Freshwater Pearl Mussel Conservation in the Armorican Massif

Programme Report, 2010–2016

LIFE+ Nature «Freshwater Pearl Mussel Conservation in the Armorican Massif»

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Introduction

The European freshwater pearl mussel conservation programme was launched on 1 September 2010 and continued for 6 years, ending on 31 August 2016. The goal of the programme as it was rolled out in Brittany and Normandy was to breed this species, which is endangered in the Armorican Massif, and to maintain and develop the living rivers which are necessary for its survival there.

Numerous studies have described a similarly urgent situation for mussels in both Brittany and Normandy, due to progressive disappearance and ageing populations.

The strong heritage significance of the freshwater pearl mussel, a living witness to the development of the valleys of the Armorican Massif, as well as its bio-indicator qualities, its living requirements and its status as an umbrella species, make it an excellent candidate for conservation with regards to the current state of its populations in the Armorican Massif.

The project was carried out in harmony with both the freshwater pearl mussel National Action Plan and the European Water Framework Directive, which aimed to reach the goal of healthy watercourses by 2015.

Goals

Over the programme's six years, its main objective was to maintain and improve mussel numbers through the building of a mussel hatchery, a flagship action providing for the availability of various age groups in the aim of preventing their disappearance from their natural habitat.

The freshwater pearl mussel's complex life cycle, ecological requirements, and longevity highlight the importance of its conservation, and characterise it as an umbrella species whose conservation is beneficial to an entire ecosystem. At the heart of the enormous network that is biodiversity, the well-being of this species takes on special significance.

Watercourse stakeholders and managers are indispensable allies in conservation efforts, and were accompanied by the programme in their actions in favour of river rehabilitation and habitat quality improvement. In addition to the conservation of this heritage species, the project also dedicated resources to educating the public, elected officials, and professionals through (among other initiatives) site visits; a film documenting the project; and publications to inform and to raise awareness.

In the long term, the cooperation of stakeholders and the public around the issue of habitat restoration will improve the species' chances of once again enjoying access to good-quality watercourses.

Natura 2000 Zone	Watercourse	Department	Region	2016 Freshwater pearl Mussel Population	Proportion of Population in the Armorican Massif
FR530C013	Elez	Finistère	Brittany	1,000 – 1,500	27.8%
FR530C007	Loc'h	Côtes-d'Armor	Brittany	100 – 200	2.8%
FR530C025	Bonne Chère	Morbihan	Brittany	2,000 – 3,000	55.6%
FR250C113	Airou	Manche	Normandy	200 – 300	5.6%
FR250C091	Rouvre	Orne	Normandy	100 – 200	2.8%
FR2502015	Sarthon	Orne	Normandy	200 – 300	5.6%

Partners and Co-financiers

Two partners collaborated with Bretagne Vivante in this initiative: the Fédération de Pêche du Finistère, which insured the *ex-situ* conservation of freshwater pearl mussels; and CPIE Normandy Hills, which acted as a hub for field operations and communication in Normandy.

Operations in Normandy were also piloted by the Sienne River Planning and Management Authority and by the Normandy-Maine Regional Nature Reserve, for the Airou and Sarthon Rivers respectively.

This project was financed through the European LIFE+ and Natura 2000 programmes, with contributions from the DREALs of Brittany and Normandy; the Regions of Brittany and of Normandy; the Departmental Councils of the Côtes d'Armor, Finistère and Manche; and the Seine-Normandy Water Agency.

Why this Report?

The publication of this report provides an opportunity to share the LIFE programme's 6 years of experience with other organisations in the hope of facilitating further initiatives in favour of freshwater pearl mussel conservation.

A situational analysis of the Armorican Massif will be followed by sections on population monitoring methods, environmental conditions and habitat restoration. *Ex-situ* breeding techniques as well as those of population reinforcement will be described.

In conclusion, the tools for raising awareness and communication developed in the context of the project, as well as the Regional Action Plans for Brittany and Normandy, will be presented.

Situational Analysis

Description

The freshwater pearl mussel is a bivalve once commonly found in the oligotrophic (see glossary) rivers of France, and is classed in the order Unionida. Otherwise known as naiads, this order includes eleven species of freshwater mussel found in France. Two of these French species are classed in the family Margaritiferidae, including *Margaritifera margaritifera*, the freshwater pearl mussel.

*Various freshwater mussels, from top to bottom: the swan mussel (*Anodonta cygnea*); *Unio mancus*; and the freshwater pearl mussel (*Margaritifera margaritifera*).*

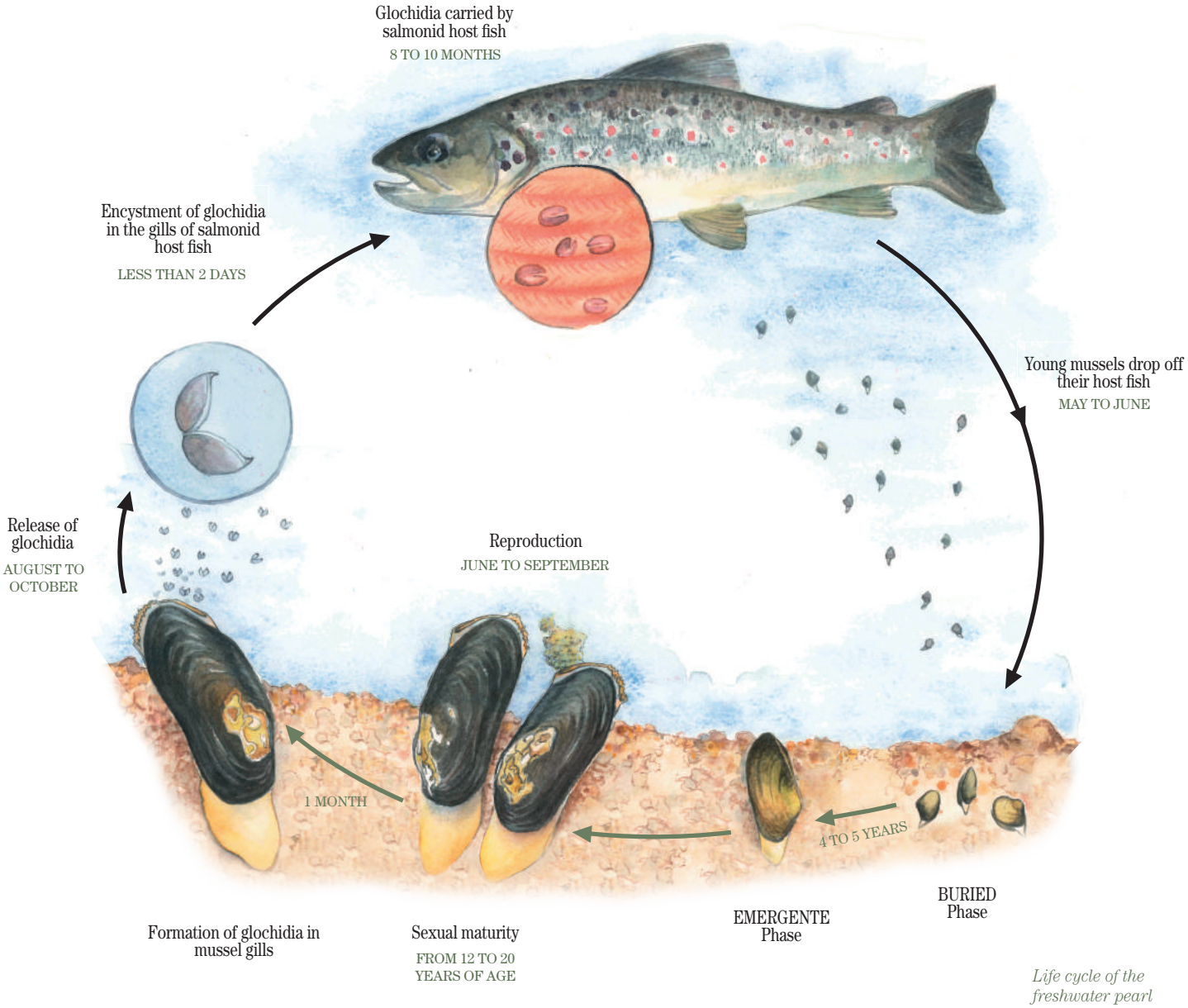
The elongated shell of the freshwater pearl mussel changes from brown during its juvenile stages to black at the adult stage. Adult shell length varies considerably from one watercourse to another, with a maximum length of around 150mm. Shell width ranges from 40 to 50mm. The freshwater pearl mussel can be identified through an examination of its teeth, which interlock when the shell is closed. Freshwater pearl mussels possess two cardinal teeth on the left valve and only one on the right; they have no lateral teeth.

With an exceptionally long lifespan, individuals of this species can live to be more than 100 years old. A filter feeder, the freshwater pearl mussel passively filters suspended particles carried in river water. An individual mussel can filter around 50L of water per day.

Life Cycle

At around 15 to 20 years of age, freshwater pearl mussels are sexually mature (see diagram below), and males and females become differentiated. Males release spermatozoa, which females intercept through filtration. Fertilisation takes place at the end of spring or during the summer, depending on geographic location. Under certain conditions, such as stress or low population density, freshwater pearl mussels may become hermaphroditic (Bauer, 1987).

Larvae, known as glochidia, are held within the gills of female mussels, where they receive oxygen. Glochidia, measuring 60–70µm, are released into the water between June and October and attach themselves to the gills of host fish (brown trout or Atlantic salmon), where they remain encysted for around 10 months (Bauer, 1994). The following spring, the young mussels, measuring 500µm, drop off their host fish and fall into the riverbed, where they burrow and will continue to grow for the next 5 years. After this period, mussels return to the surface and continue to grow, half-buried, as adults.



Life cycle of the freshwater pearl mussel.

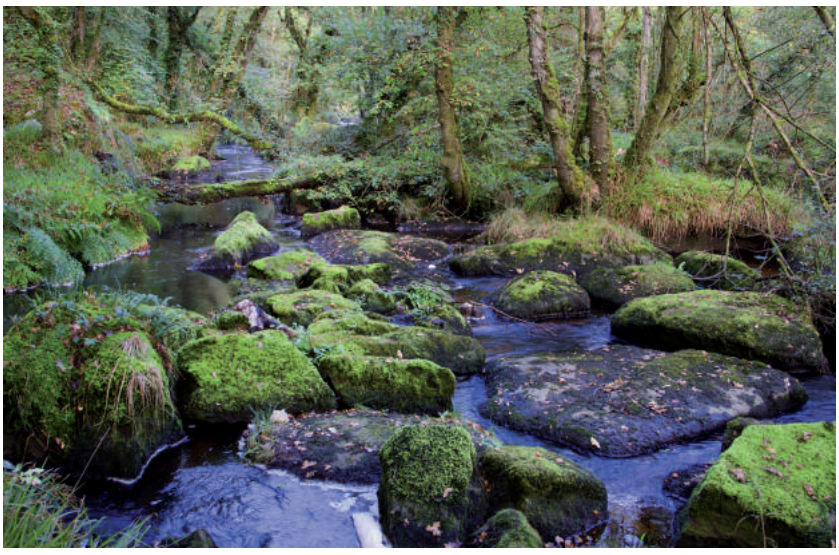
(CPIE Normandy Hills, Manuela Tétrel)

Habitat

In France, the freshwater pearl mussel is found in oligotrophic watercourses with siliceous beds and healthy populations of Atlantic salmon (*Salmo salar*) or brown trout (*Salmo trutta fario*), its host fish species. Pearl mussel habitat must comprise gravelly or stabilised sandy areas with structural elements such as cobbles or boulders, and must not be subject to strong currents such as those found in riffles. Mussels are sometimes observed behind stabilised stones where they shelter from the current.

Good habitat quality, particularly as regards sediment, is vital for young mussels. They must be able to burrow to a depth of several centimetres and to find enough oxygen at this depth to survive for at least 5 years (Geist, 2005). The sediment must therefore not be clogged but must permit sufficient exchange between free-flowing and interstitial water layers, and must be relatively stable over time.

Water quality is also important to freshwater pearl mussel survival, particularly at the adult stage. The species is very sensitive to water temperature, oxygenation, pH and mineral levels. The habitat required for a functioning population seems nevertheless to depend more on the physical properties of the substrate than on the chemical properties of the environment (Geist & Auerswald, 2007).



Rivers and habitat favourable to the freshwater pearl mussel in Brittany.

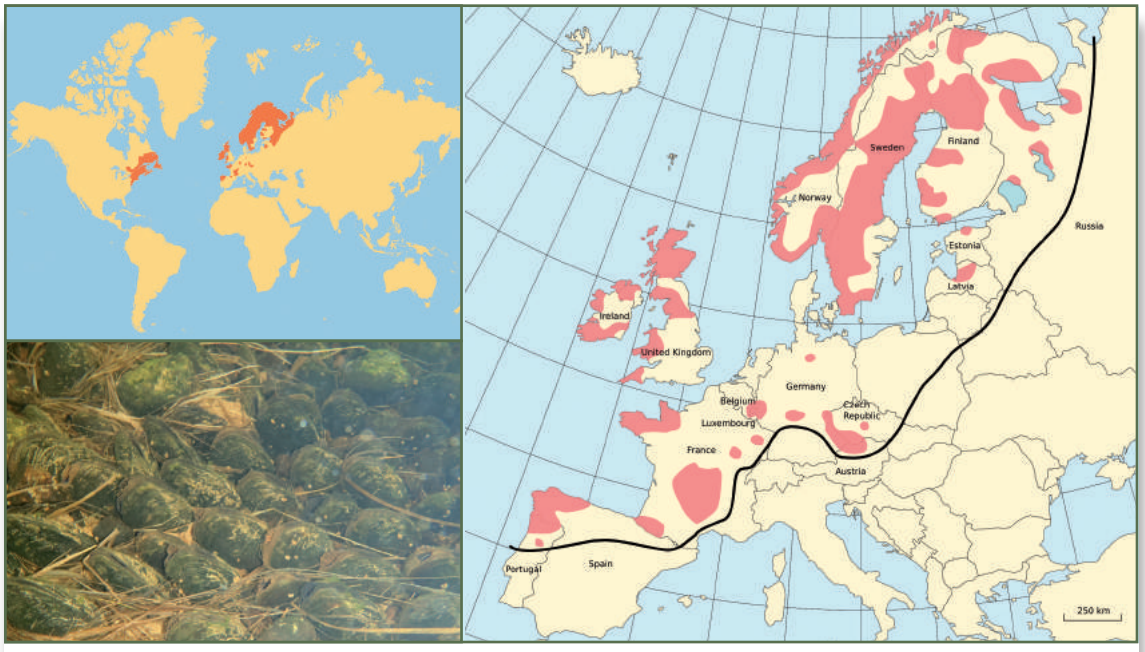
[Hervé Ronné]

Population Distribution and Conditions

Worldwide freshwater pearl mussel distribution correlates more or less with the distribution of Atlantic salmon, one of the species' host fish (see figure below). Its habitat is therefore to be found in North America (Canada and the United States) and along the western edge of Europe, from Spain to Scandinavia. Populations are also found in Central Europe, the Czech Republic, Austria and Germany.

In France, distribution became quite fragmented during the 19th century. Today's total population is around 100,000 individuals, with numbers having declined rapidly over the last century. In the past, the species was likely present in all oligotrophic rivers flowing over crystalline massifs. Today, it has disappeared from over 60% of watercourses and its population has diminished by at least 90% (Cochet, 2004).

Most freshwater pearl mussel populations are still able to reproduce, but it is the noted absence of young individuals (that is to say of recruitment), together with ageing populations, that have led to the urgency of the actions being put into place to conserve the species in the watercourses of Brittany and Normandy.



Country	Estimated number of population	Estimated number of individuals	References
Norway	380	143,000,000	Larsen (2010)
Sweden	618	39,000,000	Söderberg *et al.* (2012)
Finland	100	1,500,000	Oulasvirta (2010), Oulasvirta *et al.* (2015)
Russia	110	143,500,000	Mahkrov *et al.* (2014), Popov & Ostrovsky (2014)
Estonia	1	35,000	*cf.* Geist (2010)
Latvia	8	25,000	Rudzite *et al.* (2015)
Germany	69	144,000	Geist (2010), Altmüller (2015)
Czech Republic	5	16,000	Simon *et al.* (2015)
Austria	20	35,000	Csar *et al.* (2012)
Belgium	5	2,500	Motte *et al.* (2013)
Luxembourg	1	60	Arendt *et al.* (2010)
Scotland (UK)	115	12,000,000	Cosgrove *et al.* (2016)
Northern Ireland (UK)	6	22,000	Reid *et al.* (2012)
Wales (UK)	12	2,000	Killeen I. (pers. comm.)
England (UK)	10	550,000	Killeen I. (pers. comm.)
Ireland	139	12,000,000	Moorkens (2010)
France	82	100,000	Cochet (2004)
Spain	54	188,000	Lois *et al.* (2014)
Portugal	8	1,000,000	Reis (2003), Sousa *et al.* (2015)

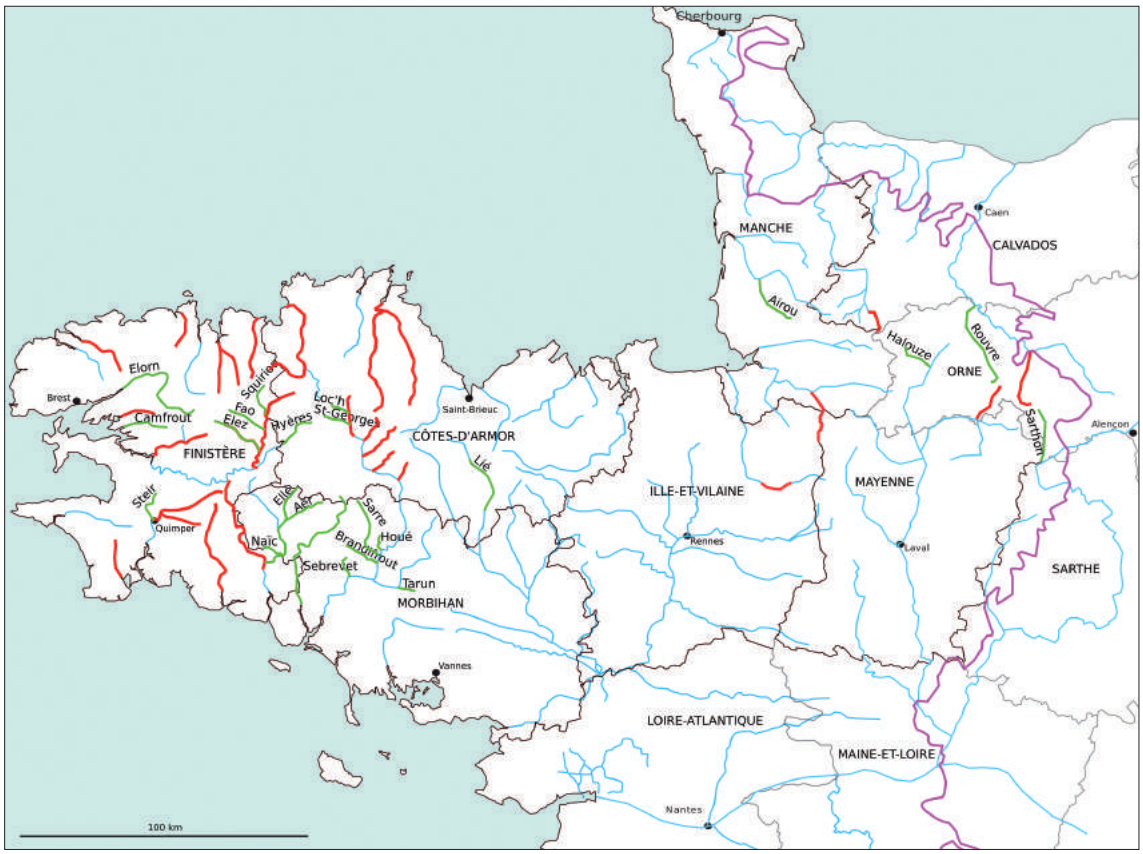
European and global Freshwater Pearl Mussel Distribution.

Situation in the Armorican Massif

The Armorican Massif can be said to constitute a 58,000km^2 natural area, on the one hand because of the geological unity of its subsoil, which is composed exclusively of primary structures, and on the other hand because of its isolation from other primary massifs by secondary or tertiary plains (the Parisian and Aquitaine Basins).

Its overall relief is relatively low, ranging between 100m and 400m in western Brittany where the Montagnes Noires and the Monts d'Arrée are located. In Normandy, the Normandy and Bas-Maine Hills have similar altitudes, while sometimes exceeding 400m (as in the case of the Monts des Avaloirs, the site of the Armorican Massif's apex of 417m).

Western Brittany has a hilly topography composed mostly of granite, and a yearly precipitation of over 900mm which is similar to that of the Normandy and Bas-Maine Hills. The relief in eastern Brittany and in the rest of the Armorican Massif is less uneven and is schist-based; its yearly precipitation is less than 800mm. The rivers of western Brittany and the Normandy and Bas-Maine Hills bear many similarities to mountain rivers, being quite steep with steady flow and cool summer temperatures.



Freshwater pearl mussel distribution in the Armorican Massif. In red: rivers hosting a mussel population prior to 2010; in green: rivers hosting a mussel population after 2010.

[Pasco & Hesnard, 2015 – updated in 2016]

Historically, throughout the Armorican Massif, at least 52 rivers in 29 watersheds were home to a freshwater pearl mussel population (see map opposite).

Today, 24 rivers in 11 watersheds still host the species. In 14 of these rivers, there are fewer than 100 individuals in a population showing no sign of recent recruitment. Only 10 rivers have a population of more than 100 (see table below) comprising a few young individuals, most notably in the sub-watershed of the Sarre River.

The total Breton and Norman population is estimated at between 5,000 and 6,000 individuals, with the Aulne and Blavet watersheds hosting more than half of these.

Region	Watershed	Sub-watershed	Estimated population
Brittany	Aulne	Elez	1,000 - 1,500
		Fao	100 - 200
	Ellé	Aër	100 -200
	Blavet	Loc'h	100 - 200
		Sarre	2,000 - 2,300
		Brandifrout	100 - 200
		Tarun	100 - 200
Normandy	Sienne	Airou	200 - 300
	Orne	Rouvre	100 - 200
	Loire	Sarthon	200 - 300

Rivers with more than 100 individuals as of 2016.

Taking into consideration all extant freshwater pearl mussel populations, traces of mussel presence or found shells, and making a reasonable estimate of about 2,000 individuals per mussel population at the beginning of the 20th century, it is possible to estimate a minimum 95% decline in freshwater pearl mussel numbers in the Armorican Massif over a period of 50 years.

Threats

As elsewhere in Europe (Lopes-Lima *et al.*, 2016),the causes of decline are varied, being attributable to pearl-fishing at the beginning of the 20th century and water-quality degradation and watercourse dysfunction (largely due to hydromorphological changes) in the latter half of the 20th century.

The first of these factors is no longer an issue in France today, as the species is protected by law. Conversely, the problems linked to watercourse dysfunction are not resolved and have multiple causes, including lack of ecological continuity, water body degradation, clogging and pollution, among others. The issues vary depending on the watercourse and watershed concerned, and are multiform, complex and unfortunately not always well-identified.

Pearls from freshwater pearl mussels.

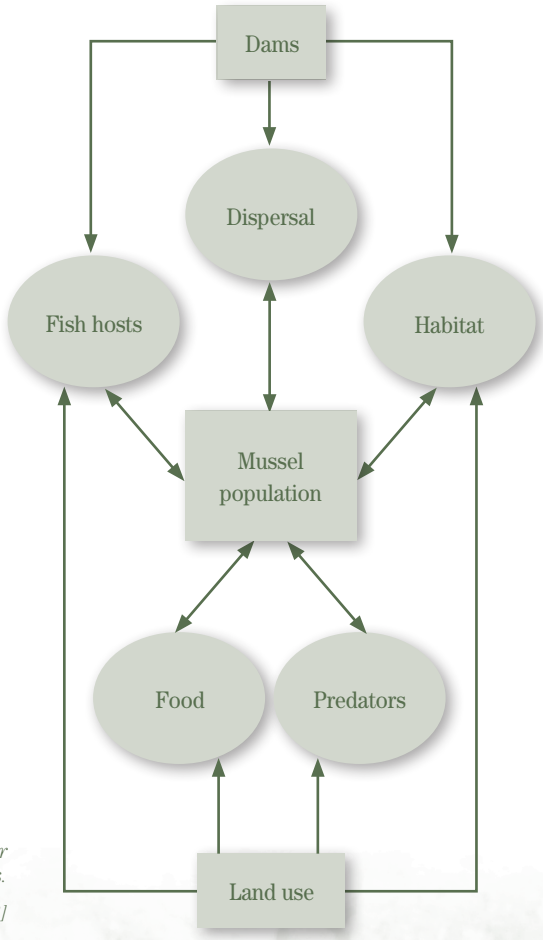
Cattle watering provoking changes to the riverbank.

Problems occur at various stages of the mussels' complex life-cycle, or that of its host fish. Firstly, land use can have a significant effect on watercourse function, particularly through fine sediment input stemming from bare soil erosion. These fine particles can then cause clogging in the spawning areas of host fish, resulting in egg mortality. Similar problems can occur in areas where young mussels are buried in the sediment. Further, land use also has a likely influence on a watercourse's primary production, which is the mussels' food source.

A healthy host fish population is essential for pearl mussels. The health of a population may be affected by, among other factors, obstacles between fish and the areas necessary for their reproduction, growth, feeding or shelter.

Although mussels have few natural predators, the introduction of muskrat and raccoons can be a threat.

The various factors acting and interacting with freshwater pearl mussel populations can be brought together as Strayer (2008) proposes in the following figure:



A predictive model of freshwater pearl mussel population densities.

[Strayer, 2008]

Status

The freshwater pearl mussel is a species of community interest and appears in Annexes II and V of the European Habitats Directive as well as in Annex III of the Berne Convention. It is also protected under French law, as per this extract from the decree of 23 April 2007:

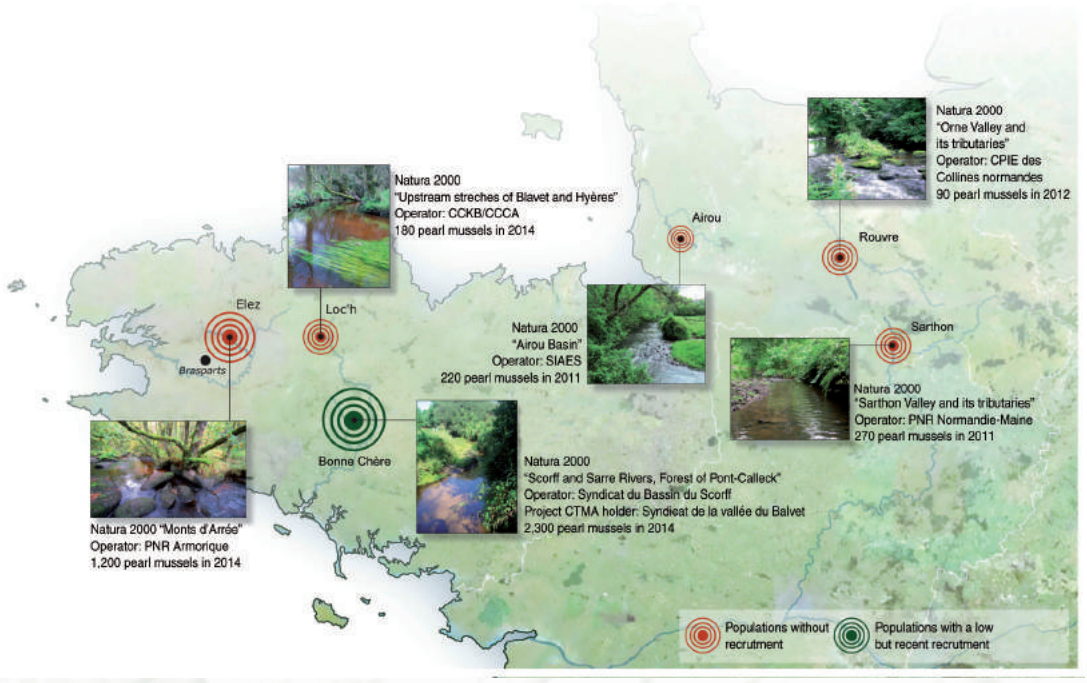
> **« … on French territory, at all times, are prohibited the destruction, alteration or degradation of particular environments (…), the destruction or intentional disturbance of individuals (…), their trafficking, their advertisement for sale, their sale or their purchase ».**

The IUCN (see glossary) classes the freshwater pearl mussel as globally endangered and, since 2011, this international NGO for nature conservation has classed it within Europe as critically endangered, the next stage being extinct in the wild.

Study Sites

Three rivers in Brittany host its remaining pearl mussel populations: the Elez River, which winds through the peaty plains of the Monts d'Arrée; the Bonne Chère River in the upstream reaches of the Sarre watershed; and the stream of Loc'h Pond, which runs into the drinking-water reservoir of Kerné Uhel.

In Normandy, the principle populations have been counted and identified in three watercourses: the Rouvre River, which runs through Swiss Normandy; the Sarthon River, which has its source in the upper Ecouves Forest; and the Airou River, which has seen remarkable success with regards to Atlantic salmon reproduction.



Location of study sites in the Armorican Massif.
[Carte Bretagne Vivante]

Elez

The Elez River and the Roudoudour, one of its affluents, are included in the Natura 2000 site "Central and Eastern Monts d'Arrée", no. FR5300013 (Department of Finistère, Brittany). In 1997, when Bretagne Vivante inventoried the various Breton mussel sites, there were 2,000 individuals on the Elez site. A 2004 study found only 500 individuals. All the sampled individuals were over 80 years old, which demonstrates an absence or failure of recruitment since the 1920s. Almost all the mussels were concentrated in a single area upstream of the entry point of Saint Herbot Pond, near a blockfield.

The absence of host fish is the principal threat identified with this site. With two hydraulic structures in place since 1920, there is significant water flow management which is now regulated by prefectoral decree (after a dry spell in 2003, combined with poor water-level management, the Elez almost ran dry). Water quality is relatively good but could be further improved, and the main problems seem to have been identified: private ponds and runoff from water purification stations, quarries, etc.

Loc'h

The stream of Loc'h Pond is part of the Natura 2000 site "Basin Heads of the Blavet and Hyères Rivers" no. FR5300007 (Department of the Côtes d'Armor, Brittany). 180 individuals were counted there in 2008, and the inverted age pyramid of this group points to a declining population and life cycle dysfunction. In 2008, electric fishing revealed a population of young trout with mussel larvae in their gills.

Water quality measurements showed nitrate levels varying between 10 and 20mg/L over the course of the year. The spruce forests bordering numerous parts of the watercourse were causing a clogging-up of the aquatic environment and were weakening the banks.

The Elez River freshwater pearl mussel site.

The Loc'h stream freshwater pearl mussel site.

Elez River freshwater pearl mussels.

Loc'h stream freshwater pearl mussels.

Bonne Chère

The Bonne Chère River is part of the Natura 2000 site "Scorff and Sarre Rivers, Pont-Calleck Forest" no. FR5300026 (Department of Morbihan, Brittany). In 2000, the population was estimated at 620 individuals, many of which were grouped together tightly in certain spots.

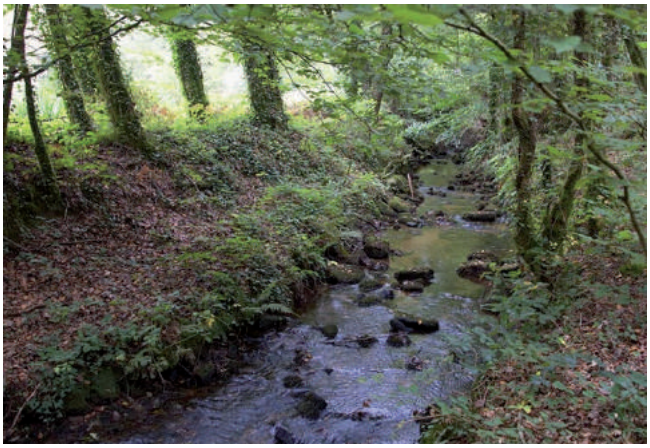
In 2009, an updated inventory counted around 1,000 individuals in this watercourse. Their distribution corresponded with that of wooded banks, and the area of maximum density was in an area with a relatively strong current. Electric fishing carried out in 2008 revealed the presence of young trout with glochidia in their gills.

Airou

The Airou River is in the Natura 2000 site "Airou River Watershed" no. FR2500113 (Department of Manche, Normandy). In 2008, 59 individuals were counted there; these mussels were of an advanced age and no signs of reproduction were observed.

Water quality measures showed a relatively high level of organic pollution which had persisted over a period of 20 years and was due to corn farming, bank trampling, bank erosion, fertiliser applications on permanent or temporary fields, etc. Other sources of disruption were noted, such as the Bourguenolles quarry which caused occasional low-pH runoffs and high electrical conductivity due to the presence of pyrite in the quarried rock.

The Bonne Chère River freshwater pearl mussel site.



The Airou River freshwater pearl mussel site.

A Bonne Chère River freshwater pearl mussel.

Airou River freshwater pearl mussels.

Rouvre

The Rouvre River is part of the Natura 2000 site "Orne Valley and its Affluents" no. FR2500091 (Department of Orne, Normandy). In 2002, the mussel population was estimated at 110 individuals spread over 10km, with no reproduction observed among its elderly individuals. In 2009, electric fishing revealed the presence of young trout bearing mussel glochidia in their gills.

The majority of this mussel population is located within the Natura 2000 site; however, the greatest threat to it is located in the upstream portion of the watershed (outside the Natura 2000 zone) in an area of flatter land where agricultural activity has intensified. Environmental and water quality are mediocre in this area, with high levels of nitrates, pesticides and turbidity which have their origins in agricultural runoff from fields upstream.

Sarthon

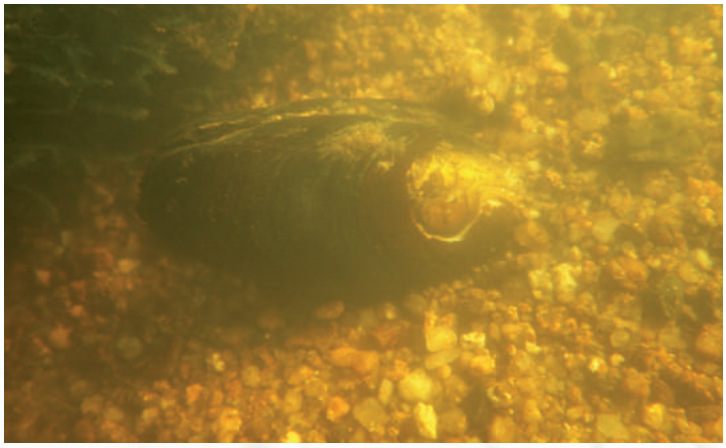
The Sarthon River is part of the Natura 2000 site "Sarthon Valley and its Affluents" no. FR2502015 (Department of Orne, Normandy). 152 freshwater pearl mussels were counted in the Sarthon and one of its affluents, the Roche-Elie, in 2006; no reproduction was observed. The population, composed of aged individuals, was mostly concentrated within a 4km stretch.

The principal threats to this site's mussel population are high levels of agricultural inputs and their negative effects (soil runoff, bank erosion, etc.).

The Rouvre River freshwater pearl mussel site.

The Sarthon River freshwater pearl mussel site.

A Rouvre River freshwater pearl mussel.



A Sarthon River freshwater pearl mussel.

River	Watercourse Width (m)	Strahler Number	Average Flow (m^3/s)	Altitude (m)	Watershed Surface (km^2)
Elez	8	3	1.5	210 - 220	61
Loc'h	4	2	0.33	220 - 230	18
Bonne Chère	4	2	0.25	120 - 130	17
Airou	10	2	1.96	30 - 40	115
Rouvre	12	4	3.5	100 - 130	324
Sarthon	7	3	0.7	200 - 230	120

Characteristics of the rivers and watersheds studied

(numbers relate to mussel sites, with the exception of watershed surface figures)

Population Monitoring

In any species conservation programme, it is necessary to collect data on populations, including distribution, size and evolution, structure, reproductive data, etc.

Preliminary Survey

Based on existing information, estimates were made of the location of each site's mussel population in order to determine in particular the up- and downstream limits of various clusters and population size.

Inventorying was carried out both up- and downstream, most often in pairs, with a hydroscope (also known as an aquascope). In some cases, a light was added inside the aquascope in order to improve visibility. In deep areas, such as on the River Elez, inventories were carried out by snorkelling.

The best time for observing river bottoms is during the low water season, when water levels are lower and the current is weaker. This period often falls between June and September.

River	Distance Covered (m)	Average Watercourse Width (m)	Surface Covered (m^2)	Number of Individuals Observed	Mussel Density ind./m^2
Elez	350	8	2,800	1,160	0.414
Loc'h	800	3.75	3,000	180	0.060
Bonne Chère	1,000	3	3,000	2,320	0.773
Airou	9,000	10	90,000	223	0.002
Rouvre	12,170	12	146,040	92	0.001
Sarthon	5,400	7	37,800	268	0.007

Table of survey.

Around 30km of watercourses were searched, resulting in the observation of more than 4,000 mussels. More than 80% of this number was located on the Elez and Bonne Chère rivers, where the highest population densities were also observed. Indeed, on the Bonne Chère, densities of 30 to 40 individuals per m^2 were recorded.

An area with high population density on the Bonne Chère.

Control-Site Monitoring

To obtain a more precise idea of population size and to follow populations' evolution over time, control stretches were selected on each watercourse for implementation of the capture-mark-recapture method.

On these stretches, several searches were carried out with each observed individual being marked.

Depending on the number of passes carried out (between 2 and 4), various indexes could be used to estimate the size of the population. From the data obtained, species detectability and population density could be estimated.

River	Sector	Surface Sampled (m^2)	Number of samples	Seber Estimate	Bailey Estimate	Schnabel Estimate	Confidence Range at 95%	Average Detectability	Average Density
Elez	1	45	2	117	117	--	109-128	0.86	2.60
	2	116.1	4	45	44	46	31-79	0.58	0.40
Loc'h	1	87.4	4	25	25	23	15-34	0.65	0.26
	2	82.8	4	18	17	16	10-25	0.69	0.19
	3	86.4	4	17	17	17	10-26	0.86	0.20
	4	101.2	2	18	18	--	16-24	0.94	0.18
Bonne Chère	1	56	2	345	344	--	16-24	0.60	6.14
	2	58	4	13	12	10	5-18	0.60	0.17
	3	58	3	39	38	26	17-38	0.65	0.45
Airou	1	640	4	9	9	8	6-13	0.97	0.01
Rouvre	1	1,680	4	11	10	11	7-21	0.52	0.01
Sarthon	1	290	4	34	33	30	24-40	0.75	0.10
	2	353	4	23	23	22	17-314	0.76	0.06
	3	246	4	20	20	17	13-25	0.81	0.07

Results of CMR surveys in the control stretches

These results partly reflect the variety within the stretches and watercourses studied. Detectability varied between 0.52 and 0.97, being lowest on the Rouvre due in great part to the turbidity, the greater depth, and the low population density of mussels on this river.

The nature of the substrate and shade projected by riparian vegetation can also contribute to low detectability. Stretches with high detectability are usually flatter and more shallow with clearer water.

These results show that on a single pass, in most cases, not all the mussels present are observed. However, with two passes, the estimate obtained seems to be representative of actual numbers. Multiplying passes contributes to better estimates, but can also disrupt mussel habitat and possibly lead to individuals being crushed underfoot. In the case of annual or biannual monitoring, two passes are sufficient to estimate the number of individuals on a stretch.

Population Structure

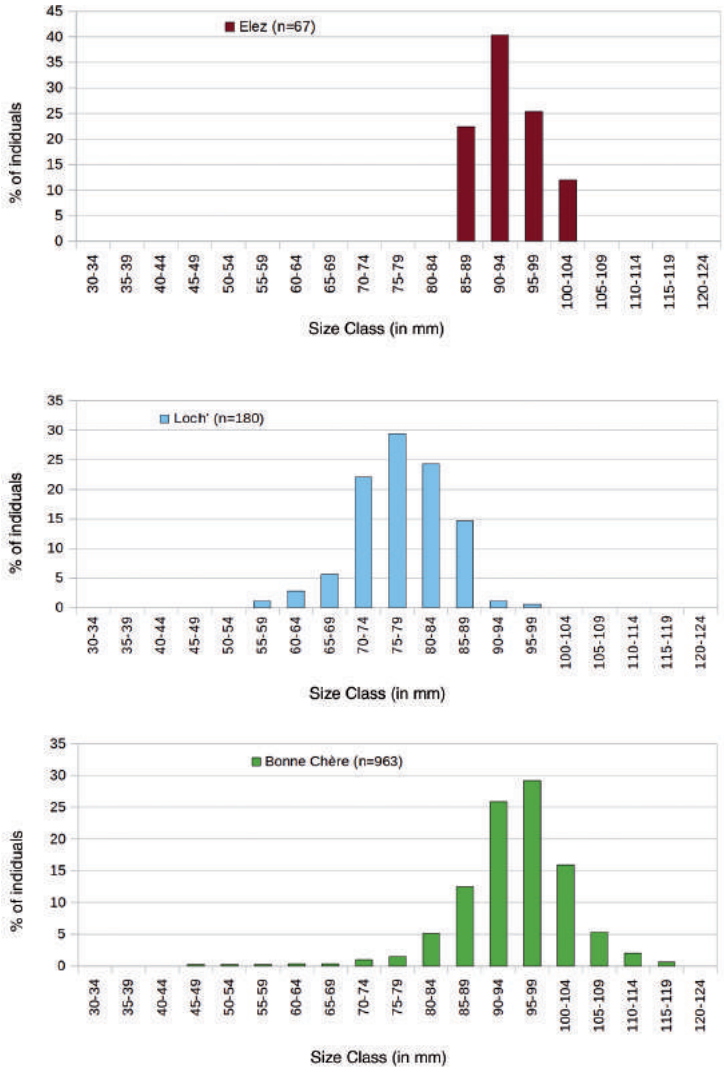
To establish population structure, the shell length of several dozen mussels was measured, and the measurements were classed by size (per 5mm). These measurements were only taken for Breton populations.

The opposite graphs illustrate an absence of recruitment in the Elez and Loc'h, and some recruitment in the Bonne Chère, which was recently verified by the observation of individuals measuring less than 30mm.

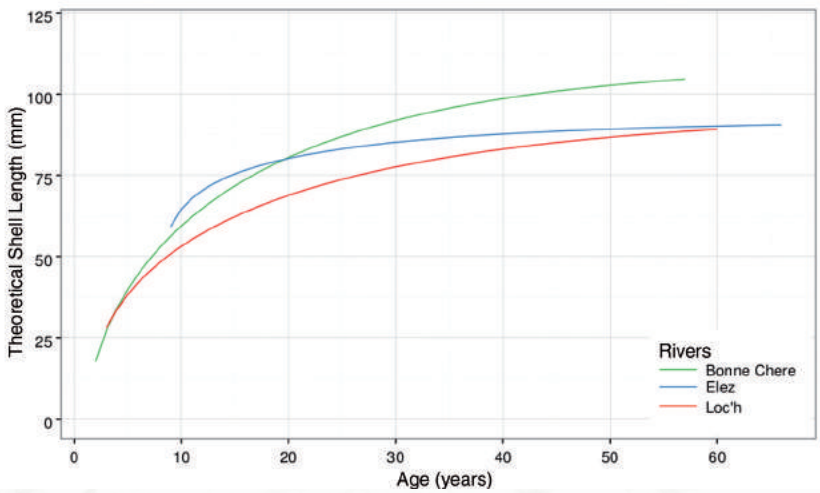
In Normandy watercourses, all observed individuals were in the same size range and an absence of recent recruitment was noted.

A sclerochronological study of empty shells carried out with the help of the University of Western Brittany's *Institut Universitaire Européen de la Mer* (IUEM) allowed theoretical growth curves to be plotted for various populations (Thebault et al., 2015). Through this study, shell length could be related to the age of a specimen.

Measurement of a mussel with slide callipers.



Distribution of mussel samples for each river, classed by size.



Von Bertalanffy growth model for the 3 Breton populations.

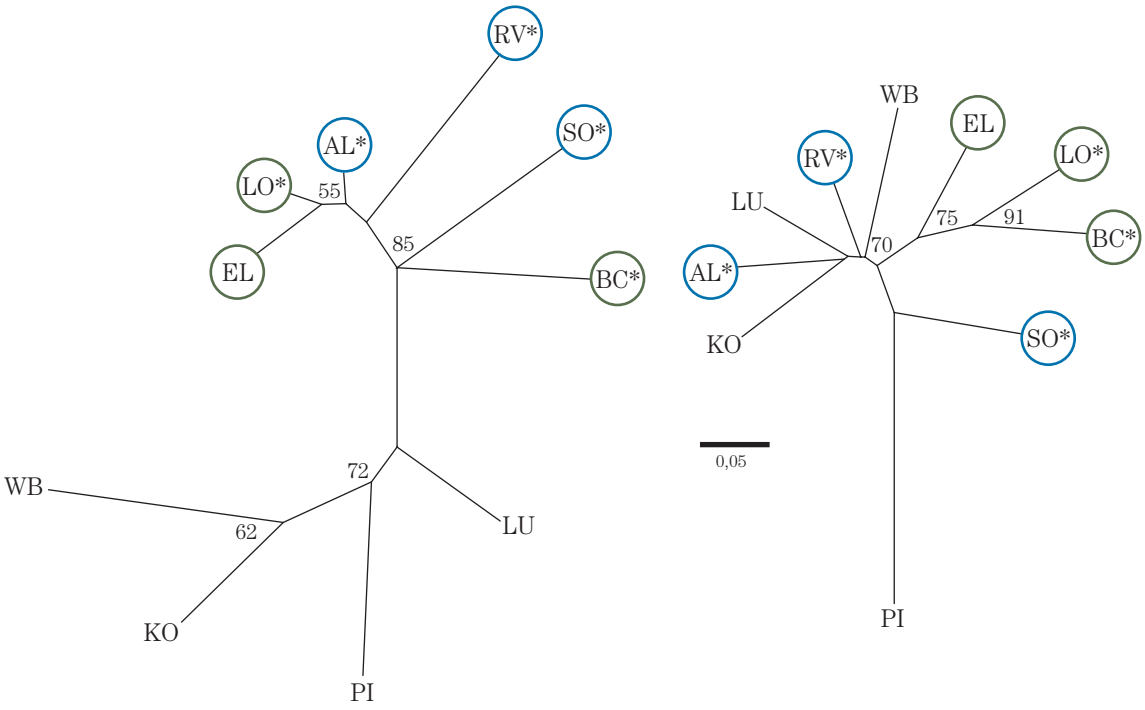
Genetic Analysis of the Populations

In 2011, Jürgen Geist of the University of Munich sampled the pearl mussel populations in the 6 watercourses in order to carry out genetic analyses. In 2013, samples were also taken from trout populations in each watercourse for the purposes of genetic analysis.

Neighbour-joining phenograms (Nei *et al.*, 1983) indicating the genetic distance between various pearl mussel populations. Breton populations (BC, EL, LO) for the two species are indicated with a pink circle. (WB: Wolfsbach [Germany]; KO: Danube [Germany]; PI: Kemijoki [Finland]; LU: Lutter [Germany]) (based on Geist, 2014).

There is a geographic logic to genetic variation in trout populations, but this variation in pearl mussel populations is less well-defined. The 3 Breton trout populations are relatively similar genetically, while the 3 Norman populations are very different, which correlates with the geographical distance between the watersheds studied: the Sienne, the Orne and the Loire.

However, the pearl mussel populations of the Loc'h and Elez are genetically similar, while the Bonne Chère population's genetics differ significantly from those of all other populations. Furthermore, the Airou population is more similar to that of the Loc'h, which is a Breton population, than to that of the Rouvre, to which it is closer geographically.



Margaritifera margaritifera *Salmo trutta*

Neighbour-joining phenograms (Nei et al., 1983) indicating the genetic distance between various pearl mussel populations (left) and brown trout (right). Breton populations (BC, EL, LO) for the two species are indicated with green and blue circles. (WB: Wolfsbach [Germany]; KO: Danube [Germany]; PI: Kemijoki [Finland]; LU: Lutter [Germany])

(Geist, 2014).

Environmental Monitoring

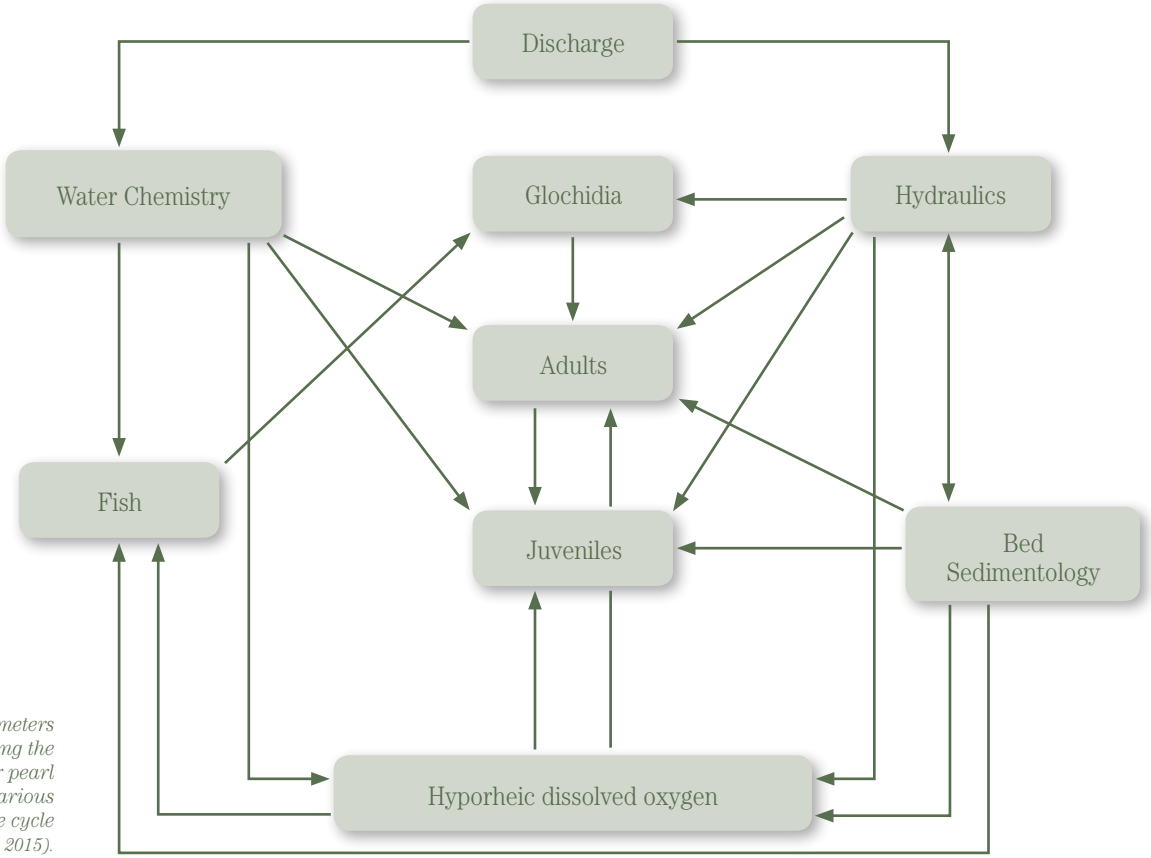
Throughout all its life stages, the freshwater pearl mussel is very sensitive to the quality of its environment, and requires a functional habitat that is suited to each of its three biological stages:

– glochidia (free phase, then stationary in the gills of a salmonid);

– juvenile (fully-buried phase);

– adult (half-buried phase).

Adults are, however, more tolerant of slight variations in environmental conditions than are young mussels. The state of mussel habitat depends on numerous parameters, of which some are described here. Monitoring these parameters should be helpful in identifying possible reasons for population dysfunction.



Parameters influencing the freshwater pearl mussel in the various stages of its life cycle (Quinlan et al, *2015).*

Water Quality

The freshwater pearl mussel is a filter feeder: water quality is important to its survival. Regular monitoring of the main physico-chemical properties of the water in its environment is thus strongly recommended.

Physico-chemical Parameters

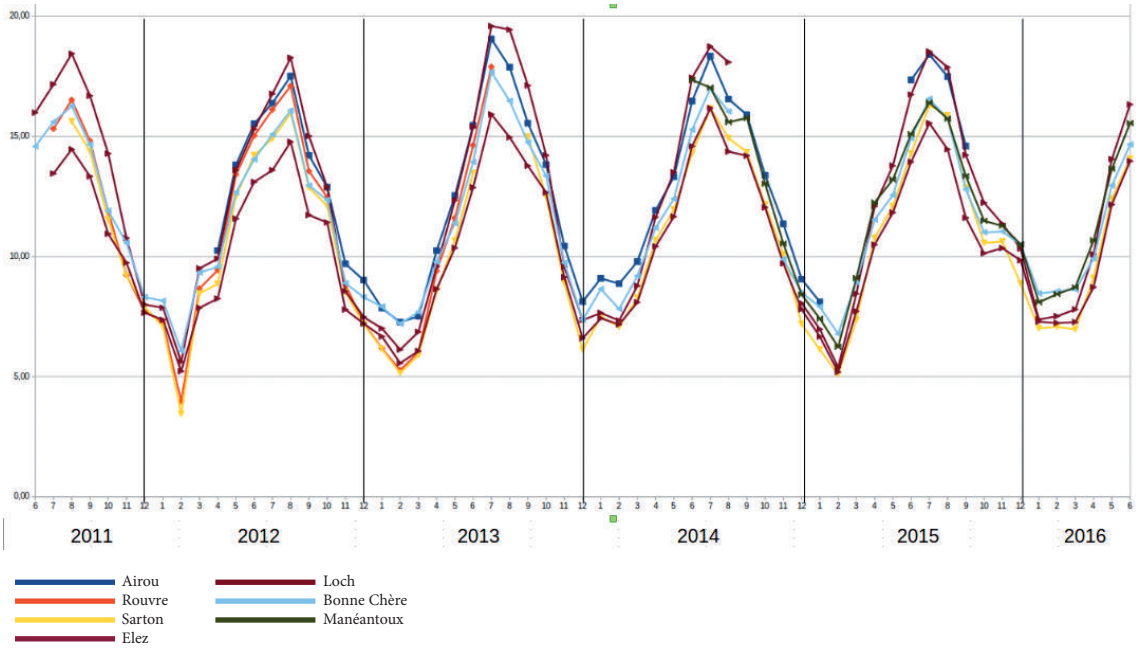
Several physico-chemical parameters were selected for their representativeness of a general level of quality, for their significance in freshwater pearl mussel ecology and for their significance relative to anticipated disruptions.

The parameters selected were: temperature; pH; dissolved oxygen; conductivity at 25°C; nitrates (measured in NO_3^-); and orthophosphates (measured in PO_4^{3-}). For each study location, the measurement and sampling site was located upstream of the mussel bed (or of the area with the highest population density).

Each parameter was measured once per month throughout the project, with the exception of temperature, which was recorded hourly with a probe installed at each site. Alkalinity was measured several times throughout the project during periods with varying water flow. Tests for pesticides were also carried out on several occasions.

Dissolved oxygen, conductivity and pH were measured on-site with a HANNA HI9828 multiparameter meter. Temperature was measured with HOBO probes. Other parameters were measured in a laboratory using water samples.

Materials: a multiparameter meter, sampling containers and a HOBO temperature data logger.



Evolution of the monthly average temperature in the rivers studied.

	Conductivity at 25°C (µS/cm)	pH	Nitrates (NO_3^- mg/l)	Nitrates (N mg/l)	Ortho-phosphates (PO_4^{3-} mg/l)	Ortho-phosphates (Pmg/l)	Dissolved Oxygen (O_2 mg/l)	Alcalinity (Ca mg/l)	Alcalinity ($CaCO_3$ mg/l)
Elez	71 ± 18	6.2 ± 0.6	2.6 ± 1.2	0.6 ± 0.3	0.03 ± 0.01	0.01 ± 0.004	10.6 ± 1.8	1.7 ± 1.3	4.3 ± 3.2
Loc'h	131 ± 21	6.8 ± 0.3	11.2 ± 3.5	2.5 ± 0.8	0.07 ± 0.02	0.02 ± 0.008	10.6 ± 1.8	4.8 ± 3.9	11.9 ± 9.7
Bonne Chère	158 ± 24	6.6 ± 0.4	22.6 ± 4.4	5.1 ± 1.0	0.11 ± 0.09	0.04 ± 0.029	10.4 ± 1.6	5.6 ± 4.2	13.9 ± 10.4
Airou	194 ± 89	7.4 ± 0.5	19.5 ± 2.6	4.4 ± 0.6	0.08 ± 0.05	0.03 ± 0.018	9.6 ± 1.6	13.7 ± 3.8	34.2 ± 9.5
Rouvre	256 ± 76	7.2 ± 0.6	17.4 ± 6.0	3.9 ± 1.3	0.22 ± 0.20	0.07 ± 0.064	11.0 ± 3.2	14.7 ± 0.5	36.8 ± 1.1
Sarthon	109 ± 15	7.2 ± 0.5	15.7 ± 7.8	3.5 ± 1.8	0.06 ± 0.03	0.02 ± 0.012	10.1 ± 2.4	9.4 ± 2.4	23.4 ± 4.2

Averages (± standard deviation) of the various physico-chemical parameters monitored.

Biological Indicators of Water Quality

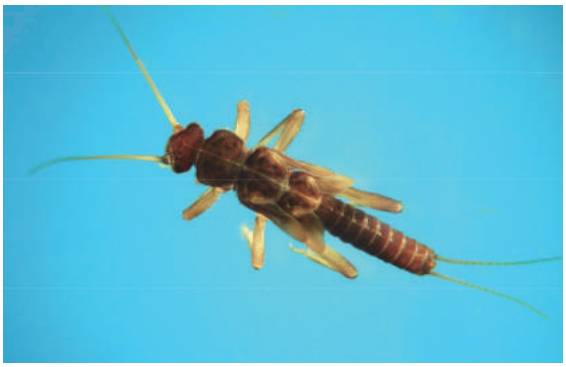
Macroinvertebrates

The quality of freshwater pearl mussel river habitat can be measured by the composition of its benthic macroinvertebrate community. These populations reflect in their structure any modification, however temporary, in their environment, such as physico-chemical or biological perturbations of natural or anthropogenic origin. They are an essential link in the trophic chain of an aquatic ecosystem.

Each country has its own system of measuring the quality of macroinvertebrate populations. In France, the IBG-DCE (Standardised Global Biological Index), a method standardised by the AFNOR Group, is used to describe general environmental quality with a grade between 1 and 20.

The IBG-DCE index is often used in tandem with the biogenic coefficient (Cb2), providing further pertinent and detailed information and taking into account the biogenic capacity and water quality of a site. 5 of the studied sites receive a rating of "very good" quality on the IBG-DCE index; quality on the Sarthon is rated as "good".

Macro-invertebrate sampling on the Elez



Plecoptera larva (F. Parais - DREAL Normandy)

Watercourse	IBG-DCE	Cb2
Elez	18	17
Loc'h	19	17
Bonne Chère	19	18
Airou	18	17
Rouvre	18	16,5
Sarthon	16	15

Results obtained for the various watercourses in 2014.

Mayfly larva (F. Parais – DREAL Normandy)

Diatom Index

The diatoms are brown microscopic algae made of a siliceous skeleton. They are a major component of the algal population of rivers and water courses. Considered as the algae the most sensitive to environmental conditions, they react to various types of pollution.

In France, the Diatom Index is a standardized method (NF T90-354 (2007)). This index indicates an "excellent" quality of water for the Elez river and a "good" quality for the Loc'h and the Bonne Chère rivers.

Watercourse	Diatom Index
Elez	17
Loc'h	14.6
Bonne Chère	14.3

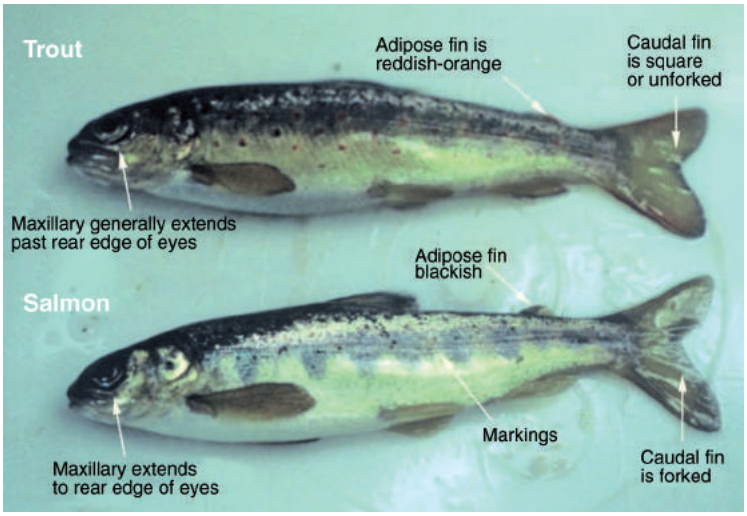
Results obtained for the various watercourses in 2014.

Host Fish

Host Fish Preference

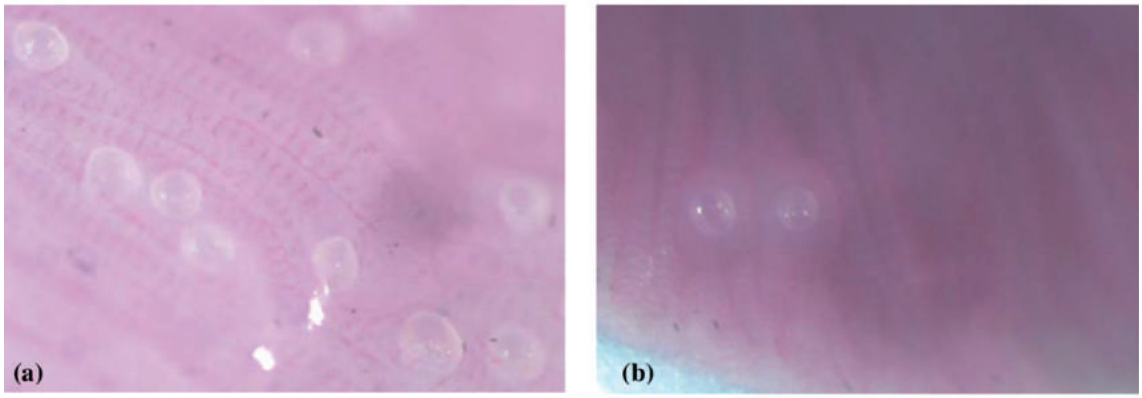
INRA carried out studies on the Bonne Chère River in Brittany (Evanno, 2013) and on the Airou River in Normandy in 2014. These studies set out to define freshwater pearl mussels' host fish preference (Atlantic salmon or brown trout) in those watercourses.

These studies showed that glochidia performed better on brown trout than on Atlantic salmon, and suggested that the brown trout is the preferred host fish species of the pearl mussel in the Bonne Chère and Airou Rivers.



Brown trout and Atlantic salmon juveniles

(photo : INRA)



Glochidia on the gills of a) brown trout and b) Atlantic salmon

(Photo: INRA).

Health of Host Fish Populations

Electric fishing was carried out in order to measure the health of brown trout populations in the various watersheds. The fish caught were measured, providing information about their age and the number of juvenile individuals in the population.

	Average Density (ind. / 100m²)	
Watercourse	0+	1+
Elez	4.8	2.8
Loc'h	4.6	12.6
Bonne Chère	12.1	4.7
Airou	6.4	5.7
Rouvre	7.9	6.5
Sarthon	3.2	6.8

Average density of brown trout (individuals/100m²) (0+ : fish born during the year 1+ : fish with more than 1 year age).

Electric fishing on the Loc'h river.

Searching for Larvae on Host Fish Gills

In spring, further electric fishing was carried out upstream of pearl mussel sites. On this occasion, the gills of captured fish were checked for encysted glochidia.

Infested fish were observed at all sites excepting the Elez. However, the density of glochidia was

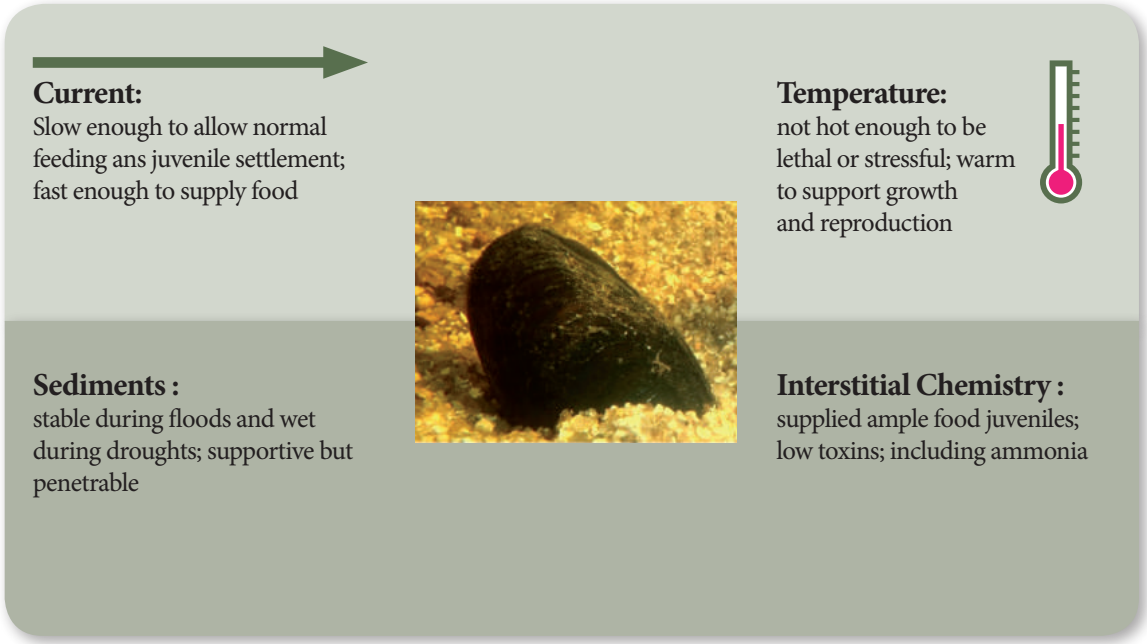
Encysted glochidia, visible as white spots on the gills of a brown trout from the Bonne Chère River.

Measuring a brown trout.

Trout in their environment.

Hydromorphology

Various hydromorphological parameters play a role in the suitability of habitat to the freshwater pearl mussel throughout its development: they are presented in the diagram below.



Significant parameters for the suitability of pearl mussel habitat (Strayer, 2008).

Habitat and Water Flow Characteristics

The freshwater pearl mussel generally prefers shallow watercourses in siliceous terrain with some current and clear, oligotrophic water. However, mussel habitats present much variety, and only the presence of unclogged, oxygenated sediment can guarantee the species a habitat suitable for burrowing and therefore survival.

There has been relatively little work done on characterising the micro-habitat of adults, and even less on that of juveniles. What studies there have been are comparatively similar with regards to methodology and are essentially based on observation and correlations made in the field. Little is known about the processes which control the correlations observed between habitat conditions and the abundance of the pearl mussel (Quinlan *et al.*, 2015).

One juvenile mussel on the River Aër, Department of Morbihan.

The current in low-water periods must remain strong enough to ensure water oxygenation and to prevent the substrate from becoming clogged through particle settling; also to be prevented is the formation of algal film and the corresponding rise in water temperature, which is harmful to pearl mussels. For the low-water period, Moorkens and Killeen (2014) place optimal current speed at around 0.30m/s near the riverbed, and at almost 0.40m/s at 60% depth. During high water periods, with a rise in flow (and current speed), mussels tend to burrow more deeply into the substrate; however, under certain conditions, some individuals may be dislodged by the current (Clements, 2015).

Several authors have indicated that critical shear stress could be useful in evaluating sediment stability (Allen & Vaughn, 2010; Gangloff & Feminella, 2007).

All activities and interventions on a watercourse which might alter current, flow, temperature, sediment displacement, levels of fine particles etc. should be monitored to evaluate their environmental impact. Although this aspect was not studied in the context of this programme, it seems important that it be a focus of future studies.

Substrate Quality

The nature of both the sediment and interstitial water impact greatly on the health of mussel populations and the possibility of recruitment. They are the best physical parameters to describe mussel habitat (Geist & Auerswald, 2007). Although adults can tolerate the sporadic presence of mud or silt, young mussels are found only in areas with stabilised cobbles or rocks and sufficient sand in which to bury themselves (Wahlström, 2006).

The stage during which young mussels burrow completely into the sediment is the most critical life cycle phase for this species (Bauer *et al.*, 1980). It is therefore important that the sediment be relatively free of organic matter, permitting exchanges between free-flowing and interstitial waters. In the interstitial zone, young mussels must benefit from the same water quality as that found in the river, at least in the first 5 to 10cm (Geist & Auerswald, 2007).

According to Geist and Auerswald (2007), some measures may be taken to describe areas where mussels survive and to locate potential sites for population reinforcement (see table below).

	Suitable Sites	Unsuitable Sites
Penetration Resistance	Homogeneity of Values 0.04-0.39kg/cm² (moy = 0.16kg/cm²)	Heterogeneity of Values 0.001-4.00kg/cm² (moy = 0.18kg/cm²)
Redox Potential	> 300mV	< 300mV
Conductivity Gradient	< 20%	> 20%
pH Gradient	< 20%	> 20%
Redox Potential Gradient	< 20%	> 20%

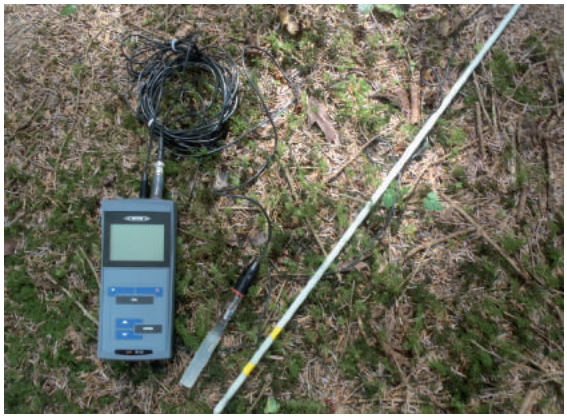
Guide values based on the functionality of a pearl mussel site.

A pronounced red-ox potential gradient, a difference between the conductivity of surface and interstitial waters and an excessively high or low penetration resistance together suggest a partitioning of surface and interstitial waters, and characterise an unsuitable site.

Water column characteristics in and of themselves are not sufficient to determine favourable habitat for the freshwater pearl mussel: sediment quality is decisive in young mussels survival. In general, interstitial and free-flowing water must be of good quality and possess very similar values.

To measure penetration resistance in the substrate, a pocket penetrometer was used (0–500kN/m²) with 4 discs of various diameters (15, 18, 20 and 25mm) to be used depending on the grain size of the sediment. To

A penetrometer.



pH meter with a Pt probe.

Syringe for sampling interstitial water.

Materials used in a series of measurements.

measure redox potential, a WTW 3110 pH meter was used together with a platinum probe[1] and a control Ag/AgCl probe. A HI 9828 multiparameter meter was used to measure conductivity and pH. A syringe attached to a plastic hose with a metal tube at the end was used to sample interstitial water at various depths.

The procedure followed for the various measurements is that recommended by Geist & Auerswald (2007). Measurements were taken during the low-water period, when conditions seem to be the most critical. At each site, penetration resistance was measured at 3 separate locations, while conductivity, pH and redox potential were measured at 3 depths: on the river bottom (0cm), and in the sediment at depths of 5 and 10cm.

1 - The Pt platinum probe has been created by Paleoterra : https://paleoterra.nl//

Corrections to be made to measurements depending on disc surface.

Disc diameter (mm)	No disc	15	18	20	25
Surface (cm^2)	1	1.77	2.54	3.14	4.91
Corrections To be Applied	n/a	Reading ÷ 1.77	Reading ÷ 2.54	Reading ÷ 3.14	Reading ÷ 4.91

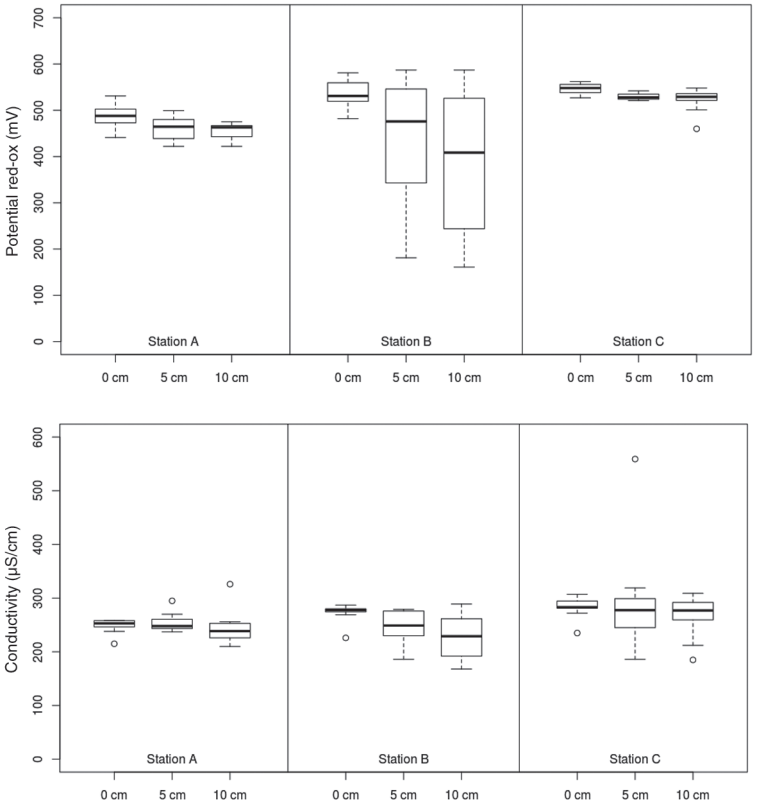
Redox potential (Eh) = Measured potential (Em) + Correction to be applied (Eref)

Table of corrections to be applied. For example, a measurement (Em) of 220mV at 12°C corresponds to a correction (Eref) of 217mV. The redox potential measurement at the electrode is 437mV.

Temperature in °C	Eref in mV
0-5	+224
5-10	+221
10-15	+217
15-20	+214
20-25	+210
25-30	+207
30-35	+203

The diagrams above illustrate the results of conductivity and redox potential measurements at three sites on the Airou River. For these 2 parameters, the results of sites A and C are compatible with the guide values described earlier.

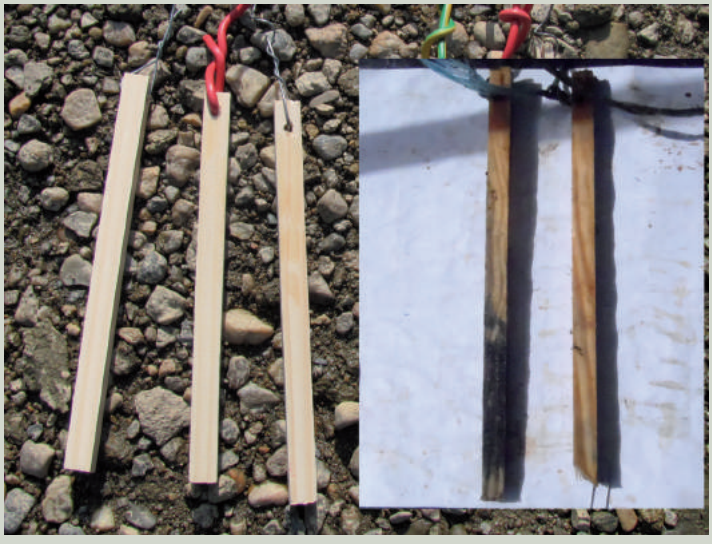
On each watercourse, several sites' results fell within the guide values for the various parameters studied.



Box plots of conductivity and redox potential measurements for the 3 sites on the Airou.

Estimation of Sediment Clogging using the "Pine Stick" Method

The presence of oxygen in the substrate of a watercourse is essential to its ecological health. Clogging prohibits exchanges between free-flowing water and the first few centimetres of the substrate. Marmonier et al. propose a simple and cost-effective technique for measuring oxygen levels in the substrate. This method consists of sinking 1cm-square, 30cm-long sticks of untreated pine or fir wood into the substrate and leaving them in place for one month. In the presence of oxygen, the colour of the wood will not change, while an oxygen-poor environment will cause the surface of the wood to discolour and turn grey.



Pine sticks placed in the bed of the Rouvre (left, before placement; right, 3 weeks after placement).

(CPIE Normandy Hills)

Caveats and Recommendations

In the context of the LIFE+ freshwater pearl mussel programme, the objectives of environmental quality measurements were as follows:

- to obtain an overall evaluation of environmental quality and its evolution over time;
- to locate areas favourable to young mussel population reinforcement; and
- to identify new sources of pollution or new problems to be resolved.

In the process of deciding whether to reinforce specific mussel populations, guide values drawn from the various environmental-quality studies carried out among healthy mussel populations (see the following tables) are taken into account.

Water Column Guide Values.

Water Column Parameters	values
pH	6.3-8
Nitrates N-NO_3 (mg/L)	< 2
Orthophosphates P-PO_4^{3-} (mg/L)	< 0.15
Conductivity (µS/cm) à 25°C	< 150µS/cm
Dissolved Oxygen (mg/L)	> 9
Temperature (°C)	< 19

Substrat Parameters	values
pH	6.3-8
Conductivity (µS/cm) à 25°C	< 150µS/cm
Corrected Redox Potential (mV)	~ 300
Potentiel red-ox Gradient	< 20%
Temperature (°C)	< 19

Substrate Guide Values.

It is important to highlight the fact that the measures used to describe a high quality environment for the species are imperfect, and that this sort of environment may be difficult to achieve whatever the means at our disposal. Indeed, these guide values depend on circumstances at a given moment in time, and cannot guarantee a continuous healthy functioning of the ecosystem and its inhabitants. The various measures taken into account represent but a small part of an ecosystem and probably an even smaller part of the parameters required by the freshwater pearl mussel.

Sporadic departures from guide values do not mean that a single parameter will necessarily become a limiting factor for mussel populations; however, recurrently exceeding guide values and a cumulation of limiting parameters would be more worrying for the future of the species. In no case should the guide values be considered as a prerequisite guaranteeing the successful return of the species.

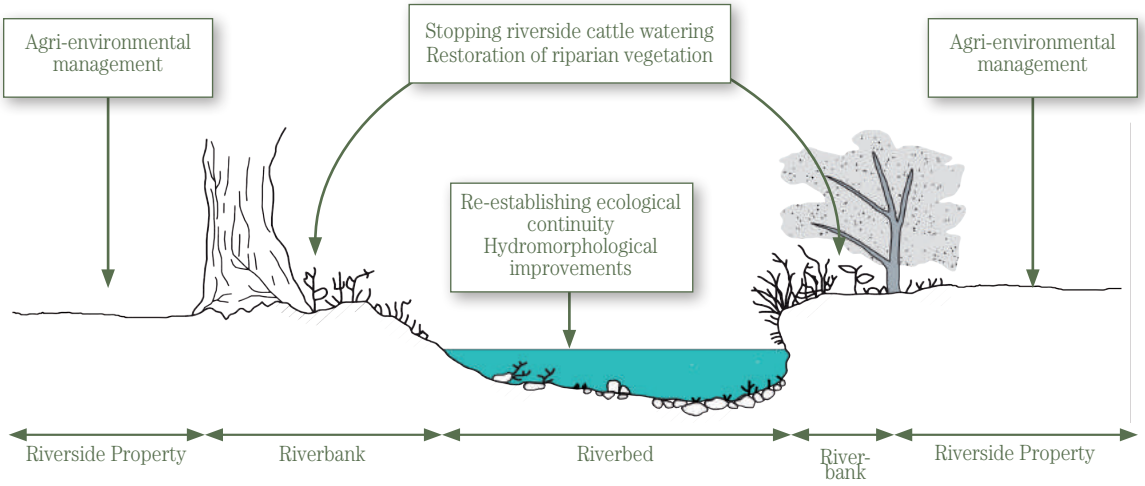
Depending on the watercourse, guide values do not necessarily represent limits for the species; they can, however, act as indicators of dysfunction in watersheds hosting the pearl mussel and point the way to identifying causes of environmental degradation and the restoration measures that can be taken to counter them.

Habitat Restoration

Pearl mussel population conservation must include habitat restoration, taking into account such factors as water and substrate quality, host fish quantities, and riverbank conservation, among others. All stakeholders—elected officials, associations, users, landowners, and watershed authorities—are concerned.

The majority of restoration efforts made in the various watersheds included in the programme were piloted by the stakeholders most apt to take responsibility for them on their territory; that is to say, in most cases, watershed authorities, commune communities, and Natura 2000 organisations. In every case, the LIFE programme was involved in these efforts, certain of which were initiated by the project.

In carrying out restoration measures, it is essential to work on all levels of the hydrosystem, including the low-water channel, the banks, and properties adjoining the riverbanks. All possible issues stemming from activities in the watershed must also be taken into account.



Components of a hydrosystem.

At the project's outset, fieldwork helped to identify and geographically locate problems related to freshwater pearl mussel conservation in each watershed. The number of problems identified differed with the size and conservation status of each watershed. Working with stakeholders in each watershed, efforts were made to find the practical and financial means to resolve as many issues as possible.

The measures implemented are summarised in the following table:

	Elez	Loc'h	Bonne Chère	Airou	Rouvre	Sarthon
Re-establishing Ecological Continuity		X	X		X	X
Hydromorphological Improvements						X
Stopping Riverside Cattle Watering			X	X	X	X
Riparian Vegetation Restoration	X	X	X	X		X
Agri-Environmental Management	X	X	X	X	X	X
Other		X	X		X	X

Examples of measures put in place in the various watersheds.

Riverbed

Re-establishing Ecological Continuity

The ecological continuity of a watercourse is defined as the free movement of living organisms and their ease of access to areas necessary for their reproduction, growth, nutrition and shelter; and the proper functioning of natural sediment transport and of biological reservoirs (connections—particularly lateral—and favourable hydrological conditions).

When properly restored, ecological continuity allows rivers to follow their course from up- to downstream, and to occupy their flood channel during annual flooding.

Removal of a dam on the Rouvre.

Replacement of a narrow culvert —an impassable barrier to fish— with an Ecopal plastic tunnel on an affluent of the Loc'h.

Replacement of an undersized metal culvert (left) by a rigid-frame bridge (right) on the Bonne Chère.

Installation of a rigid-frame bridge on an affluent of the Rouvre.

Hydromorphological Improvements

There are solutions for helping a watercourse return to a more natural morphology. Each case must be taken as unique, and the success of measures taken depends on the resilience of the environment. Current and stream gradient play an important role, as does the nature of the soil. It is important to involve local stakeholders in improvement initiatives, as these may be unwelcome and can even be perceived as regressive by local users.

Aggregate addition on the Pas d'Ânes stream in the Sarthon watershed (before/after).

Thalweg restoration on the Croix-Sellos stream in the Sarthon watershed (before/after).

Riverbanks

Stopping Riverside Cattle Watering

On some sections of watercourse, cattle trampling alters the banks, releasing fine particles (sand and earth) into the watercourse, which contribute to sediment clogging.

Riverside landowners whose cattle water directly at the riverside were contacted in order to set up cattle watering systems which preserved the banks, as well as fencing to prevent livestock from damaging them. In some cases, willow fascines were set up to stabilise riverbanks..

Riverside cattle watering on the Loc'h (left) and on the Bonne Chère (right).

An alternative to riverside cattle watering: nose pumps and fencing on the Airou River.

Restoration of banks damaged through cattle watering (left) by the installation of willow fascines (right) on the Bonne Chère.

Riparian Vegetation

Riparian vegetation comprises all tree and shrub growth along a river's banks. Restoration of riparian vegetation consists of maintaining and/or planting suitable local species. Riparian growth diversifies habitat, preserves fragile banks from erosion, maintains the natural flow of watercourses, slows water flow during flooding, regulates water temperature through shade, and improves water quality by taking up a portion of polluting elements as they move through the watershed.

However, conifer plantings do not represent functional riparian vegetation along riverbanks in Brittany and Normandy. Their shallow root systems are not effective in protecting banks from erosion, and they completely block out sunlight, which does not favour the overall healthy function of rivers. It is best to replace such plantings with local species on a 10- to 20m-wide strip along the banks.

Riparian vegetation maintenance on the banks of the Sarthon.

Planting local species on the banks of the Bonne Chère.

Removal of Sitka spruce plantings on land adjacent to the Loc'h.

Riverbank Property Adjoining Mussel Sites and Throughout the Watershed

Agri-Environmental Management

Wetlands adjacent to watercourses are essential to their good health. Wetlands are an integral part of water systems, contributing greatly to flow throughout the year, and representing a buffer zone between properties further away from the watercourse and the watercourse itself.

Wetland maintenance can be helped by agri-environmental management or by Natura 2000 contracts. Measures can include, for example, limiting fertiliser applications on properties close to a watercourse; late mowing and removal of cuttings; wet meadows; and scything on wet moorlands.

A wet meadow along the Bonne Chère which is subject to an agri-environmental measure.

Other Problem Sources

Water retention structures, however far upstream from pearl mussel sites, can have an impact on the watercourse and therefore potentially on mussel populations. For example, reservoirs or other sorts of water retention on the main stem of a river represent barriers to fish as well as impacting on sediment transport and causing a rise in water temperature.

On the other hand, water treatment facilities have contributed to real progress in terms of improving water quality. They cannot, however, completely rid water of nitrates or phosphates: such facilities may thus add to the nutrient content of the watercourse downstream of their discharge. Nevertheless, supplementary measures exist that may allow the treatment capacity of such facilities to be improved.

The Nestavel Dam on the main stem of the Elez River.

Lagoons at the Malguénac wastewater treatment plant in the Bonne Chère watershed.

The Carneille wastewater treatment plant in the Rouvre watershed.

Ex-Situ Breeding and Conservation

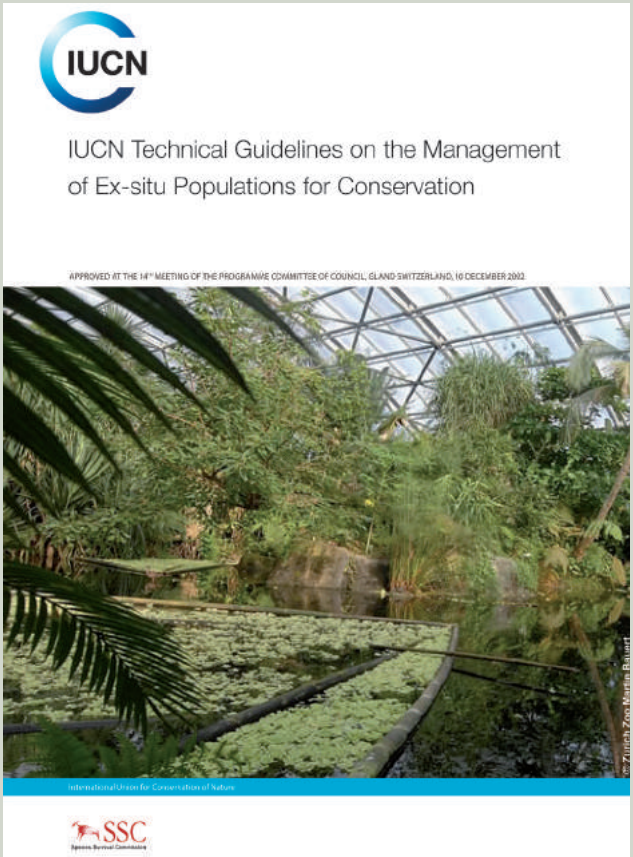
This measure, piloted by the Fédération de Pêche du Finistère, was aimed at insuring the *ex-situ* preservation of the various populations included in the programme at the first freshwater pearl mussel hatchery established in France.

Notes on Breeding and Population Reinforcement

According to the IUCN, one of the goals of conservation is the preservation of existing genetic diversity and viable populations for all wild taxa in order to maintain biological interactions and ecological processes and functions. Towards this goal, conservation managers and stakeholders must adopt a realistic and integrated approach to conservation efforts. Threats to biological diversity are continually increasing, and taxa must survive in environments that are subject to increasing anthropogenic pressures.

The reality of the current situation is such that it is not possible to ensure the survival of an increasing number of threatened taxa without employing a set of diverse and complementary conservation approaches and techniques, including—for certain taxa—the heightened role and practical use of *ex-situ* techniques. These conservation measures are considered as a tool to enable the survival of wild populations: they are not a replacement for necessary *in-situ* management methods, and an efficient integration of both in- and *ex-situ* approaches must be sought wherever possible. Habitat restoration and management as well as reintroduction and support for wild populations are included in these complementary actions.

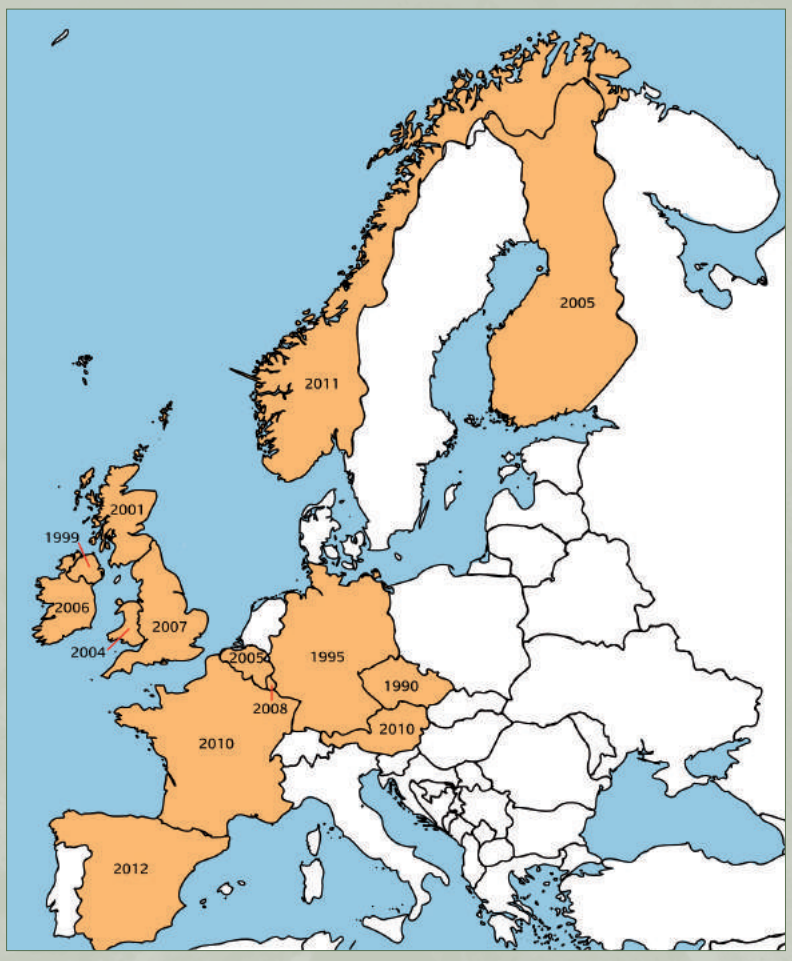
In the context of this project, the lack of recruitment observed in the 6 populations at the beginning of the LIFE programme led to the development of an emergency breeding programme. It is clear today that these ex-situ conservation measures must absolutely be accompanied by high-profile measures to restore wild habitat favourable to this species.



A Brief History of Pearl Mussel Breeding in Europe

(based on Thielen, 2015)

In Europe, Hruska was the first to attempt the breeding of *Margaritifera margaritifera* between 1980 and 1990 in Czech Republic (Hruska, 1992, 1999). Buddensiek pursued this work in 1995 with a series of in-situ trials using, for the first time, mesh cages or "Buddensiek cages" (Buddensiek, 1995). From 1999 to 2001, the first Scottish attempts at breeding took place under the supervision of Hastie (Hastie & Young, 2003). It was Michael Lange who, in the state of Saxony in Germany, improved Hruska's methods and developed very useful guidelines for breeding young mussels in Buddensiek cages or gravel boxes (Lange & Selheim, 2011). Since then, other breeding programmes have been developed, of which several are ongoing in 14 European countries.



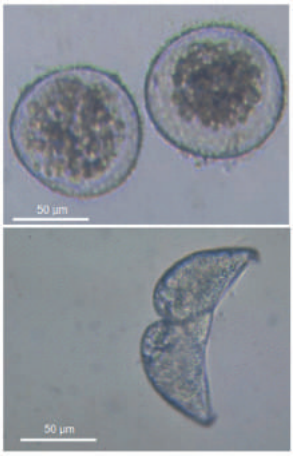
European countries with pearl mussel breeding programmes (in orange) and the year they began breeding.

The Luxembourg freshwater pearl mussel hatchery.

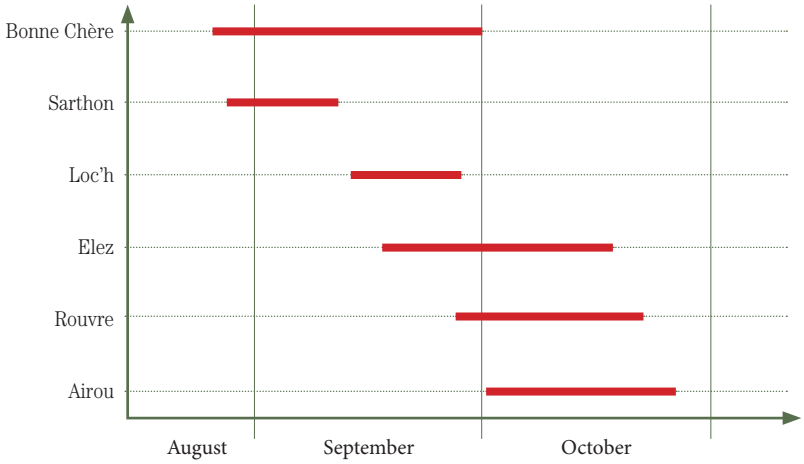
The Norwegian freshwater pearl mussel hatchery in Bergen.

In-situ Glochidia Collection

In the Armorican Massif, glochidia develop from July to October. During this period, various adults are tested in the field for gravidity, and individuals testing positive are marked with tags for future testing. Glochidia develop over a period of 3 to 4 weeks and pass through 5 stages (Scheder *et al.*, 2011) (see figure below right). Monitoring takes place with increasing frequency as development draws to a close. When the larvae are mature, they are collected and taken to the hatchery. From one watercourse to the next, the period of gravidity may differ by as much as weeks in the same year, and may also vary from one year to the next in the same watercourse (see figure below left).



Glochidia at stage 1 (above) and stage 5 (below).
(photos : B. Degonne)

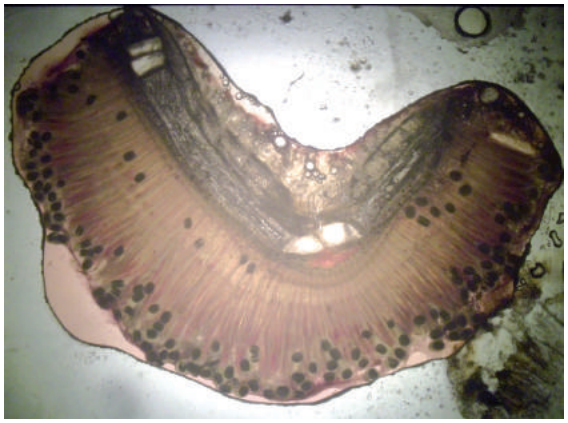


Dates of glochidia collection from 2011–2015 on various watercourses.

Host Fish Infestation

The brown trout (*Salmo trutta*) is used as the host fish at the hatchery. The choice of this species was confirmed by studies carried out in 2012 and 2014 which showed that the brown trout was the preferred host fish for pearl mussels in Brittany and Normandy (Evanno, 2013 & 2016).

Once they have arrived at the hatchery, glochidia are put into contact with parr (around 1,000 glochidia per fish) for 30 to 60 minutes. After this contact, the fish are kept in traditional hatchery conditions for 8 to 10 months (see figures below).



Brown trout gills with encysted larvae.

Breeding tanks for infested host fish.

Breeding

The Hatchery

The hatchery was built on the site of the Favot fish farm in Brasparts, Finistère, and measures approximately 300m². It houses two mussel breeding rooms, one algae production room, one quarantine room for the Lower Normandy strains, a meeting room, and a laboratory (see figures below).

Aerial photo of the Favot fish farm.

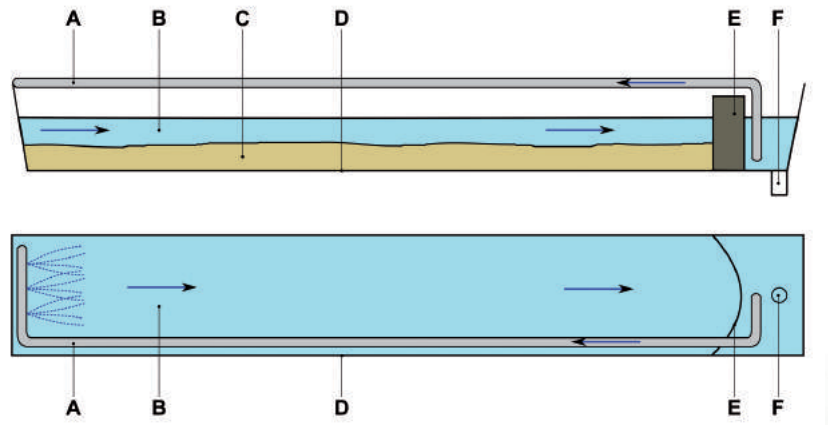
The mussel hatchery.

The quarantine room.

The Rearing System

The rearing system used consists of large 100 to 200L troughs filled with 2–3cm of aquarium substrate in which continual current is created by a pump (see figure below). Within each breeding system, water flows in a closed circuit. Each week, 80% of the water in the troughs is changed after agitating the sediment to eliminate algal growth. The water used is pre-filtered at 36µm before being decanted. Water temperature in the troughs is maintained at between 10 et 16°C. Physico-chemical parameters are regularly monitored: in particular, the temperature, dissolved oxygen and nitrates.

Young mussels drop off their host fish during several weeks in May and June and are sorted, counted and then placed into the breeding troughs, each of which can contain more than 20,000 young mussels which have just dropped off their host fish. Each strain is raised in a separate trough.



Breeding troughs. Above, side view; below, top view (A: water return pipe fed by a pump; B: water filtered at 36µm; C:aquarium substrate; D: plastic trough; E: grille holding the substrate to one side; F: trough purging system).

One-year-old mussels coming to the substrate surface in a breeding trough at the hatchery.

Despite the availability of material and skills for producing freshwater microalgae on-site, the hatchery does not produce its own microalgae, and mussels are fed with commercially-sourced microalgae. 1ml of Shellfish Diet 1800 and 1ml of Nanno (see glossary) are added daily to each trough.

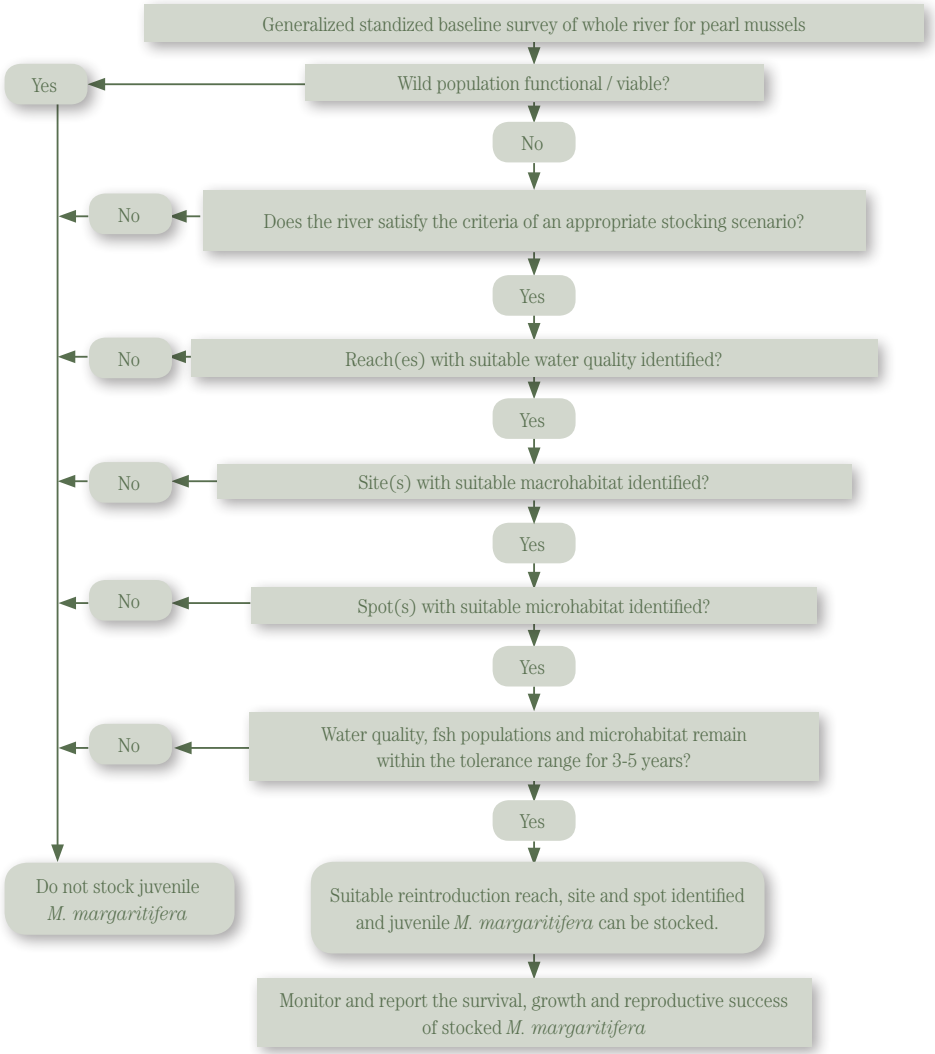
Today, the hatchery is home to more than 100,000 mussels (see table below), thus fulfilling its role as the conservatory of the various mussel strains of the Armorican Massif.

	Elez	Bonne Chère	Loc'h	Airou	Sarthon	Rouvre	Total
Cohort 0+ (0-1 an) - 2016	-	10,000	10, 000	10,000	-	6,000	**36,000**
Cohort 1+ (1-2 ans) - 2015	10,000	10,000	-	2,000	5,000	15,000	**42,000**
Cohort 2+ (2-3 ans) - 2014	10,000	8,600	1,155	40	1,500	0	**21,295**
Cohort 3+ (3-4 ans) - 2013	5,000	5,000	2,400	-	-	-	**12,400**
Cohort 4+ (4-5 ans) - 2012	1,220	5	30	-	-	-	**1,255**
Total	**26,220**	**33,605**	**13,585**	**12,040**	**6,500**	**21,000**	**112,950**

Numbers of freshwater pearl mussels at the hatchery in June 2016.

Population Reinforcement

In the context of the LIFE programme, wild freshwater pearl mussel population reinforcement must be seen as a measure taken on the path to spontaneous natural recolonisation. The success of various partners' actions to restore environmental quality, outside the limits of the LIFE programme but accompanied by it, is a necessary factor in the favourable outcome of the project. Proceeding to the stage of population reinforcement is not conceivable until habitat quality is sufficient to meet the needs of freshwater pearl mussels bred *ex-situ*. Indeed, the role of reinforcement should be to accelerate a process which is already taking place, albeit very slowly (Chatain & Choisy, 1990).



Criteria in the selection of suitable sites for young mussel reintroduction (Bolland et al., *2010).*

Note: macrohabitat: a 10–100m stretch of river; microhabitat: a less than 5m² stretch of river.

As a precaution, only spawning individuals coming from the same watercourse are used in reinforcement.

Depending on the quality of the environment, it is possible to consider *in-situ* population reinforcement techniques such as:
• infesting local host fish with glochidia harvested on-site;
• releasing young mussels of various ages directly into the substrate; and
• installing *in-situ* breeding systems.
Techniques may be combined to optimise the chances of success.

These efforts are aimed at the reinforcement of an existing population, not at reintroduction, and the mussels are released in close proximity to known mussel sites. Reinforcement sites were selected based on the information collected in the environmental quality survey and by refining the measures to suit specific areas.

The efficacy of directly releasing young mussels into the substrate in terms of survival and growth rates can only be judged when the mussels reappear on the surface after about 4–5 years. This is why, in addition to this method, in-situ conservation systems were put into place in order to give an idea of the success of the population reinforcement carried out.

Host Fish Infestation

First, gravidity monitoring must be carried out on the mussel population in order to find individuals with glochidia, to evaluate the development stage of the glochidia, and to harvest mature specimens. On the same day as harvesting takes place, local (preferably juvenile) host fish must be captured by electric fishing. The captured fish are then put into contact with glochidia for about 45 minutes. Taeubert and Geist (2013) recommend using 350 to 7,000 glochidia per fish (between 5 and 100 glochidia per gram-weight of fish). After infestation, the host fish are released into their environment.

Electric fishing.

Infestation with glochidia. *(© Bretagne Vivante)*

Watercourse	Number of Local Trout Infested and Released
Elez	32
Loc'h	30
Bonne Chère	321
Airou	80
Rouvre	102
Sarthon	63

Population Reinforcement by Direct Release

When young mussels reach a length of 2.0–2.4mm, they begin to filter-feed (Schartum *et al.*, 2016) and become less sensitive to being moved. Ideally, mussels should be left to reach this size before being moved to reinforcement sites. However, space at the hatchery is limited, and not all the mussels bred can be kept there. Therefore, every year, a portion of each cohort is made available for reinforcement efforts.

Young mussels are released into the watercourse using two methods:
– The first consists of sinking a 15cm PVC tube into the substrate and pouring the solution containing the young mussels into it. The tube is left in place for 45–60 minutes, giving young mussels time to burrow into the riverbed.
– The second consists of injecting around 100 young mussels at a time directly into the substrate using a large syringe.

When mussels reach a length of several millimetres, it is possible to mark them before their release.

Depending on the amount of glochidia harvested and the success of host fish infestation at the hatchery, in some years and for certain populations the number of young mussels harvested when they

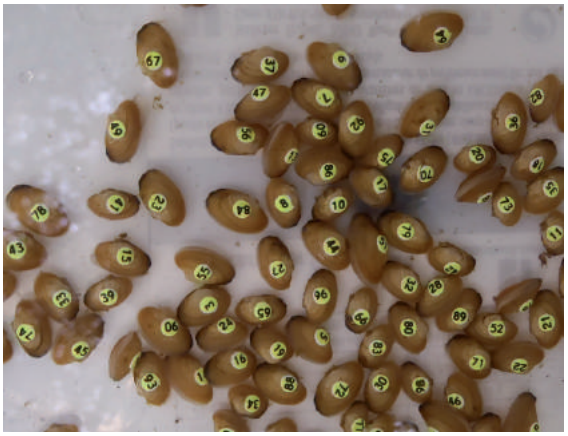
excyst can be very high, and may greatly exceed the breeding goals that have been set. In this case, these mussels (0+) are released into their native watercourse. This explains the high number of 0+ cohort mussels released into the various sites.

Direct reintroductions into the substrate don't make it possible to judge the effectiveness of this operation in terms of survival and growth before the appearance of mussels at area, ie after about 4-5 years.

A 4-month-old mussel about to be introduced into the site.

Two methods of introduction are used: decanting (using PVC tubes) (centre) and direct (using plastic syringes) (right).

(© Bretagne Vivante)



Mussels marked with plastic tags before being released into the Elez River.

Cohort	Number of Mussels Directly Released into the Substrate
0+	> 5 millions
1+	180,000
2+	4,000
3+	0

Number of Mussels Directly Released into the Substrate.

In-situ Rearing Systems

The efficacy of directly releasing young mussels into the substrate in terms of survival and growth rates can only be judged when the mussels reappear on the surface, after a minimum of 4–5 years. This is why, in addition to direct release, various *in-situ* conservation systems were put into place in order to give an idea of the success of the population reinforcement carried out.

Silos

The technique of using concrete silos to raise pearl mussels directly in the river was developed in the United States by Chris Barnhart (Barnhart *et al.*, 2007).

It consists of building a hollow concrete structure with a cage for mussels in its centre.

This method was tested on the Elez where, after 5 months, the young mussel survival rate was 46%.

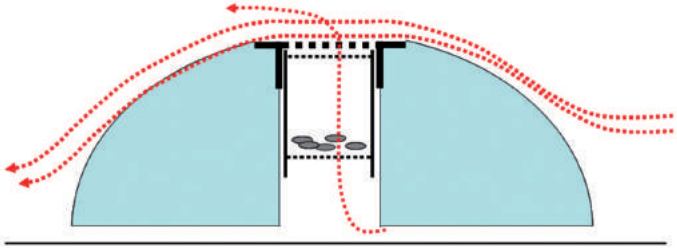
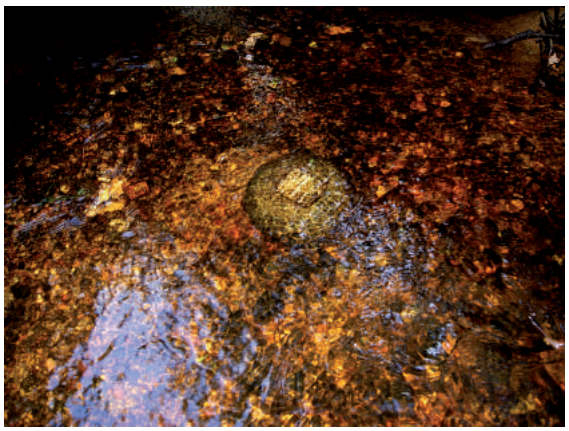


Diagram of a mussel silo.

A silo viewed from above.



A silo in the Elez River.

A silo seen from below.

Plastic Boxes

Plastic boxes have been used for *in-situ* breeding in the Czech Republic and in Germany for several years (Spisar & Lange, personal communication). Holes are made on all sides of the boxes and are then covered with 1mm plastic mesh. Mussels placed in these boxes are longer than 2mm. At present, such boxes have been installed in the Elez and in the Loc'h.

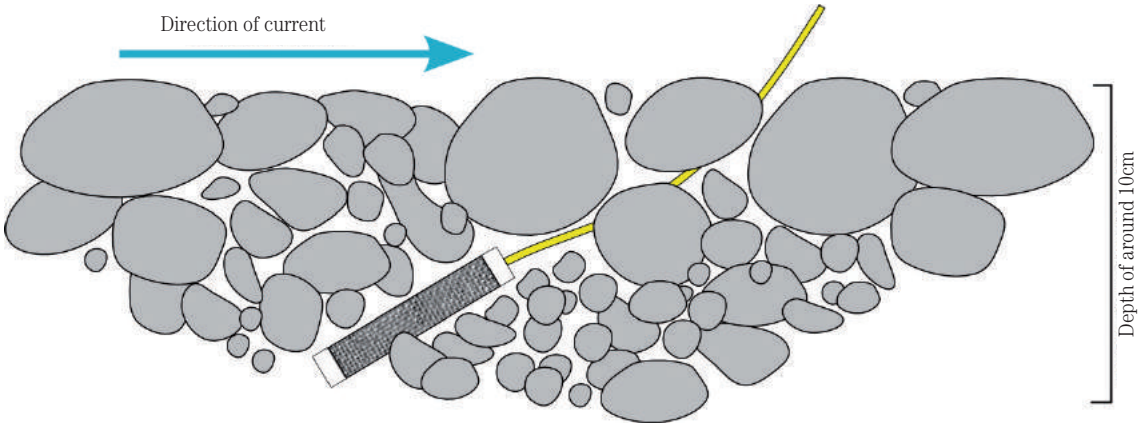
Plastic box in the Loc'h.

Mesh Tubes

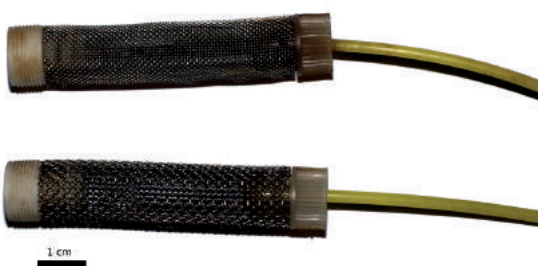
INRA developed the mesh tube method to test salmonid egg survival in river sediments (Dumas & Marty, 2006). Similar tubes were used to test the in-situ survival and growth of young mussels. These are made by Gantois[3] and are 50mm long with a diameter of 11mm, and a mesh size of 0.42mm or 0.80mm. Both ends are stoppered with plastic plugs. A 40cm-long nylon thread is attached to one tube at each site in order to facilitate the tubes' relocation for monitoring purposes.

On each watercourse, at distances of tens of metres to hundreds of metres apart, five sites were selected on the basis of substrate quality measurements. 4 mesh tubes, each containing 10 young mussels, were placed at every site in July 2015. Monitoring was carried out 2, 10 and 12 months after placement.

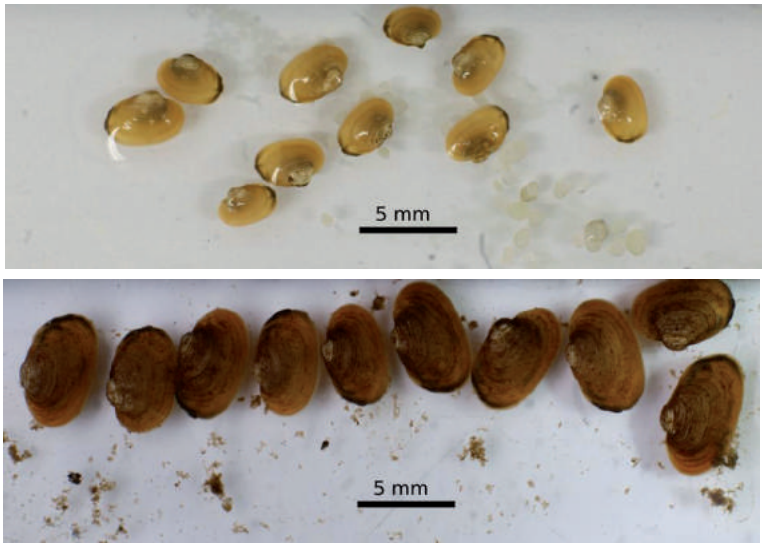
3 - Gantois Industries, Saint-Dié-des-Vosges, France. http://www.gantois.com/en/home.php



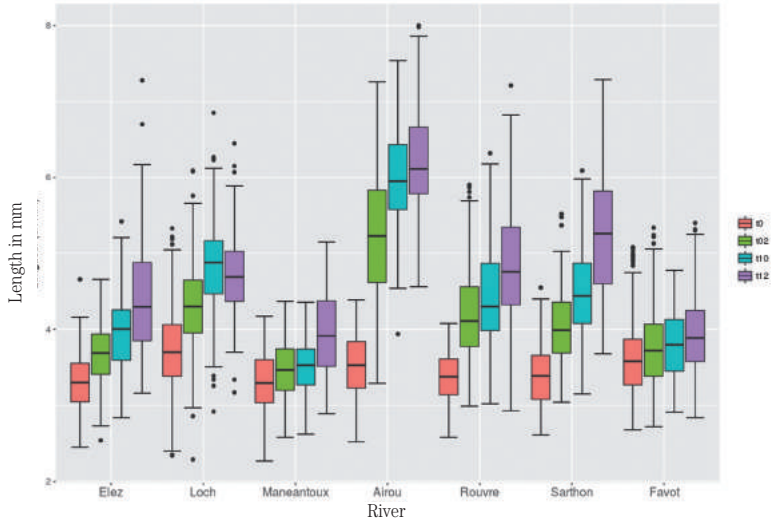
Mesh tube installation.



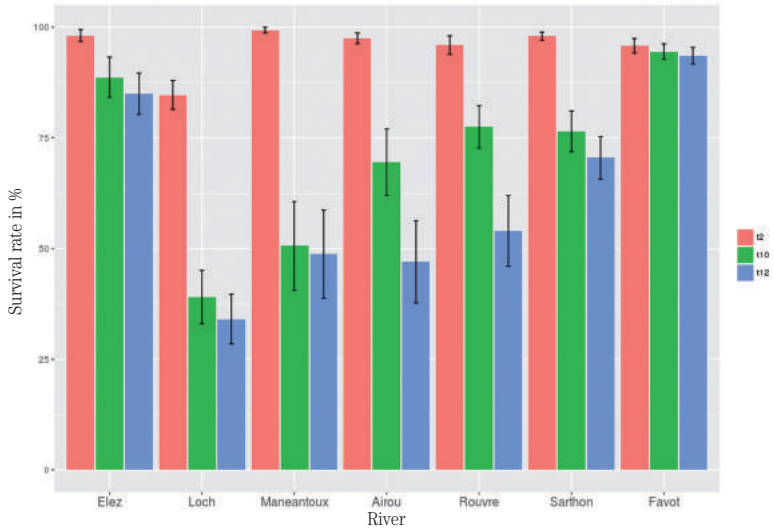
Mesh tubes with a mesh size of 0.42mm (above) and of 0.80mm (below).



t0 (above) and t+2 months (below) mussels at one of the sites on the Airou.



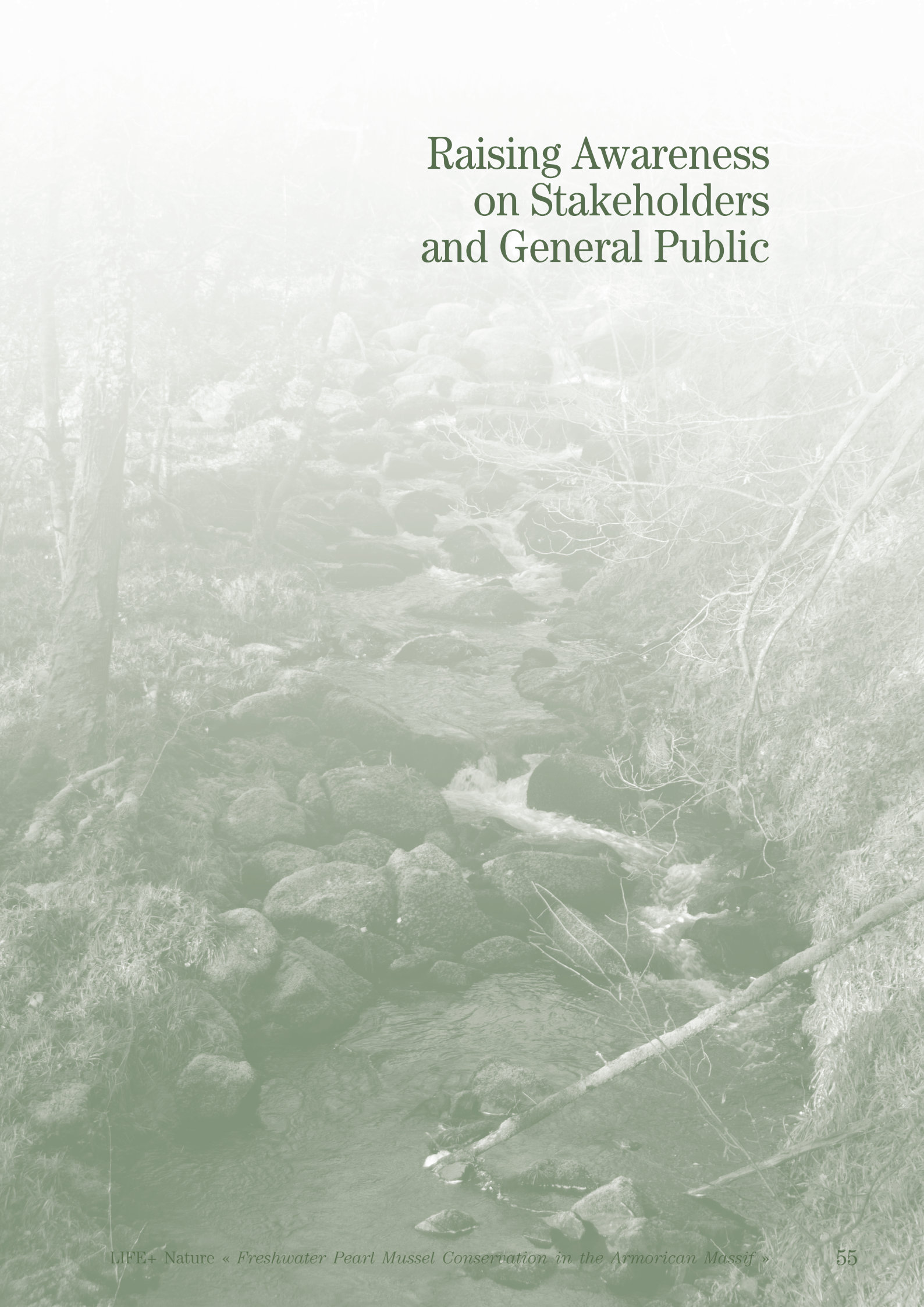
Mussel shell length by river, at t0 (June 2015), t2 (September 2015), t10 (April 2016) and t12 (June 2016).



Survival rates, by river, at t2 (September 2015), t10 (April 2016) and t12 (June 2016). (The error bars represent standard error)

After 12 months, survival rates varied between 35% and 85% and growth rates between 0.6 and 2.5mm depending on the watercourse. These results demonstrate that young mussels can survive at each site, which is encouraging for the future of the project.

Raising Awareness on Stakeholders and General Public



Freshwater pearl mussel conservation must include measures to raise public awareness, and communication tools to make the species known.

This section describes these communication tools and the means employed in their development.

General Public

The main goal of the public awareness campaign developed through the LIFE programme was to help the public and stakeholders get to know the species.

Introductory Documentary Distributed by Public Screenings, DVDs and YouTube

Hervé Ronné created a film entitled Les moules perlières du Massif Armoricain [Pearl Mussels of the Armorican Massif] to introduce viewers to the species. The film was printed and 1,000 DVDs were made at the end of 2014. Currently, copies have been distributed to Bretagne Vivante's contacts as well as being given out at meetings and awareness-raising presentations. Screenings took place at "nature cafés", theme days, festivals and at some libraries in Brittany and Normandy.

All of the films produced in the context of the programme have been uploaded to YouTube and may be viewed online at : www.youtube.com/user/LifeMulette.

Information Panels

Seven panels were made (one per site in Brittany and Normandy plus one for the hatchery) in the same style and mounted on the same sort of base. The panels detail the project goals, the history of the freshwater pearl mussel and information relative to the site where the panel is located.

One or more panels were printed depending on the site, and the information on panels in Brittany was translated into Breton.

Panels near the Elez (Brittany) and the Airou (Normandy).

Website

A website dedicated to the freshwater pearl mussel LIFE programme (http://www.life-moule-perliere.org/accueilmoule.php) was regularly updated throughout the project. It presents the LIFE programme, the species studied, the study sites and the measures carried out with project partners. Website visitors can discover news related to the project, learn more about project partners and co-financiers, and download European Commission reports and meeting minutes.

There are tabs are dedicated to flagship measures such as the hatchery, where people wishing to visit the structure can find information about it; and the international conference organised in Brest, where visitors can find details on presentations, posters and conference proceedings (available as free downloads in English and in French).

Hatchery Visits

The hatchery is an awareness-raising tool in and of itself, and visits to it were organised throughout the project.

Since its construction, there have been 35 guided tours allowing around 500 people to visit the hatchery.

A group visiting the hatchery in June 2016.

School Activities in Normandy

In Normandy, extra emphasis was put on raising awareness in schoolchildren. Presentations given in schools have a significant impact on young people discovering and learning more about the species, and therefore on local awareness of it.

Around 2,000 students attended the 75 presentations which took place in Normandy since the beginning of the LIFE programme. For these presentations, several educational materials were created, such as life-sized resin mussel models—including an anatomical model—and a poster on freshwater bivalves and their host fish.

A group of schoolchildren visiting the Airou River.

Document Development and Distribution

Several publications were developed and published in order to inform the general public of the project, and their publication occurred at various stages of the project so as to ensure a continuity of communication. A special edition of the *Hermine Vagabonde*, a nature magazine for youth, was published. *L'Hermine Vagabonde* no. 49 - *Il était une fois la mulette perlière* [Once upon a time, there was the pearl mussel] was published in January 2014 and told the surprising tale of the freshwater pearl mussel, which lives a peaceful yet risky life at the bottom of some Breton rivers.

Bretagne Vivante publishes its own nature magazine, *Penn ar Bed*, which reaches a large and diverse readership. Issue no. 215, *Sauvons la mulette perlière du Massif Armoricain* [Save the Armorican Massif freshwater pearl mussel], published in December 2013, presents a situational analysis of the species in this region and the actions carried out by the project. Issues were distributed to organisations planning youth activities on the theme of rivers and the environment.

*Covers of l'*Hermine Vagabonde *no. 49 and* Penn ar Bed *no. 215.*

Stakeholders and Local Authorities

Newsletter

The annual newsletter provided a means of communicating with stakeholders and organisations about the project. It was made available on the website where interested parties could download it.

Published yearly for six years, the newsletter detailed projects carried out, the various methods employed and important steps being taken at the time of publication.

English cover of the Newsletter no1

Assessment Meetings by Site

In the interests of the project's success, it was important that actions were understood, accepted and supported by local authorities and stakeholders.

Yearly information meetings were organised by watershed, providing an opportunity to present the programme, its objectives and expectations regarding habitat quality for the freshwater pearl mussel, and also to explain actions put in place in the aim of ensuring their durability.

A meeting with local stakeholders and co-financiers in Gavray (Normandy), June 2016.

National and International Contact with the Scientific Community

Because of the number of ongoing European projects on freshwater pearl mussel conservation, particularly through LIFE programmes, communication is necessary to obtain the best results from each experience.

Conference Hosting

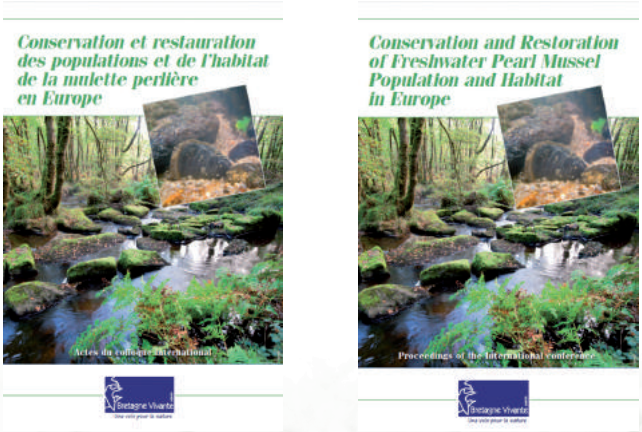
On 26 and 27 November 2014, Bretagne Vivante and the Institute of Geoarchitecture at the University of Western Brittany in Brest organised an international conference entitled "Conservation and Restoration of Freshwater Pearl Mussel Population and Habitat in Europe".

More than 150 people representing 9 countries attended this conference, whose goals were to gather information on the conservation status of European pearl mussel populations, and to present species restoration experiments. Presentations on host fish habitat restoration and on rivers home to these species were also given.

The conference aimed at attracting all stakeholders active in the restoration of salmonid habitat restoration, including scientists, managers, technicians, and the heads of various organisations (local authorities, planning departments, associations, etc.).

Over the two days of the conference, 17 presentations were made and 13 posters were presented and described. The conference proceedings were sent to all participants, and French and English versions are downloadable from the project website.

More than 150 people representing 9 countries attended this conference..



Covers of the Proceedings of the International Conference in French and in English.

Participation in International Conferences

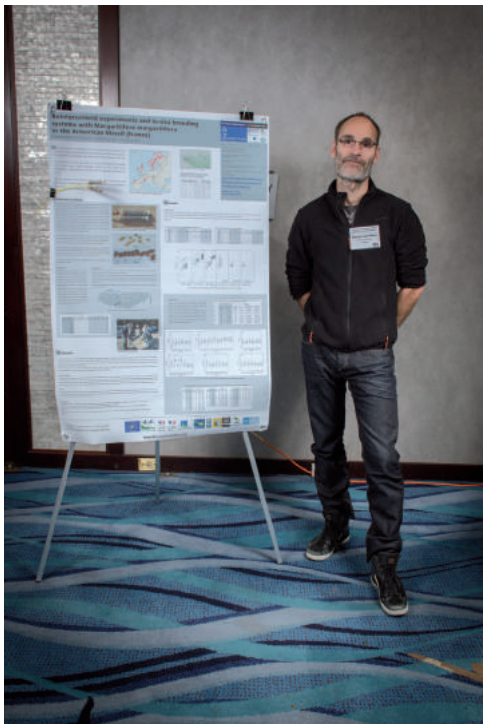
Throughout the project, there were opportunities to participate in European and overseas conferences, to share experiences and to learn about developments in other countries that are home to the species.

Participation in such meetings is important as they provide an opportunity to meet experts and stakeholders working to preserve the species, as well as other people interested in the subject. The exchange of knowledge and experience that takes place at these meetings helps to improve practices and to develop new breeding methods, and thereby save certain species and populations.

Each participation in an international conference was accompanied by either an oral presentation or the development of a poster, all of which are available for download on the project website.

Event	Location	Dates
2nd International Seminar Rearing of unionoid mussels	Clervaux, Luxembourg	24 - 27 November 2015
2nd International meeting on biology and conservation of freshwater bivalves	Buffalo, USA	4 - 8 October 2015
International Meeting « Improving the environment for the Freshwater Pearl Mussel »	Kefermarkt, Autriche	13 - 14 November 2013
1st International meeting on biology and conservation of freshwater bivalves	Bragança, Portugal	4 - 7 September 2012

Presentation at the 2014 conference in Brest..



Presentation at the 2015 conference in Buffalo, NY.

Presentation at the 2015 International Seminar in Luxembourg.

Study Trips and Sharing Experiences

Several trips were made to various European countries to learn about other ways of working, as well as about pearl mussel conservation.

Czech Republic, June 2011.

Wales, November 2010.

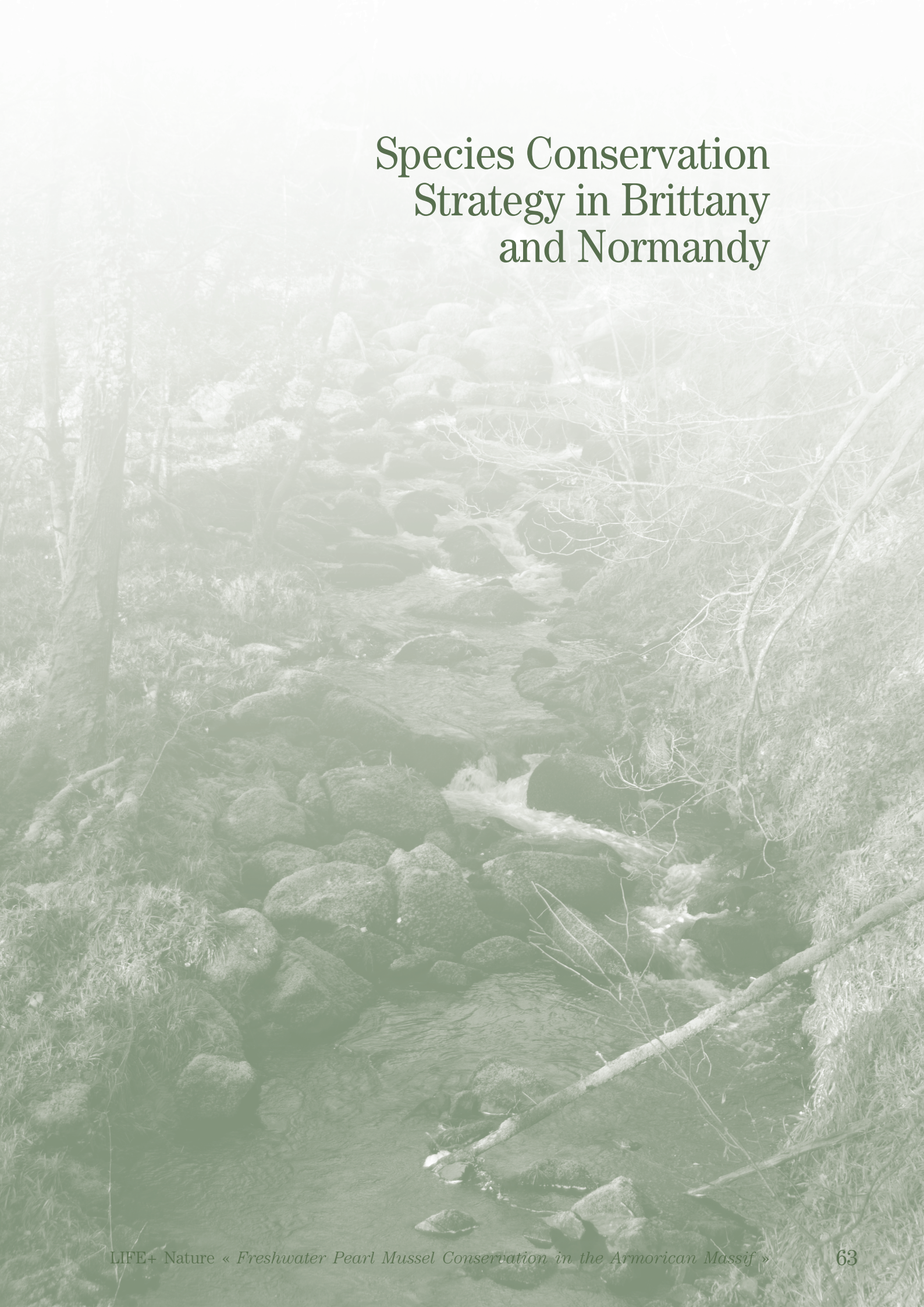
Luxembourg, September 2010.

In addition to visiting European partners, the latter were invited to Brittany and Normandy to see the hatchery and observe the conservation techniques in place here.

Visiting the hatchery with a group from the Czech Republic, November 2011…

… and a field trip with a group from Norway, April 2015.

Species Conservation Strategy in Brittany and Normandy



Regional Action Plan (RAP) Objectives

As the Breton and Norman versions of the National Action Plan for the freshwater pearl mussel (2012–2017), the objective of the RAP is to maintain current populations and to improve their conservation. To reach this goal, various operational objectives were laid out:

- Improve knowledge of historic and current species distribution in Brittany and Normandy;
- Update the knowledge base on species biology and ecology;
- Improve the ecology of Breton and Norman watercourses that are home to the species;
- Enable species conservation and population reinforcement;
- Enable active protection of the species;
- Implement conditions for the rapid recovery of the species; and
- Coordinate actions and improve communication and awareness.

Sustaining Conservation Efforts

The efforts undertaken were concentrated on improving knowledge of the 6 populations and their habitat; population protection; habitat restoration; developing a hatchery; and population reinforcement where environmental conditions permit.

The programme included the conservation of three Breton populations: those of the Elez River (Department of Finistère); the Bonne Chère River (Department of Morbihan); and the stream of Loc'h Pond (Department of the Côtes d'Armor). The three Norman populations were located on the Rouvre and Sarthon Rivers (Department of Orne) and on the Airou River (Department of Manche).

The programme made it possible to mobilise local stakeholders to take action in favour of the pearl mussel, such as knowledge improvement and watercourse restoration.

Although the LIFE programme ended on 31 August 2016, some of the measures it implemented should be pursued in order to fully profit from the energy invested in them, and to ensure the long-term conservation of the six mussel populations. Furthermore, conservation efforts for this species must now be extended to the other Breton and Norman watercourses in which it is still present.

The RAPs are designed to enable the alignment of the various conservation measures of the LIFE programme and to extend them to all Breton and Norman freshwater pearl mussel populations.

Acting to Maintain Freshwater Pearl Mussel Populations in Brittany and Normandy: the Importance of Habitat Restoration

In Normandy, of the 10 watercourses once home to the species, the freshwater pearl mussel is still present in three, all located in the Department of Orne: the Halouze, Rouvre and Sarthon Rivers. The species seems to have disappeared from 6 Lower Normandy rivers. In 2006 and 2008, the species was found in two watercourses hitherto unknown to have hosted pearl mussel populations: the Roche-Elie, an affluent of the Sarthon (Department of Orne), and the Airou (Department of Manche).

In Brittany, according to historical data, 45 watercourses spread over 23 watersheds once hosted pearl mussel populations. Today, the species is present in only 20 rivers in 8 watersheds, with the entire known population estimated at being between 4,000 and 5,000 individuals.

Taking into consideration all extant freshwater pearl mussel populations, traces of mussel presence or found shells, it is possible to estimate a minimum 95% decline in freshwater pearl mussel numbers in Brittany over a period of 50 years.

As elsewhere in Europe (Lopes-Lima, Sousa, Geist. *et al.*, 2016), the causes of this decline are varied but are essentially linked to watercourse dysfunction: lack of ecological continuity, water body degradation, clogging, pollution, etc. Each watercourse and watershed faces its own set of issues, which are multiform, complex and unfortunately not always well-identified.

Water, substrate quality, habitat functionality and the presence of host fish are necessary elements for the success of freshwater pearl mussel populations, whose conservation therefore demands a thorough knowledge of their habitat requirements as well as the implementation of watercourse restoration measures.

At the end of the 6-year LIFE programme, there remain gaps in the knowledge of the species' ecological requirements with regards to habitat. There is still room for improvement, then, in understanding what constitutes favourable habitat for the pearl mussel in Breton and Norman watercourses, especially at the juvenile development stages, and in defining the characteristics of a healthy and viable population.

It is crucial that stakeholders continue to be mobilised around the species and the improvement of its habitat. Restoration plans pointing out problem areas need to be developed and put into place for every watercourse that is home to a viable pearl mussel population. In view of the species' level of ecological requirements, restoration measures must seek to exceed the criteria for good ecological status as laid out by the EU Water Framework Directive.

Restoring true living rivers will benefit not only the freshwater pearl mussel, but the entire ecosystem as well as ecosystem-dependant services relied upon by human populations.

Links to Scientific and Field Partners

Through the establishment of its scientific advisory board, the LIFE programme was able to form scientific partnerships in France and in Europe. Such partnerships ensure the soundness of the knowledge-base improvement and environmental restoration measures taken, and are therefore vital to maintain in the context of the RAPs, for which a scientific advisory board will be formed. This body will establish guidelines for knowledge acquisition and monitor the efficiency of implemented measures. There will be a single group formed for Brittany and Normandy, to continue the common dynamic already in place.

The LIFE freshwater pearl mussel programme inspired real interest in people and groups working for watercourse restoration and water quality improvement. The RAPs will foster this dynamic and make the conservation of this umbrella species a transversal subject which allows all stakeholders in areas home to the pearl mussel—including local residents, elected officials and technicians in municipalities, commune communities, administrative areas, departments, and regions—to feel involved and responsible. Their involvement is key to the success of freshwater pearl mussel conservation in Brittany and Normandy.

The RAPs are largely made up of measures to facilitate and support partners in the field as they put conservation measures in place. These measures can include raising stakeholder awareness of the importance of taking the pearl mussel issue into account in planning initiatives; support in identifying problem areas in need of resolution; support in launching environmental restoration projects; and, if necessary, project leadership.

In general, any projects which may favour pearl mussel conservation must be monitored and highlighted through the RAPs. The synergy of measures with other environmental policies will be given special attention, in particular watercourse restoration activities falling within the EU's Water Framework Directive, but also actions taken in the context of Natura 2000.

Stable Long-term Conservation of the Principal Pearl Mussel Strains

In the context of the LIFE programme, the Fédération de Pêche du Finistère put a breeding programme in place. This emergency conservation measure for the principal Breton pearl mussel strains was taken because of their negative conservation situation, with little or no recruitment taking place.

The first pearl mussel hatchery in France is home today to more than 100,000 mussels, and acts as a conservatory for the various mussel strains.

The work carried out by the hatchery must continue until wild populations are deemed to be healthy and stable, and concurrent watercourse restoration measures must of course also continue. When the species' habitat has achieved good ecological status, the pearl mussels in the hatchery can be used for population reinforcement or released into rivers with favourable habitat conditions. Some captive-bred individuals may also be used in reintroduction initiatives under semi-controlled conditions for the purposes of acquiring knowledge about habitat.

Conclusion

The LIFE programme was successful in mobilising stakeholders around the species and the improvement of its quality of life. Some strains can be considered to have been saved from sudden extinction thanks to the hatchery, which acts as a freshwater pearl mussel conservatory. However, the condition of wild populations is not yet stable enough to let nature take its course, and the majority of populations have yet to benefit from any specific conservation measures.

Furthermore, at the end of the programme's 6 years, certain information is yet to be acquired:

Nutrition: The diet of freshwater pearl mussels in the watercourses of Brittany remains largely unknown, and this factor could play a role in population maintenance.

Viability: The procedures used to define a population's viability or health differ by country, and various approaches are possible. There is a need to define and adapt these procedures for Breton and Norman mussel populations.

Young Mussel Habitat: Although the freshwater pearl mussel is a much-studied species in Europe, information about its habitat—and especially that of young mussels in the wild—is still incomplete (Quinlan *et al.*, 2014). The acquisition of such information is key to species conservation.

The processes set in motion by the LIFE project must continue in the hopes of saving the species in Brittany and Normandy.

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Glossary & Definitions

AAPPMA: *Association agréée de pêche et de protection des milieux aquatiques* [Accredited association for fishing and aquatic environment protection]

Benign Introduction Conservation: The purposeful introduction of members of a species into an appropriate habitat, outside its known habitat or area, for the purposes of the conservation of that species. This conservation measure is only implemented when there is no suitable terrain left within a species' distribution area.

CATER: *Cellule d'Animation Technique pour l'Eau et les Rivières* [Technical resource and development centre for water and rivers]

CPIE: *Centre permanent d'initiatives pour l'environnement* [Centre for environmental initiatives]

DDPP: *Direction départementale de la protection des populations* [Departmental population protection directorate]

DDT: *Direction départementale des territoires* [Departmental land directorate]

DDTM: *Direction départementale des territoires et de la mer* [Departmental land and sea directorate]

DREAL: *Direction régionale de l'environnement, de l'aménagement et du logement* [Regional environmental, planning and housing directorate]

EPAGA: *Etablissement public d'aménagement et de gestion du bassin versant de l'Aulne* [Aulne watershed planning and management authority]

FDAAPPMA 29: *Fédération des associations agréées de pêche et de protection du milieu aquatique du Finistère* [Finistère federation of associations for fishing and aquatic protection]

FDSEA: *Fédération départementale des syndicats d'exploitants agricoles* [Departmental federation of farmers' unions]

INRA: *Institut national de la recherche agronomique* [National agronomic research institute]

Nanno: a microalgal solution of 750 million 1–2µm *Nannochloropsis* sp. cells/ml.

Oligotrophic: An oligotrophic environment is one that is relatively poor in nutrients, whereas a eutrophic environment is one that is rich in nutrients.

ONEMA: *Office nationale de l'eau et des milieux aquatiques* [National agency for water and aquatic environments]

Reintroduction: The attempt to implant a species in an area it previously inhabited, but from which it has disappeared or been eliminated (re-establishment, an associated term, assumes that reintroduction has been successful.

Reinforcement: The input of individuals to an existing population of the same species.

SAGE: *Schéma d'aménagement et de gestion des eaux* [Water development and management scheme]

Shellfish Diet 1800: A microalgal solution with a concentration of 2 billion 5–20µm cells/ml composed of 40% Isochrysis, 15% Pavlova, 25% Tetraselmis and 20% Thalassiosira weissflogi.

SIAES: *Syndicat intercommunal d'aménagement et d'entretien de la Sienne* [Sienne River planning and management authority]

SHEMA: *Office public d'aménagement et de construction* [Regional semi-public planning and building agency]

SMKU: *Syndicat mixte du barrage de Kerné-Uhel* [Upper Kerne Dam joint authority]

Transfer: The deliberate, human-engineered displacement of wild individuals to another population of the same species.

IUCN: International Union for Conservation of Nature and Natural Resources

Summary

The freshwater pearl mussel is a species of community interest and appears in Annexes II and V of the European Habitats Directive as well as in Annex III of the Berne Convention. It is also protected under French law (decree of 23 April 2007).

The species appears as endangered on the IUCN Red List of Threatened Species. Since 2011, this international nature conservation NGO has classed it within Europe as critically endangered, the next stage being extinct in the wild. Indeed, the species is considered to be facing a great risk of extinction in the wild in the near future, and has disappeared from nearly 60% of French watercourses in which it was present at the beginning of the 20th century, with a population decline of more than 90%.

From 2010 to 2016, the project's goal was to contribute to population restoration for the freshwater pearl mussel (*Margaritifera margaritifera*) in the Armorican Massif. Six Natura 2000 sites in Brittany and Normandy, known to host the main pearl mussel populations in western France, were included in the project.

The pearl mussel is a key indicator species of river ecosystem quality, and also a model species for the development of conservation strategies. Its life cycle includes a planctonic phase and a parasitic phase on the gills of salmonid host fish. Rises in temperature, pollution, eutrophication (even periodic), sediment extraction, riverbed trampling, etc., affect populations, and especially young mussels living in river sediments.

The principle objectives of the LIFE programme were to maintain and improve mussel numbers through the building of a mussel hatchery, a flagship action providing for the availability of various age groups towards preventing their disappearance from natural habitat.

This report shares the experience gained over the 6 years of the LIFE programme in the hope that it may facilitate other initiatives in favour of freshwater pearl mussel conservation, and contribute to the protection and survival of the species.