
2.2.1	Identify impacts on freshwater bivalves that can be confidently attributed to climate change.	National Nature Conservation Authorities, relevant Competent Authorities, advice from EFBEN, Academia, local NGOs
2.2.2	Develop translocation plans for the most threatened and/or range restricted species/populations.	National Nature Conservation Authorities, relevant Competent Authorities, advice from EFBEN, local NGOs
2.2.3	Ensure freshwater bivalves are included in wider strategic management plans for freshwater systems.	National Nature Conservation Authorities, WFD managers, relevant Competent Authorities, advice from EFBEN

GOAL 2: RECOMMENDATIONS		
2.2.4	Develop and publicise emergency actions for bivalve populations affected by disasters.	National Nature Conservation Authorities, relevant Competent Authorities, advice from EFBEN
2.2.5	Restore natural catchment habitats and implement nature-based solutions to reverse hydrological damage and mitigate the effects of climate change and natural disasters on freshwater bivalve populations.	National Nature Conservation Authorities, relevant Competent Authorities, advice from EFBEN
2.3	**The effects of pollutants are quantified and their sources controlled.**	
Recommended action		**Current or potential leads and collaborators**
2.3.1	Quantify the toxicity of pollutants (e.g. chronic, acute, LC50s) to different freshwater bivalve species, different host fishes, and different life stages.	Academia, EFBEN, relevant Competent Authorities, National Nature Conservation Authorities, WFD technical groups
2.3.2	Identify and manage sources of pollutants relevant to freshwater bivalves.	National Nature Conservation Authorities, relevant Competent Authorities, advice from EFBEN
2.3.3	Design appropriate catchment buffers which can protect freshwater bivalves (e.g. taking into account tree planting, cattle trampling, ditching).	National Nature Conservation Authorities, relevant Competent Authorities, advice from EFBEN
2.4	**The role of diseases and parasites in freshwater bivalves are better understood and appropriate measures are identified to manage them**	
Recommended action		**Current or potential leads and collaborators**
2.4.1	Increase and disseminate knowledge of the role of parasites and disease in freshwater bivalve conservation, including use of molecular and morphological tools.	Academia, EFBEN, relevant Competent Authorities, National Nature Conservation Authorities
2.4.2	Identify and quantify the pathways and risks of different parasites and diseases of importance to freshwater bivalves.	Academia, EFBEN, relevant Competent Authorities, National Nature Conservation Authorities
2.4.3	Develop and disseminate appropriate biosecurity plans and disease risk management plans for catchments.	National Nature Conservation Authorities, relevant Competent Authorities, advice from EFBEN, EU

GOAL 2: RECOMMENDATIONS		
2.5	**High risk invasive alien species (IAS) are identified, prioritised and managed.**	
Recommended action		**Current or potential leads and collaborators**
2.5.1	Quantify the potential impacts of IAS to freshwater bivalves and develop a priority list of most detrimental IAS. This can be done using the Environmental Impact Classification for Alien Taxa (EICAT), an IUCN global standard.	National Nature Conservation Authorities, relevant Competent Authorities, IAS technical groups, EFBEN, Academia, EC
2.5.2	Understand the vectors and pathways of high-risk IAS and develop appropriate management/rapid response plans.	National Nature Conservation Authorities, relevant Competent Authorities, IAS technical groups, EFBEN, Academia, EC
2.6	**Suitable populations of unionid host fishes are maintained**	
Recommended action		**Current or potential leads and collaborators**
2.6.1	Develop and apply methodologies that facilitate the identification of freshwater systems where there is a lack of suitable hosts for unionids.	National Nature Conservation Authorities, relevant Competent Authorities, WFD technical groups, fish technical groups, EFBEN, Academia
2.6.2	Develop fishery management plans that support appropriate populations of unionid fishes.	National Nature Conservation Authorities, relevant Competent Authorities, fish technical groups, fisheries, EFBEN, Academia

3. Lack of awareness about bivalves and bivalve-friendly behaviour

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3.1 Challenges relating to awareness about bivalves

Freshwater bivalves perform important ecosystem services such as: water purification and filtration, nutrient recycling and storage, removal of bacteria from wastewater, habitat modification, environmental monitoring, provision of food sources for fish, birds, and mammals. However, there is not a widespread awareness of freshwater bivalves, their needs, threats and conservation value.

Conservation and awareness of freshwater bivalves would be greatly enhanced by a programme of education for industry, agriculture, the general public, and even within the conservation sector. A wider understanding of the benefits that freshwater conservation and healthy water systems have for people can help to build support for bivalve conservation, and that freshwater bivalves act as a good indicator species for clean water. Increasing awareness that dead bivalves and mass die-offs indicate freshwater disasters can help to strengthen their conservation concern.

3.2 Opportunities for filling gaps relating to awareness about bivalves

3.2.1 Healthy Bivalves=Healthy Water=Healthy People

Awareness about freshwater bivalves and education focused on the general public should include both local/regional and national/international level approaches (see Box 11). Local actions should focus on education and increasing public involvement such as presentations to schools, wildlife volunteers, anglers and kayakers (for example). Including stakeholders such as farmers, landowners and those directly involved in water management or flow in regional conservation efforts can increase their understanding of negative and positive actions for freshwater bivalves as they are normally undervalued by decision-makers and managers.

Currently there is a lack of awareness of the major declines in freshwater bivalves occurring across Europe. Larger-scale awareness PR campaigns can highlight new publications and data that show freshwater declines and their conservation status and raise the alarm. Collaboration with other educational institutions such as museums, universities, zoos, and national or regional media can help to spread informative materials and increase the impact of educational materials. Cooperation with other NGOs that may have similar goals or messages (e.g. freshwater habitats, fish, insects, etc.) may help to strengthen the conservation message. Special focus should be on addressing the rapid loss of traditional ecological knowledge on native freshwater bivalves, which is being substituted by modern ecological knowledge about non-native invasive counterparts. Therefore, it should be necessary to increase media coverage (e.g. articles in local newspapers) to avoid negative perceptions related to invasive counterparts.

Synergies with other conservation goals or existing projects (e.g. focusing on climate change, fishes, etc.) needs to be assessed as to reduce overlapping efforts. Certain EU LIFE integrated projects and European Innovation Partnerships (EIP) already exist that include stakeholder guidance, and these should be identified and used where possible. However, these often lack follow-up and need additional guidance for larger-scale policies. Adapting and translating existing out-reach materials ensuring they are available in minority and minoritised languages, are inclusive and available in sign and Braille languages. Existing digital resources should also be utilised, for example through unique QR codes that, when scanned, direct users to digital platforms (e.g. e-mussels.eu; other digital resources).

Materials and guidance for key sectors that affect freshwater bivalves need to be compiled with simple recommendations that can benefit freshwater bivalves or reduce negative impacts. Training may need to accompany guidance for effective freshwater management including good information provided on practices that are potential risks to bivalves; e.g. avoiding training implementation in critical habitats for threatened and protected species and being cautious around mentioning of data-sensitive species (e.g. specific localities of threatened species).

Box 11: Raising Awareness

Author: Frankie Thielen

Many freshwater mussel species fulfil

the concept of being a flagship-, indicator-

or umbrella-species. Their fascinating way of life

and the connection with the host fish makes

freshwater mussels a very interesting topic for children.

For the pearl mussel in particular, a lot of informative material has already been developed.

From games, stories to comics, everything is included and the stories of e.g.

Maggie and Klappi are well received by the children.

Children having fun, exploring a river with freshwater mussels and analysing the catch under a microscope. Photo credit Frankie Thielen.

3.3 Goals and recommendations

The following section identifies a pathway to addressing the challenges discussed above over the next 5-10 years. It describes a major goal with associated sub-goals and recommended actions, with examples of organisations that could lead or support the implementation of those actions in Europe.

GOAL 3: INCREASED AWARENESS AND ENGAGEMENT IN BIVALVE CONSERVATION

Achieved through:

- Increased recognition of the importance and beneficial roles of freshwater bivalves.
- Increased involvement in local and regional conservation efforts.
- Improved cooperation between all key sectors.
- Development and use of existing tools for guidance and training for a wide audience, at multiple levels.

GOAL 3: RECOMMENDATIONS		
3.1	**Increased recognition of the importance and beneficial roles of freshwater bivalves.**	
Recommended action		**Current or potential leads and collaborators**
3.1.1	Organise dissemination and information campaigns for key stakeholder groups and the general public (e.g., Red List assessment, existing policy, legislative instruments).	IUCN media, IUCN SSC MSG, media, EFBEN, EU, national governments, regional authorities, Academia, NGOs, malacological and natural history societies
3.1.2	Raise awareness with policy makers (local, regional, national and EU) about the conservation status and conservation requirements of bivalves.	IUCN media, IUCN SSC MSG, NGOs, Academia, EFBEN, National Nature Authorities, EU, relevant Competent Authorities
3.2	**Increase involvement in local and regional conservation efforts**	
Recommended action		**Current or potential leads and collaborators**
3.2.1	Organise education initiatives for the general public and citizen engagement.	NGOs, Academia, EFBEN, malacological societies, local and regional governments
3.2.2	Increase stakeholder involvement in conservation efforts through training.	Academic collaboration, NGOs, fisheries cooperatives, anglers and sport fishing clubs/associations, water sports clubs and organisations, local and regional administrative authorities, conservation clubs, wildlife volunteers, landowners/ land managers and policy makers

GOAL 3: RECOMMENDATIONS		
3.2.3	Promote educational activities: handcrafts, games, field notebooks, etc.	Schools, Scout and Guide groups, youth groups, NGOs, museums, zoos/ aquariums, academia, educational departments, outreach elements in EU projects
3.3	**Improve cooperation between all key sectors**	
Recommended action		**Current or potential leads and collaborators**
3.3.1	Build partnership and increase communication with key stakeholders, organise joint initiatives between key sectors.	EFBEN, Malacological societies, local and regional governments, NGOs, professional organisations and institutes (e.g. aquaculture, fisheries, anglers, water management, ecologists, engineers), tourism bodies
3.3.2	Build partnership and increase communication with key stakeholders, organise joint initiatives between key sectors.	EFBEN, Malacological societies, local and regional governments, NGOs, professional organisations and institutes (e.g. aquaculture, fisheries, anglers, water management, ecologists, engineers), tourism bodies
3.4	**Develop and use existing tools for guidance and training for key sectors at multiple levels**	
Recommended action		**Current or potential leads and collaborators**
3.4.1	Develop/produce/promote digital and printed materials (e.g. educational, best practice guidelines, ID book, posters) to exhibit in nature centres, museums, schools, universities.	EFBEN, Local and regional governments, EU projects, Academia, teachers, NGOs, professional organisations and institutes (e.g. aquaculture, fisheries, anglers, water management, ecologists, engineers)
3.4.2	Give academic and dissemination talks to raise awareness and citizen science effort.	EFBEN, Academia, NGOs, EU projects, malacological societies

4. Policy support for freshwater bivalve conservation

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4.1 Introduction

Freshwater bivalves are often overlooked and rarely explicitly considered in environmental conservation policies. Even in cases where policies and legislation do exist, their conservation would benefit from improved enforcement.

For such a highly threatened group of animals and the value they provide in indicator and ecosystem services, there is not enough support for their conservation. While some lake and flowing river type habitats are included in Annex I of the Habitats Directive and some are covered by the Natura 2000 sites, there is a need for an adequate coverage of habitats and sites where freshwater bivalves would be protected. Additionally, promoting species level identification of bivalves during river monitoring under the Water Framework Directive would also be an important step forward for their conservation.

The following discusses the policy requirements needed in order to implement conservation measures for the freshwater bivalve species that are identified as threatened in this report.

All European freshwater bivalves have been assessed for the IUCN Red List. Many European countries have produced at least a country-level Red List or Red Data Book that include freshwater bivalves. Some countries have provided legal protection for their red-listed molluscs while others have not. National legal protection for threatened species, and their hosts and habitats, is an important first step in their conservation.

The Red List assessment of freshwater bivalves at a national/regional level currently lacks a sufficient number of taxonomic specialists for these species, leading to missing data across parts of species ranges. Targeted monitoring of freshwater bivalves also needs to increase to a level that can accurately and efficiently detect trends to allow for conservation measures to be taken in a timely manner and before population extinctions occur. Red listing continues to be a hugely important resource in understanding the status of these molluscs and as a foundation to plan measures for their conservation.

4.2 Challenges relating to policy support for bivalves

4.2.1 Measuring bivalve population declines and endangerment

An important challenge for the conservation of freshwater bivalves is the potential underestimation of bivalve population declines and associated endangerment, due to insufficient monitoring of the species. Monitoring of freshwater bivalve populations is for instance often limited to protected species, and even more limited for species that are not covered by legal protection. The situation for sphaeriids is considerably worse, as identification of species in this group is challenging for non-specialists. Data from the Water Framework Directive and other macroinvertebrate monitoring is generally only identified to family level, which does not provide sufficient information on the true indicator value of freshwater bivalves, or important data on their locations. Records are only generated by a limited number of specialists, and lack of taxonomic education has resulted in far fewer specialists than before. Consequently, many available distribution records of freshwater bivalves are outdated and it should not be assumed that these populations have not declined since their previous monitoring, for example, species living in wetlands where severe drainage has taken place are likely to have declined over the intervening period since the species was recorded. In addition, available distribution records are incomplete for parts of the European region.

4.2.2 Knowledge required to care for freshwater bivalves at site level

There is a lack of knowledge that is needed for the effective conservation of freshwater bivalves at site level. Freshwater bivalves after all cannot be protected where a) their presence is not known, b) they are known to be present by surveyors but site managers are unaware of their presence or c) they are known to be present by surveyors and site managers, but information needed for their effective and sustainable management is not known. Therefore, all these aspects of information are needed at site level for the effective conservation of freshwater bivalves.

4.2.3 Legislation

This section concentrates on European level legislation, mainly through EU Directives and how they relate to the requirements of the Habitats Directive, but also the Bern Convention in those countries outside the EU but within the wider remit of the Bern Convention.

Although some freshwater bivalve species and habitats are covered by international legislation, there is still a substantial gap in the coverage of sites and species.

Even within protected areas, the socio-economic demands (e.g. hydro power plants, agriculture) are regularly prioritised over the needs of aquatic and wetland areas. Some provisions exist within Natura 2000 sites for protected species in rivers, but elsewhere invertebrates are not taken into consideration even if they are seriously threatened. In particular, swamp and ditch habitats support some sphaeriid species that are very rare and should be prioritised for further targeted investigations.

Where permits are needed for new developments or plans, impacts on freshwater bivalves that are not covered by Habitats Directive protection may not be considered or included in application details. In planning, Environmental Impact Assessments for the creation or removal of dams or for water abstraction do not adequately account for the protection of freshwater bivalves.

EU Habitats Directive and Bern Convention

A number of bivalve species are protected under the EU Habitats Directive. Two freshwater unionids are listed under Annex II of the Habitats Directive, the Freshwater Pearl Mussel and the Thick-shelled River Mussel. Strict protection under Annex IV is given to the Spengler's Freshwater Mussel (*Pseudunio auricularius*). The Freshwater Pearl Mussel (*M. margaritifera*), *Microcondylaea bonelli* and *Unio elongatulus* are listed under Annex V, which requires restrictions on taking in the wild and exploitation. Protection of these species under the EU Habitats Directive has increased access to funding sources from the EU (e.g. through LIFE projects) and motivated national governments to contribute financially to projects designed to improve their condition, thus benefitting their conservation.

Four European freshwater bivalve species are listed in Bern Convention Annexes. Spengler's Freshwater Mussel is protected under Annex II (strictly protected fauna species), and the Freshwater Pearl Mussel (*M. margaritifera*), *M. bonelli*, and *U. elongatulus* are protected under Annex III (protected fauna species).

In addition to the freshwater bivalves that are covered by Habitats Directive and Bern Convention and benefit from their protection, there are other bivalve species in need of conservation. Some Natura 2000 sites cover relevant habitats for unprotected species of conservation value, which can have a positive impact on these species. In any case, when EU member states are looking for the designation of new protected areas, they could take the habitats of freshwater bivalve species that are not covered by the EU Habitats Directive or the Bern Convention into consideration, particularly essential habitats for sphaeriid and dreissenid species. In any case, it is relevant to note that specific site protection under the Natura 2000 network should be given to Spengler's Freshwater Mussel, *M. bonelli* and *U. elongatulus* to provide equivalent protection to Annex II. This is not currently the case for *M. bonelli* and *U. elongatulus,* which are only included in Annex V (sustainable use), and neither of which have any known use for exploitation, commercial or otherwise, but are in need of conservation.

Water Framework Directive 2000/60/EC

Current Water Framework Directive policy provisions are inadequate for effective and comprehensive bivalve conservation. Legislation often focuses on chemical water quality or organic enrichment controls (gross pollution, quantities of chlorates etc.) rather than sedimentation or catchment hydrology, both essential aspects of the ecological environment needed for successful conservation of freshwater bivalves' habitats.

Although the Water Framework Directive addresses water quality and management, it focuses on good ecological status, rather than the high ecological status needed for some species, particularly the Freshwater Pearl Mussel. The decline of long-lived freshwater bivalves started long before the implementation of the Water Framework Directive. However, the requirement to maintain or restore high status in some water bodies is missing from the standard directive rules and is brought in only through the Habitats Directive requirements. In turn, this requirement to restore high status is not always acted on through national policy and it does not legally cover non-protected species. Where ecological status targets are not met, there needs to be much more focused effort to reduce the stressors that cause the ongoing degraded habitat status for areas of high relevance for freshwater bivalves.

Assessment of groundwater quality, particularly regarding quantity as well as quality, is poorly assessed from a bivalve perspective. There is also a discrepancy between the assessments of the Water Framework Directive and the Habitats Directive, where the same sites that receive positive groundwater assessments from Water Framework Directive monitoring, are often assessed negatively under the Habitats Directive monitoring. In addition, there is little effort made to address why bivalve populations continue to decline in relevant habitats where current ecological status targets have been met.

EU Nitrates Directive 91/676/EEC

Nitrate levels are an important factor for freshwater bivalves to thrive, making the EU Nitrates Directive essential legislation as this directive limits the nitrate level in waters. A review of the results of changes brought about by the Nitrates Directive would provide essential information to see whether they have resulted in improvements for freshwater bivalves. This could also make another case to limit allowed derogations for member states.

Four EU countries are currently availing of a derogation from the Nitrates Directive: Ireland, the Netherlands, Belgium and Denmark. These nitrate derogations have resulted in permission to pollute waters hosting freshwater bivalves. These derogations from strict nitrate limits should have expired in 2021, giving them ample opportunity to change agricultural practice to non-polluting practices. There is now a further extension to the derogations for three of the four countries, with only Belgium not opting to ask for an extension. It is important to assess how their derogations have affected freshwater bivalve populations, and to take their ecological requirements into consideration for additional extensions for allowed derogations from the strict nitrate limits provided by this Directive.

The Urban Waste Water Treatment Directive 91/271/EEC and amendments Directive 98/15/EC

This Directive resulted in the removal of much of the gross pollution that damaged freshwater bivalve populations by requiring the collection and treatment of wastewater in all urban areas of more than 2000 people and improved treatment for higher population densities. It also required pre-authorisation of all urban wastewater discharges, discharges from the food-processing industry and industrial discharges into urban wastewater collection systems, and the monitoring of the performance of treatment plants and receiving waters. This Directive has provided clear benefits to waters that had previously suffered from serious pollution in urban areas. Freshwater bivalves would furthermore benefit from legislation that covers rural waters, where outfall pollution can act in combination with on-site single house discharges and agricultural discharges to negatively affect the habitats of freshwater bivalves. This would particularly help to promote the protection of freshwater bivalve habitats outside Natura 2000 sites.

EU Common Agricultural Policy

The EU Common Agricultural Policy (2021-2027) contains some measures towards greener, more sustainable practices for farmers and for the environment. At the moment, the water quality and quantity surrounding agricultural land are not at the levels needed to safeguard many species of threatened freshwater bivalves. The current environmental requirements in the EU Common Agricultural Policy, such as the voluntary Good Agriculture Practice requirements, are insufficient to improve freshwater bivalve habitats. It is also important to consider the delay in the impact of environmental improvements on the land to improvements in the surrounding water. Here, legacy quantities of pollutants continue to move into the aquatic environment over an extended period of time. A better consideration and integration of environmental requirements for water pollution in agricultural practices within the EU Common Agricultural Policy would be essential for the safeguard of freshwater bivalve habitats in catchments dominated by agricultural land. Additional targets are needed to ensure that the positive effects on the freshwater bivalves can accrue before many bivalve populations are extirpated.

EU Floods Directive 2007/60/EC

The EU Floods Directive aims to assess and manage flood risks and to limit the negative consequences of flood damage in the EU. Integrated flood risk management must focus on sustainable water management and needs to go hand in hand with nature protection and restoration. In practice, engineering approaches are favoured to manage flood risks with measures that disturb the ecological environment of these areas and ignore the ecological requirements of freshwater bivalves. Flood Management Plans of member states should focus more on a better coherence between the mandatory chapters of Environmental Impact Assessments dealing with flood risk and ecological risk when considering measures to limit the risk and impact of flooding. This would ensure that measures would do no harm to freshwater bivalves and would contribute to a better protection and restoration of their habitats under this Directive.

Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')

While the European Climate Law is to be welcomed, it is important that it does not result in formulaic approaches to achieving climate neutrality at the expense of freshwater bivalve requirements. For example, the promotion of afforestation at the expense of peatland habitat restoration could result in further damage to freshwater bivalve habitats.

4.2.4 Enforcement

Although various legislation (e.g. WFD) exists that covers the protection and regulation of freshwater habitats as well as catchment management in these areas, a stricter implementation of this legislation is needed to protect and restore the highly sensitive freshwater bivalve species.

An example of this is that when new management plans and projects are designed in areas covered by existing legislation, they are often not assessed according to the ecological requirements of freshwater bivalves. For threatened species, the aim should be to restore their populations and the habitats on which they rely. This is an objective and legal requirement in the case of species and habitats covered by the Habitats Directive and the Bern Convention. Even when key sites for freshwater bivalves are covered by these international legislations, permissions are in some cases granted on a national level that derogate or undermine the implementations of these international commitments. An example is the permission to release sewage during rain events due to inadequate infrastructure that negatively affects the conservation of freshwater bivalves in the respective area.

Full enforcement of these legal requirements is needed to achieve the restoration of populations, this is especially important for freshwater bivalves due to their sensitivity to small deviations in their environment and the lack of regard for these sensitive species has caused their continued decline and extinction. In addition to adequate coverage of freshwater bivalves' species and their relevant habitats, support for education, awareness and training to facilitate restoration and enforcement are in addition essential to advance their conservation.

4.3 Opportunities relating to policy support for bivalves

4.3.1 Opportunities in existing directives

Habitats Directive (92/43/EEC):

It is important to give focus to freshwater bivalves inhabiting Natura 2000 sites designated for their Annex I habitat and typical of these habitats. The conservation of these species should form part of the protection of these sites under Site Specific Conservation Objectives. This is a key opportunity for species that are otherwise not protected. It is recommended for future Article 17 reporting that freshwater bivalves are taken into consideration as species typical of the Annex I habitats that they inhabit.

Monitoring programs required for protected bivalves are now undertaken that would otherwise not have occurred. It is important that monitoring and its interpretation is undertaken in a harmonised manner and that the results are clearly published with data associated with quantifiable species population numbers and habitat condition levels.

Bern Convention on the Conservation of European Wildlife and Natural Habitats (1979):

The protection of freshwater bivalves varies considerably between countries. While the Habitats Directive Annex species require protective measures within the EU, other threatened species rely on national protection and this varies considerably between countries. Management plans to restore conditions that are sustainable for threatened freshwater bivalves via the Natura 2000 and Emerald Network are critical over the next decade, while the Water Framework Directive should be better aligned with the requirements of the Habitats Directive and the Bern Convention to maximize the benefits for these legislations. Resolution 8 (2012) specifies reporting required under the Bern Convention implementation at national level, equivalent to the Article 17 Habitats Directive reporting. The Strategic Plan, adopted in 2021 by the Standing Committee of the "Vision for Bern Convention for the period to 2030", four goals and the slogan "Healthy Nature for Healthy People" fit in very well with the needs of bivalve conservation, such that "*by 2030, declines in biodiversity are halted, leading to recovery of wildlife and habitats, improving the lives of people and contributing to the health of the planet*".

Water Framework Directive 2000/60/EC

The problems with the Water Framework Directive have been highlighted in Section 4.2.3. With challenge comes opportunity and there is much opportunity for improvement in aligning the WFD with the needs and legal requirements of the Habitats Directive and Bern Convention in particular relation to the ecological requirements as well as water quality and quality needed for the successful conservation of freshwater bivalve populations and habitats.

EU Floods Directive 2007/60/EC

There is an important synergistic opportunity between nature restoration and flood risk reduction using nature-based solutions for slowing the flow, and through increasing the capacity of the catchment for water absorption through the raising of ground water levels in catchment land that has previously been drained. The nature-based approach provides a superb opportunity for restoring hydrological function to water bodies in catchments where intensification damage has resulted in poor or no juvenile recruitment and ongoing losses of freshwater mussels.

EU Groundwater Directive 2006/118/EC

Some freshwater bivalves are restricted to groundwater source water and most waterbodies, including rivers and lakes are affected by inputs from groundwater, especially during low rainfall periods. Therefore, both groundwater quality and quantity are important for freshwater bivalves. This may be especially important for southern countries where there has been an extensive reduction in aquifers due to overexploitation for agriculture, tourism, and other industries. These reductions in groundwater are possibly influencing the amount of surface water in rivers and streams. There is an opportunity with the implementation of this directive by taking important areas for freshwater bivalves into consideration.

Environmental Impact Assessment Directive 2011/92/EU and Directive 2014/52/EU

The EU Environmental Impact Assessment Directive aims to ensure that projects that are likely to have a significant impact on the environment are identified and assessed before these projects proceed to development, including potential impacts on Red Data Book, rare and legally protected species. Once impacts on freshwater bivalves are well understood, this can be used to inform the Environmental Impact Assessments and thus support freshwater bivalve conservation for new developments. Guidance is essential to ensure that the implementation of EU policies and legislation does not prevent the conservation of freshwater bivalves (e.g. power plant usage is often prioritised over wetland flows).

Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')

Achieving climate neutrality to address the growing climate-related risks, including a contribution from all economic sectors for which emissions or removals of greenhouse gases are regulated in Union law, can provide great opportunities for improving habitats for freshwater bivalves.

The law states that the restoration of ecosystems would assist in maintaining, managing and enhancing natural sinks and promote biodiversity while fighting climate change.

This has the potential for further conservation measures in freshwater bivalve habitats and the wider catchments that influence their habitats. The restoration of wetland habitats that are not listed in Annex I such as swamp and marsh areas that support spheriids would be of great benefit to their conservation. The restoration of functional open peat habitats that were previously drained would benefit the water delivery to riverine habitats for freshwater bivalves. Planting and protection of native tree species in their appropriate habitat can also be beneficial for some bivalve habitats.

Invasive Alien Species (IAS) legislation (Regulation (EU) 1143/2014)

The IAS Regulation establishes an EU-wide framework to prevent, minimise and mitigate the adverse impacts of IAS on biodiversity and ecosystem services, focusing on taking action against IAS that are included on a list of "species of Union concern" which is periodically updated, but excludes some of the most detrimental invasive species (ex. *Sinanodonta woodiana, Corbicula fluminea, Dreissena bugensis* and *D. polymorpha*). IAS are only added to the Union list following a risk assessment process. The Regulation includes three distinct hierarchical approaches to combatting IAS: (i) introduction prevention, (ii) early detection and rapid eradication, and, once established in the EU, (iii) management of IAS to contain further spread and to minimise impact. Further information on the Regulation can be found here.

At present, only one freshwater bivalve, the Golden Mussel (*Limnoperna fortunei*), is listed in the EU IAS legislation as an '*invasive alien species of Union concern*'. Countries can propose further species for inclusion on the IAS Regulation Annexes (Commission Implementing Regulation 2016/1141), but this is problematic where a species is transboundary.

Any policy changes and improvements need to consider the severe effects that IAS have on native bivalve species, including where there may be negative effects to native species and their habitats from treatments that are used to eliminate IAS.

4.3.2 Opportunities in future legislation

EU Nature Restoration Law (pending):

The European Commission's proposal for a Nature Restoration Law is the first comprehensive law of its kind. It is a key element of the EU Biodiversity Strategy, which calls for binding targets to restore degraded ecosystems, in particular those with the most potential to capture and store carbon and to prevent and reduce the impact of natural disasters. It fits in with the Bern Convention objectives for the wider non-EU countries.

Restoration at a catchment-wide level is vital for the most sensitive and threatened bivalves if we are to prevent their extinction. It is critical to include priority sites for freshwater bivalve species for restoration at a catchment level in a way that gets the most value for wider habitats, climate protection and carbon storage. The network of freshwater bivalve experts has an important role to play in advising on both national and Europe-wide site networks for restoration. Advice on which catchments need total restoration, and which can be sustainably managed with current levels of intensification but where improved protection measures are needed, must include bivalve specialists.

Projects that seek to increase catchment connectivity and biodiversity are on the rise. In the Nature Restoration Law, the European Biodiversity Strategy target for at least 25,000 km of free-flowing rivers by 2030 through the removal of obsolete barriers and restoring wetlands has been made legally binding. Also the Open Rivers Programme supports the removal of small dams across Europe. It is important that the impacts of dam removals are understood for freshwater bivalve species and that relevant mitigation protocols can be provided.

Some initiatives such as the AMBER LIFE project (*Adaptive Management of Barriers in European Rivers*) have begun to investigate the effects of barrier removal.

River restoration guidance

Guidance on best practice during and after river restoration needs to specify that freshwater bivalve communities should be considered in addition to fish species. Expert guidance on freshwater bivalves is needed from the start of the planning and pre-implementation phases.

4.3.3 Subsidies and incentives

Subsidies and initiatives must be based on results that benefit freshwater bivalves, such as shown in Section 2.3 (see Box 6). Generalised payment schemes based on wide-ranging Good Agricultural Practice (GAP) must not be assumed to be good enough for sensitive bivalves requiring restoration. For example, GAP rules for slurry spreading are not appropriate in catchment areas that require the deintensification and restoration of wetlands.

Subsidies and incentives must be based on the long-term efforts needed to restore catchments, often 100 years or more, and cannot be achieved by short schemes with the possibility of abandonment of restoration efforts when these initiatives end.

A prime example of a conservation success story is the rescued population of the Freshwater Pearl Mussel in the Vltava River, located in the Šumava National Park, Czechia. This achievement follows more than 40 years of active protection efforts involving both state and private sectors since the 1980s. Through semi-natural breeding programs (started by Jaroslav Hruška), this effort has successfully managed to significantly increase the population size and improve the age structure of this species. While the restoration of the habitat is still ongoing, these efforts have already yielded remarkable results.

This success story demonstrates the effectiveness of sustained and collaborative conservation initiatives. The combined efforts of government agencies, private organizations, and dedicated conservationists have played a pivotal role in reversing the decline of the Freshwater Pearl Mussel in this river. It is a testament to how well-implemented regulations and innovative conservation strategies can positively impact mussel conservation. This success story also shows how it is a long-term matter, literally for several generations of conservationists and thus sustained funding and efforts are fundamental for the successful conservation of freshwater bivalves.

4.3.4 National policy frameworks for species

All legislation that arises from international legislation must ultimately be implemented by national legislation. If international policy or objectives are not matched at a national level by effective policies and proper legal implementation, then the decline of bivalves will continue.

For each of the challenges and opportunities above, implementation at a national and local level is essential.

Local and national agencies may traditionally have had a greater influence on implementation of actions on the ground compared to environmental protection agencies at EU level. Moreover, some sectors have had a considerable impact on the conservation of freshwater bivalves. The agricultural and flood risk reduction lobbies exert a high level of influence, and the commercial forestry sector is often noted as perpetuating poor practice across Europe. This results in a mismatch of effort being put into freshwater bivalve conservation by some sectors (e.g. farmers in voluntary schemes), while commercial forestry damage overrides positive efforts in other parts of the catchment (see Box 12). For the successful conservation of freshwater bivalves, it is thus essential to ensure that all sectors are on board to improve the environment for freshwater bivalve populations and habitats.

Priority Action Frameworks (PAF) are multi-annual strategic planning tools, intended to provide an overview of the measures necessary for the implementation of the EU-wide Natura 2000 network and infrastructure associated with it, to specify the financing needs of these measures and to link them to the corresponding European financing programs. As very long-term efforts are needed before declining freshwater bivalve populations can be turned around towards recovery, identifying the finance needed for conservation actions over longer periods is hugely important. While the PAF is mainly about attributing costs to the conservation of Annex II species, i.e. the Freshwater Pearl Mussel and the Thick-shelled River Mussel, and Annex I habitats (hence the importance of identifying any threatened bivalves present in the Natura 2000 network within Annex I sites), but it is also noted in the EU guidance that the PAF may also include funding for requirements of Annex IV and V species where needed. This is a very important way of obtaining funding for Spengler's Freshwater Mussel (Annex IV), *M. bonelli* and *U. elongatulus* (Annex V).

4.3.5 Implementation of conservation policies through plans for populations of threatened species

For freshwater bivalve species assessed as threatened through IUCN Red List assessments, practical conservation measures must be driven at the catchment level influencing the status of each population. To protect threatened species, conservation measures are needed to maintain populations that are in the best condition, and to restore populations that are declining.

Each population should have Site-Specific Conservation Objectives that reflect the ecological requirements of the relevant freshwater bivalve species. These objectives should have targets that are clear and precise, so that they can be assessed as to whether they are being achieved, and also assist with assessing the risk of any current management or change of management, including new plans or projects.

These Site-Specific Conservation Objectives should then form the basis for a Catchment Management Plan for each population. At the very least, these should be undertaken for populations of species assessed as Critically Endangered or Endangered in the IUCN European Red List by 2030.

The Management Plan should provide maps and land use information on the aquatic and terrestrial areas that make up the catchment where each population occurs. This plan needs to identify pressures, and the scale of each pressure, and the conservation measures needed to reverse the pressures leading to population decline, including pressures on host fish. Measures need to include timescales, locations, and who is responsible for each action. The Management Plan should include details of who and how each action is monitored and analysed for its effectiveness, and dates for review and updating of the plans.

While the responsibility for conservation action is likely to include a range of authorities, the writing, coordination and regular updating of each Catchment Management Plan should be under the responsibility of the National Conservation Agencies. Funding for this work needs to be incorporated into biodiversity funding schemes as well as nature restoration and climate schemes that act synergistically with catchment restoration.

Implementing an appropriate Catchment Management Plan as described above will be critical to achieving the Kunming-Montreal Target 4 of the CBD's Global Biodiversity Framework for threatened European freshwater bivalves, including Habitats Directive Annex IV and V species.

Box 12: The failure of forestry legislation and policy to protect freshwater systems in Norway: Implications for freshwater bivalves

Author: Jon H. Mageroy

Logging in Norway is regulated through the Forestry Law[1] and the Act for Sustainable Forestry[2]. The latter is applied through the forestry industry developed PEFC standard[3]. The standard even includes special protection for the Freshwater Pearl Mussel (FPM; *Margaritifera margaritifera*). However, both the law and the standard are poorly implemented.

Why? The forestry industry itself is primarily responsible for monitoring and reporting breaches, and local authorities do not have the capacity to follow them up. As biologists, we often observe breaches of both law and standard along water courses with freshwater mussels, especially logging of the riparian vegetation and poorly constructed logging roads. However, we only report the most egregious ones, as there is no simple reporting or monitoring system to capture the extent of breaches.

Why? Reporting and taking action on breaches is not integrated in the industry's or authorities' management systems. This has been clearly shown in an ongoing Norwegian public service broadcaster (NRK) investigation into forestry practices. From 2005 to 2022, breaches of the law and standard have been reported to the police 48 times. It has only resulted in 7,000 EUR in fines and no convictions. From 2015 to 2022, the four largest forestry companies reported breaching the PEFC standard 200 times. Breaches of the PEFC standard has not led to any company losing its certification since 2000[4].

There are some signs of change though. In 2020, a poorly constructed logging road resulted in sludge covering FPM beds in a river in central Norway. This was reported to the police and the logging company received 85 000 EUR in fines, although the fines have not been accepted[5] and the case will go to court[6].

There is an increased awareness of the need to improve legislation, standards and implementation. Both managers, law enforcement, local authorities, politicians and even the forestry industry, at least to some degree, see the need for change[4,5,7-12]. Proper systems and requirements for reporting of breaches, as well as following these up with prosecution by law enforcement, would result in better protection of our freshwater mussels.

Runoff due to poorly constructed logging road colouring a FPM river brown in central Norway. Photo: Anonymous, with permission.

See appendix 1 for references.

4.4 Goals and recommendations

The following section identifies a pathway to addressing the challenges discussed above over the next 5-10 years. It describes a major goal with associated sub-goals and recommended actions, with examples of organisations that could lead or support the implementation of those actions in Europe.

GOAL 4: SUFFICIENT POLICIES PROTECTING FRESHWATER BIVALVES AND THEIR EFFECTIVE ENFORCEMENT

Specifically:

- Assessment, legal protection, and planning for threatened species.
- Review of national legislation to ensure that there is no conflict with freshwater bivalve conservation. Ensure existing laws are effectively implemented and enforced with better outcomes for freshwater bivalves.
- Ensure EU legislation supports ecological gains for freshwater bivalves.
- Promote and provide sufficient guidance for project assessment, that is fit for purpose and fulfils all legal requirements for freshwater bivalves.
- Ensure compliance with best practice guidelines.
- Revise water quality status thresholds to comply with freshwater bivalve requirements.

GOAL 4: RECOMMENDATIONS		
4.1	**Assessment, legal protection, and planning for threatened species.**	
Recommended action		**Current or potential leads and collaborators**
4.1.1	Countries that do not already have a Red List/Red Data Book for molluscs should have assistance to develop these for their country.	IUCN and SSC; national CBD focal points and national biodiversity authorities
4.1.2	Countries that already have molluscan Red Lists should revise them at least every 10 years or in response to changing threat levels.	National CBD focal points; national legislators for biodiversity
4.1.3	National legal protection for threatened species, their hosts (for unionids) and habitats, and implement catchment-level planning and protection.	National conservation bodies, EFBEN, national legislators for biodiversity
4.1.4	Invest in government-led recovery plans for all nationally threatened freshwater bivalves as a vehicle for driving recovery (e.g. as done in Sweden, Aragon region of Spain).	National and regional conservation bodies, authorities with climate, flood and nature restoration responsibilities
4.1.5	Following survey for the presence, distribution and status of freshwater bivalves in Annex I habitats and Bern Convention equivalents (Section 4.3.1), ensure these species are fully incorporated into management plans.	National Nature Authorities, relevant Competent Authorities, EU, Standing Committee to Bern Convention

GOAL 4: RECOMMENDATIONS		
4.1.6	Populations of Critically Endangered and Endangered freshwater bivalves to each have a Catchment Management Plan by 2030, with detailed mapping and descriptions of threats, conservation actions, responsibility for actions, monitoring and review of efficacy of actions. Catchment Management Plans should be reviewed, updated and republished at least every six years.	National Nature Authorities to write; relevant Competent Authorities to implement
4.2	**Review of national legislation to ensure that there is no conflict with freshwater bivalve conservation. Ensure existing laws are effectively implemented and enforced with better outcomes for freshwater bivalves.**	
Recommended action		**Current or potential leads and collaborators**
4.2.1	High level review of national legislation with expertise from legal, scientific, and competent authority management input.	Relevant governmental bodies; EU, Standing Committee to the Bern Convention, Priority Action Frameworks, EFBEN
4.2.2	Where conflicts exist, revise national legislation to ensure that it doesn't prevent the Conservation Objectives of protected sites from being achieved in the timescale needed to restore functioning populations of threatened freshwater bivalves.	Relevant governmental bodies, Priority Action Frameworks
4.2.3	Identify and close policy conflicts that are especially damaging to freshwater bivalves (e.g. special permission to release sewage during rain events due to inadequate infrastructure).	Relevant governmental bodies
4.2.4	Ensure cumulative negative effects of projects at the scale of watercourses and watersheds are accounted for in planning and permitting (e.g. direct and indirect destruction of individuals, alteration of the habitat in the riverbed and the banks of the watercourse, for river management measures).	Relevant governmental bodies, Catchment-level managers, guidance from EFBEN
4.2.5	Harmonise/integrate existing actions, plans, freshwater initiatives, drinking water regulations, freshwater and terrestrial restoration projects, strategies and policy and ID existing overlap.	National Nature Authorities, relevant Competent Authorities, EFBEN, Academia, WFD technical groups, NGOs, EU, decision/policy makers, EIPs, land managers
4.3	**Ensure EU legislation supports ecological gains for freshwater bivalves.**	
Recommended action		**Current or potential leads and collaborators**

GOAL 4: RECOMMENDATIONS		
4.3.1	For climate mitigation actions (e.g. European Climate Law), each catchment level action should be evaluated to ensure that there are no conflicts with bivalve conservation objectives, and that actions act in synergy with conservation aims.	EU, Relevant government bodies, guidance from EFBEN
4.3.2	For flood mitigation actions (e.g. Floods Directive), each catchment level action should be evaluated to ensure that there are no conflicts with freshwater bivalve conservation objectives, including their host fish (for unionids), and that actions act in synergy with conservation aims, e.g. natural rather than engineered flood relief, protection and restoration of wetlands and floodplains.	EU, Relevant government bodies, guidance from EFBEN
4.3.3	For the new EU restoration law, the highest level of nature restoration should be prioritised for the most important bivalve population areas. Each country should identify a set of priority catchments that would benefit most from full restoration at catchment level. A synergy between bivalve restoration, wider nature restoration, flood protection and climate action is needed.	EU, Relevant government bodies, guidance from EFBEN
4.4	**Promote and provide sufficient guidance for project assessment, that is fit for purpose and fulfils all legal requirements for freshwater bivalves.**	
Recommended action		**Current or potential leads and collaborators**
4.4.1	Develop assessment guidance, promote and train Competent Authorities, developers and ecological consultants.	EFBEN, EU, National Nature Conservation Authorities
4.4.2	Develop and promote best practice guidance for catchment and river habitat restoration actions. Identify and target key cascades of influence (e.g. digger-operator modifying the river < manager < commissioning authority < hydro-project planners < universities & institutes who train/certify hydro-project planners).	EFBEN, EU, National Nature Conservation Authorities, relevant Competent Authorities, professional organisations and institutes
4.4.3	Require that all planning applications, forestry actions, and strategic planning include a map layer showing catchment boundaries so that the influence and impact on freshwater is readily available. Build into a national regulation and legislation framework.	National Nature Conservation Authorities, relevant Competent Authorities
4.5	**Ensure compliance with best practice guidelines**	
Recommended action		**Current or potential leads and collaborators**
4.5.1	Planning and other permissions must include evaluation, surveillance and feedback of actions, including mitigation, successes or failures. If necessary, national regulation changes where needed.	National Nature Conservation Authorities, relevant Competent Authorities

GOAL 4: RECOMMENDATIONS		
4.5.2	Instigate or increase penalties for not following exact permissions or regulations. Penalties to reflect the cost of restoring any damage. If necessary, national regulation changes where needed.	National Nature Conservation Authorities, relevant Competent Authorities
4.5.3	Permissions for projects either by planning authorities or competent authorities such as the forestry sector to include mandatory reporting of monitoring undertaken, including mitigation, successes or failures, and any breaches or pollution incidents. These should be transparent and available to the public.	National Nature Conservation Authorities, relevant Competent Authorities
4.6	**Revision of water quality status thresholds to comply with freshwater bivalve requirements**	
Recommended action		**Current or potential leads and collaborators**
4.6.1	Water quality status thresholds and targets must be assessed and revised where they are currently not sufficient for sustainable freshwater bivalve populations. Revision of WFD river basin/catchment plans where needed.	Water Framework Directive, EFBEN, CEN Standards
4.6.2	Ensure thresholds for regulation of pollutants accounts for sensitivities of freshwater bivalves and their different life-stages. Revision of WFD river basin/catchment plans where needed.	Water Framework Directive, EFBEN, CEN standards

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Appendix 2. Freshwater bivalve species included in the European Red List

Order	Family	Species	Common name	Global/Pan Europe Red List Category	EU Category	Endemic to Pan Europe region	Endemic to EU27
Dreissenids							
MYIDA	DREISSENIDAE	*Congeria jalzici*	North Dinaric Cave Clam	EN	EN	Yes	Yes
MYIDA	DREISSENIDAE	*Congeria kusceri*	South Dinaric Cave Clam	EN	EN	Yes	
MYIDA	DREISSENIDAE	*Congeria mulaomerovici*	Bosnian Dinaric Cave Clam	VU	VU	Yes	
MYIDA	DREISSENIDAE	*Dreissena bugensis*	Quagga Mussel	LC	NA	Yes	
MYIDA	DREISSENIDAE	*Dreissena carinata*		LC	LC	Yes	
MYIDA	DREISSENIDAE	*Dreissena polymorpha*	Zebra Mussel	LC	NA		
Sphaeriids							
SPHAERIIDA	SPHAERIIDAE	*Euglesa casertana*	Caserta Pea Mussel	LC	LC		
SPHAERIIDA	SPHAERIIDAE	*Euglesa conventus*	Arctic-alpine Pea Clam	LC	NT		
SPHAERIIDA	SPHAERIIDAE	*Euglesa edlaueri*		EN	Not Recorded	Yes	

SPHAERIIDA	SPHAERIIDAE	*Euglesa globularis*	Rotund Pea Mussel	LC	LC		
SPHAERIIDA	SPHAERIIDAE	*Euglesa henslowana*	Henslow's Pea Mussel	LC	LC		
SPHAERIIDA	SPHAERIIDAE	*Euglesa hinzi*		LC	VU		
SPHAERIIDA	SPHAERIIDAE	*Euglesa interstitialis*		DD	DD	Yes	Yes
SPHAERIIDA	SPHAERIIDAE	*Euglesa korniushini*		DD	Not Recorded	Yes	
SPHAERIIDA	SPHAERIIDAE	*Euglesa lilljeborgii*	Lilljeborg's Pea Mussel	LC	LC		
SPHAERIIDA	SPHAERIIDAE	*Euglesa maasseni*		CR	Not Recorded	Yes	
SPHAERIIDA	SPHAERIIDAE	*Euglesa milium*	Rosy or Quadrangular Pea Mussel	LC	LC		
SPHAERIIDA	SPHAERIIDAE	*Euglesa nitida*	Shining Pea Mussel	LC	LC		
SPHAERIIDA	SPHAERIIDAE	*Euglesa obtusalis*	Porous Pea Mussel	LC	LC		
SPHAERIIDA	SPHAERIIDAE	*Euglesa parvula*	Globular Pea Mussel	LC	LC		
SPHAERIIDA	SPHAERIIDAE	*Euglesa personata*	Red-Crusted Pea Mussel	LC	LC		
SPHAERIIDA	SPHAERIIDAE	*Euglesa ponderosa*	Robust Pea Mussel	DD	DD		
SPHAERIIDA	SPHAERIIDAE	*Euglesa pseudosphaerium*	False-orb Pea Mussel	VU	VU	Yes	
SPHAERIIDA	SPHAERIIDAE	*Euglesa pulchella*	Irridescent Pea Mussel	LC	LC		
SPHAERIIDA	SPHAERIIDAE	*Euglesa shcherbinai*		DD	DD	Yes	
SPHAERIIDA	SPHAERIIDAE	*Euglesa subtruncata*	Short-ended Pea Mussel	LC	LC		
SPHAERIIDA	SPHAERIIDAE	*Euglesa supina*	Hump-Backed Pea Mussel	LC	LC		

SPHAERIIDA	SPHAERIIDAE	*Euglesa waldeni*	Walden's Pea Mussel	LC	LC	
SPHAERIIDA	SPHAERIIDAE	*Musculium lacustre*	Lake or Capped Orb Mussel	LC	LC	
SPHAERIIDA	SPHAERIIDAE	*Odhneripisidium annandalei*		DD	DD	
SPHAERIIDA	SPHAERIIDAE	*Odhneripisidium moitessierianum*	Pygmy Pea Mussel	LC	LC	
SPHAERIIDA	SPHAERIIDAE	*Odhneripisidium tenuilineatum*	Fine-lined Pea Mussel	LC	LC	
SPHAERIIDA	SPHAERIIDAE	*Pisidium amnicum*	River Pea Mussel	LC	LC	
SPHAERIIDA	SPHAERIIDAE	*Pisidium dilatatum*		LC	DD	
SPHAERIIDA	SPHAERIIDAE	*Sphaerium corneum*	Horny Orb Mussel	LC	LC	
SPHAERIIDA	SPHAERIIDAE	*Sphaerium nitidum*	Arctic Orb Mussel	LC	LC	
SPHAERIIDA	SPHAERIIDAE	*Sphaerium nucleus*	Swamp Orb Mussel	LC	LC	
SPHAERIIDA	SPHAERIIDAE	*Sphaerium ovale*	Oval Orb Mussel	LC	LC	
SPHAERIIDA	SPHAERIIDAE	*Sphaerium parenzani*		DD	DD	Yes
SPHAERIIDA	SPHAERIIDAE	*Sphaerium rivicola*	River Orb Mussel	VU	VU	
SPHAERIIDA	SPHAERIIDAE	*Sphaerium solidum*	Witham Orb Mussel	EN	EN	

Unionids						
UNIONIDA	MARGARITIFERIDAE	*Margaritifera margaritifera*	Freshwater Pearl Mussel	CR	CR	

UNIONIDA	MARGARITIFERIDAE	*Pseudunio auricularius*	Spengler's Freshwater Mussel	CR	CR	Yes	
UNIONIDA	UNIONIDAE	*Anodonta anatina*	Duck Mussel	VU	VU		
UNIONIDA	UNIONIDAE	*Anodonta cygnea*	Swan Mussel	VU	VU		
UNIONIDA	UNIONIDAE	*Anodonta exulcerata*		EN	EN	Yes	
UNIONIDA	UNIONIDAE	*Microcondylaea bonellii*		CR	CR	Yes	
UNIONIDA	UNIONIDAE	*Potomida acarnanica*		EN	EN	Yes	Yes
UNIONIDA	UNIONIDAE	*Potomida littoralis*		EN	EN		
UNIONIDA	UNIONIDAE	*Pseudanodonta complanata*	Depressed River Mussel	EN	EN	Yes	
UNIONIDA	UNIONIDAE	*Unio bruguierianus*		EN	EN		
UNIONIDA	UNIONIDAE	*Unio carneus*		VU	Not Recorded	Yes	
UNIONIDA	UNIONIDAE	*Unio crassus*	Thick Shelled River Mussel	EN	EN	Yes	
UNIONIDA	UNIONIDAE	*Unio delphinus*	Iberian Dolphin Mussel	EN	EN	Yes	Yes
UNIONIDA	UNIONIDAE	*Unio desectus*		EN	EN	Yes	Yes
UNIONIDA	UNIONIDAE	*Unio elongatulus*		EN	EN	Yes	
UNIONIDA	UNIONIDAE	*Unio gibbus*		CR	CR		
UNIONIDA	UNIONIDAE	*Unio gontierii*		VU	Not Recorded		
UNIONIDA	UNIONIDAE	*Unio ionicus*		EN	EN	Yes	
UNIONIDA	UNIONIDAE	*Unio mancus*		EN	EN	Yes	Yes

UNIONIDA	UNIONIDAE	*Unio nanus*		EN	EN	Yes	
UNIONIDA	UNIONIDAE	*Unio pictorum*	Painter's Mussel	NT	NT		
UNIONIDA	UNIONIDAE	*Unio ravoisieri*		CR	CR		
UNIONIDA	UNIONIDAE	*Unio tumidiformis*		CR	CR	Yes	Yes
UNIONIDA	UNIONIDAE	*Unio tumidus*	Swollen River Mussel	NT	NT		
UNIONIDA	UNIONIDAE	*Unio vicarius*		VU	VU	Yes	
Not Applicable (non-native to European region)							
MYIDA	DREISSENIDAE	*Mytilopsis leucophaeata*	Dark False Mussel	NA	NA		
SPHAERIIDA	SPHAERIIDAE	*Euglesa compressa*	Ridgedbeak Peaclam	NA	NA		
SPHAERIIDA	SPHAERIIDAE	*Musculium transversum*	Long Fingernail Clam	NA	NA		
UNIONIDA	UNIONIDAE	*Sinanodonta woodiana*	Chinese Pond Mussel	NA	NA		
VENERIDA	CYRENIDAE	*Corbicula fluminalis*		NA	NA		
VENERIDA	CYRENIDAE	*Corbicula fluminea*	Asian Clam	NA	NA		

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