Return of the Thick-shelled River Mussel

Restoring floodplains, habitats and connectivity, using mussels and brains
The thick-shelled river mussel (Unio crassus) has a fascinating life cycle and is very useful for teaching purposes. (Photo: Ivan Olsson)
Return of the Thick-shelled River Mussel Creates Rings in the Water

At a time when warnings of environmental disaster come one after another, there is a great need to provide good examples that can instil hope and faith in the future.

“Return of the River Mussel” Project is such an example. During a five-year period we have carried out restoration measures on 200 kilometres of river channels and 300 hectares of floodplain. Those measures have resulted in positive effects on water quality and biodiversity in twelve Swedish rivers that empty into the Baltic Sea, which in time will also benefit.

In addition, research connected with the project has significantly improved our knowledge of Sweden’s most endangered freshwater bivalve, *Unio crassus* (thick-shelled river mussel). For the first time ever, the species has been cultivated and reintroduced to Swedish waters!

With *Unio crassus* established as an indicator species, we have not only succeeded in fulfilling all of the project’s objectives. We have also helped to raise awareness of the wider significance of restoring streams and rivers, using *Unio crassus* as a teaching example. The project has applied an interdisciplinary scientific method, with a good mixture of various competencies.

A key factor in its success has been collaboration among national and international scientists and public officials. Chiefly responsible for implementation have been several county administrative boards, Karlstad University, the Swedish Agency for Marine and Water Management, and the European Commission’s LIFE Programme, all of which jointly financed the project.

The project can be seen as a cost-efficient and sustainable investment in the environment, with positive effects on water purification, biodiversity, fish production and recreation. The societal benefits of the project are indisputably large.

The project is summarized in this handbook and, as it nears its conclusion, progress toward better aquatic environments has just begun. The “Return of the River Mussel” project is an attempt to create rings in the water by providing an example that may inspire other river restoration projects throughout Europe.

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*Return of the Thick-shelled River Mussel*
Contents

Introduction  5  Södermanland Region  56
Thick-shelled river mussel  10  Unforeseen difficulties  68
Species information  12  Substrate composition  70
Restoring streams and rivers  14  Success factors  71
Skåne Region  16  Public information  72
Blekinge Region  28  Conservation measures  74
Jönköping Region  36  Monitoring and follow-up  89
Östergötland Region  44  References  96

Photo: Jakob Bergängen.
Freshwater Mussels in Europe:
Focus on the Thick-shelled River Mussel

Freshwater mussels: ecosystem engineers

Freshwater mussels, also known as freshwater bivalves or naiads, are remarkable organisms. They can live for over a century on the bottoms of lakes, streams and rivers. Their unique life cycle includes: parental care — of eggs and larvae by the mother; and larval parasitism, primarily on freshwater fish but sometimes also on other vertebrates (Lopes-Lima et al., 2014).

Freshwater mussels are also important elements of aquatic ecosystems (Vaughn & Hakenkamp, 2001) where they sometimes comprise more than 90% of the biomass on lake, stream and river bottoms (Negus 1966). A single mussel can filter some 40 litres of water every day (Tankersley & Dimock 1993), and the combined filtration of a single mussel population can retain circa 50% of fine suspended particles which otherwise would greatly increase water turbidity during summer.

Due to their direct and indirect effects on freshwater ecosystems, mussels are often referred to as "ecosystem engineers". As they filter water to feed, mussels transfer energy from the water to bottom fauna, and that process can strongly influence primary and secondary biological production, biogeochemical cycles, sedimentation rates and visibility depth (Strayer et al., 1999). In addition, their shells are an important source of substrates and habitats for many other organisms (Vaughn & Hakenkamp, 2001; Spooner et al., 2013).

Freshwater mussels contribute to ecosystem services to humans, such as water purification. They also produce valuable materials such as pearls and mother-of-pearl in their shells (Haag 2012).

Species diversity among freshwater mussels is experiencing a drastic decline throughout the world. For example, 224 (44%) of the 511 known species of freshwater mussels (Unionini) are classified as endangered (EN) or near threatened (NT) on the IUCN Red List of Threatened Species.

Much of the knowledge regarding the global decline of freshwater mussel populations concerns North American species, which are among the most endangered fauna on that continent (Williams et al., 1993; Strayer et al., 2004). Over 70% of the North American species are regarded as threatened. The number of species is declining and 37 are assumed to be already extinct (Lydeard et al., 2004).

Major worldwide threats to the biodiversity of freshwater ecosystems include: the loss, fragmentation and deterioration of habitats; over-exploitation; pollution; introduction of species; and climate change (Dudgeon et al., 2006; Geist, 2011). European freshwater mussels are vulnerable to all of these threats; but other, currently unknown factors may also be involved.
The IUCN European Red List of non-marine molluscs includes assessments of the threat status of the 16 European large freshwater mussel species. Twelve of them are classified as follows:

Three are Critically Endangered — *Margaritifera margaritifera*, *Margaritifera auricularia* and *Unio gibbus*.

Two are Endangered — *Unio crassus* and *Potamida littoralis*.

Two are Vulnerable — *Unio tumidiformis* and *Microcondylaea bonelli*.

Five are Near Threatened — *Anodonta cygnea*, *Pseudanodonta complanata*, *Unio delphinus*, *Unio mancus*/*Unio cf. ravoisieri* and *Unio elongatulus*. Note: *Unio mancus* is a synonym of *Unio cf. elongatulus*.

One of the twelve species, *Unio ravoisieri*, has not yet been assessed, and the remaining three are regarded as unthreatened — *Anodonta anatina*, *Unio pictorum* and *Unio tumidus*.

Source: Lopes-Lima et al., 2014b, 2016)
The maps below show the European distribution of various large freshwater mussel species (Unionini). Grey-coloured areas indicate their distribution in various watersheds prior to 1992. The grey areas indicate their distribution today. The black dots show the locations of currently known populations.

(A) Distribution of *Unio crassus* (grey) and *U. tumidiformis* (red)
(B) Distribution of *U. pictorum*
(C) Distribution of *U. mancus* (blue), *U. cf. elongatulus* (blue), *U. delphinus* (grey) and *U. ravoisieri* (red)
(D) Distribution of *U. tumidus* (grey) and *U. gibbus* (red)

These distribution maps are based on recent surveys and published data. (Source: Lopes-Lima et al., 2016)
Freshwater mussels in Europe

European freshwater mussels have received increased attention in recent years. A growing number of European lakes, streams and rivers have been studied, and molecular analysis techniques have helped to determine species relationships which have previously been difficult to resolve.

Also, increased co-operation among Central European states has led to the discovery of rapid and extensive declines of mussel populations in that region. Despite increased awareness of the problem, conservation efforts to date have focused only on a few species — for example, *Margaritifera margaritifera* (freshwater pearl mussel) which has an interesting history in relation to human cultures, and its south European relative, *M. auricularia*. Some populations of those two species have long since disappeared, or been reduced to small local remnants with poor reproduction.

Unfortunately, much less attention has been paid to the other freshwater mussel species in Europe. That appears to be reflected in the assumption that those species are so widely distributed and have such good reproduction rates that they do not require attention. It is difficult to quantify changes in the populations of these other species, due to a lack of extensive basic studies on them. Recent discoveries of new populations of some species may have given the probably false impression that their total numbers are increasing (Aldridge, 2004).

At the start of the 20th century, the diversity of large freshwater mussels in Europe was greatly overestimated at circa 1500 species (!) due to the application of a great many name synonyms to highly variable shell forms (Graf, 2010). By the close of the 1920s, after combining and revising previous descriptions, a total of twelve species were acknowledged along with several subspecies.

In recent years, however, the number of European large freshwater mussel species has increased, largely as a result of advances in molecular taxonomy. The number of species may increase further, since more research is being conducted in this area.

As of year 2016, sixteen species of European large freshwater mussel have been acknowledged. The *Unio* genus is represented in all European countries and, although it is comparatively rare, *Unio crassus* is widely distributed in Central, Southeast and Northern Europe — from France in the west to the Russian border in the east. The latest systematics and geographical distribution of all acknowledged species of this group are described in Lopes-Lima *et al.*, 2016.

**Biology and life cycle**

Freshwater mussels can be very long-lived, up to more than one hundred years, and have a remarkable life cycle. Female mussels keep their eggs and developing larvae in the marsupium, a modified gill inside the shell.

Fertilization occurs when male sperm enters a female’s mantle cavity via its incurrent siphon. The fertilized eggs develop into specialized larvae called glochidia. The larvae then attach to the gills of a host fish. During that time they mature into fully developed mussels.

When the small young mussels have finished developing on the host fish, they detach themselves and fall to the bottom. They bury themselves in sand or gravel until they have grown to circa one centimetre in length. Then they crawl up and perch on the bottom surface, where they begin to filter the passing water as the older mussels do.
themselves as parasites to host fish and continue to develop within cysts on the skin or gills of the fish. In rare cases they may also parasitize other vertebrates — amphibians, for example.

The parasite stage can help to spread the mussel to new habitats via the host fish, which in turn increases the potential supply of nutrients for the larvae as they develop. The nature and degree of parental care, and the choice of host fish, vary among mussel species. There may be local adaptations to specific host fish. But current knowledge of which fish species are suitable as hosts in various contexts is limited (see for example Taeubert et al., 2010 and 2012b; Karlsson et al., 2014).

Ecology and habitat requirements
The factors which determine the presence or absence of mussel species can be best described in terms of biogeographical history, the availability of host fish and the local environment, including biotic and abiotic conditions (Vaughn & Taylor 2000). In Europe there are several biogeographical barriers that can explain the distribution of mussels. Examples include the Alps and Pyrenees mountain ranges, which may explain the isolated populations of several mussel species on the Italian and Iberian peninsulas. Wider ranges of some freshwater mussel species may have resulted from past ice ages and interglacial periods (Froufe et al., 2014).

One important factor is that the presence of mussels is largely determined by the availability of host fish. Mussel species that are specialized on host fish with relatively small populations and very specific habitat requirements usually have more limited distributions than species that are generalists.

At the local level, the composition, density and distribution of mussel species are determined by such factors as habitat characteristics, rate of stream flow, water quality, sedimentation, and biotic factors such as competition, predation and parasitism. (For an overview see Strayer, 2008.).

Historically, pearl fishing has been a great threat to many populations of Margaritifera margaritifera in Central and Northern Europe (Young et al., 2001; Makhrov et al., 2014). There are now strict laws that prohibit pearl fishing, but poaching continues in some countries — Scotland and Russia, for example (Hastie, 2006; Bespalaya et al., 2007a). There have also been a few reports that some mussel species have been used as food by people and domestic animals in Europe. But even if over-exploitation of freshwater mussels accounts for reductions in local populations, it cannot explain the extensive decline in Europe as a whole.

Red listing and threat factors
In the latest assessment of the IUCN Red List, twelve of Europe’s sixteen freshwater mussel species have been classified as endangered, vulnerable or near threatened. Among the genus Unio mussels, U. crassus is classified as endangered (EN).

Unio crassus was once considered to be the most prevalent mussel species in Europe. It declined dramatically — by as much as 50% in number of both individuals and populations — in Western and Central Europe during the latter 1920s (Lopes-Lima et al., 2014a). The species is now legally protected, but is regarded as critically endangered in several European countries. Local populations appear to be stable only in the east, i.e. in the Baltic States (Lopes-Lima et al., 2014b). But recent surveys have discovered new, reproducing populations in Germany (Stoeckl et al., 2015), indicating that there are gaps in current knowledge of this species’ distribution.

The accumulation of mud and other fine-grained sediments on bottom habitats appears to have caused problems for M. margaritifera. But that is probably not responsible for the observed decline of Unio crassus (Denic et al., 2014). The most likely primary causes, at least in Central Europe, are direct threats such as predation by the invasive Ondatra zibethicus (muskrat), excavation in the mussel’s aquatic habitats, and insufficient host fish populations (Zahner-Meike & Hanson, 2001; Stoeckl et al., 2015).

Frequent variations in the volume of water that is released from hydropower plants often result in flow rates that are both slower and faster than normal. Faster rates can have negative effects on both juveniles and adults, which may also impair reproduction. Longer periods of slower flow rates downstream from dams can result in mussel mortality due to low oxygen levels and parched habitats. Also, changes in water temperature can severely affect fish communities, mussel reproduction capacity (Heinricher & Layzer, 1999), and both the timing and success of the development of mussel larvae on their host fish (Taeubert et al., 2014).

Cleaning, excavation and vegetation removal on aquatic bottoms with the use of machines can eliminate a large number of mussels. Such measures also increase the risk of insufficient oxygen due to the increased sedimentation that often results (Aldridge, 2000; Cosgrove & Hasting, 2001).

Unio crassus has previously been widespread and very abundant in the lakes, streams and rivers of Sweden and Central Europe. Under favourable conditions, this species which lives in flowing water could be found in dense populations of up to several hundred individuals per square metre on the bottoms of those watercourses (Tudorancea & Gruia, 1968; Zettler & Jueg, 2007). Today, Unio crassus is classified as endangered in the IUCN Red List of Threatened Species (Lopes-Lima et al., 2014b), and is even threatened with extinction in several European countries. Due to drastic population declines within its entire natural range, the species has become a high conservation priority.
Unio crassus and it’s Habitat

There are seven native species of the family Unionidae in Sweden. Unio crassus and Margaritifera margaritifera live only in flowing water, but the other five species also live in ponds and lakes. Unio crassus and many other species are negatively affected when streams and rivers are straightened and cleaned, and when dams block fish migrations.

Artist’s mortar
There are three Unio species in Sweden. They all have thicker shells than the three Anodonta mussels. Unio crassus has the thickest shell, as indicated by its common name: thick-shelled river mussel. The Swedish common name for Unio species is målarmussla, ”painter’s mussel”, a reference to the fact that artists in former times used its shells like mortars for mixing paints.

Today, Unio crassus occurs only in southeast Sweden, but was previously much more common. Now its range extends only from Södermanland and Örebro counties in central Sweden to Skåne County in the south. In the past it was observed somewhat further north, in Uppsala and Dalarna counties; but no living individuals have been observed there in modern times. An inventory conducted in recent years found Unio crassus in quite a few more streams and rivers than previously known. Much more is today known about the sizes and reproduction capacities of individual mussel populations.

Cleaning water by eating
When necessary, a large freshwater mussel can move over distances of up to several metres in 24 hours. It creeps along slowly by extending its soft, shapeless foot from its shell and then drawing itself forward.

Mussels feed on particles that they filter from the water, which they suck in through a tube-like siphon. After gathering the edible particles, they squirt out the now cleansed and filtered water through another opening. Through yet another opening, the anus, they eject firm excrement which lies on the stream bed.

A single Unio crassus mussel can filter several dozen litres of water every 24 hours. Large and dense communities of mussels can have a significant effect by removing fine particles from water and thereby helping to make it cleaner and more transparent.

Parasitic larvae hitch rides on fish
It is not only food particles that mussels ingest with their siphons. It is through them that the females also take in sperm which males release into the water. Inside a female’s gill chamber, sperm fertilize her eggs which remain there as they develop into very small (0.2 millimetre) larvae called glochidia. The first critical stage of the mussel life cycle comes when the female sprays the glochidia into the water: They need to find a suitable host fish. Few succeed in attaching themselves to the gills of a host fish and utilize the oxygen-rich blood that flows through them. In this stage the mussel is a parasite.

Which fish species are used by Unio crassus as hosts is a question that has not been thoroughly investigated. Research conducted in Germany and Sweden has identified five species that can serve as host fish: Cottus gobio (bullhead), Phoxinus phoxinus (minnow), Rutilus rutilus (roach), Lota lota (burbot) and Albunus alburnus (bleak). (Wengström, 2012; Taubert et al., 2015)

Additional knowledge has emerged from the UC4LIFE project (“Unio crassus for LIFE”), and the results from our studies of host fish are presented in this report under the heading of “Conservation measures” (page 74). As the host fish move through the water, the mussel larvae hitch a ride and are thus able to establish themselves in new areas. This is a precondition for the dispersal of mussels in their aquatic environments, since mature mussels are able to move only short distances by themselves.

After the larvae have clung to the host fish’s gills for about one month, they detach themselves. They have now undergone a transformation into juvenile mussels about half a millimetre in size. It is time for the next critical phase: The tiny mussels must now find suitable bottom habitats with coarse sand or fine gravel in which to bury themselves and remain there for several years. After they have grown to lengths of 10 - 12 millimetres, they crawl up to the bottom surface and begin to feed on food particles which they filter from the surrounding water (Zinko, 2013).
### Species identification guide for Nordic species of large freshwater mussels

1a. Shell is an acute triangular shape; umbo positioned at the end of the pointed part

   **Dreissena polymorpha**
   (Zebra mussel)

1b. Shell not acute triangular shape: umbo position on the upper edge of the shell

2a. Shell relatively thick; has hinge teeth

2b. Shell relatively thin; no hinge teeth

3a. Hinge plate with only anterior lateral and cardinal teeth

   **Margaritifera margaritifera**
   (Freshwater pearl mussel)

3b. Hinge plate with anterior lateral, cardinal and posterior lateral teeth

4a. Shell approximately equally round at the distal and front end; powerful anterior lateral and cardinal teeth wedge-shaped; in the left valve they are separate from each other and form a line

   **Unio crassus**
   (Thick-shelled river mussel)

4b. Shell with pointed elongated distal end and rounded front end; anterior lateral and cardinal teeth are thin and sharpened; the left anterior and cardinal teeth are joined or partially covering each other

5a. The lower margin of the shell is almost straight, parallel with the upper margin; all anterior and cardinal teeth are thin; the left cardinal tooth overlaps the anterior tooth, or is reduced and much smaller than the anterior.  

   **Unio pictorum**
   (Painter’s mussel)

5b. The lower margin of the shell is markedly curved, not parallel to the upper margin; the right anterior lateral and cardinal teeth are well developed, thin and wedge-shaped; the left cardinal tooth relatively elongated and mostly lower than the anterior lateral tooth, and slightly overlapping

   **Unio tumidus**
   (Swollen river mussel)

6a. Markedly flattened/compressed shell; front part is strikingly low and short; umbonal rugae in the form of irregular, crosswise ridges

   **Pseudanodonta complanata**
   (Depressed river mussel)

6b. Shell not markedly flattened; front part not strikingly low and short; umbonal rugae in the form of long, wavy ridges

7a. Shell markedly high in relation to the length; umbonal rugae in the form of strong, coarse ridges, relatively far apart

   **Sinanodonta woodiana**
   (Chinese pond mussel)

7b. Shell not markedly high in relation to length: umbonal rugae in the form of fine, thin ridges

8a. The upper and lower margins are almost parallel; umbonal rugae parallel with the growth lines on the shell; the incurrent siphon is thin with long papillae; soft tissues are orange

   **Anodonta cygnea**
   (Swan mussel)

8b. The upper and lower margins of the shell tend to diverge backwards; umbonal rugae crosswise to the growth lines; incurrent siphon is wide with short papillae, soft tissue is grey-yellow

   **Anodonta anatina**
   (Duck mussel)

Thick-shelled River Mussel: Species Information, Biology and Ecology

Description: How to identify a thick-shelled river mussel

The shell is very thick. Its length is 4 – 7 centimetres (up to 10 cm. in exceptional cases) and usually less than twice as long as the height. The shape is elliptical to slightly oval, and the centre section of the bottom valve is straight. The rear and front are similarly curved, but the rear edge is bent slightly downward. The umbonal sculpture consists of dense wavy ridges on the shell’s “hump” (umbo), but often they have completely disappeared from mature mussels due to corrosion. The shell’s colours are dark green, brown and black, and become darker with age. The surface is often covered with crust-like deposits of lime or a coating of ferro manganese. Powerful cardinal teeth arrayed in a line on the left side of the shell. The cardinal tooth on the right side is also very large and powerful, and conical in shape.

Misidentification risk

To the untrained eye, there is a significant risk of confusing Unio crassus with other Swedish species of freshwater mussel, especially those of the genus Unio. However, there are very clear differences in the appearance of the various hinge plates.

Unio crassus (Thick-shelled river mussel). The shell’s rear and front are similarly curved. The cardinal tooth on the right side is very prominent and shaped like a large, thick triangular wedge. (Photo: Stefan Lundberg)

Unio pictorum (Painter’s mussel). The shell’s bottom valve is nearly straight, and parallel with the upper valve. All of the cardinal teeth are thin. The left rear cardinal tooth overlaps most of the one in front, or is smaller and in that case much smaller than the front tooth. (Photo: Stefan Lundberg)

Unio tumidus (Swollen river mussel). Shell’s lower valve bow-shaped, not parallel with upper valve. The cardinal tooth on the right side is quite powerful and has a narrow, wedge shape. The left rear cardinal tooth is higher but usually shorter than and slightly overlapping the one in front. (Photo: Stefan Lundberg)
Distribution and status

*Unio crassus* sites in Sweden

Although there are large gaps in its range, *Unio crassus* is present throughout most of Europe. The main exceptions are Italy, the Iberian Peninsula, the British Islands and northernmost Scandinavia. It is also present in some areas of the Black Sea region and the Near East. In addition, there are a number of subspecies and local forms.

All occurrences within the Weichselian glaciation region in the north are of the nominate form, *Unio crassus crassus*, for which Sweden is the *terra typica* — i.e. the geographical location of the species on which the original scientific description was based.

*Unio crassus* occurs in eastern Sweden from the Skåne region in the south to the Uppland and southern Dalarna regions in central Sweden. Its range is divided into four areas: Skåne, northeast Småland/Östergötland, eastern Södermanland/southern Närke and northwest Uppland/southeast Dalarna. The species is extinct or endangered in many places throughout its range.

The species has declined catastrophically in Central Europe since the 1950s. It has also disappeared from many of its previously known sites in Sweden. The species must be regarded as extinct within the entire northwest Uppland/southeast Dalarna area. It should be noted that some new *Unio crassus* sites have been discovered in recent years, primarily in northeast Småland/Östergötland and eastern Södermanland/southern Närke.

Ecology and habitats: Where does *Unio crassus* live?

*Unio crassus* occurs in running water on sandy or gravel bottoms. In Central Europe it occurs mainly in larger brooks and rivers but also in smaller streams, and in Sweden mainly in the major river systems in the south and southeast. There are also a few sites in littoral zones of lakes, near inlets and outlets with continual flows of water.

The species has separate sexes and, after the eggs on the female’s gills are fertilized by male sperm, they develop into larvae called glochidia which are unique to large freshwater mussels. The larvae attach themselves to host fish as parasites for a period of 4 – 5 weeks. Analyses of *Unio crassus* shells have found that the median age in Sweden is between 50 – 60 years and that individuals can live up to 90 years. The shells are therefore valuable “archives” of environmental chemistry.

Legal protection

*Unio crassus* is included in Annexes II and IV of the European Union’s Species and Habitats Directive. Special preservation areas within the Natura 2000 network are designated for the species listed in Annex II. Sweden is obligated to ensure that the listed species within its jurisdiction have a favourable preservation status. Inclusion in Annex IV confers legal protection, which is regulated in Swedish law by the Species Protection Ordinance (1998:179) and the Fisheries Ordinance (1994:1716). These ordinances require that permission to conduct inventories must be granted by the relevant county administrative boards. This legal protection went into effect in Sweden in year 2001.
Return of the Thick-shelled River Mussel
Project Measures and Outcomes

Restoration measures have been carried out in the twelve rivers included in the project. They are: Fyleån and Klingaväljsån in Skåne County; Mörrumsån and Bräkneån in Blekinge County; Emån and Brusaån in Jönköping County; Storån, Kisaån and Kapellån in Östergötland County; Vretaån, Svärtaån and Vedaån in Södermanland County.

The types of measures applied have been determined by the nature of the environmental disturbances affecting the project areas, but they can be sorted into three categories: habitat restoration to create more diverse aquatic environments; floodplain restoration by re-meandering of rivers and hydrological rehabilitation of valleys; and increasing connectivity by removing migration barriers.

The measures have been applied to river sections with a combined length of 251 kilometres, 82 hectares of bottom area and 300 hectares of floodplain areas. Eight migration barriers have been removed or bypassed by constructing fauna passages and bio-channels.

The restoration work has been carried out in order to improve both water quality and living conditions for many aquatic species.

A key objective is to re-establish, within a period of ten years, self-sustaining populations that produce new generations of young mussels — by reintroducing *Unio crassus* to waters where the species has either died out, or is still present but only with a few individuals and with inadequate reproduction.

Changing Rivers —
A Threat to *Unio crassus*

*Unio crassus* has disappeared from several of the streams and rivers where it previously occurred, due to changes made by humans. Originally, the rivers meandered through their landscapes and, during the spring and autumn, flooded adjacent land areas. But the flooding interfered with farming and forestry, and the response was to straighten and deepen rivers so that the adjacent lands would drain faster.

That has resulted in faster currents through straighter, much shorter channels that no longer flood their banks. Those changes have also led to increased levels of nutrients and inorganic particles in the water, which in turn has made it necessary to repeatedly clean the channels in order to maintain drainage of adjacent farmland or forests. The cleaning often results in the removal of mussels and the bottom substrates they require. An additional side effect is increased water turbidity, which can indirectly threaten mussels by its negative effects on their host fish.

Another problem consists of barriers that block natural migration routes of host fish between lakes, rivers and the sea. Dams and improperly constructed culverts often make it impossible for fish to “help” mussels reproduce, disperse and increase their range. If the fish cannot reach their spawning grounds, they will eventually disappear.

River restoration and other measures can save *Unio crassus*

Demands for river cleaning are often raised when vegetation such as reeds and club-rush expands, or when fine sediment accumulates on a riverbed. The latter may occur when flowing water erodes the banks — entire sections may glide into the water — or when tiny particles transported by the water settle and accumulate at places where the current is slower.

Riverbank erosion can be hindered if the angle of the slope is not too steep. In most landscapes, a natural river develops a winding course — it meanders. Sediments are constantly moving in streams and rivers. This is a natural process, and it is better to work with it than against it. One way to avoid flooding of more elevated adjacent farmland is to let the river be flanked by a low-lying floodplain on which sediments (including nutrients) settle when the river overflows its banks. If the shoreline is left in place along a river’s natural course, there is no need to invest in repeated dredging and cleaning activities.

Overgrowth of reeds and club-rush can be hindered or prevented if trees and shrubs are allowed to grow along the shore and shade the water. If the shoreline and bordering trees are preserved, the eventual result will be a shoreline forest that stabilizes the riverbank.

The highest-priority measure is to add fine gravel in order to recreate bottoms in which small young mussels can bury themselves. Adding stone and gravel to create aquatic habitats for mussels’ host fish also provides the fish with spawning areas. The presence of large stones increases the variation in water flow conditions and habitat types, and thus biodiversity.

Many people attempt in various ways to remove obstacles which impede the migration of aquatic animals. At dams, various types of fishway can be built. But removing dams or creating fauna passages around them is normally a much better...
alternative, because it enables all aquatic organisms to migrate freely. If the sides of the river channel are very steep and there is no place to build a fauna passage, some type of fishway may be appropriate. Among the types that have been tried are those called pool-weir, denil and vertical slot fishways. It should be noted, however, that this solution generally functions poorly, especially for fish that are not strong swimmers.

An important restoration measure is to correct improperly constructed culverts. The main problem is that they do not lie on the bottom, but higher up in the water. This results in an obstacle that hinders or prevents migration.

Another measure to improve water environments is to re-meander channels that have previously been straightened and canalized. This re-establishes the original winding channel, which in turn results in more varied habitats and a longer shoreline. Often formed among tree roots and rocks along the shoreline are pools and hollows where aquatic animals can find food and shelter.

In order for *Unio crassus* to survive and spread to additional streams and rivers, it is essential to continue all of these measures. Continued co-operation with affected hydropower owners and landowners is a precondition for success. (FIS-RWG, 1998; Baudou, 2006; Degerman, 2008; Zinko, 2013; www.restorerivers.eu)

The project “Return of the Thick-shelled River Mussel” includes 12 project areas which are fairly evenly distributed across the historic range of *Unio crassus*. 
The Fyleån River, is one of the Nybroån River’s main tributaries. It is nine kilometres long and runs southeast through the Fyle Valley to a place called Fylan, where it joins the main channel of the Nybroån. The Nybroån River runs south and eventually empties into the Baltic Sea east of Ystad on the southeast coast of Skåne. In its course through the valley, the Fyleån runs through the municipalities of Sjöbo, Tomelilla och Ystad.

Fyledalen is a long, flat glacial valley flanked by slopes covered in broad-leaved forest. The river meandered along the valley floor until the mid-1800s when a new, straight channel was excavated and ditching of adjacent areas began for two purposes: to create more cropland, and to prepare the ground for a railway through the valley. The last ditching in the valley took place during the 1930s. After that, the river was cleaned on a regular basis until the start of the new century. During that time, several small streams which ran down the lateral slopes to the river were led through culverts.

Today, the valley floor consists mainly of dry land which is used primarily for grazing livestock. Small remnants of fenland remain, including Vällerödskärret which is an extremely rich fen with an especially valuable flora that thrives on lime. Traces of the old, meandering stream and river channels can be seen here and there.

Essentially, the Fyleån River has been converted into a straight ditch, even though there are no ditching companies in the valley. The river’s width varies from 1.5 – 7 metres, with an average width of 3 metres. Average depth to hard bottom is circa 0.8 metre; but in large parts of the river, the water is much more shallow due to the accumulation of organic matter mixed with mud. At some places, the bottom consists primarily of sand with some gravel. There are almost no boulders or dead wood in the river.

There is no shade along some stretches of the Fyleån, and the entire valley section of the river is to a greater or lesser extent overgrown with vegetation which includes Phragmites australis (club-rush), Sparganium erectum (branched bur-reed), Berula erecta (lesser water-parsnip) and substrate algae.

The river does not provide the necessary conditions for fish to thrive. Although there are no migration obstacles, Salmo trutta (brown trout) is present only in the lower reaches of the river. Also present are Cottus gobio and Pasifastacus leniusculus (signal crayfish).

There are no living communities of large freshwater mussel in the Fyleån River. But shells from a previous occurrence of Unio crassus were found in 2005 (Svensson & Ekström, 2007), and above the confluence of the Trydeån River in 2010. Unio crassus has previously occurred in most parts of the Nybroån River system, but has very likely disappeared from all of it — probably as recently as the start of the 21st century.
Only shells of *Unio crassus* have been found in the Nybroån River system. The individuals which survived the longest, probably until the start of the 21st century, were found in the Trydeån River. (Photo: Marie Eriksson)

Before restoration measures were carried out, the Fyleån River ran like a straight ditch through the Fyledalen Valley. (Photo: Christian Lindh)

Habitat restoration and re-meandering measures have been carried out along a six-kilometre stretch of river (black lines). In addition, eight small ponds in the Valley have been restored, and five previously culverted feeder streams have been opened up during the restoration. *Unio crassus* has been reintroduced in the area.

Start of excavation to re-meander the Fyleån River. (Photo: Vibeke Lirås)
Large quantities of *Unio crassus* shells have been found, primarily in the Trydeån River but also in Örupsbäcken Brook and the Nybroån River’s main channel. Communities of *Anodonta anatina* and, most likely, a few *A. cygnea* individuals still live in the Nybroån River system (Eriksson & Bergengren, 2004).

There are few commercial activities in the area, other than agriculture and forestry. Previously there was a smaller mining operation (quartz) close to the river; but that is no longer active and the industrial area has been dismantled.

Ideas and plans for restoring the Fyledalen Valley’s river and streams, along with its wetlands and flooding regime, began to form before the start of the UCALIFE project. For the purpose of restoring the Fyleån River, Högestad & Christinehof Fideikommis Co. (now Högestad & Christinehof Förvaltnings Co.) developed a project proposal with necessary supporting materials in 2008 – 2010, along with related inventories, water use rulings, bidding information, etc. The proposal was approved and the project was carried out in collaboration with the Nybroån Management Committee and the owners of properties Röddingeberg 3:19 and Röddinge 7:12. However, the problem of financing the restoration work was not solved.

Around the same time, the UCALIFE project began to take shape. The idea of using *Unio crassus* as an emblematic species for the restoration work turned out to be fruitful. So were the attempts to cultivate and introduce juveniles of the species into the Fyleån River, and the decision to incorporate the previously developed restoration plans.

**Restoration measures**

Few restorations have been implemented on meandering, slow-moving flatland rivers with a holistic perspective on the landscape. The overriding goal was to alter the artificially straightened channel so that the river would again have a meandering course, with a natural flooding regime and with bottom substrates and other structures that are natural in the region. Another objective was to benefit plant and animal life, in both water and on land, by reducing the transport of nutrients in the river.

The section of the Fyleån River in and around which measures have been implemented is 4.9 kilometres long. It extends from Eriksdal to the bridge at Fylan Farm, just upstream from the confluence of the Fyleån and Trydeån rivers.

Within this section of the river, 3.7 kilometres have been excavated to become more winding and thereby lengthened by 1.2 km. By following elevation changes in the landscape and remaining traces of the old meanders, the Fyleån’s original course has been restored to the fullest possible extent.

Along the entire section, including the part that was not re-meandered, a new river bottom has been laid for the benefit of fish and other aquatic animals. This has resulted in more varied habitats with different types of bottom material and flow conditions.

The earth embankments along the river which resulted from previous dredging have been removed. That has enabled repeated flooding of adjacent areas when the river is high, and rapid draining when the water recedes.

After the river began running through its new, winding channel, the old straight channel was filled in. Also restored were several feeder streams which had previously been culverted or deeply eroded.

When the restoration work was completed, *Unio crassus* juveniles were planted on the river bottom. See “Conservation measures” on page 74 for details on the results.

Vällerödskärret Fen was also restored. It had been negatively affected by changes in land use and hydrological conditions. An area of overgrown calcareous fen covering 0.1 hectare was excavated so that its lime-rich soil was exposed. Its flora and fauna were then re-established by the immigration of species from nearby fens.

Ten shallow decorative ponds have also been created for the benefit of various amphibians in the area. Another purpose is to trap nutrients that would otherwise over-fertilize the river.

In addition to these measures, a road culvert has been replaced by a more ecologically functional semi-culvert, and several bridges have been restored to facilitate the passage of machines, animals and people over the river.

**Measures taken**

- 3.7 km of straight river have been excavated to raise the river bottom on 4.9 km of meandering river.
- New bottom substrate has been added to 1.1 of straight river channel.
- New bottom substrates amounting to 1100 metric tons of stone and gravel have been added to river.
- Culverts have been removed from five feeder streams.
- A culvert has been replaced with an arch where the river passes under Röddingehultsvägen.
- Accumulated mounds of dredging material have been removed.
- One existing large bridge has been restored. Two large bridges that can bear heavy machines and animals, and three small footbridges have been built.
- An extremely rich fen, Vällerödskärret, has been restored by removing overgrowth from 0.1 hectare of its surface.
- What many regard as Sweden’s most beautiful outdoor sports arena, Röddinge IP, is now watered with over flow water in order to trap nutrients.
Success factors

The most important success factor was undoubtedly the positive attitude of the affected landowners toward the project (Höggestad & Christinehof Fideikommiss Co. and Röddingeborg Estate). That attitude, and their knowledge and experience of water and nature conservation were essential to the rapid and successful implementation of the project.

Since re-meandering a river is a very large task, it was decided that a permit was required in accordance with the Swedish Environmental Code. The legal process of obtaining the necessary permit is comparatively brief. From the date of application, it took just over one year until the Swedish Land and Environment Court issued its ruling.

In its submission to the Court, the Skåne County Administrative Board stated that it would be good if the river could be allowed to meander freely again. An important success factor was that the court’s decision included a so-called general condition: “Unless otherwise stipulated in this ruling, the work of restoration and future water regulation will be conducted in general agreement with what the applicants have stated or committed themselves to in their application.” It was the court’s opinion that this formulation (a) would satisfy the administrative board’s wish that the river should be allowed to meander freely, and (b) that it was not necessary to specify exact geographic co-ordinates in the ruling.

Research and Monitoring

From the beginning, it was thought that the Fyleån River project would be fairly easy to carry out, since it was an initiative of the affected landowners and there were relatively few other interested parties. But it turned out to be more complicated than anticipated due to concerns that the area’s highly valuable natural features might be negatively impacted by the work of restoration. It was therefore important to conduct preliminary studies. A number of experts were engaged to document the area’s flora and fauna, and also to review the proposed measures.

In addition, intensive efforts were made to find living communities of *Unio crassus* in the Fyleån River and in the other components of the Nybroån River system. Participating in those efforts were regional environmental monitoring personnel of the Skåne County Administrative Board (Eriksson & Bergengren, 2004), a threatened species conservation programme (Svensson & Ekström, 2007) and members of the UC4LIFE project.

That was important for two reasons: One was to determine if there were any mussel communities in the river that (a) would be suitable as mother populations for the planned infection of host fish by their parasitic larvae, and (b) could raise the young mussels that might result from a larval infection of host fish. The other reason was to completely eliminate the possibility that living individuals of *Unio crassus* were still present in the Nybroån River system. If there were none, mother populations from another river system could be used — the Tommarpsån River in this case.
Fyleån River after restoration measures were carried out. A 3.7 kilometre stretch of river has been altered so that it again meanders, thereby increasing its length by 1.2 km. (Photo: Johan Hammar)
Other objectives were to maintain a continual flow of water during the river’s passage through the project area, and to perform the work in such a way that turbidity would be prevented to the fullest possible extent. This was accomplished by:

- Digging the new river channel during dry periods and low flow conditions.
- Performing the restoration work during the summer, when the water level was lower and vegetation could quickly re-establish itself on the excavated open surfaces.
- Releasing the water gradually into the newly dug river sections in order to minimize the risk of high levels of turbidity downstream.
- Widening and deepening the river channel in two places in order to reduce the speed of the water current and to create conditions for increased sedimentation of particles at those locations.
- Seeding large exposed areas of land with a grass seed mixture so that grassy vegetation could re-establish itself where most needed to impede erosion. The seed mixture included *Lolium multiflorum* (Italian ryegrass) which establishes itself quickly but cannot survive cold Swedish winters and is eventually replaced by the native flora.
- Using protective ground mats under excavating machines where there was a risk of significant damage from their movements.
- Equipping vehicles with computerized measuring instruments to ensure digging at the correct depth and location.

### Required permissions

- Water use permit as required by chapter 11, paragraph 9 of the Swedish Environmental Code
- Permit for measures to be taken within a Natura 2000 site, chapter 7, paragraph 28a of the Swedish Environmental Code
- Exemption for work in a protected habitat area, chapter 7, paragraph 11 of the Swedish Environmental Code
- Consultation regarding the cleanliness and placement of earth volumes, as required by chapter 12, paragraph 6 of the Swedish Environmental Code
- Exemptions from legal protection of *Bombina bombina* (fire-bellied toad) in order to deepen one of its spawning ponds
- Exemptions from nature reserve regulations
- Exemption for work in protected shoreline area. (It was determined that the Fyleån River project would not violate shoreline protection regulations.)
- Exemption for protection of landscape appearance
- Exemptions to enable collecting of legally protected mother mussels from the Tommarpsån River.
- Exemption from the Fisheries Ordinance's prohibition against the collection of living *Unio crassus* mussels
- Exemption from the Species Protection Ordinance as it applies to *Unio crassus*
- Permit to introduce young mussels
- Agreement with owners of fishing rights to plant young mussels
- Exemption to use electrofishing to collect samples
The source of Klingavälsån River is located just west of Lake Ellestadsjön in the Municipality of Ystad. After passing through Ellestadsjön, the river runs north through lakes Sno-geholmsjön and Sövdesjön. It continues through forest land, then heads northwest through Vombsänkan Valley before taking a more northerly course and eventually merging with the Kävingeån River at the village of Harlösa. The stretch of river between Sövdesjön and the Kävingeån is about 20 kilometres long and in some places forms part of the boundary between the municipalities of Lund and Sjöbo.

Located south of Lake Vombsjön, the Vombsänkan Valley is the long and very flat bottom of a former glacial lake, as its sandy soil attests. The valley consisted mainly of wetland with alder forest, through which the Klingavälsån River meandered until the start of the 19th century. It was then that ditching and straightening of the river began. A circa two-kilometre-long section upstream from Hemmestorps Mölla was straightened during 1812 - 1832, when the Hemmestorp water mill was moved a bit north to the lowest point in the landscape in order to increase hydropower capacity.

Beginning in 1968 the river was cleaned every fifth or sixth year. Mud banks and unwanted vegetation were carefully removed, partly by hand. Cleaning has been more extensive since the start of the 21st century, with the use of machines to dredge sediment from the river channel. That is one of several causes of increased erosion, which has resulted in increased sedimentation on the riverbed and the need to clean the river more frequently, usually every two years.

Today, the Vombsänkan Valley is well drained and is used primarily for livestock grazing. Here and there in the landscape can be seen remnants of the former meandering channel of the river. The Klingavälsån still has a winding course from Lake Sövdesjön to its confluence with Orehusabäcken Brook. From there to Hemmestorps Mölla, the river is essentially a straight ditch. Further downstream, the river channel has been restored by re-meandering it in stages to the place where it joins the Kävingeån River.

The straightened section of river varied in width from four to six metres, with an average depth of circa 1.6 metres. The riverbed consisted mainly of sand and fine sediment, with some gravel. There were almost no rocks or boulders, but there were some small remains of dead wood. There was hardly any shade, but along the shoreline was a border of dry-land plants which included Glyceria maxima (reed sweet-grass), Sparganium erectum (branched bur-reed) and Butomus umbellatus (flowering-rush). Growing abundantly in the river channel were Potamogeton spp. (pondweed), Elodea canadensis (Canadian waterweed), substrate algae, etc.

Although fish of some species were previously able to get past a migration obstacle at Hemmestorps Mölla when the water level was high, water quality in the river was not very...
good for fish. However, *Salmo trutta* (brown trout), *Cottus gobio* (bullhead), *Barbatula barbatula* (stone loach), *Alburnus alburnus* (bleak), *Anguilla anguilla* (European eel) and *Esox lucius* (northern pike) have been caught downstream from Hemmestorps Mölla.

An inventory revealed that *Unio crassus* is now extinct in the Klingavälsån River, but shell findings indicate that the species has previously occurred there. The inventory also revealed that several mussel species were still present in the straightened section. *Anodonta cygnea* (swan mussel) was the most prevalent species, but also present were *A. anatina* (duck mussel), *Unio tumidus* (swollen river mussel) and *U. pictorum* (painter’s mussel). Density for the entire section was estimated to be circa 0.6 mussels per square metre (Eriksson & Ljungberg, 2011).

It is most likely that *Unio crassus* has previously occurred in most of the Kävlingeån River system. Living communities have been found primarily in the Bråån River, but also upstream from Lake Vombsjön, i.e. in the Björkaån, Åsumsån, Tolångaån, Vollsjöån and Sniperupsbäcken tributaries (Eriksson & Bergengren 2004; Ljungberg & Svensson, 2010). Downstream from Lake Vombsjön in the Kävlingeån River’s main channel, a single individual of *Unio crassus* was found during a river cleaning.

Today, the Klingavälsån Valley is one of Skåne County’s largest nature reserves. Due to its highly valuable natural features, the area has also been designated as a Ramsar Site under the Convention on Wetlands of International Importance. Large parts of it are also included in the European Union’s Natura 2000 network of valuable natural areas.

Apart from farming and forestry, few other commercial activities are conducted in the Klingavälsån drainage basin. The river has in the past been affected by two wastewater treatment facilities in the villages of Sövde and Blenstorp. Those facilities were recently shut down, however, and the wastewater they had treated is now pumped to treatment plants in the Municipality of Sjöbo.

### Restoration measures

Few river restorations have been implemented on meandering, slow-moving flatland rivers on such scale as in the Klingavälsån River. The overriding goal was to alter the artificially straightened channel of the Klingavälsån so that the river would again have a meandering course — with bottom substrates and other structures that are natural in the region, and with wetter adjacent land areas even when water flow volumes are at low to medium levels. Another objective was to benefit plant and animal life in both water and on land by reducing the transport of nutrients to the sea.
The restored section of the Klingavälsån River is circa two kilometres in length, starting just upstream from the confluence of Orehusabäcken Brook and continuing to around 150 metres downstream from Hemmestorps Mölla. That entire section of straightened channel has been re-meandered, which has increased its length by 1.3 kilometres. By interpreting elevation differences in the landscape, traces of the former meandering channel and information from historical maps, the Klingavälsån’s original course has been re-established to the fullest extent possible.

New bottom substrate has been added to parts of the restored section for the benefit of fish and other aquatic animals. That has resulted in more diverse habitats, due especially to variations in bottom materials and flow conditions. Also, the course of the river has been altered where it passes Hemmestorps Mölla, which has been a migration obstacle since long in the past. That has enabled free passage of fish and other aquatic organisms during most of the year.

The existing straight river channel has been left in place for a distance of 750 metres from Hemmestorps Mölla. It is intended to reduce flow in the new main channel during episodes of high water-flow conditions. The remainder of the empty straight channel has been filled with material that was excavated to make the new channel.

After the restoration work was complete, juvenile *Unio crassus* that had been cultivated at Hemmestorps Mölla, were introduced in the river; for more details, see “Conservation measures” on page 74. A small brook located close to Hemmestorps Mölla has been converted into a “mussel canal” in which young mussels have been placed in order to study their survival and growth rates.

Several fords and smaller bridges have been restored and re-constructed to facilitate the passage of machines, animals and people over the river, and also to provide access to the “islands” of land that are now grazing areas.

A special impediment, a Jambor’s Shelf, has been built upstream from the road bridge. Its height will determine the water level upstream.

### Measures taken

- 2.2 kilometres of straightened river have been excavated and increased to 3.5 km of meandering river with a higher bottom level.
- Construction of shallow areas between the channels, circa 450 metres wide, onto which the river can overflow when necessary. These were made by filling the old straight channel to a level 0.3 – 0.4 metre below the surrounding land. Where the old channel is still in use, shallow areas have been dug; for the most part they follow natural depressions and traces of other old river channels. Thus, running along the entire length of the new channel is a shallow side channel which is normally empty but into which the river can overflow during episodes of high water.
- Jambor’s Shelf — 13-metre-wide impediment constructed.
- Eight footbridges have been built over the river.
- Five river fords have been constructed to provide livestock with access to “islands” of grazing land.
- Circa 850 metric tons of new stone and gravel substrate has been added to the river.
- A “mussel canal” has been prepared in a small brook running close to the Mill.

### Success factors

Because re-meandering the river was an extensive project, it was decided that — as in the case of the Fyleån River — a permit was required in accordance with the Swedish Environmental Code, stipulating that the Swedish Environmental Protection Agency was solely responsible for maintenance of both the newly dug channel and the remaining section of old, straight channel. The ditching company will continue to have some influence, as the court’s ruling grants it the right to request maintenance by the Environmental Protection Agency.
Monitoring

Several studies have been conducted on the Klingavälsån River project. An overview of existing reports from the area was prepared in connection with the environmental impact statement on the proposed restoration measures. The affected area is well-studied for several reasons: its proximity to Lund University; its status as a Ramsar Site; and its inclusion in the Natura 2000 network with reference to both the Birds Directive and the Habitats Directive of the European Commission. In addition, a preliminary study of bottom fauna in the relevant section of the Klingavälsån River was commissioned before the project started.

Some studies were also conducted by the Skåne County Administrative Board in connection with its environmental monitoring programme (Eriksson & Bergengren, 2004), its measures on behalf of threatened species (Svensson & Ekström, 2007; Ljungberg & Svensson, 2010) and its efforts to find living communities of Unio crassus mussels in the the Kävlingeån River system.

When the UC4LIFE project was launched in 2011, the ditching company gave notice that the affected section of the Klingavälsån River would be cleaned. The entire section was therefore inventoried by snorkelling to eliminate any possibility that the species might still be present (Eriksson & Ljungberg, 2011).

The inventories were also taken as part of the regional monitoring programme, in order to find communities of Unio crassus that would be suitable as mother populations for infecting host fish with mussel larvae, and for the associated cultivation of mussels for re-establishment of the species in the Klingavälsån River.

In order to determine what effects the restorative measures have had on the Klingavälsån, it is necessary to have knowledge of conditions both before and afterward. For that reason, water chemistry, periphyton, bottom fauna and fish are being monitored as part of the project. Flow conditions, bottom substrates and vegetation have been described for a number of river sections. Also, flow meters and temperature loggers have been placed in the river.

Precautionary measures

During the proceedings on the water use permit, concerns were raised that the project might have negative effects on the affected area, including commercial interests located there. It seemed at first that it could be easy to reach consensus on plans to re-meandering of the Klingavälsån River, as the land in question was state-owned and no buildings would be affected. But there was considerable scepticism among local residents who regarded flooding as a big problem.
The main objectives were to maintain a continual flow of water during the river's passage through the project area while the restoration measures were being carried out, and to perform the work in such a way that turbidity would be prevented to the fullest possible extent. Those objectives were accomplished by:

- Digging the new river channel during dry periods.
- Digging the meanders during the summer, when the water level was lower and vegetation could quickly re-establish itself on the excavated surfaces.
- Releasing the water gradually into the newly dug river sections in order to minimize the risk of high level of turbidity downstream.
- Digging deep holes at places where water from the new channel enters the existing river in order to trap larger particles in sediments.
- Seeding large exposed areas of land with a grass seed mixture, so that grassy vegetation could re-establish itself where most needed to impede erosion. The seed mixture included Lolium multiflorum (Italian ryegrass) which establishes itself quickly but cannot survive cold Swedish winters and is eventually replaced by the native flora.
- Using protective ground mats under excavating machines where there was a risk of significant damage from their movement.
- Equipping vehicles with computerized measuring instruments to ensure digging at the correct depth and location.

So as not to completely “lose their river”, some landowners wanted the main channel to continue bordering their properties. The new channel was therefore dug so that its meanders followed the old channel at several places. As a result, there are now several “islands” of grazing land surrounded by water, making access difficult. Several fords were therefore built so that it would be possible to drive vehicles onto those areas if any grazing animal became ill.

Before the new water use permit was issued, the section of river to be restored was managed by a cleaning company. There was great concern among the members of the cleaning company that the new channel might block the river if the work was not done properly. Therefore, a separate agreement regulating management of the area was signed with the cleaning company.

One mistake that was made: Leaseholders with grazing rights felt that they had been informed about the proceedings on the water use permit much too late.

Since the restoration area lies within a legally protected watershed, special safety regulations must be observed:

- Only vehicles that use biodegradable hydraulic oil may be used.
- When fuelling diesel-driven vehicles within the watershed protection area, double-bottomed tanks must be used.
- Fuelling of excavating machines must be done via leak-tight couplings.
- Absorptive material for cleaning up oil spills must be available in all vehicles, and in larger amounts in environmental containers.

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- Fuelling of excavating machines must be done via leak-tight couplings.
- Absorptive material for cleaning up oil spills must be available in all vehicles, and in larger amounts in environmental containers.
Required permissions

- Water use permit as required by chapter 11, paragraph 9 of the Swedish Environmental Code
- Permit for measures to be taken within a Natura 2000 area in accordance with chapter 7, paragraph 28a of the Swedish Environmental Code
- Exemption for work in a legally protected habitat in accordance with chapter 7, paragraph 11 of the Swedish Environmental Code
- Notice to the relevant municipality in accordance with chapter 29, paragraph 14 of the Environmental Testing Ordinance on the use of waste materials for construction purposes
- Exemption from regulations concerning watershed protection area
- Exemption from nature reserve regulations
- Exemption for work in protected shoreline area. (It was determined that the Fyleån River project would not violate shoreline protection regulations.)
- Permit from Swedish Board of Agriculture to transport legally protected mussels from the Bråån River.
- Exemption from the Skåne County Administrative Board regarding the prohibition by the Fisheries Ordinance and the Species Protection Ordinance against the collection of living *Unio crassus* mussels and the planting of mussels
- Exemption from the Skåne County Administrative Board regarding the Fisheries Ordinance’s prohibition against electrofishing.
The Bräkneån River is regarded as especially valuable and of national significance. The entire river is included in the European Union’s Natura 2000 network, mainly to help maintain favourable conservation status of *Margaritifera margaritifera*, *Unio crassus*, *Lutra lutra* (Eurasian otter) and the moss *Dichelyma capillaceum*.

The river’s drainage basin measures 458 square kilometres, of which 150 are in Blekinge County. All of its larger source lakes are located in neighbouring Kronoberg County. There are several rapids along the upper river until it reaches the village of Dönhult, where agricultural terrain takes over. But the largest and most powerful rapids run south from the county border to the village of Norra Bälganet.

The river has long continuous stretches of deep water, and there is a long meandering section above the village of Björkeryd. The entire natural course of the river has remained unaltered, but it has long been used by humans for a variety of purposes. There are several old dam foundations, and some dams that are still in use. Large rocks have been removed from much of the river in order to enable timber floating in the past. The absence of large rocks has influenced the river’s flora and fauna.

The Bräkneån Valley has a very distinctive topography. In the north it has the form of a nearly continuous deep fissure valley, then widens as it intersects with other fissure valleys. This is most pronounced in the Hålåbäck area, where bogs cover most of what has become a wide valley floor. The river basin north of Bräkne-Hoby consists mainly of forest land, which gives way to farmland south of the town. Here the river changes character, from an oligotrophic (nutrient-poor) to a eutrophic (nutrient-rich) body of water.

The vegetation often consists of narrow shoreline belts that are dominated by one or two of the following species: *Equisetum fluviatile* (water horsetail), *Phragmites australis* (common reed), *Menyanthes trifoliata* (bogbeam) and *Schoenoplectus lacustris* (common club-rush). The vegetation that predominates along the rapids is more diverse. Growing on most of the open water surfaces are *Nymphaea alba* (white water-lily) and *Nuphar lutea* (yellow water-lily).

Typical species of the river’s more nutrient-poor section include *Osmunda regalis* (royal fern), *Ranunculus lingua* (greater spearwort), *Myriophyllum alterniflorum* (alternate watermilfoil), *Fontinalis spp.* (aquatic mosses) and *Potamogeton gramineus* (various-leaved pondweed). Typical species of the nutrient-rich section include *P. pusillus* (lesser pondweed), *P. perfoliatus* (perfoliate pondweed), *Elodea canadensis* (Canadian waterweed) and *Cicuta virosa* (cowbane).

The river is home to several migrating fish species, including *Salmo trutta* (brown trout), *Anguilla anguilla* (European eel), *Coregonus lavaretus* (European whitefish), *Lampetra fluviatilis* (river lamprey) and *Phoxinus phoxinus* (minnow). Non-mig-
Three migration obstacles in the Bräkneån River have been eliminated or circumvented (black dots on upper map). Two have been bypassed with new biocanals, which has resulted in a doubling of the reproduction area for fish and mussels; their potential ranges have increased by 14 kilometres. In addition, habitat improvement measures have been carried out at 17 sites along 90 kilometres (black dots on lower map) with the addition of over 250 metric tons of gravel. That has resulted in the establishment of new spawning and feeding grounds for the fish species and mussel communities that are present in the river.
Some extractive industry took place here in the past and dams have been built for hydropower generation.

A small population of *Unio crassus* is thinly distributed in nutrient-rich sections of the river. *Margaritifera margaritifera* is present along the entire length of the river, but its reproduction is very limited.

**Background**

There is a great need for environmental enhancement measures in the Bräkneån River due mainly to two historical factors: the great impact of removing large rocks in order to enable extensive timber floating; and the effects of dams built for mills and hydropower facilities. Measures are needed to ensure that healthy, self-sustaining populations of species such as *Margaritifera margaritifera* and *Unio crassus* will remain in the river for the foreseeable future.

Although *Unio crassus* was known to be present in some sections of the Bräkneån, the general status and full extent of the mussel’s population was relatively unknown before the UC4LIFE project was launched. The sites chosen for restoration were located in sections of river where *Unio crassus* was previously known to be present. Two major migration obstacles were chosen for the construction of fauna passages, and one obstacle could be partly dismantled without encroaching on any other interests.

**Restoration measures**

The aim of the habitat restoration measures was to re-establish variation in the river by adding rocks and boulders to create better flow conditions, and gravel to improve areas of riverbed where mussels are present.

In addition to improving the habitats of *Unio crassus*, the project’s restoration plan was also designed to improve habitats for *Salmo trutta* and *Margaritifera margaritifera* (Erlandsson-Hammargen, 2012a). For that reason, the gravel chosen for the new spawning beds was a bit larger. At readily accessible places, rocks and gravels were deposited in the river with an excavating machine during the autumn of 2014. In less accessible places, gravel was transported to the riverside by machine. But together with rocks found on site, the gravel was deposited in the river with the manual labour of students and teachers from the fisheries management programme at Blekinge Folk High School. Their work was lightened with the use of a movable transport cable.

Two fauna passages were built around the hydropower dams at the villages of Tararp and Trånhem which were the major...
obstacles to migration in the lower reaches of the Bräkneån River. Planning began in 2012, the process of obtaining permits was carried out during 2014, and the passages were completed during the winter of 2015. They were built in collaboration with the dam owners, who covered the cost of obtaining permits for both the hydropower stations and the fauna passages. They also financed the addition of slightly angled, fine-meshed gratings over the power stations’ intake openings in order to prevent injury to fish migrating downstream. The angles of the gratings are 2% and 3.5% respectively, which allow all fish species in the river to pass them unharmed. The rate of flow through the fauna passages will be circa 500 litres per second when the river’s water level is high enough (Nydén & Johansson, 2014, 2015).

A dam at Lindefors was a smaller migration obstacle which was dealt with by partly dismantling it. The obstacle consisted mainly of wooden slats that were used to regulate water flow in the old spillway. They were removed by hand, and the dam is no longer a problem for fish passing by.

Results
The river has been studied by means of electrofishing in a sample of restored sections, but not every year. The quantity of different fish species varies widely from year to year and from place to place. That makes it difficult to observe any significant results of the habitat improvement measures. But brown trout have been observed spawning at several locations. Results of the measures applied to the three migration barriers are expected to be published sometime during year 2017. As for possible effects on the mussel fauna, it is too early to draw any conclusions. Additional follow-up with electrofishing and inventories of large mussels will be conducted during the coming years.

Summary of measures taken in the Bräkneån River
- Circa 250 metric tons of gravel were distributed among 17 sites. Rocks and boulders were moved from the riverside to the main channel.
- 500 square metres of new gravel bed were added to the river bottom.
- Two fauna passages were constructed.
- Three migration obstacles were removed.
- A 14-kilometre section of river was made accessible to migrating anadromous fish.

Above: Area alongside the Bräkneån River at Tararp before a fauna passage was built. (Photo: Thomas Nydén)
Below: Area at Tararp after the fauna passage was built. (Photo: Andreas Nilsson)
The Mörrumsån is Blekinge County’s largest river, and it is very important for the reproduction of *Salmo salar* (Atlantic salmon), among other species. The entire river is included in the EU’s Natura 2000 network, and large parts of it are also protected within nature reserves. Historically, the Mörrumsån has been important for humans ever since the Stone Age for such purposes as fishing, timber floating and power generation — all of which have left many traces along the river.

Despite the substantial negative impacts to which the Mörrumsån has been subjected, it is one of the most biologically diverse rivers in Sweden. More than half of the native fish species and all of the large freshwater mussel species have been found in its waters. There is also a valuable and diverse bottom fauna with species that are vulnerable to acidification and require clean water, including several mayflies and one stonely species.

The bird fauna is also diverse, with such characteristic species as *Cinclus cinclus*, *Motacilla cinerea* and *Alcedo atthis*.

Background

Previous generations have removed large rocks and fallen trees from the river in order to enable timber floating and power generation. As one result, gravel and more fine-grained materials have been washed downstream, and the river has become more uniform in character. Unfortunately, living space for fish and mussels has also decreased, due primarily to two factors: dams have been built across the river, creating obstacles to fish migration; and variation in the river environment has decreased when side channels have been closed, and when rocks and boulders have been moved from the river channel to the shoreline.

*Unio crassus* has long been known to occur in the Mörrumsån, but its distribution and general condition have been relatively unknown because it has been difficult to take inventories due to the size of the river. The sites chosen for restoration were judged to be suitable for *Unio crassus*, but inventories of them had found only isolated individuals or none.

Restoration measures

The aim of the planned measures was to re-create habitat variability by adding dead wood, rocks and boulders to the main channel. Gravel was also to be added, to serve as bottom substrate and provide habitats for mussels. Another aim was to increase habitat availability by opening up blocked side channels and parallel channels.

The side and parallel channels that were chosen for restoration had low water flows and were at risk of drying out during periods of low volume in the main channel, or had previously been closed off for the benefit of human activities.

The planned measures were intended to improve the quality and increase the amount of habitat — not only for *Unio crassus*, but inventories of...
but also for *Salmo trutta* and *Margaritifera margaritifera*. For that reason, the size of gravel added to the riverbed was of somewhat larger dimension than in other places.

Prior to the UC4LIFE project, a habitat conservation plan had been developed by the consulting firm, Salmokonsult (Hammargren, 2012). The primary focus of that plan was on *Salmo trutta* and *Margaritifera margaritifera*. The measures it proposed were adjusted to increase the number of target species, in hopes that greater diversity of the habitats to be created would also benefit the host fish of *Unio crassus*.

During an intensive week in September 2012, a helicopter “bombed” the Mörrumsån River at several places near the villages of Vittskövle and Härnäs. Meanwhile, an excavating machine was depositing boulders elsewhere in the main channel, opening side channels, and spreading the gravel which the helicopter had dropped at several locations.

The excavating machine was also used to push trees down into the river in order to provide dead wood, and to move rocks which had previously lain in rows along the shoreline into the main channel.

Altogether, 332 metric tons of gravel were added to the Mörrumsån River at places near Härnäs and in several other sections of river near Vittskövle. Two partially blocked parallel channels near Vittskövle were opened up to improve water flow conditions and increase the quantity of available habitats.

In the Mörrumsån River’s northern section, habitat improvement measures consisted of adding gravel, rocks and boulders (black dots) and opening up blocked side and parallel channels to provide habitats for fish and mussels. The potential increase in distribution along the river was significant, with a combined total of circa 80 kilometres.
Habitat improvement measures in the southern section of the Mörrumsån River included the planting of trees and the addition of dead wood, gravel and rocks to the riverbed (black dots). Also, side channels were opened to increase the habitat area for fish and mussels. The result was a significant increase in potential species distribution, corresponding to a north-south stretch of river circa 80 kilometres in length.
Summary of measures taken in Mörrumsån River

- 332 metric tons of gravel distributed among 21 sites
- 350 square metres of new gravel beds
- 2000 square metres of improved habitat in several side channels.

Results

Six of the restored sites were electrofished during 2011 – 2015, but not all of them every year. The fish species that were found were *Salmo salar*, *S. trutta*, *Phoxinus phoxinus*, *Squalius cephalus* (European chub), *Alburnus alburnus*, *Gobio gobio* (gudgeon), *Leuciscus idus* (ide), *Cottus poecilopus* (bullhead) and *Anguilla anguilla*.

The populations of the river’s fish species vary widely from year to year and from place to place. That makes it difficult to observe any significant results of the measures taken after only a short time. However, electrofishing surveys of the restored sites have found a greater diversity of fish species, and higher densities of both *S. trutta* and *S. salar* juveniles.

As for possible effects on the mussel fauna, it is too early to draw any conclusions. Additional follow-up with electrofishing and inventories of Unionid mussels will be conducted during the coming years.
A side channel of the Emån River, the Lillån River is circa three kilometres long and is located near the village of Kvillsfors in the Municipality of Vetlanda. The river varies in width from around one metre to 3 – 4 metres, and has an average depth of just under a half metre.

The total fall of the Lillån River is about 19 meters — from Turefors to the Qvillö horse farm where the Lillån joins the Emån River. The bottom substrate is dominated by sand, gravel and stone in the more shallow sections, and by boulders and gravel in the deeper and steeper sections. Most of the land along the Lillån River belongs to Vetlanda and the water regulation rights are owned by Skånska Energi Co. The river runs through Kvillsfors village, and the shoreline has been affected by roads, bridges, and to some extent even a railway. Several sections of the river have been carefully cleaned; but some have been left undisturbed, with numerous boulders left in the riverbed to provide high-quality habitats for invertebrates and fish including Salmo trutta.

Prior to restoration, the Lillån River had experienced negative hydrological and other physical effects (Nydén & Johansson, 2012). The waters of both the Emån and the Lillån rivers have long been used as power sources for mills and electricity generators. Since the 1920s there have been two hydropower stations in the Emån River with water use permits that also regulate the Lillån River.

According to old maps, grain mills once operated at several places along the river. The oldest map, dated 1645, includes a reference to “Quill’s domicile”, which indicates that most of the Lillån’s water was diverted into hydropower facilities downstream. It is estimated that the Lillån River’s average flow volume has been just under 200 litres per second since the Emån River power plant first went into operation. Due to low water volumes and resulting slower currents, the rate of sedimentation in the Lillån River has been high.

The Lillån River is part of the Natura 2000 site named West Emån River, which includes circa 40 kilometres of the entire Emån’s 220 kilometres (Wandin, 2006). Most of the watershed along the Lillån River consists of forest land. Farmland is relatively scarce and is located mainly in the valleys. In general, the river has been judged to have substantial natural values due to its largely natural condition and species diversity, both in and adjacent to the river (Rydberg & Johansson, 2013).

Presence of fish and Unionid freshwater mussels

Neither Unio crassus nor any other species of Unionid freshwater mussel has been found in the Lillån River. But Unio crassus has been found in the Solgenån River, a tributary of the Emån, and downstream near the Lillån’s outlet at Qvillö where thorough inventories of large mussels were conducted in 2006, 2010 and 2015 (Lind & Bergengren, 2015). In addition
to *Unio crassus*, four other mussel species were found there: *Unio pictorum*, *U. tumidus*, *Anodonta anatina* and *Pseudanodonta complanata*. Since small young individuals have been found, all communities of those five species are regarded as healthy and self-sustaining. The smallest *Unio crassus* individual was 30 millimetres long and was found on a bottom of sand, stone and gravel at a depth of three metres where the river is 12 metres wide.

The aim was to reintroduce individuals of *Unio crassus* from the Emån River’s main channel to suitable parts of the Lillån where habitats have been treated with conservation measures. An electrofishing survey of the Lillån River in August 2012 indicated that the *Salmo trutta* population was in relatively good condition, including a large proportion in the first year of life. Other fish species found were *Phoxinus phoxinus*, *Tinca tinca* (tench), *Abramis brama* (bream), *Squalius cephalus*, *Perca fluviatilis* (perch), *Esoc lucius*, *Lampetra planeri* (river lamprey) and *Cottus poecilopus*. *Pacifastacus leniusculus* (signal crayfish) was also present.

Monitoring of the *Unio crassus* population in the Emån’s main channel and evaluation of its condition have in past years been carried out just downstream from the outlet of the Lillån River. Five species of large freshwater mussel have been found there, including *Unio crassus* (photo). Because young individuals were found among all communities of all five species, they were all judged to be healthy and self-sustaining (Photo: Jakob Bergengren.)

Eleven migration obstacles in the Lillån River have been removed or circumvented (black dots) and two new fauna passages have been built. In addition, habitat conservation measures have been carried out at many places along the three-mile-long river (blue line), resulting in 1000 square metres of new spawning and maturing grounds for fish and mussels. Measures taken upstream in the “West Emån River” Natura 2000 site include habitat conservation and the addition of rocks and gravel to the river bottom. Trees have been planted along the river and the new bypass. The combined effect of these measures will help to increase the rate of species dispersal along the 35-kilometre-long stretch of river. In addition, *Unio crassus* mussels have been transplanted to this area from other parts of the river.
Restoration measures

The primary objective of the measures taken in the Lillån River was to provide an unimpeded migration route past the two hydropower stations in the Emån River (Turefors & Nybyholm). Before the measures were carried out, there were eleven migration obstacles in the Lillån. Four of them were regarded as completely impassable by aquatic fauna.

By utilizing the existing river, a fauna passage with a total length of three kilometres has been created. An important element of the initial effort was to ensure a stable flow of water by revising the existing water use permit.

In addition to serving as an unobstructed migration route, the Lillån River also provides high-quality habitats for diverse flora and fauna following the restoration (Anckarman & Nydén, 2013). As a result of the newly built fauna passages and habitat conservation measures, 1000 square metres of the river bed have been restored, and now provide good spawning and nursery areas for fish, mussels and other benthic fauna.

Lillån River near Kvillsfors. The conduit at the wooden dam has been completed, and a new channel has been excavated and lined with rocks and stones. (Photo: Peter Johansson)

Lillån River near Kvillsfors. Fish of several species caught in a trial survey of the river before restoration. Top to bottom: Tinca tinca, Perca fluviatilis, Phoxinus phoxinus, Esox lucius and Salmo trutta. (Photo: Jakob Bergengren)
Lillån River near Kvillsfors. Construction of the Turefors bypass began in early June of 2015 with initial excavation to form the planned fauna passage.

Lillån River near Kvillsfors. The conduit at the wooden dam is finished. The new stream channel has been excavated and lined with rocks and stones.

Lillån River near Kvillsfors. The conduit from Turefors Pond is in place and water is being released into the fauna passage.

Lillån River near Kvillsfors. During October 2015, the footing of an old concrete dam at Qvillö was removed to create a passage for fish and other aquatic animals.

Foto: Peter Johansson.
The Brusaån River is located in the Municipality of Eksjö, within the upper half of the Emån River drainage basin. From its source near the village of Stensgöl, the Brusaån runs southeast through the villages of Bruzaholm, Hjältevad and Ingatorp, and ends just outside the town of Mariannelund where it joins the Silverån River.

The restored section of the Brusaån River extends from the railway bridge at Högebro to Lake Åsjön. A site named Bru-saån was added to the Natura 2000 network in 2007 (Gustafsson, 2007). The principal reason for that decision was the presence of *Unio crassus* in the Brusaån River.

Restoration of the Brusaån River was implemented in several sections of fast-flowing water. They vary in width from 3 – 8 metres and have an average depth of just under a half metre. The bottom substrate consists mainly of sand in the slow-moving sections, while gravel, rocks and boulders predominate in the sections with faster currents.

Most of the Brusaån River is bordered by coniferous forest. But there is some farmland and quite a lot of residential property in and around Mariannelund. For most of the river’s length, trees provide fairly good shade. Most of the land along the restored section of river is owned by the Municipality of Eksjö.

The average flow volume of the Brusaån River is 1.8 m$^3$/s and the highest recorded volume is 33 m$^3$/s. Before the restoration measures were carried out, there were two mill dams which completely blocked the migration of fish and other aquatic animals. There were also some partial obstacles in both the Brusaån and Hässlebybäcken, a feeder stream.

The section of Brusaån River extending downstream from Mariannelund to the southern part of Lake Åsjön and the village of Silverdalen has long been affected by cleaning and straightening of the river channel. The single largest impact has been on water quality, due especially to effluent from a sulphite paper mill that was located beside the river in Mariannelund from 1877 – 1977. During those 100 years, the paper mill discharged all of its sulphite-process and other waste effluents into the Brusaån River. Most aquatic life was therefore eliminated from the river for the first three quarters of the 20th century.

The former mill area is now a contaminated site, classified at the highest environmental risk level. Since the sulphite mill closed, the Brusaån’s flora and fauna have recovered and a stretch of river upstream from the mill has functioned as a refuge, making it possible for fish and mussels to disperse downstream.
Presence of fish and large freshwater mussels

The Brusaån River has been inventoried three times — in 2001, 2004 and 2010 (Lind & Bergengren, 2015). *Margaritifera margaritifera* was found on all three occasions. Both *U. crassus* and *M. margaritifera* were found in a cursory inventory conducted in 2001. A total of 33 *M. margaritifera* individuals were found in the inventoried section of river, upstream from the bridge at Linneryd to the dam at Högebro. Two individuals of *U. crassus* were also found.

The Brusaån River has been included in Sweden’s national programme for monitoring Unionid freshwater mussels (Lundberg & Bergengren, 2008). Eight living individuals of *Margaritifera margaritifera* were found when a section of the river was inventoried the same year with the national survey method (Bergengren et al., 2010). Only adults were found, indicating that reproduction of mussels in the river had ceased.

*Margaritifera margaritifera* and *Unio crassus* have re-established themselves since the sulphite paper mill shut down. One contributing factor is that the old mill dam at Mariannelund completely blocks migration of all aquatic organisms, including *Salmo trutta* and other fish species, for example. Fish migration is an important precondition for the dispersal of mussel species along the river.

An electrofishing survey of the Brusaån in August of 2012 indicated that the river’s population of *Salmo trutta* was relatively numerous with a large proportion in the first year of life. Among the other fish species caught were *Perca fluviatilis, Alburnus alburnus, Cottus poecilopus, Cottus gobio, Phoxinus phoxinus, Esox lucius, Lota lota* and *Rutilus rutilus*. *Pacifastacus leniusculus* was also present in the river.
Restoration measures

Due to the lengthy physical, chemical and hydrological impacts on the river in past years, extensive restorative measures have been carried out in the Brusaån River. The principal focus has been on eliminating migration obstacles in order to enable migration and dispersal of fish and other aquatic animals. Among those measures was the construction of a fauna passage around the upper mill dam in the town of Mariannelund (Nydén & Johansson, 2009; Nydén, 2013) and the removal of a dam downstream from there. Another migration obstacle, a dam in the feeder stream Hässlebybäcken Brook, has also been removed.

In addition to removing migration obstacles, habitat improvement measures have been carried out. A great deal of preparation was required, but some measures had already been implemented before the start of the UC4LIFE project (Nydén & Johansson 2009). A preliminary planning document which had earlier been produced provided the basis for the continuing work of eliminating the migration obstacles.

The project began in 2012 with an information meeting of the Jönköping County Administrative Board, the Municipality of Eksjö and participating consultants. The initial focus was on inventories, contacts with landowners, detail planning, environmental impact reports, and clarification of the legal situation regarding water rights.

During June of 2015, a migration obstacle was removed from Hässlebybäcken Brook, and the bypass around the upper mill dam was completed; it began functioning in November that year.

The *Unio crassus* population was strengthened in the spring of 2016 when mussels from the Emån River near Kvillsfors were transplanted to areas in the Brusaån River where riverbed restoration had been carried out.
Brusaån River at the Herrgård Dam in Mariannelund. The new stream channel is taking form, and the bottom has been supplied with rocks and stones of various sizes.

Brusaån River at the Herrgård Dam in Mariannelund, October 2015. Extensive excavation is forming the new channel, starting downstream. The slopes are stabilized with ground cloths.

Herrgård Dam in November 2015. Water runs through the fauna passage and its functionality is tested with a trial run.

The prefabricated conduit for water from the pond is lifted into place.

The fauna passage around Herrgård Dam was completed in November 2015.

Photos: Peter Johansson.
The upper part of the Kisaån River runs from Lake Nedre Föllingen through the beautiful landscape around Föllingsö Farm in the Municipality of Kisa. A 1200-metre-long section of the river flows through a Natura 2000 site where the land is owned by Riddarhuset, an organization of Sweden’s vestigial aristocracy. Six of the seven native species of large freshwater mussel are present here; the only one missing is *Margaritifera margaritifera*. Some reproduction of *Unio crassus* has been confirmed.

Fish species observed in this section of the Kisaån River are *Salmo trutta*, *Perca fluviatilis*, *Gymnocephalus cernuus* (ruffe), *Esox lucius*, *Lota lota*, *Rutilus rutilus*, *Lampetra* sp., *Anguilla anguilla* and *Pacifastacus leniusculus*.

The upper part of the Kisaån flows quietly through a wetland forest dominated by alder and dwarf willow. The bottom consists primarily of fine-grained materials, including sand, with some elements of organic material. It is in this part of the river that most of its *Unio crassus* mussels are found. (Photo: Peter Gustafsson)

Further downstream, the river splits into two channels — one that is natural, the other excavated. The flow of water into the natural channel was funnelled through a culvert in an earthen dike. Due to the culvert’s narrow diameter (90 centimetres) and smooth interior, the stream of water rushing through it was powerful and acted as an obstacle for migratory fish and other aquatic animals.

Below the dike, the river has been straightened and deepened for a distance of 150 metres. The bottom there consists of sand, gravel and rocks, with a small portion of finer-grained material and boulders. The speed of the water current is moderate.

Further downstream the river changes to a slow-flowing section which is influenced by a sawmill dam further downstream.

The entire river branch called Kvarnfåran was excavated by humans in order to power a water mill. Its bottom substrate is stony, and the current is moderate to rapid. There is little suitable substrate for mussels and none have been observed.

When the two channels converge downstream, the current becomes moderate to slow where the river runs through several wetland areas. Those areas are partly open, with vegetation that includes *Carex* spp. (sedges), *Filipendula ulmaria* (meadowsweet) and *Poaceae* grasses. Much of the land is grazed. This entire section of river is judged to have great habitat diversity and good conditions for mussels.
Just downstream from Lake Nedre Föllingen, the Kisaån enters the beautiful Föllingsö landscape. Seen in this photo is a stretch of river just downstream from a branch of the original channel. (Photo: Lars Gezelius)

Presence of *Unio crassus*

Mussels occur at a few places where the bottom substrate is suitable and the current is not too rapid for them. Mussels are abundant in the upper part of the river in places where it passes through wetland forest and where the water current is more moderate.

**Restoration measures**

Downstream from the Natura 2000 site, the river flows past the Swedish Tissue paper mill which has a water right permit that entitles it to a given volume of water. It was therefore important to measure total flow volume and perform hydraulic modelling before starting the restoration work. Modelling helped to determine if there was any risk that the restoration measures would alter the lake’s water level and the river currents.

The measures were implemented during six days at the end of May 2014. Rocks and boulders were added to the bottoms of cleaned and fast-flowing sections of river, so that habitats would become more natural and diverse. The rocks and boulders were deposited by hand, with an excavating machine and with a crane equipped with a clamshell bucket. Gravel and sand accumulate in backwater behind rocks, making good substrate for mussels to bury themselves in.

Gravel suitable for fish and mussels is added to the Kisaån River. (Photo: Henry Stahre)
Unio crassus mussels taken in a sample survey of the Kisaån River. (Photo: Jakob Bergengren)
The larger boulders also caused the river to widen and create more variation in both habitats and current speed. The new aquatic environment benefits fish and bottom fauna, as well. It was also important to maintain and strengthen the spawning and nursery areas of the river's small and threatened population of *Salmo trutta*. For that purpose, somewhat larger gravel was added at suitable places. Some finer-grained materials were already present.

Altogether, 22 metric tons of rocks measuring 100 – 500 millimetres, and 41 tons (24 m³) of gravel measuring 20-50 millimetres were added to the river. In addition, many dozen tons of boulders and rocks were moved from the shoreline to the channel.

The narrow culvert has been replaced with one that is more than twice as wide (circa two metres in diameter), and it has also been moved lower. The resulting decrease in the speed of water current in the culvert, together with the stones and gravel along its bottom, make it easier for fish and other aquatic animals to move upstream.

An overgrown side channel upstream from the culvert was cleared to make a so-called bifurcation. Water is led into the channel by large boulders placed in front of its inlet.

During the restoration work, the sawmill pond was drained to implement the measures. It can now be stated that draining the pond resulted in a faster current at that location.

Biodiversity has increased due to the restoration. In an electrofishing survey conducted in August of 2015, the catch was dominated by *Salmo trutta*. But individuals of *Lota lota*, *Perca fluviatilis* and *Anguilla anguilla* were also caught. The presence of *Salmo trutta* in their first year indicates that the newly established spawning grounds are functioning. Several large *Salmo trutta*, up to 40 centimetres in length, were observed among the larger boulders.
The source of the Storån River is located near the village of Åtvidaberg. From there it runs through the Uknadalen, an exceptional fissure valley framed by 100-metre-high cliffs. The river meanders through the valley and passes through lakes Åkervristen and Storsjön before emptying into the Baltic Sea. The river has been affected by eutrophication, toxins, and the physical effects of hydropower stations during early industrialization. The entire river is affected by the Forsaström power plant which regulates water flow. Regulation involves the risks of overgrowth by Phragmites australis (common reed) and drying up of habitats for fish, mussels and other animals. Those risks are greatest in the upper part of the Storån River. The lower part is less vulnerable because it is fed by tributaries which increase the water flow.

At the time of this report's publication, it is permitted to block the river completely at the power plant, during which time very little water flows downstream. But even at other times, unnatural variations in water flow due to the power plant’s operation can affect the flora and fauna of the river. To rectify the problem, water flow from the power plant should be environmentally adapted. Preferably, the flow regime should resemble that of an unregulated natural river.

The negative physical impacts on the river, especially from previous cleanings, are substantial. But they have affected only 17 per cent of the river's total length, which is an unusually small proportion.

The eight-kilometre-long section of the Storån River between the lakes Båtsjön and Åkervristen is relatively unspoilt. It has some high quality habitats with fast-flowing water and is a Natura 2000 site. There are several key limnic habitats in the area — brook ravines, parallel channels, natural inlets and outlets, and shoreline banks.

In the section of the Storån that is closest to Lake Båtsjön, the river flows at a leisurely pace through broad, open marsh meadows whose vegetation includes Carex spp. and Poaceae grasses. In and around Falerum village, there are many rapids and stretches of fast-flowing water. Much of this section has rapid currents and stony bottom. Unfortunately, most of the channel has been cleaned, even here. There are some fine, unspoilt areas, among them a wetland forest dominated by Alnus glutinosus and a parallel channel that runs through a ravine. There are also some ravines with broad-leaved forest. Matteuccia struthiopteris (ostrich fern) grows at several places.

Approaching Lake Åkervristen, the river meanders and flows quietly for the most part. Short stretches of fast-flowing water contribute to the area’s special character. The riverbed consists mainly of sand or gravel. Here the river is surrounded by farmland, a large portion of which is used to grow crops. But
there is a natural shoreline zone with shrubs and trees which is 5 – 15 metres wide. Due to a lowering of Lake Åkervisten in the past, the river’s eroding effect has created a shallow ravine which has poor lateral connectivity with the surrounding land (Nolbrant et al., 2014).

The Storån River provides valuable spawning and maturing grounds for *Salmo trutta*, as well as nesting sites for *Alcedo atthis* and *Cinclus cinclus*. An electrofishing survey found *S. trutta*, *Scardinius erythrophthalmus* (rudd), *Lota lota*, *Rutilus rutilus*, *Esox lucius* and *Perca fluviatilis*.

**Presence of *Unio crassus***

Large communities of *Unio crassus* live in the slow-moving lower part of the Storån River. Further upstream, various species of Unionid freshwater mussels are abundant, but *U. crassus* is much less prevalent (Bergengren & von Proschwitz, 2012).
Restoration measures

The restoration work was carried out at three locations in August 2014. It consisted mainly of habitat restoration measures — the return of previously removed rocks to the river, and the addition of new bottom substrate and dead wood in order to increase habitat diversity. An old concrete shelf that had partially blocked migration was removed from the river and replaced with a shelf of natural stone.

In the previously cleaned parts of river sections with rapid currents, rocks and boulders were placed on the bottom to make habitats more natural and diverse. The rocks were placed in the channel by hand, excavating machine and a crane equipped with a clamshell bucket. This widened the river and created more variation in the speed of the current. Sand and gravel accumulate in backwater behind the rocks, providing good substrate for mussels to bury themselves in. The new environment also increases the biodiversity of fish and bottom fauna.

Altogether, 27 metric tons of spawning gravel (16 – 32 millimetres), and 20 tons of sand (2 – 4 mm) were added. The materials were placed in quiet pools. The new bottom material will undoubtedly benefit mussels. In addition, many dozen tons of rocks and boulders on the shoreline were moved back into the river.

The Storån River before restoration: This stretch of river at Branthäll, south of the church in Gärdsrum village, has been extensively cleaned. (Photo: Lars Gezelius)
Tons of sand being added to the river with an excavating machine. The sand was placed in some river pools to create favourable habitat for *Unio crassus*. (Photo: Lars Gezelius)

The Storån River during restoration at Gärdserum. Rocks and boulders are being rolled back out into the river channel. (Photo: Lars Gezelius)

The Storån River just downstream from the village of Falerum. The river is home to many different types of nature. Here, just upstream from its inlet to Lake Åkervristen, the river meanders through an agricultural landscape. *Unio crassus* is abundant at this location, but lateral connectivity is poor due to the deep channel. (Photo: Peter Gustafsson)
The Kapellån River, which runs through a forested ravine near Lagerlunda Farm, is set in an unusual natural environment that is worthy of protection. The area has highly valuable hydrological and biological features in both the river and in the springs formed by groundwater forced to the surface on the sides of the ravine.

Stream conditions are varied, with some sections of fast current and rapids. Fish in the Kapellån include *Cottus gobio*, *Alburnus alburnus* and the more unusual species *Squalius cephalus* and *Cobitis taenia* (spined loach). The river also serves as a migration resting place for *Cinclus cinclus* and a nesting area for *Alcedo atthis*.

The ravine was worn deep into fine-grained sediment by the river. The broad-leaved forest growing on the sides is dominated by elms. The ravine’s spring-fed streams are suitable for several demanding moss species (Bryophyta). A relatively large population of *Unio crassus* mussels also inhabits this part of the river.

**Presence of *Unio crassus***

Within the section of the Kapellån River which is included in the UCALIFE project, there are several areas with large communities of *Unio crassus* mussels. But in other areas only isolated individuals are present.

**Restoration measures***

The restoration measures were carried out in September 2015. Rocks and boulders were placed on the cleaned bottoms of fast-flowing sections of river to make habitats more natural and diverse. The rocks were put in place by hand, excavating machine and a crane equipped with a clamshell bucket.

After thorough hydraulic modelling, the measures were carried out — but not until all the mussels present were moved out of harm’s way.
Site A: circa 150 metres long

Previously cleaned areas were restored by placing around 50 boulders in the river channel. About half of them were taken from on-site piles of materials cleaned from the river, and the other half was from external sources. The average diameter of the boulders was circa 800 millimetres. Farthest upstream in the restoration area, about 30 cubic metres of sand and gravel were added to the river bottom. Those materials were also from external sources.

Site B: circa 50 metres long

A previously cleaned stretch of river was restored by returning rocks and about 30 large boulders to the main channel. In addition, a number of smaller boulders and circa 20 m$^3$ of stone and gravel were added to the river.

Site C: circa 200 metres long

A previously cleaned stretch of river was restored by returning around 70 boulders to the river. Also, circa 30 m$^3$ of gravel from external sources were added to the riverbed. Old side channels were opened at a couple of places in order to broaden the flow of river water through the area.
Boulders are rolled out into the Kapellån River with a crane after the contractor dislodges them from the shoreline. (Photo: Lars Gezelius)

The Kapellån River between Lagerlunda and Tolefors before restoration. (Photo: Lars Gezelius)

A previously cleaned section of the Kapellån is restored by moving some 50 boulders back into the river. (Photo: Lars Gezelius)
Habitat improvement measures contribute to a more diverse river environment. More species thrive as a result, including mussels and fish. (Photo: Lars Gezelius)

The Kapellån River between Lagerlunda and Tolefors before and after restoration. (Photo: Lars Gezelius)
The Vretaån and Ålbergaån rivers both originate at Lake Stavsjön, and both run from there to the village of Kila where they merge to form the Kilaån River. The Vretaån runs from west to east along the northern side of the Kolmården area, where it has sculpted the exceptionally beautiful Kiladalen Valley which terminates at the Baltic Sea near the city of Nyköping. *Unio crassus* is present in the lower reaches of the Vretaån and the Ålbergaån, and in large parts of the Kilaån, but is absent from much of the Vretaån (Bergengren *et al.*, 2002; Lundberg & von Proschwitz, 2004; Nekoro & Sundström, 2005).

The Vretaån River is unique because long sections of it have been left to meander freely in an agricultural landscape without being cleaned or straightened to any great extent. There are also lengthy stretches that pass though deep ravines flanked by steep slopes (Länsstyrelsen i Södermanlands län, 1991). Large parts of the Vretaån and its tributaries are protected as nature reserves and/or privately owned Natura 2000 sites (Länsstyrelsen i Södermanlands län, 2004).

Growing along both sides of the river are dense borders of broad-leaved trees. In time, many of them fall into the river and enrich it with dead wood which benefits both fish and bottom fauna. Confirmed observations of *Unio crassus* have been made only in the lower part of the Vedaån, near its confluence with the Ålbergaån River. Fish species that occur in the river include *Perca fluviatilis*, *Rutilus rutilus*, *Lota lota*, *Esox lucius*, *Cottus gobio*, *Gymnocephalus cernuus*, *Salmo trutta*, *Lampetra fluviatilis* and *L. planeri*.

Even though long stretches of the Vretaån River remain unspoilt, many areas have long been affected by human activity. There are, for example, several fords and bridges which for practical reasons have been located where the river is shallow and where both soil and bottom substrates are relatively stable. It is not unusual that bridges have been built where the river cuts through a ridge or moraine. At such places, rocks and boulders from the river have often been used as bridge-building material. In addition, rocks and boulders have been cleared from sections of river with rapid currents to increase and equalize the rate of flow, which in turn has deepened the channel.

Running alongside the river are several large roads, both old and new, including European motorway E4 and national road 800. Seven bridges were determined to be in need of repair due to various deficiencies, including the absence of rocks and boulders, improperly located culverts, and a concrete foundation that partially blocked the migration of aquatic animals.

The focus of restoration has been on rectifying those problems. The measures implemented have consisted primarily of eliminating migration obstacles for weak-swimming fish,
and adding new gravel along with a few large rocks to the river channel. The addition of rocks and gravel creates greater variation in the water flow, providing living space for more species. It also promotes the reproduction of mussels and increases the survival chances of young mussels.

Since *Unio crassus* was only present in the lower part of the Vretaån, some individuals were relocated to a restored section of the upper part.

**Restoration of bottom substrate with additional rocks and gravel**

At seven of the road bridges crossing the river, the bottom substrate has been improved by adding new gravel, rocks and boulders. A number of tree trunks have also been placed in the river to further increase variation. Upstream from one of the bridges, the river bottom has been raised to eliminate a migration obstacle during periods of low water flow — a protruding bridge foundation. This required a large volume of rocks and boulders to prevent the added material from being washed downstream during the spring flood.

Near one of the bridges was an improperly placed culvert that was an obstacle to the migration of fish and other aquatic organisms. This problem was resolved by raising the bottom level at a section of riffles a few metres downstream from the
culvert, so that water would continue to flow through it even during periods when the river level is low. The riffle section was made longer and flatter, with several pools and boulders, to create good spawning and nursery grounds for fish.

Since the restoration took place near road bridges, rocks and gravel were added with a crane parked on the bridges, thus minimizing the risk of ground damage from machines being driven in and alongside the river. In some places, however, it was necessary for a machine to be driven beside the river at some distance from the road. In those cases, a lighter excavating machine on tracks was used. Some rocks and finer material were distributed by hand.

Rocks, boulders and other large objects in the river, such as fallen trees and branches, block the flow of water and force it to take detours. This creates a diverse bottom environment, including some areas of fine sand behind rocks; it also creates stretches of rapid current where the water is oxygenated and fine particles are washed away so that only rocks and large gravel remain. That diversity contributes to a river environment in which many different species with various needs can live.
Transplanting mussels

To hasten the re-establishment of *Unio crassus* in the upper part of the Vretaån River, some individuals were collected from a section of the Kilaån River where they were abundant. The mussels were transported to their destination in the Vretaån, where they were measured and marked before being placed in one of the restored sections. (More details under “Conservation measures” on page 74.)

In the initial trial, 40 *Unio crassus* individuals were transplanted. If a follow-up indicates that the trial has been successful, an additional 160 mussels will be transplanted to the upper Vretaån River.

By the Vretaån near Kråkvasken croft. Transplanting *Unio crassus* to the upper part of the river began in 2015. The mussels were measured and marked before being placed in the river. (Photo: Ursula Zinko)
The Svärtaån River is circa 13 kilometres long. It starts at Lake Runnviken and empties into Sjösaviken Bay on the Baltic coast just east of Nyköping. Its drainage basin is 372 square kilometres, stretching from the Municipality of Gnesta in the north to Nyköping in the south. The river meanders through a mainly open agricultural landscape with fine-grained soil (Länsstyrelsen i Södermanlands län, 1991). The lowest section, extending downstream from Svärta Farm, is protected as a Natura 2000 site (Länsstyrelsen i Södermanlands län, 2005).

All native species of Unionid freshwater mussel are present in the Svärtaån, with the exception of Margaritifera margaritifera. However, Unio crassus only occurs in the lower part of the river, downstream from Svärta Farm (Nekoro and Sundström, 2005). Large numbers of Unio crassus are found at some locations; but few young individuals have been found, indicating poor reproduction (P. Ljungberg, verbal report).

The Svärtaån also has a diverse fish fauna which includes Perca fluviatilis, Rutilus rutilus, Blicca bjoerka (white bream), Alburnus alburnus, Esox lucius, Gymnocephalus cernuus, Tinca tinca, Lota lota, Pungitius pungitius (nine-spined stickleback), Gasterosteus aculeatus (three-spined stickleback), Vimba vimba (vimba bream), Abramis brama, Salmo trutta, Anguilla anguilla, Osmerus eperlanus (European smelt) and Barbatula barbatula, the last-named, a species that is rare in this part of Sweden.

Restoration of bottom substrate with rocks and gravel
As with many rivers in farmland areas, parts of the Svärtaån have been cleaned and straightened, and that has resulted in reduced habitat diversity for aquatic species. The lower part of the river flows slowly and has few stretches with rocks, gravel and rapid currents that are important for many fish and other aquatic animals.

The aim of restoration has therefore been to improve existing sections of rapid current with the addition of more gravel, rocks and boulders. In addition, Phragmites australis and Typha spp. (cattails) have been pulled up by the roots. Other aquatic plants have also been removed, because dense vegetation prevents fish and mussels from utilizing bottom substrate. Another measure has been to plant new trees along the shoreline to reduce overgrowth in the river by increasing the amount of shade as the trees grow larger.

Before the work of restoration began, the affected landowners were invited to walks along the river during which they received information about the project and the proposed measures. Afterward, agreements on the measures to be taken were signed with all landowners. Dialogue was also conducted with other interested parties, including the Södermanland County Administrative Board and the Swedish Transport Administration.
Sportfiskarna, a national association for sport fishing and fish conservation, was contracted to lead the project. That involved developing a detailed plan for all measures to be taken, obtaining all the permissions required, and leading the on-site work. The County Administrative Board managed procurement of the contractor.

Several preliminary studies were conducted and formed the basis of the detailed plan (Ljunggren & Gustafsson, 2012). Since the Svärtaån is a couple of metres deep and has very turbid water, divers were employed to delineate the areas to be restored and to inventory the locations of mussels on the river bottom before any measures were implemented.
A basic archaeological survey was conducted to determine the locations of any historical remains. The planned measures were then adjusted to ensure that such remains would not be negatively affected. Also conducted in advance of the restoration work were a survey of benthic fauna (Larsson, 2013) and an electrofishing survey.

Measures were implemented in three sections of the Svärtaån River. Before work began, divers were employed to collect all living mussels on the bottoms of the areas to be restored. The mussels were temporarily kept in upstream waters, and returned to their original sites after the restoration measures were completed.

Near Svärta Farm is a short stretch of river just downstream from an old and partly collapsed mill dam. The gravel on the river bottom had become hard due to the pressure of the rushing water, and further downstream the bottom was covered by a dense mat of plant roots. There was also a lack of boulders and large rocks, which had probably been removed to be used as building material for the dam and associated buildings.

The first restoration measures were to remove the aquatic vegetation and loosen up the existing bottom gravel. Then new gravel was added, along with boulders, large rocks and several tree trunks. This created resting places for fish and more variation in the water flow.

The added materials were distributed over a river section and placed between several deeper pools to enhance the restored area with a greater diversity of habitats for fish, mussels and other invertebrates.

To eventually increase the amount of shade and thereby reduce plant overgrowth in the river, trees were planted along the shoreline. The species chosen were *Alnus glutinosa* (alder), *Salix caprea* (goat willow), *Salix sp.* (willow), *Fraxinus excelsior* (ash) and *Prunus padus* (bird cherry). Since the competition from surrounding vegetation is high, only a relatively few but large (1.5 metres high) young trees were planted. The area around the new trees was covered with ground cloth, and the trunks of all new trees were encircled with a protective shield of wire mesh. This was done to reduce the risk of damage to the trees, as *Cervidae* (deer) and *Castor fiber* (beaver) are numerous in the area. Wire mesh was also used to protect some important existing trees against damage from beavers.

Similar restoration measures were carried out in two other areas, but somewhat less extensively. Upstream from the bridge to Säby Farm, aquatic vegetation was removed and new gravel was added to the bottom. New trees were also planted here and, together with existing trees, they were protected with wire mesh.

Near the mouth of the river, at the village of Sjösa, a stretch of river below a railway bridge was improved and lengthened with the addition of gravel, rocks and boulders. The same substrate was also added to a slightly deeper area further downstream in order to provide a more varied bottom structure which could enable more species to find suitable habitats.
Adding gravel to the Svärtaån River. An excavating machine with an extra long arm was essential to implementation of this measure (Photo: Ursula Zinko)

When working in the Svärtaån, the excavating machine was supported by large wooden mats to minimize damage to the river bottom. (Photo: Ursula Zinko)

To prevent newly planted alders from being grazed by animals, their trunks were encircled with wire mesh. All new trees were numbered to facilitate monitoring in the future. Ground cloth was used to limit competition from other vegetation. (Photo: Helena Herngren)

Upstream from the bridge to Säby Farm, divers inventory and collect living mussels before the start of restoration work. (Photo: Nils Ljunggren)

Trees including Alnus glutinosa were planted along the Svärtaån River to increase shade cover. To increase growth rates and survival chances, relatively large plants were chosen, as they are less vulnerable to competition from tall grass and other vegetation. (Photo: Helena Herngren)
The Vedaån River is a tributary of the Svärtaån. It is six kilometres long and is known for the good quality of its water. The Vedaån runs from Lake Likstammen to Lake Svarvaren at Lästringe village in the Municipality of Nyköping. It passes through a partly wooded small-farm landscape and is bordered by trees, especially along its upper reaches. The surrounding terrain is gently rolling.

Today, the Vedaån River is unregulated. But in the past, there was a mill dam and a sawmill about three kilometres upstream from the outlet into Lake Svarvaren (Länsstyrelsen i Södermanlands län, 1991). Both Lake Likstammen and the Vedaån River are protected as Natura 2000 sites (Länsstyrelsen i Södermanlands län, 2004, 2005). Lake Likstammen and the upper part of the Vedaån are also included in the Likstammen-Trön area of national interest for nature conservation (Naturvårdsverket, 2000).

Several inventories of the river have found a highly diverse benthic fauna, with several rare species that require high water quality. *Unio crassus* is present along a ca. three-kilometre-long stretch of river — from its outlet into Lake Svarvaren upstream to Tuvekvarn, the site of an old sawmill and grain mill (Nekoro & Sundström, 2005). No other species of Unio-nid freshwater mussel has been found in that part of the river. But at its inlet from Lake Likstammen, four other species occur: *Unio tumidus, Anodonta anatina, A. cygnea* and *Pseudanodonta complanata* (Lundberg & von Proschwitz, 2002).

The fish species that have been found in the river are *Alburnus alburnus, Perca fluviatilis, Abramis brama, Rutilus rutilus, Lota lota, Esox lucius* and *Lampetra planeri*. Also present is *Pacifastacus leniusculus*, an alien species.

Two mayfly species that are rare in Södermanland County have been observed in and around the Vedaån River — *Caenis rivulorum* (angler’s curse) and *Nigrobaetis digitatus* (scarce iron blue mayfly). Also present is the rare caddis fly, *Beraeodes minutus* (Lingdell & Engblom 1982, Länsstyrelsen i Södermanlands län, 1994).

Restoration of bottom substrate and removal of migration obstacles

The focus of restoration measures in the Vedaån River was on eliminating two small migration obstacles and improving bottom substrates by adding rocks and gravel. Boulders and tree trunks have also been added to produce more variation in the water flow. In order to re-establish *Unio crassus* in the upper part of the Vedaån, individuals from populations downstream were transplanted.
As in the case of the Svärtaån River (see above), information meetings and river walks were conducted with landowners before the restoration work began, after which agreements were signed with all landowners affected by the restoration process. Dialogue was also conducted with other interested parties, including the Södermanland County Administrative Board, the Swedish Meteorological and Hydrological Institute, and the Swedish Transport Administration. As with the Svärtaån, the Sportfiskarna association was contracted to lead the project, develop a detailed plan for all measures to be taken, obtain all the permissions required, and lead the on-site work. Once again the County Administrative Board managed procurement of the contractor.

In preparation of the detail planning, an inventory of mussels and restoration needs was conducted. Benthic fauna and electrofishing surveys were conducted before the work of restoration began.

Another preliminary step was to collect all mussels living in the areas to be restored and move them upstream. They were kept there until the work was completed, then returned to their original sites.

The restoration measures were carried out in the lower part of the river, from European motorway E4 downstream to Lake Svarvaren. There were two sections of riffles which obstructed the migration of weak-swimming fish during periods of low to normal water levels. Some of the rocks on them were moved to extend the riffles and lower their height, while new rocks and boulders were added downstream to raise the water level.

New gravel was added to improve the bottom at several other places. Large rocks, boulders and tree trunks were distributed along the entire length of the restored section of river to create more variation in water flow.

It is planned that during coming years some Unio crassus mussels from the lower part of the Vedaån River will be moved to its upper part, where they will be placed just downstream from Lake Likstammen. That will be an initial attempt to re-establish Unio crassus in the upper reaches of the river. If that succeeds, it will also minimize the risk that a large portion of the Unio crassus population in the river might be wiped out — for example, by a tank-lorry accident on motorway E4 that results in toxic substances running into the Vedaån and damaging or even eliminating the existing mussel population downstream.
Unio crassus mussel from the Vedaån River. (Photo: Helena Hemgren)
The Vedaån River, upstream from the river’s outlet into Lake Svarvaren. Shoal of Cyprinidae (mainly roach and probably other Cyprinid species) below one of the migration obstacles in the river. (Photo: Helena Herngren)

The Vedaån River, upstream from the river’s outlet into Lake Svarvaren. Before the start of restoration measures, all mussels living in the affected areas were collected. Many young Unio crassus mussels were found here. (Photo: Helena Herngren)

The Vedaån River, upstream from the river’s outlet into Lake Svarvaren. Water flow, bottom substrate, etc. was investigated before the restoration measures were carried out. (Photo: Helena Herngren)

The Vedaån River, upstream from the river’s outlet into Lake Svarvaren. The river bottom in this area was improved with the addition of gravel, rocks and boulders. (Photo: Helena Herngren)

Moving boulders into the Vedaån River by hand. (Photo: Helena Herngren)

The Vedaån, upstream from the river’s outlet into Lake Svarvaren. Rocks and boulders were moved by hand to make these rapids passable for fish and create a more diverse bottom substrate. (Photo: H. Herngren)
Unforeseen difficulties

During the course of the project, several difficulties arose that had not been anticipated. The most serious problem became known when information emerged about the presence of previously unknown anthrax graves — news which threatened to nullify the Fyledalen Valley component of the UC4LIFE project. But problems exist to be quickly resolved. Some of the unforeseen difficulties encountered and how they were solved are described in the following pages.

Anthrax burial pits

Anthrax is a disease which is caused by a bacterium, *Bacillus anthracis*. It can infect humans and several warm-blooded mammal species, of which ruminants are especially vulnerable. The bacteria that cause anthrax develop spores that are highly persistent and can survive in soil for over 70 years if conditions are favourable.

When the water use permit for the project was approved, news of the Fyleån restoration project was published in the media. It was not long before an archive researcher got in touch. She had studied farms which in the past had been quarantined due to outbreaks of anthrax, and had information about documented cases in the Fyledalen Valley from as recently as 1953. Livestock that had died as a result of anthrax infection had been buried in the area to be restored. This raised the risk of the disease spreading due to the excavation to be carried out.

Experts from the National Veterinary Institute and the Swedish Board of Agriculture were called in, and an information meeting was held with all interested parties in the area. That resulted in a new action plan which involved fencing off the project area so that grazing animals could not come in contact with excavated earth or exposed ground surfaces. Areas where excavated earth was piled up were to be sequestered from livestock and grazing crops. Growing grain crops for fodder was permitted, however, as long as the straw was not used as litter for grazing animals.

Vaccinating grazing animals was discussed, but dismissed for safety reasons. Since it involved very large herds of meat animals moving freely in the area, the risk of injuries that could occur in connection with vaccination was deemed too great.

There was some discussion in the media concerning the risk of anthrax once again spreading in the area, and the project was burdened with a sizable added cost for several kilometres of fencing. Fortunately, all went well and no new anthrax contamination was detected.

Excavated earth

A very large expense for the project was the transport of excavated earth. Some of it was used to fill the old river channel, but it was still necessary to remove 23,200 cubic metres. Around 8,500 m³ of that amount was used for other purposes and the remainder was spread on nearby cropland.

Some of the land near the river is boggy and cannot support much weight. After periods of rain, it was necessary to lay down thick ground mats to enable excavating machines to move about. So many mats were used by the project that, at one point, it was not possible to find any more of them in southern Sweden.

The excavated earth was spread on the cropland of area landowners. It was not necessary to consult the county administrative board, as the material was judged to be uncontaminated and would not be involved in any commerce.

Overhead power lines

Overhead power lines carrying high-voltage electricity pass through the Fyledalen Valley, and there are long stretches where they pass close to the river. At first, it was believed that the restoration work would not affect the power lines; but it turned out that at some locations it was necessary to excavate beneath them. In such situations the regulations of the National Electrical Safety Board apply, and it was therefore necessary to ensure that the excavating machine’s bucket could not be raised high enough to touch a power line. The contractor solved the problem by installing a height-restricting system on the machine.

Railway of national interest

Due to its highly valuable natural features, the Fyledalen Valley has been designated as an area of national interest for nature conservation. But it has also been declared of national interest for transportation, giving rise to a serious conflict of interest.

From the end of the 1800s until 1979, a passenger train ran from Malmö to Simrishamn — via Dalby, Veberöd, Sjöbo and Tomelilla — with some of the route passing through part of the Fyledalen Valley. The old railway still remains, and is used today by a trolley that is a popular tourist attraction.

During the time that the Fyleån restoration measures were being planned, there was some discussion about resuming train service between Malmö and Simrishamn, and the railway through the Fyledalen Valley was included in one of the alternative routes.

However, the Swedish Transport Administration’s preliminary study recommended that Fyledalen be excluded from further consideration, partly due to the risk of damage to the valley’s valuable natural features and partly because using the old railway would involve an excessively long travel time.
The main study had not been completed when the restoration project began. In the end it never considered the Fyledalen Valley alternative; but due to uncertainty about that possibility, the measures intended for the section of railway belonging to the Municipality of Sjöbo were not carried out. It did come to good use, however: It was rented from the municipality for the transport of excavated earth.

In March 2015 the Swedish Transport Administration issued its final decision. It rejected the proposed new train service and provided that, if the issue is raised again, any new route must exclude the Fyledalen Valley. However, the decision came too late to carry out the planned restoration of the Fyleån River.

**Flooding**

In the midst of digging a new river channel and carting off the excavated material, a powerful rainstorm moved in over Skåne County during 2014. The ground in the project area was boggy to start with, and after the downpour it was impossible to drive vehicles on it. The plan to immediately take away the excavated material had to be abandoned. Efforts concentrated instead on an attempt to complete the excavating work. But since meanders previously excavated upstream had already been opened, the water pressure on them increased and they flooded over, making any digging attempts difficult to achieve.

In all, the effect of the 2014 rainstorm was a one-year delay of the restoration work, and an added cost of approximately 150,000 Euros.

**Overhead power lines**

Several overhead power lines pass through the Klingavälsån project area. There was no problem on those occasions when it became necessary to excavate beneath them, because the contractor had installed a height-restriction system on the excavating machine.

**Grazing land**

Livestock animals could have no access to their ordinary grazing land by the river while the excavation work was being carried out. Fencing was therefore set up to keep animals out, and was moved from one area to the next as the work progressed, so that some grazing land became accessible again.

Some tenant farmers were given the use of other land for a period of three years, from 2014 through 2016. But it turned out that *Senecio jacobaea* (ragwort) was growing on some of those areas. It is a perennial herb with lobate leaves and yellow blossoms which is poisonous to grazing animals. Those areas were ploughed up and replanted as part of the UC4LIFE project.
Studies of substrate composition have been conducted in Östergötland County on river bottoms with large communities of *Unio crassus* mussels. The purpose of the research was to determine the type of substrate most common in the mussels’ habitat (Pettersson, 2012). Based on that information, a grain-size curve was produced for the work of restoration. The curve charts the distribution of various particle sizes in the substrate. Suppliers of bottom material can use it to provide the best mixture, focusing on the optimal substrate for *Unio crassus*. The median size indicated by the curve is four millimetres, i.e. fine gravel.

In producing a grain-size curve, measurements are made in a manner which yields a cumulative size distribution of the bottom substrate. A grain-size curve also makes it easy to calculate a median value and percentiles, values that are useful for several calculations which involve the size distribution of bottom substrate. The curve charts cumulative size (expressed as cumulative per cent finer than a given value) on the Y-axis, and grain size is charted on the X-axis.

The grain-size curve produced for the UC4LIFE project is slightly modified: The sizes noted on the curve are circa one millimetre larger than the actual sizes of the particles measured in the field. The reason for this is that finer substrate material was relatively abundant on the river bottoms to be restored, thus more was not needed.

Studies of suitable bottom substrate for *Unio crassus* were conducted mainly in the Storån River at Falurum village in Östergötland County, in an area with relatively fine-grained material. A small study was also conducted in the Kapellån River in the same county, in an area with larger bottom material (median size of 60 mm). It turned out that *Unio crassus* thrived on both types of substrate.

This gravel mixture has been found to be optimal for *Unio crassus* in the Storån and Kapellån rivers in Östergötland County. (Photo Lars Grezelius)
Success factors

- Develop knowledge base on valuable biological features — aquatic landscape conditions, and mussels, fish and other organisms.
- Link the project explicitly to one or more pedagogically useful emblematic species from the start.
- Ensure that the project leadership has adequate knowledge of water conservation, hydrology, mussel and fish ecology, legal aspects, and both current and historical local conditions.
- At an early stage, ensure the participation of the appropriate experts in difficult areas such as legal issues, hydrology, cultural heritage and construction technology.
- Well before implementing any measures, initiate a dialogue with experts on cultural heritage issues.
- Develop a hydraulic model of the river as a basis for determining where and how much bottom substrate can be added without negative effects on areas upstream or on the functioning of any covered ditches on adjacent cropland.
- Spread information via media and in person locally. Provide information at an early stage to landowners, municipalities and business operators. Invite and inform locally and via TV, radio and print media. Do this as measures are implemented during the entire project period. Also, spread information to everyone working on the project via direct contacts and social media (blogs, Facebook, Twitter, etc.).
- Before measures are implemented and in a positive spirit, conduct meetings and river walks with landowners and other interested parties. Invite everyone affected by the project. Maintain good relations with well-established local actors. Find local channels for spreading knowledge and messages, including community organizations, water management councils, schools and local leaders.
- Prepare written agreements on planned measures during initial discussions with landowners.
- Before hiring contractors, prepare a detailed description of measures and conditions (within the limits of the project budget) so that the appropriate capacities of machines and personnel are engaged. Appoint a leader for project planning and obtaining the necessary permits. That person should participate in the entire process, from initial planning to follow-up, and also supervise the implementation of measures.
- Develop a clear project plan with measurable objectives, then disseminate and gain approval for it. For many measures, make a plan and implement it methodically, step by step, and have a long-term plan which includes partial objectives.
- Prepare and get approval for legal measures and procurement in good time. Be prepared for the possibility that dealing with water rights aspects of the project may take more time than anticipated.
- If a restoration plan has been previously developed, it may be complemented with additional sites, and be modified in accordance with the project’s purpose. Take advantage of the possibility of implementing measures where they are legally most feasible, and adjust measures to the wishes of landowners and other interested parties.
- Utilize opportunities to sign co-operative agreements. For example, the Swedish Transport Authority has standard agreements with contractors, and in some cases restoration measures can be co-ordinated with maintenance of Transport Authority facilities.
- Hire contractors with experience of similar tasks, and conduct continual dialogue with them during the whole working phase.
- Find good substrate of stone and gravel for habitat conservation measures. Work in gradual steps and observe how the river behaves, paying special attention to changes in water level.
- Follow up and, if necessary, adjust the measures taken in order to draw lessons for application to future projects and be able to spread information about the results.

21 May 2016. Inauguration of the new fish passage around Turefors Pond in the Lillån River, near Kvillsfors village in the Municipality of Vetlanda. Public information has been a very important part of the project, and many Kvillsfors residents were present when Jönköping County Governor Anneli Wirtén opened the gates to start the flow of water. Earlier that morning, nearly 300,000 listeners could hear a live broadcast from the Lillån River on the regional channel of Swedish Public Radio.

(Photo: Jakob Bergengren)
For *Unio crassus* to survive, knowledge of and involvement in mussels and their welfare must be carried into the future. Our most important mussel ambassadors are the children who in years to come will sit on water management councils, own land and be part of the general public. For that they will require knowledge, which is why the UC4LIFE project placed a great emphasis on public information with a special focus on children.

Children from Lindesborg School in the Municipality of Tomelilla were invited to the restoration site before the inauguration of the re-meandered channel of the Fyleån River. Ranging in age from seven to nine, they learned a great deal about *Unio crassus* by playing and engaging in educational activities. They used their creativity to perform a little sketch about the mussel, dressed in costumes they made themselves representing small *Unio crassus* mussels and their host fish. Some of the children portrayed threatening toxins that can be found in the water. The children sang a song about mussels which they had written together with their teacher. The sketch concluded with the children symbolically planting some mussels in the Fyleån River.

A family day was arranged at the Fyleån restoration site by the Nybroån Water Management Council together with Högestad & Christinehof Förvaltning Co., Sportfiskarna, UC4LIFE-Skåne, et al. Information about the project and *Unio crassus* was conveyed during a walk along the river. Children could borrow waders and water scopes to search for mussels, and nets to capture bottom-dwelling animals. They could also see and learn more about mussels and host fish in aquariums and with microscopes. The family day was appreciated by both children and adults, even though some got wet due to rain showers and the odd involuntary dip in the river. The concluding grill party was an extra highlight.

The UC4LIFE project has conducted more than 200 information events attended by nearly 11,000 people. An important aspect of the project has been to involve young schoolchildren. Some 800 have participated in Skåne, Jönköping, Södermanland and other counties. Showing and explaining project measures to young children on site has been very successful and additional schools have expressed strong interest in participating. A book for children about life in Swedish rivers, *Musse målarmussla (Micky Mussel)*, has been produced and has been very well received (Herngren, 2013).
Musse målarmussla is a book for schoolchildren about *Unio crassus* mussels and life in the river. © BYBLOO.SE

Children learn a great deal about *Unio crassus* by playing and engaging in educational activities. (Photo: Ivan Olsson)
Conservation measures

In order to promote the conservation of *Unio crassus*, restoration measures should conform with the biological requirements of mussels and their host fish (Lopes-Lima *et al.*, 2015). An important step toward that end is to survey the host fish. The procedure followed is to study the mussel larvae attached to the gills of wild fish, combined with tests to determine the suitability of various fish species as hosts. Surveys of host fish have been conducted in rivers located in Skåne, Blekinge, Jönköping, Östergötland and Södermanland counties, all of which have known populations of *Unio crassus*.

Tests of various species’ suitability as hosts were conducted in aquariums at Hemmestorps Mölla in Skåne County. Those tests were also used in connection with the cultivation of young mussels for reintroduction to the Fyleån and Klingavälsån rivers in Skåne, where *Unio crassus* no longer occurs but historically was abundant. The two rivers had previously meandered through the landscape but were straightened during the 18th century, leading to the eradication of their mussel communities.

As part of the UC4LIFE project, both rivers have been re-meandered in an attempt to re-establish as much as possible of the original structures and functions. That includes the establishment of new *Unio crassus* populations by reintroducing adult and juvenile mussels along with host fish infected with mussel larvae.

Host fish survey

The main objectives of the survey were to determine which species are used by *Unio crassus* as host fish, and to chart the specific host fish fauna in every river included in the project which has known populations of *U. crassus*. Similar studies have been conducted in other parts of *U. crassus*’s range where the availability of host fish can be a limiting factor for the mussel’s reproduction success (Douda, *et al.*, 2012; Stoeckl *et al.*, 2014).

Methodology

The host fish survey was based on knowledge of *Unio crassus* biology, for example its reproduction season and when during the season host fish carry the mussel larvae on their gills. To find out when a mussel is carrying larvae, its shell is opened slightly (< 0.5 centimetre) with special tongs. The mussel’s gills can then be inspected visually to determine if there are any larvae on them (Österling *et al.*, 2008).

Since the starting point for the presence of larvae is regulated by temperature, mussels begin to reproduce early during years when the water temperature increases early in the season. It turned out that the reproduction season of *Unio crassus*, i.e. when the mussels carried fertilized larvae, was from mid-April to the beginning of May and up to the beginning of July.

When the first mussels were determined to be carrying larvae, fish were taken from the rivers by means of electrofishing and their gills were inspected to see if they had been infested with mussel larvae. It was found that fish were naturally infested a few weeks after the first mussels were fertilized. The fish then carried the infested larvae on their gills during the summer, as late as some two weeks after the last larvae-carrying mussel was found. It thus turned out that the parasitic stage started by the end of April and ended a couple of weeks into July.

Host fish surveys were conducted in the following rivers: Bråån and Tommarpsån, Skåne County; Bräkneån, Blekinge County; Emån, Jönköping County; Kilaån and Svärtaån, Södermanland County; and Storån, Östergötland County. Fish samples were taken in sections of river with large numbers of *Unio crassus*, because fish at such locations were most likely to be infected with mussel larvae (Österling, 2008).

In order to study as many fish species as possible, several fish sampling methods were used and their effectiveness evaluated.

The sampling was conducted in May, June and July during each of the four years during 2012-2015 with the use of fish traps, river nets and electrofishing. The electrofishing was carried out during the daytime in waters of wading depth. The traps and nets were left overnight in both deep and shallow areas of the rivers. (Fjälling *et al.*, 2011)
<table>
<thead>
<tr>
<th>River</th>
<th>Mussel species</th>
<th>Site GPS co-ordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Braån</td>
<td><em>Unio crassus</em>, <em>U. pictorum</em>, <em>U. tumidus</em>, <em>A. anatina</em>, <em>A. cygnea</em></td>
<td>6187823, 1363317 6187942, 1364505</td>
</tr>
<tr>
<td>Tommarpsån</td>
<td><em>U. crassus</em>, <em>A. anatina</em>, <em>A. cygnea</em></td>
<td>6159159, 1394977 6159236, 1395094 6159543, 1395513</td>
</tr>
<tr>
<td>Bräkneån</td>
<td><em>Margaritifera margaritifera</em>, <em>U. crassus</em>, <em>A. anatina</em></td>
<td>6229596, 1455989</td>
</tr>
<tr>
<td>Emån</td>
<td><em>M. margaritifera</em>, <em>U. pictorum</em>, <em>U. tumidus</em>, <em>U. crassus</em>, <em>A. anatina</em>, <em>A. cygnea</em>, <em>Pseudanodonta complanata</em></td>
<td>6364761, 1483237</td>
</tr>
<tr>
<td>Storán</td>
<td><em>U. crassus</em>, <em>U. tumidus</em>, <em>A. anatina</em>, <em>A. cygnea</em>, <em>P. complanata</em></td>
<td>6446065, 1524876 6446143, 1524715 6445930, 1524428</td>
</tr>
<tr>
<td>Kilaån</td>
<td><em>U. pictorum</em>, <em>U. tumidus</em>, <em>U. crassus</em>, <em>A. anatina</em>, <em>A. cygnea</em>, <em>P. complanata</em></td>
<td>6513471, 1544037 6513795, 1545474 6513509, 1549673</td>
</tr>
<tr>
<td>Svärtaån</td>
<td><em>U. pictorum</em>, <em>U. tumidus</em>, <em>U. crassus</em>, <em>A. anatina</em>, <em>A. cygnea</em></td>
<td>6522559, 1574425 6520282, 1573972 6518081, 1573955</td>
</tr>
</tbody>
</table>

*Not present in designated river, but in a tributary or lake within its drainage basin
1 Numerous mussels present
2 Only a few or isolated mussels

In Sweden there are seven native species of large freshwater mussel with a larval stage on the gills of host fish (and in some cases on the fins and skin). Often, several of the species occur at the same site (see Table 1). As it is difficult to visually distinguish between the various species, DNA analysis is the preferred method for identification. Some of the fish caught for the survey were therefore preserved in 95% ethanol. The length in millimetres and weight in grams of every individual was measured. The number of infested mussel larvae on each fish's gills was counted, after which some larvae were collected from the fish that were caught. The mussel larvae were then identified as to species with ITS rDNA analysis at the Swedish Museum of Natural History in Stockholm (Källersjö et al., 2005).

To find out if larvae (glochidia) have developed into juvenile mussels and detached themselves from their hosts, fish were taken from the Kilaån and Svärtaån rivers in Södermanland County in June 2015. They were then transported to Hemmerstorps Mölla in Skåne County, where they were placed in hatching tanks.

The lighting in the laboratory was regulated to follow a day–night cycle. The water temperature, measured continually and recorded on data loggers, was circa 15°C during the study period. The hatching tank water was changed once a week. The fish were fed every third day with frozen Chironomidae (midges), *Gammarus* spp. and smaller fish. Juvenile mussels were collected every day with a net, then counted and preserved in 95% ethanol. Their species were then determined with ITS rDNA-analysis (Källersjö et al., 2005).
RESULTS

FISH SAMPLING METHODS

Electrofishing is the most effective method for sampling fish in shallow water of wading depth. It is effective for species such as *Salmo trutta*, *Cottus gobio*, *Phoxinus phoxinus* and *Lota lota*, but also for more mobile and less territorial species such as *Alburnus alburnus*.

Fish traps are generally less effective than electrofishing, although the survival rate of fish caught is higher. In the present case, the effectiveness of fish traps was lowest for *P. phoxinus*, *Gasterosteus aculeatus*, *Barbatula barbatula* and *Esox lucius*. It was highest for *A. alburnus*, *Rutilus rutilus*, *Perca fluviatilis*, *Blicca bjoerkna*, *Tinca tinca* and *Scardinius erythropthalmus*. River nets were effective for catching *L. lota*, *A. alburnus*, *B. bjoerkna*, *P. fluviatilis*, *R. rutilus* and *Gymnocephalus cernua*. (See Table 2.)

Table 2. Number of fish caught, and species inspected for the presence of encased mussel larvae on gills, years 2012-2015
Fishing method: E: electrofishing; N: river net; T: fish trap.
Not shown: fish that were caught and returned to the water without being inspected

<table>
<thead>
<tr>
<th>Species</th>
<th>Fishing method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E</td>
</tr>
<tr>
<td>A. alburnus</td>
<td>111</td>
</tr>
<tr>
<td>B. bjoerkna</td>
<td>35</td>
</tr>
<tr>
<td>A. brama</td>
<td></td>
</tr>
<tr>
<td>A. vimba</td>
<td></td>
</tr>
<tr>
<td>B. barbatula</td>
<td>16</td>
</tr>
<tr>
<td>C. gobio</td>
<td>83</td>
</tr>
<tr>
<td>E. lucius</td>
<td>1</td>
</tr>
<tr>
<td>G. cernua</td>
<td>7</td>
</tr>
<tr>
<td>L. lota</td>
<td>34</td>
</tr>
<tr>
<td>P. fluviatilis</td>
<td>62</td>
</tr>
<tr>
<td>P. phoxinus</td>
<td>110</td>
</tr>
<tr>
<td>R. rutilus</td>
<td>27</td>
</tr>
<tr>
<td>S. erythropthalmus</td>
<td></td>
</tr>
<tr>
<td>S. trutta</td>
<td>41</td>
</tr>
<tr>
<td>S. cephalus</td>
<td>2</td>
</tr>
<tr>
<td>T. tinca</td>
<td></td>
</tr>
</tbody>
</table>

GLOCHIDIA (MUSSEL LARVAE) ON FISH GILLS

A total of 15,404 mussel larvae were found among 14 of the 17 fish species that were represented in the survey (total number of fish caught was 1260). Of those larvae, 3310 were removed from fish gills and analysed as to species with DNA analysis. Every step in every analysis did not always function properly, and the final total of larvae whose species could be identified was 2838. *Unio crassus* larvae comprised 1143 (40%) of the total and they were found on 13 fish species: *A. alburnus*, *B. bjoerkna*, *B. barbatula*, *C. gobio*, *G. cernua*, *L. lota*, *P. fluviatilis*, *P. phoxinus*, *R. rutilus*, *S. trutta*, *Squalius cephalus*, *T. tinca* and *Vimba vimba*. No mussel larvae of any species were found on fish of three species: *Abramis brama*, *Leuciscus idus* and *S. erythropthalmus*. (See Table 3)
SKÅNE COUNTY. In the Bråån River, *P. phoxinus*, *S. trutta* and *B. barbatula* were infested with *U. crassus* larvae. In the Tommarpsån River, *Unio crassus* larvae were found on *C. gobio* and *P. phoxinus*.

BLEKINGE COUNTY. In the Bråkneån River, *P. phoxinus* was carrying the most *U. crassus* larvae per fish — more than twice as many as *A. alburnus* and up to four times as many as *S. trutta*, although the latter species had the most larvae per unit of weight. *Unio crassus* larvae were also found on *G. cernus*, which was almost as heavily infested as *A. alburnus*, *P. fluviatilis* and *A. vimba*. However, no mussel larvae of any species were found on *R. rutilus*).

JÖNKÖPING COUNTY. In the Emån River, *U. crassus* larvae were found on five species of fish: *A. alburnus*, *P. fluviatilis*, *P. phoxinus*, *R. rutilus* and *S. cephalus*. *Unio crassus* accounted for 55% of the larvae on *A. alburnus* and 100% on *P. phoxinus*, but only 6% of the larvae on *S. cephalus* were *U. crassus*.

ÖSTERGÖTLAND COUNTY. In the Storån River, *Unio crassus* larvae were found on *A. alburnus*, *G. cernus*, *P. fluviatilis*, *B. bjoerkna* and *R. rutilus*. The first three of these are probably the most important host fish in the Storån River.

SÖDERMANLAND COUNTY. Ten fish species were caught in the Kilaån River. No mussel larvae were found on *S. trutta* or the sole individual of *S. erythrophthalmus*. *Unio crassus* larvae were found on *A. alburnus*, *C. gobio*, *G. cernus*, *S. cephalus*, *L. lota*, *P. fluviatilis* and *R. rutilus*. One of the *S. cephalus* individuals had the highest number of larvae on its gills. *Alburnus alburnus*, *C. gobio* and *L. lota* must be regarded as the most important host fish for *U. crassus* in the Kilaån River, because they were the most abundant species and had numerous mussel larvae on their gills.

In the Svärtaån River, the greatest number of *U. crassus* larvae was found on *G. cernus*, although 92% of all larvae were found on other species. There were fewer larvae on *A. alburnus*, but more than on *B. bjoerkna* or *P. fluviatilis*. The sole individual of *T. tinca* that was caught also had mussel larvae. But no *U. crassus* larvae were found on *B. barbatula*, *L. idus* or *R. rutilus* fish in the Svärtaån River. (See Table 3.)
Table 3. Number of mussel larvae found on fish gills

“Number of fish” refers to the total number of each species caught. “U. crassus ratio” is an estimate of the total number of U. crassus larvae that were found, in relation to the total number of larvae of other species. NA = No data available

<table>
<thead>
<tr>
<th>River</th>
<th>Fish species</th>
<th>Number of fish</th>
<th>Number of larvae</th>
<th>Percent of larvae analysed</th>
<th>Unio crassus larvae</th>
<th>Unio crassus larvae</th>
<th>Unio crassus ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bråån</td>
<td>B. barbatula</td>
<td>32</td>
<td>4</td>
<td>100</td>
<td>0.13 ± 0.34</td>
<td>0.07 ± 0.19</td>
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</tr>
<tr>
<td></td>
<td>P. phoxinus</td>
<td>94</td>
<td>2541</td>
<td>100</td>
<td>27.03 ± 4.93</td>
<td>11.10 ± 11.44</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>S. trutta</td>
<td>40</td>
<td>409</td>
<td>100</td>
<td>10.23 ± 8.89</td>
<td>0.64 ± 1.36</td>
<td>100</td>
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<tr>
<td>Tommarpsán</td>
<td>C. gobio</td>
<td>102</td>
<td>442</td>
<td>51</td>
<td>7.59 ± 6.70</td>
<td>4.85 ± 5.77</td>
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<tr>
<td></td>
<td>P. phoxinus</td>
<td>90</td>
<td>630</td>
<td>54</td>
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<td>S. trutta</td>
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<td>59</td>
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<td>NA</td>
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<tr>
<td>Bräkneån</td>
<td>A. albuminus</td>
<td>94</td>
<td>537</td>
<td>95</td>
<td>7.42 ± 9.39</td>
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<tr>
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<td>G. cernuus</td>
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<td>0.01 ± NA</td>
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<td>P. phoxinus</td>
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<td>6.75 ± 5.06</td>
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<td>S. trutta</td>
<td>24</td>
<td>36</td>
<td>94</td>
<td>4.70 ± 5.35</td>
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<td>A. vimba</td>
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<td>7.08 ± 7.10</td>
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<td>R. rutilus</td>
<td>33</td>
<td>935</td>
<td>98</td>
<td>0.39 ± 1.50</td>
<td>0.01 ± 0.04</td>
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<tr>
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<td>S. cephalus</td>
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<td>289</td>
<td>100</td>
<td>14.95 ± NA</td>
<td>0.39 ± NA</td>
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<td>Storán</td>
<td>A. albuminus</td>
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<td>92</td>
<td>87</td>
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</tr>
<tr>
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<td>A. brama</td>
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<td>NA</td>
</tr>
<tr>
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<td>B. bjöerka</td>
<td>36</td>
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<td>100</td>
<td>0.86 ± 0.69</td>
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<td>10</td>
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<tr>
<td></td>
<td>G. cernuus</td>
<td>30</td>
<td>543</td>
<td>54</td>
<td>4.62 ± 11.61</td>
<td>0.53 ± 1.08</td>
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<td>P. fluviatilis</td>
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<td>385</td>
<td>82</td>
<td>3.06 ± 2.96</td>
<td>0.13 ± 0.17</td>
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<td>R. rutilus</td>
<td>11</td>
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<td>100</td>
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<td>0.04 ± 0.05</td>
<td>100</td>
</tr>
<tr>
<td>Kilaån</td>
<td>A. albuminus</td>
<td>42</td>
<td>106</td>
<td>74</td>
<td>2.86 ± 2.59</td>
<td>0.31 ± 0.26</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>C. gobio</td>
<td>41</td>
<td>144</td>
<td>79</td>
<td>3.40 ± 5.91</td>
<td>0.83 ± 1.63</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>E. lucius</td>
<td>1</td>
<td>1</td>
<td>100</td>
<td>0.00 ± NA</td>
<td>0.00 ± NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>G. cernuus</td>
<td>4</td>
<td>119</td>
<td>100</td>
<td>3.93 ± 5.97</td>
<td>0.59 ± 0.97</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>L. loz</td>
<td>34</td>
<td>257</td>
<td>66</td>
<td>5.88 ± 6.81</td>
<td>0.41 ± 0.35</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>P. fluviatilis</td>
<td>12</td>
<td>77</td>
<td>99</td>
<td>1.60 ± 1.82</td>
<td>0.01 ± 0.01</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>R. rutilus</td>
<td>71</td>
<td>49</td>
<td>84</td>
<td>1.47 ± 4.47</td>
<td>0.08 ± 0.19</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>S. cephalus</td>
<td>1</td>
<td>20</td>
<td>100</td>
<td>15.00 ± NA</td>
<td>0.02 ± NA</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>S. erythrophthalmus</td>
<td>1</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>S. trutta</td>
<td>5</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Svärtaån</td>
<td>A. albuminus</td>
<td>80</td>
<td>242</td>
<td>83</td>
<td>3.53 ± 4.78</td>
<td>0.35 ± 0.48</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>B. barbatula</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>B. bjöerka</td>
<td>49</td>
<td>38</td>
<td>74</td>
<td>0.33 ± 0.71</td>
<td>0.02 ± 0.05</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>G. cernuus</td>
<td>49</td>
<td>1842</td>
<td>40</td>
<td>6.25 ± 17.51</td>
<td>0.45 ± 1.55</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>L. idus</td>
<td>1</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>P. fluviatilis</td>
<td>77</td>
<td>4317</td>
<td>72</td>
<td>0.74 ± 2.26</td>
<td>0.04 ± 0.12</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>R. rutilus</td>
<td>12</td>
<td>7</td>
<td>57</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>T. tinca</td>
<td>1</td>
<td>112</td>
<td>100</td>
<td>3.73 ± NA</td>
<td>0.00 ± NA</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 4. Mussel larvae on fish gills, and juvenile mussels detached from gills of fish from the Kilaån and Svärtaån rivers in Södermanland County, year 2015. NA = no data available.

<table>
<thead>
<tr>
<th>River</th>
<th>Fish</th>
<th>U. crassus on fish gills</th>
<th>Juvenile U. crassus detached from gills</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Species</td>
<td>No of fish</td>
<td>% fish with U. crassus</td>
</tr>
<tr>
<td>Kilaån</td>
<td>A. alburnus</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>C. gobio</td>
<td>20</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>L. lota</td>
<td>12</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>R. rutilus</td>
<td>9</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>S. trutta</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Svärtaån</td>
<td>A. alburnus</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>B. bjoerkna</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>L. idus</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>P. fluviatilis</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>R. rutilus</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>T. tinca</td>
<td>NA</td>
<td>0</td>
</tr>
<tr>
<td>Svärtaån &amp; Kilaån</td>
<td>G. cernuus</td>
<td>NA</td>
<td>0</td>
</tr>
</tbody>
</table>

From 142 of those fish, 314 juvenile mussels were collected and 14% of those were identified as U. crassus. Alburnus alburnus had the largest number of U. crassus larvae, followed by L. lota, C. gobio and R. rutilus. (See Table 4.) Larvae of U. tumidus, U. pictorum and Pseudanodonta complanata were also found on fish from the two rivers.
Discussion

This is the first large-scale study of *Unio crassus*’s host fish in Sweden and it has identified several suitable species. On the whole, *A. alburnus*, *P. phoxinus* and *C. gobio* appear to be the most suitable host fish, because:

1. They were infested with the greatest number of mussel larvae.

2. The greatest number of juvenile mussels had detached from those species (when also taking into account the results noted under “Mussel cultivation and reintroduction”).

3. Fish of those species are present in large numbers in the rivers studied.

It may also be noted that *G. cernuus* was identified as a host for *U. crassus* larvae in four of the seven rivers studied. Additional studies of *G. cernuus*’s suitability as a host fish are desirable, with a particular focus on the extent to which juvenile mussels detach from their gills.

The high rate of larval infection of *S. trutta* may be important in some locations, since that species appeared to be suitable as a host fish in only two of the rivers studied. *Lota lota* and *R. rutilus* were also suitable as host fish; but as in the case of *S. trutta*, their importance varies due to large differences in their numbers at various locations. Another species that can be suitable as a host fish in some waters is *P. fluviatilis*, large individuals of which can carry numerous mussel larvae on their gills and thus have great significance for the number of juveniles added to the mussel population.

On the other hand, the study results indicate that *A. brama*, *B. björkna* and *T. tinca* are comparatively unsuitable as host fish for *U. crassus*.

A comparison between the number of *U. crassus* larvae that infest a fish and the number of juveniles that detach from the fish indicate that determining the rate of larval infestation is a good method for evaluating the suitability of various fish species as hosts for mussel larvae. It can thus suffice to study only the parasitic stage of the process and not the number of juveniles that detach from the fish (Österling, 2011; Zieritz et al., 2012). That conclusion is supported by research which indicates that few mussel larvae die after they have infected a host fish (see below, “Mussel cultivation and reintroduction”). The same method can to some extent distinguish which species are not suitable as host fish.

The number of host-fish species in the rivers studied varied widely, which can affect the growth and survival of mussel populations. For example, migrating fish species can be expected to increase the dispersal of mussels and thereby increase genetic exchanges between mussel subpopulations. Migrating fish can also be important in relation to human disturbances, since the larvae they carry as host fish can spread mussels between different locations in various bodies of water.

Accordingly, mussel populations may differ in their vulnerability to disturbances in their environments, depending on the number and species of host fish that are available. Mussels in a river with a wide variety of host species may be more resistant to disturbances than mussels in a river with only one or a few host species. The composition of the host fish population in a river may therefore be an indicator of its mussels’ resilience to disturbance.

In the Bråån River in Skåne County, *P. phoxinus* is the most important host fish and is present in great numbers, whereas *S. trutta* is not quite as suitable as a host. Together with *P. phoxinus*, however, *S. trutta* can contribute to the production of juvenile mussels and increase the potential for the dispersal of mussels in that river.

Three suitable species were found in the Tommarpsån River in Skåne County. Although not many different host-fish species were found there, *C. gobio* and *P. phoxinus* are highly suitable as hosts and are present in great numbers. Together with *S. trutta*, they provide a sufficient variety of host fish to contribute to the reproduction of juvenile mussels.

The Bräkneån River in Blekinge County has at least six host species. The large number of *A. alburnus* that was caught probably indicates that it is an important host species. It was noted that large schools of spawning *A. alburnus* appeared during the reproduction season of mussels, indicating that the dispersal of parasitic larvae in this river can be significant when the fish leave their spawning grounds. There are host species from at least three families of fish in the Bräkneån River — Cyprinidae, Salmonidae and Percidae. The Bräkneån thus appears to have a high diversity of fish species, which should contribute to a high level of resilience to environmental disturbances.

There are at least three host species in the Emån River in Jönköping County. But there are probably other suitable species in the river — *S. cephalus* for example (Taeubert et al., 2012). However, the species encountered during the study are probably the most important hosts for *U. crassus* at the locations where fish samples were taken in connection with the project. As in the Bräkneån River, mussels in the Emån probably have a strong resilience to environmental disturbances due to the presence of many different host-fish species.
The Storån in Östergötland County is one of the four rivers where it was found that G. cernuus had a high rate of infestation by mussel larvae. Furthermore, there are great numbers of that species in the river. Another suitable host is A. alburnus, whose presence in the Storån indicates that it is an important host fish in general, as it occurs in five of the seven rivers that were studied. Perca fluviatilis was also identified as an important host in the Storån. So were B. bjöerkna and R. rutilus, but their infection rates were lower.

There are many species and individuals of host fish in the Kilaån River in Södermanland County. Large numbers of C. gobio are present, and L. lota is also an important host fish in some locations. Also abundant in the Kilaån is A. alburnus, which may be regarded as an important host species in the river.

The Svärtaån River in Södermanland County was the only river where T. tinca was found to be carrying U. crassus larvae. Only one individual of T. tinca was caught, however, indicating that more research is needed to assess its suitability as a host. Other important host species in the Svärtaån are A. alburnus, B. bjöerkna, G. cernuus and P. fluviatilis, demonstrating the wide variety of potential hosts in the river.

The research has shown that the composition of host fish populations varies widely between rivers, as do the numbers of various species and their suitability as host fish. It is therefore desirable to find out how many individuals of various species are present (for example, via the Swedish Electrofishing Register, SERS). It can therefore be stated that the strength of resilience to environmental disturbances — as indicated by the number of host fish species and the ecological differences between fish species — varies widely.

It is also important to study the suitability and composition of host-fish species in individual rivers when restoration measures are being planned, so that measures which benefit those species can be properly implemented. In addition, it is desirable to conduct tests of various species’ suitability as hosts before mussels are reintroduced, because mussels from different rivers may vary in their compatibility with local fish species (see below, “Mussel cultivation and reintroduction”).

Finally, the research findings indicate that, if the objective is to reintroduce Unio crassus mussels, the presence or absence of host fish at the planned sites should also be studied. (See also: Lundberg et al., 2009; Wengström, 2009; Lundberg & Pettersson, 2010.)
**Mussel cultivation and reintroduction**

In order to cultivate and reintroduce mussels, it was first necessary to investigate, describe and evaluate:

- **Working with host fish:** Capacity of host-fish species to tolerate various methods and treatment, from initial capture to management in aquariums and detachment of juvenile mussels from the gills of host fish.

- **Parasitic stage and detachment of juvenile mussels:** Suitability of various species as host fish, i.e. infection by mussel larvae and detachment of juvenile mussels from fish species that live in streams and rivers where *U. crassus* is present, including those to which *U. crassus* has been reintroduced.

- **Juvenile mussels:** Survival and development of juvenile *U. crassus* mussels in laboratories after detachment from host fish.

- **Reintroduction:** Methods for reintroducing juvenile and adult mussels to streams and rivers, and measuring their subsequent survival.

**Methods**

**WORKING WITH HOST FISH**

Fish sampling methods were designed to maximize catches of all species present in the streams and rivers included in the study. Various methods and combinations of methods were therefore tested. Samples were taken during 2012 – 2015 at sites in the Klingavälsån, Fyleån, Bråån and Tommarpsån rivers.

Electrofishing, fish traps and fly fishing were used to catch fish. The fish traps were placed in streams and rivers during the afternoon and emptied the following morning. The trap models used were "Rapula", "Ufo" and "Gäddryssja", all manufactured by Laxen Specialnät (www.laxen.com). Fly fishing was used as a complement to catch *A. alburnus*.

The fish caught were continually supplied with oxygen while being transported to the laboratory. The various species were kept separate from each other during transport.

In some of the samples, the fish were checked with a stereo microscope to make sure that none was infected with mussel larvae.

Electrofishing was conducted by two or three persons. Samples were taken both before and after it was determined that *U. crassus* mussels began their annual release of larvae. (Photo: Stefan Berthold)

Cage used to hold fish caught during the night. (Photo: Lea D. Schneider)
After transport to the laboratory, the fish caught were placed in aquariums containing 160 litres of water each. All fish were inspected for possible disease. They were then gradually acclimated to tap water or river water and kept in the aquariums until the start of the test of infection by mussel larvae. A natural day-night cycle was established. The aquarium water was changed once a week and continually filtered using EHEIM 600 filters. The fish were fed regularly with frozen Chironomidae (midge) and Gammarus spp.

**FERTILIZED, LARVAE-BEARING MUSSELS**

Fertilized female mussels from the Bråån and Tommarpsån rivers were used for the tests of host fish suitability. Each individual was kept in an aerated 2-litre water tank kept at a temperature of 14 – 16 °C. The water was changed and released mussel larvae were collected daily. The larvae were kept in tap or river water at a temperature of 4° C until they were used to infect host fish. Vital and healthy larvae were then acclimated to a temperature of 14 – 16 °C. The concentration of the larvae was measured in samples of homogenized stock solution. After the mussel larvae were collected, the adult mussels were returned to the river sites where they had been collected.

**PARASITIC STAGE AND DETACHMENT OF JUVENILE MUSSELS**

The individual fish used in the tests were kept separately in infection baths whose composition was adjusted to each fish species. A sample containing 350 mussel larvae per fish was added to each bath. In order to increase the rate of infection, the bath was carefully and continually stirred for 30 minutes.

An initial pilot test of host fish suitability was conducted in 2012. Its purpose was to study potential host fish in the two rivers where *Unio crassus* was to be reintroduced during the project. Fertilized female mussels were collected from the Bråån and Tommarpsån rivers, and fish of eleven species were caught with electrofishing in the Klingavälssån and Fyleån rivers. The fish and mussels were transported to a laboratory at Lund University, where the fish were infected with mussel larvae and kept in aquariums. The fish were inspected twice, after three and twenty days, and any mussel larvae on their gills were counted.

A “common garden experiment” was conducted in 2013. It is a test designed to study local adaptation patterns. The purpose in this case was to determine if mussels adapt to the fish in their native aquatic habitats — so-called sympatric fish populations. In theory, it may be assumed that mussels that infect sympatric fish produce more juveniles than those that infect allopatric fish, i.e. fish that are not from the same aquatic habitat. Finding out whether or not that theory is correct is important for the conservation of streams and rivers occupied by mussels — for example, when mussels or fish are to be reintroduced, or when restoration measures are to be implemented.

Fish swimming in a bath with mussel larvae while the water is carefully stirred. Infested fish were then moved to randomly selected aquariums or hatching tanks where the water temperature was kept at 15 – 18° C. The two fish species were kept separate, so that each aquarium held only one species. The tanks (40 litres and 80 litres) were constructed to enable collection of juvenile mussels after they detached from their host fish. Mussel survival and function for the two fish species was compared continually between the aquariums and hatching tanks used in the experiment. (Photo: Martin Österling)
Nine different experiments were conducted, in addition to the pilot test and common garden experiment. Some of the fish were sacrificed three days after being infected with mussel larvae. Their lengths and weights were measured, after which their gills were dissected and inspected.

In some of the experiments, samples were also taken 20 days after infection. Juvenile mussels which had detached from their host fish were studied to determine their survival rate, and their lengths were measured to indicate the amount of growth.

Juvenile mussels
All living juvenile mussels were transplanted to 500-millilitre plastic containers holding 400 millilitres of river water. Juveniles from different rivers were kept separately in 15 – 16°C water that was changed once a week. They were fed with microscopic bits of decaying organic matter and single-celled green algae (Eybe & Thielen, 2010).
The first method used was to fill boxes with gravel, and cover them with mesh sized 500 microns so that the juvenile mussels could not crawl out. The mussels were placed in Eppendorf tubes in the laboratory. In the field, the tubes were turned upside down in the boxes so that they could crawl down to the gravel in the boxes. (Photo: Lea D. Schneider)

The second method used a construction of perforated bricks. The juvenile mussels were placed in the perforations and closed in with fine-mesh netting (200 microns) on the bottom and (4 millimetres) on the top of each brick. (Photo: Lea D. Schneider)

The third method used plastic pipes of various sizes into which the juvenile mussels were placed and closed in with fine-mesh netting (200 microns) on the bottom and (4 millimetres) on the top. (Photo: Lea D. Schneider)

The fourth method used Buddensiek boxes, sandwich-like constructions which were previously known and tested. With these, the mussels are enclosed in small chambers surrounded by netting. (Photo: Lea D. Schneider)

The fifth method used water-permeable Whitlock-Vibert boxes filled with gravel and containing four tubes measuring 6 by 1.5 centimetres. The tubes are perforated and covered with 200-micron netting. Five juvenile mussels were transferred to each tube before it was placed in the gravel box, which was ten secured to the riverbed with reinforcing iron. (Photo: Valentina Zülsdorff)
Results

WORKING WITH HOST FISH

Electrofishing is generally an effective method, considering the amount of time it takes to catch the desired number of fish to be studied in the laboratory. Electrofishing is more effective in small than in large bodies of water, for example when the task is to catch *S. trutta*, *C. gobio* and *P. phoxinus* in the first year of life.

In general, fish traps were less effective than electrofishing, although the survival rate of fish caught with them was high. Fish traps were least effective for *P. phoxinus*, *G. aculeatus*, *B. barbatula* and *E. lucius*. But they were comparatively effective for catching *A. alburnus*, *R. rutilus*, *P. fluviatilis*, *B. bjoerkna*, *T. tinca* and *S. erythrophthalmus*. The survival rate of fish in the cages placed in rivers over night was nearly 100%. It must therefore be regarded as a good method for keeping fish during longer periods.

The fish were tolerant of infection by mussel larvae and no fish died during the research process.Nearly every fish species studied could be kept in the two types of aquarium used in the laboratory. The smaller aquariums (40 litres) were less suitable than the larger (80 litres) for *A. alburnus*, *S. trutta*, *R. rutilus* and *B. bjoerkna*—probably because those species require larger volumes of water and more space to thrive. Certain fish species were more prone to injury and illness when the space available to them was too small.

*Phoxinus phoxinus* could be cultivated in relatively high densities, but their aquariums had to be covered in order to prevent them from leaping out. *Cottus gobio* fish tended to have an aggregated distribution in still-water aquariums and sometimes developed fungal infections. In running water aquariums, however, they did not aggregate and did not develop fungal infections. They could therefore be kept in greater densities in such aquariums.

*Alburnus alburnus* fish were very active and swam around a great deal in both types of aquarium, which sometimes resulted in skin injuries. Their survival rate increased when their water was changed more than twice a week and they were treated with salt baths.

*Rutilus rutilus* and *B. bjoerkna* were sometimes infected with fungi and with a skin parasite that causes white spot disease.

Nearly all fish species ate Chironomidae. The exceptions were *C. gobio*, *P. fluviatilis* and *G. cernuus* which preferred *Gammarsus* sp., and *E. lucius* which preferred fish. (See Table 5a-b.)

**Attaching transponders and bee tags to *Unio crassus* mussels**

Mature mussels collected from the Bråån and Tommarpsån rivers were equipped with transponders (PIT-tags) and bee tags before reintroduction to the Fyleån and Klingavålsån Rivers. The transponders were the smallest available (12 mm) and were cemented to the mussels’ dried upper valves near the umbo with super glue (“Precision” from Locite). It is important to avoid any trace of glue on the top of the transponder, as that would result in a rough surface on which algae could grow; it would also create a risk of signal interference.

After cementing, marine epoxy (brand name Plastic Padding) was used to smooth the edges of the transponder and strengthen its attachment to the mussel shell. The transponder’s serial number was then noted, along with other information about each mussel—shell length, height, width and weight. Round bee tags, whose serial numbers are laser printed on waterproof paper, were attached to the shells with super glue, only.

Thus equipped, the mature mussels were kept in aerated plastic containers with enough water to reach up to the mussel siphons until the super glue had dried. The marine epoxy dries only partially at this stage of the process. But since it dries even when submerged in water, the mussels could be transferred to aerated plastic aquariums and kept there over night before transport to their respective riverbed sites.
### Table 5a.

<table>
<thead>
<tr>
<th>Fisk species</th>
<th>Fishing method</th>
<th>Method effectiveness</th>
<th>Survival – cages</th>
<th>Survival – transport</th>
<th>Food intake &amp; type</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. phoxinus</em></td>
<td>minnow cage, fish traps, electrofishing</td>
<td>1, 1, 4</td>
<td>5</td>
<td>5</td>
<td>5. Chironomidae. Swims around and eats.</td>
</tr>
<tr>
<td><em>C. gobio</em></td>
<td>fish traps, electrofishing</td>
<td>1, 3</td>
<td>5</td>
<td>5</td>
<td>3. Gammarus. Takes long time to find food.</td>
</tr>
<tr>
<td><em>A. alburnus</em></td>
<td>fish traps, electrofishing, river net, fly fishing</td>
<td>3, 4, 4, 5</td>
<td>3</td>
<td>3, 4</td>
<td>5. Chironomidae</td>
</tr>
<tr>
<td><em>G. aculeatus</em></td>
<td>fish traps, electrofishing</td>
<td>1, 4</td>
<td></td>
<td></td>
<td>4. Chironomidae</td>
</tr>
<tr>
<td><em>L. lota</em></td>
<td>fish traps, electrofishing</td>
<td>3, 3</td>
<td>5</td>
<td>5</td>
<td>3. Chironomidae</td>
</tr>
<tr>
<td><em>S. trutta</em></td>
<td>fish traps, electrofishing</td>
<td>1, 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>R. rutilus</em></td>
<td>fish traps, electrofishing</td>
<td>3, 4</td>
<td>4</td>
<td>4</td>
<td>5. Chironomidae</td>
</tr>
<tr>
<td><em>P. fluviatilis</em></td>
<td>mjärde, electrofishing</td>
<td>3, 4</td>
<td>4</td>
<td>5</td>
<td>5. Gammarus sp.</td>
</tr>
<tr>
<td><em>G. cernuus</em></td>
<td>fish traps, electrofishing, river net</td>
<td>2, 3, 4</td>
<td>5</td>
<td>5</td>
<td>5. Gammarus sp.</td>
</tr>
<tr>
<td><em>B. bjoerkna</em></td>
<td>fish traps, electrofishing, river net</td>
<td>3, 3–4, 4</td>
<td>4</td>
<td>4</td>
<td>5. Chironomidae</td>
</tr>
<tr>
<td><em>E. lucius</em></td>
<td>fish traps, electrofishing</td>
<td>1, 4</td>
<td></td>
<td>5</td>
<td>3. Fish</td>
</tr>
<tr>
<td><em>T. tinca</em></td>
<td>fish traps, electrofishing</td>
<td>3, 4</td>
<td>5</td>
<td>5</td>
<td>5. Chironomidae</td>
</tr>
<tr>
<td><em>V. vimba</em></td>
<td>fish traps</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>L. planeri</em></td>
<td>fish traps, electrofishing</td>
<td>1, 3</td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td><em>S. erythrophthalmus</em></td>
<td>fish traps, electrofishing</td>
<td>3, 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>B. barbatula</em></td>
<td>fish traps, electrofishing</td>
<td>1, 3</td>
<td></td>
<td>5</td>
<td>3. Chironomidae</td>
</tr>
</tbody>
</table>

### Table 5b.

<table>
<thead>
<tr>
<th>Fisk species</th>
<th>Glass aquarium</th>
<th>Small hatching tank</th>
<th>Large hatching tank</th>
<th>Suitability as host</th>
<th>Escape potential</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. phoxinus</em></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>Can be cultivated in higher densities than <em>C. gobio</em> and may be a better host fish. Can leap out of aquariums.</td>
</tr>
<tr>
<td><em>C. gobio</em></td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4-5</td>
<td>5</td>
<td>Aggregate when in glass aquariums and are prone to fungal infections due to slow water circulation. Produces mucus. Water changed once per week.</td>
</tr>
<tr>
<td><em>A. alburnus</em></td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2-3</td>
<td>3</td>
<td>May need salt treatment, as skin is easily injured. Should be kept in low densities, with adequate swimming space and water changed 2-3 times per week.</td>
</tr>
<tr>
<td><em>G. aculeatus</em></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>Few individuals in the field and difficult to catch. Can avoid electrofishing.</td>
</tr>
<tr>
<td><em>L. lota</em></td>
<td>3</td>
<td>5</td>
<td></td>
<td>5</td>
<td></td>
<td>Can easily escape cages in the field. Probably important in some locations due to high densities.</td>
</tr>
<tr>
<td><em>S. trutta</em></td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td><em>R. rutilus</em></td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>Sometimes develops fungal infections and white spot disease.</td>
</tr>
<tr>
<td>Abborre, <em>P. fluviatilis</em></td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td><em>G. cernuus</em></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td><em>A. bjoerkna</em></td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>Sometimes develops fungal infections and white spot disease.</td>
</tr>
<tr>
<td><em>E. lucius</em></td>
<td>5</td>
<td></td>
<td></td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td><em>T. tinca</em></td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>V. vimba</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>L. planeri</em></td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 5a: Evaluation of: fishing method effectiveness; survival rate; food intake & type; tolerance for being held in aquariums & hatching tanks; suitability as host fish; escape potential. Evaluation scale: 1 = lowest level of effectiveness, survival rate, etc. 5 = highest level.
PARASITIC STAGE AND DETACHMENT OF JUVENILES

In the pilot test, it turned out that C. gobio, G. aculeatus, P. phoxinus and S. trutta from the Fyleån River were infected with U. crassus mussel larvae. The decrease of infection between three and twenty days after the start of the experiment was greatest among S. trutta, followed by C. gobio and G. aculeatus. For some unknown reason, there was an increase among P. phoxinus. The results for C. gobio and G. aculeatus were similar to those among fish from the Klingavälšån River.

Barbatula barbatula and R. rutilus from the Fyleån were not infected with mussel larvae. In the samples taken three days after the start of the pilot test, B. bjoerkna and E. lucius were both infected, but not in the samples taken after 20 days. No individuals of A. alburnus or P. pungitius were still alive after 20 days, but both species were infected with mussel larvae after three days.

In the common garden experiment, the number of juveniles that detached from their host fish varied with different combinations of U. crassus populations and fish populations/species. For P. phoxinus fish, the number of juvenile mussels that detached themselves was highest with one sympatric fish-mussel combination, but not with other such combinations. For C. gobio fish, the number of detached juveniles was highest among the allopatric fish-mussel combination (i.e. with fish from outside the mussels’ aquatic habitat). The juvenile mussels from this combination also had the highest growth rate after detaching from their host fish.

It appears that none of the infested mussel larvae died during the period from three to twenty days after the start of the pilot test. The larger the host fish, the greater the number of infested larvae.

Juvenile mussels in the common garden experiment began to detach from their host fish 15 days after the fish were infected. Most detached after 17 – 18 days and 26 – 27 days; the last remaining larvae detached after 30 – 31 days. A total of 2412 juveniles detached from C. gobio and P. phoxinus, which corresponded to 12% of the larvae used to infect the fish.

In the experiments conducted in laboratory aquariums, juvenile mussels were observed to detach from five fish species. The highest rate of detachment was from P. phoxinus, C. gobio and G. aculeatus. Low rates were observed for A. alburnus and P. fluviatilis. Also, juvenile mussels detached from R. rutilus and L. lota which had been naturally infected in rivers (see “Host fish survey” on page 74). Both S. trutta and B. barbatula were found to be infected with mussel larvae 20 days after the start of the pilot test, but no juveniles subsequently detached from those species. (See Table 2.)

The number of detached juvenile mussels varied widely between the various experiments. For example, the detachment rate from C. gobio was 2.2 juvenile mussels per gram weight of fish in one experiment, and 55.6 juveniles per gram in another. The two species which appeared to have the highest detachment rates were C. gobio and P. phoxinus. (See Table 2.)

The juvenile mussels were ca. 200 microns in size when they detached from the gills of their host fish. During the years when mussels were cultivated in the laboratory, juveniles were kept for a maximum of 8 – 10 weeks before they were released into rivers. There was great variation in the survival and growth rates of juvenile mussels cultivated in the laboratory. For example, 14% of juveniles survived for at least ten weeks after detaching from their host fish. During those ten weeks they grew to an average length of 500 microns. The juveniles that grew the most during the parasitic stage also grew the most and had the highest survival rate after detachment. The size of the juvenile mussels released into rivers varied annually from 200 – 500 microns, depending on the length of time they had been kept in the laboratory.

REINTRODUCTION

Among the infected fish kept in cages in rivers, the survival rates were generally high and only a few died during the weeks they were kept there. During the same period, fish that had been infected in the laboratory were released into the rivers. Both methods resulted in thousands of young mussels developing and detaching from the gills of host fish, thereby contributing to reintroduction of U. crassus to the Fyleån and Klingavälšån rivers.

Juvenile U. crassus mussels cultivated in the laboratory were also planted carefully on known mussel sites in the Fyleån and Klingavälšån rivers. Four methods were used to compare survival rates during a period of nearly one year — gravel boxes, perforated bricks, tubes and Buddensiek boxes. It turned out that none of those methods functioned when the juveniles were placed in the river during the winter months. But the use of Whitlock-Vibert boxes, which were tested during the summer of 2016, yielded promising results. Juveniles survived for at least four months in the field with that method. The adult U. crassus mussels that were transplanted to the Fyleån och Klingavälšån rivers survived from the initial summer to the next.
Table 6. Result summary of experiments during 2012-2015: Survival rate, parasitism of host fish and detached juveniles.

<table>
<thead>
<tr>
<th>Fisk species</th>
<th>No. of fish</th>
<th>Survival rate 3 DAI</th>
<th>Larvae/host fish 20 DAI</th>
<th>Larvae/host fish 3 DAI</th>
<th>Larvae/host fish 20 DAI</th>
<th>Detached juveniles (No./gram fish wt.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. alburnus</td>
<td>110</td>
<td>96.7</td>
<td>59.9</td>
<td>-</td>
<td>-</td>
<td>0.71</td>
</tr>
<tr>
<td>B. bjoerkna</td>
<td>26</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>B. barbatula</td>
<td>5</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>0.8</td>
<td>0</td>
</tr>
<tr>
<td>C. gobio</td>
<td>569</td>
<td>98.7</td>
<td>97.4</td>
<td>56.0</td>
<td>6.0</td>
<td>2.2 – 55.6</td>
</tr>
<tr>
<td>G. aculeatus</td>
<td>51</td>
<td>100</td>
<td>96.7</td>
<td>63.1</td>
<td>-</td>
<td>0.3 – 106.5</td>
</tr>
<tr>
<td>G. cernuus</td>
<td>3</td>
<td>100</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>L. lota</td>
<td>22</td>
<td>100</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>L. idus</td>
<td>1</td>
<td>100</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>P. fluviatilis</td>
<td>35</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>-</td>
<td>0 – 0.50</td>
</tr>
<tr>
<td>P. phoxinus</td>
<td>344</td>
<td>95.2</td>
<td>85.4</td>
<td>18.1</td>
<td>15.3</td>
<td>30.9</td>
</tr>
<tr>
<td>R. rutilus</td>
<td>107</td>
<td>94.9</td>
<td>77.5</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>S. trutta</td>
<td>38</td>
<td>65.8</td>
<td>36.3</td>
<td>162.0</td>
<td>1.8</td>
<td>0</td>
</tr>
<tr>
<td>T. tinca</td>
<td>2</td>
<td>100</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*DAI = Days after infection
New knowledge about *Unio crassus* and its host fish — summary

Aquarium experiments on host fish suitability were conducted for 16 fish species. The results indicate that various fish sampling methods can be effective, depending on fish species and the purpose of the research. Electrofishing was the method which most often yielded good results. At some river locations with deep water, however, additional methods were needed. It should be noted that for catching *A. alburnus*, fish traps in combination with river nets were more effective than electrofishing. The overnight survival rate in river nets was low, however. If the fish caught are to be kept alive, the nets need to be emptied often and on a regular basis. The survival rate of fish and mussels during transport from the field to aquariums in laboratories was high, as long as the water was aerated during transport and kept at the same temperature as the river in which the fish were caught.

Research on the reproduction period of *U. crassus* mussels indicates when it is possible to start cultivating them. Experiments with fertilized female mussels can start in mid-April and continue until the beginning of July. Fish can also be collected from mid-April in preparation of their infection with mussel larvae. If the fish are caught before mussel larvae detach from their gills, their suitability as host fish can also be studied before they experience any immune reactions.

Knowledge concerning the length and other aspects of the reproduction season can also be useful when collecting fish to be used in the production of juvenile mussels or for the reintroduction of mussels via infected host fish. Knowledge of the period when host fish can be infected can also be used in studies of glochidia infestation of various fish species.

In addition, knowledge of the *U. crassus* reproduction period indicates when the mussels should not be disturbed during that period, something that is especially important to consider when dealing with small and vulnerable populations. Knowing when host fish can be infected also indicates when they should not be disturbed.

It can be concluded that *C. gobio*, *G. aculeatus*, *P. phoxinus* and *S. trutta* are suitable as host fish in the Klingavälsån River, and that *C. gobio* and *G. aculeatus* are suitable in the Fyleån River.

It can probably be assumed that fish in the pilot study which had mussel larvae on their gills after 20 days are suitable host fish for *U. crassus*. It may therefore be concluded that *C. gobio*, *G. aculeatus*, *P. phoxinus* and *S. trutta* are suitable host fish in the Klingavälsån River, and that *C. gobio* and *G. aculeatus* are suitable in the Fyleån River.

Other studies have found that juvenile mussels did not develop and detach from their host fish before 20 days had passed from the date of infection. However, the experiments conducted during the project found that detachment could occur earlier than 20 days. Thus, the fish that were carrying mussel larvae after three days, but had no larvae after 20 days, were in fact suitable as host fish. It may therefore be concluded that *B. bjöerken*, *A. alburnus*, *E. lucius* and *P. pungitius* can be suitable host fish for *U. crassus* in the Klingavälsån River (see Table 2). That has been confirmed for *B. bjöerken* and *A. alburnus* (see "Host fish survey" on page 74).

The common garden experiment found that the number of *U. crassus* juveniles which detach from their host fish varies between different combinations of mussels and fish species. There was no clear pattern of local adaptation for *P. phoxinus*, because the number of juvenile mussels which detached from that species was highest with only one of the two combinations of sympatric fish and mussels (i.e. involving fish species from the mussels’ aquatic habitat). For *C. gobio*, the number of detached mussels was higher with the allopatric combination (fish species from outside the mussels’ aquatic habitat).
The juvenile mussels resulting from that combination also had the highest growth rate after detaching from their host fish. These results indicate that it would be worthwhile to study the suitability of various species as host fish when restoration and reintroduction are being planned.

Mortality among the mussel larvae that were successfully infested on the gills of host fish was often low. It can therefore be determined how suitable a fish population is for hosting mussel larvae just a few days after being infected.

It is important to test compatibility when mussels are introduced to aquatic habitats that are new to them, because fish from different habitats vary with regard to their suitability as hosts.

The common garden experiment also found that mortality was often low among the mussel larvae that were successfully infested on the gills of host fish. It can therefore be determined, just a few days after being infected, how suitable a fish population is for hosting specific mussel larvae. Also, the larger the host fish, the greater the number of infested mussel larvae. Production of juvenile mussels can therefore be maximized by choosing fish of the “right” size.

These results indicate that it can be important to test compatibility when introducing mussels to new streams and rivers, because fish in different habitats vary with regard to their suitability as hosts. If the aim is to produce a large number of juvenile mussels, for example, tests can be conducted to identify the most compatible fish and mussel species. It can also be useful to measure the growth of mussel larvae from different combinations of fish and mussel populations, because larger mussels may be assumed to have higher survival rates. To minimize the cost of testing suitable host-fish species, studies can be conducted after a few days to determine how well various fish species function as hosts. Finally, if the purpose is to produce as many mussels as possible for reintroduction, large fish should be used.

In summary, the experiments and tests which were conducted found that *P. phoxinus*, *C. gobio* and *G. aculeatus* were generally suitable as host fish for the cultivation of *U. crassus* mussels. *Alburnus alburnus*, *S. trutta* and to some extent *P. fluviatilis* have also been found to be suitable host fish. Potentially suitable species are *B. bjoerkna*, *E. lucius*, *B. barbatula* and *P. pungitius*.

The results of the host fish survey revealed that *G. cernuus*, *R. rutilus* and *L. lota* can be suitable host fish in the field if infection frequency is high. Also, large numbers of juvenile mussels have been found to detach from *L. lota*.

It should also be noted that *G. cernuus* and *L. lota* have been found to be hardy species for cultivation of mussels in aquaria.

HOST FISH SUITABILITY — SUMMARY

*Phoxinus phoxinus* and *C. gobio* and *G. aculeatus* are suitable species for use in cultivating *U. crassus* mussels.

*Alburnus alburnus*, *S. trutta* and to some extent *P. fluviatilis* have also been found to be suitable host fish. Potentially suitable species are *B. bjoerkna*, *E. lucius*, *B. barbatula* and *P. pungitius*.

The results of the host fish survey revealed that *G. cernuus*, *R. rutilus* and *L. lota* can be suitable host fish in the field if infection frequency is high. Also, large numbers of juvenile mussels have been found to detach from *L. lota*.

It should also be noted that *G. cernuus* and *L. lota* have been found to be hardy species for cultivation of mussels in aquaria.
It should be stressed, however, that some genetically distinctive mussel genotypes can be adapted to certain fish species and can cease to exist if those fish species are not used for reproduction or for the reintroduction of mussels. It is therefore recommended that the greatest possible variety of fish species be used.

**Juvenile Mussels — Timing and Survival**

With knowledge of the mussels’ reproduction season and the suitability of fish as hosts, it is possible to predict when juvenile mussels are produced, how many cultivation cycles are carried out, and which fish species are selected as hosts.

The results indicate that juvenile mussels can be collected during a period of two weeks if water temperature is maintained at 16°C. With higher water temperatures during cultivation, mussels begin to detach from their host fish at an earlier stage and the time period for detachment can be shorter. It is therefore advisable to plan the schedule for reintroduction when the time period for detachment is known.

The current cultivation method for *U. crassus* (using Whitlock-Vibert boxes) has functioned satisfactorily both in aquariums and in the field. Preliminary results indicate that aquarium survival rates are as high as reported in similar studies from Central Europe (Eybe & Thielen, 2010).

**Reintroduction**

Infecting host fish artificially has turned out to be a good method for reintroducing mussels to restored rivers. During the “Return of the River Mussel” project, thousands of *U. crassus* juveniles have been reintroduced to the Fyleån and Klingavälsån rivers, where the use of cages with infected fish proved to be an effective method. If the aim is to introduce juvenile mussels at specific locations, this approach seems to be a good alternative.

After the juvenile mussels have detached from their hosts, the fish can be let out of their cages. In all likelihood, freely swimming fish contribute to the establishment of mussel populations by choosing river habitats where mussels also thrive. As a result, host fish are likely to be present when newly established mussel populations reproduce.

Infecting host fish artificially has turned out to be a good method for reintroducing mussels to restored rivers.

It turned out that the adult *U. crassus* mussels that were transplanted to the Fyleån and Klingavälsån rivers survived the winter, indicating a great potential for the successful reintroduction of *U. crassus*.

The fact that it is possible to cultivate juvenile mussels in a laboratory, with a process that includes the most sensitive stages of the mussel life cycle — larval and the earliest juvenile stages, survival and growth in the waters they are placed in — also indicates a potential for the successful reintroduction of *U. crassus*. Further confirmation came with trials conducted in the summer of 2016, when it was found that juvenile mussels kept in Whitlock-Vibert boxes can also survive in the field. However, that method should be tested during the winter until the following summer in order to confirm that the mussels can survive under that length of time.

*Lota lota* (burbot)
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Monitoring and follow-up

Cleaner water and greater biodiversity
The effects of river restoration are being monitored with standardized sampling programmes — for hydromorphology, water chemistry, diatoms, and benthic fauna including mussels — which are designed individually for each project area, based on the problems that were rectified by the project. The monitoring program follows a before-and-after model which makes it possible to quantify the effects of measures implemented, taking into account natural variations such as those caused by lengthy periods of drought. For most of the variables, the number of samples taken (replications) enables statistical analysis.

Monitoring the conservation status of the mussels
The effects of transplanting and reintroducing *Unio crassus* will be monitored in time series over a period of at least ten years. The main variables are population density, size distribution, reproduction, and availability of potential host fish.

Ecosystem services
In addition to monitoring biotic and abiotic variables, changes in ecosystem services are being studied, with the effects of restoring one river (the Fyleån) quantified economically in terms of money. Improved water quality (reduced transport of nutrients), increased fish production, greater biodiversity, and recreation value all yield societal benefits to which monetary values can be applied.

The hypothesis is that, within six years, the monetary value of the societal benefits of restoring the Fyleån River will exceed the cost of the restoration measures taken. It is hoped that the pilot study being conducted in the Fyleån can be made generally applicable and that its methods can be used to monitor other restoration projects.
Long-term follow-up of project outcomes

Sweden's county administrative boards have for many years monitored selections of their streams and rivers on a regular basis, including some of the rivers involved in the UC4LIFE project. Current objectives are to intensify some elements of regional monitoring programmes, and to incorporate some elements of the national programme for large freshwater mussels, focusing on streams and rivers where *Unio crassus* is present. The results will provide the basis for a planned revision of the *U. crassus* restoration programme to be conducted in 2018. (See also Lundberg et al., 2006.)

Postscript on the future

The mussel species *Unio crassus* is listed in annexes II and IV of the European Union's Habitats Directive (EEC 1992). The purpose of the Directive is to protect species and habitats of significant European interest, in accordance with specified criteria.

For example, special conservation areas must be designated for species listed in Annex II, while Annex IV lists species in need of strict protection. EU member states are obligated to report the preservation status of listed species every six years. For *U. crassus*, the reports are based on assessment of the species' general condition and the quality of its habitats.

One of the most important preconditions for an adequate assessment of habitat quality is a thorough understanding of a species' ecological requirements. The specific requirements of many animal species have been well-researched, but *U. crassus* is not one of them. One exception is a recent study which found that *U. crassus* is more tolerant of unfavourable conditions, such as extensive sedimentation, than previously believed (Denic et al., 2014). An abundance of juvenile mussels was observed in a river with a heavy burden of nutrients and fine sediments, and also some substances — nitrates, for example — in concentrations that exceeded levels previously regarded as threshold values (Hochwald, 2001; Zettler & Jueg, 2007; Douda et al., 2012). Another important knowledge gap concerns the hydrological conditions of streams and rivers (Pfeiffer & Nagel, 2010).

Preserving the European species of freshwater mussels is important for the maintenance of ecosystems and the ecosystem services provided by mussels. Unfortunately, the primary focus of Natura 2000 is on terrestrial biodiversity, and there is a belief that the network lacks sufficient resources to include freshwater species in general, and freshwater mussels in particular.

To be effective, conservation plans should function at several levels and concentrate on the identification of distinct populations or significant evolutionary entities which are threatened.
in local environments and in larger areas that are biodiversity "hot spots". Also, water resources should be managed so as to address the needs of affected species.

An evidence-based and well-structured preservation strategy which includes defined goals, and an evaluation of conservation measures combined with well-adapted management, could greatly increase the success of preservation efforts. But such a strategy is seldom applied in Europe (Geist, 2015).

Priorities in the work of preservation should also include socio-economic arguments regarding the value of biodiversity. As one example, experts from all over Europe have recently collaborated on the development of a European survey standard that can function as a guide and facilitate the preservation and management of *Margaritifera margaritifera*. Similar standards for the other 15 species of large freshwater mussel would be highly beneficial. The worsening conditions of European freshwater mussels and the increasing threats to them, together with the goals of Natura 2000 and the European Water Framework Directive, suggest powerful arguments for immediate measures.

**Conclusions**

Freshwater mussels are important components of aquatic ecosystems. Changes in their diversity and population structures are influenced by fragmentation and loss of habitats, over-exploitation, pollution, lack of host fish, introduction of alien species, excessive water withdrawals and climate change.

Those factors can result in mussel population declines, which can have important consequences for ecosystem function and the ecosystem services to humans that mussels provide. Although much is known about the basic ecological requirements of some mussel species — *Margaritifera margaritifera*, for example — there is still little knowledge concerning other European species such as *U. gibbus* and *M. bonellii* in Southern Europe.

Also, there is wide variation in knowledge concerning mussels in the different regions of Europe. Research has been conducted in some Central European countries, but there is almost no available data for countries in Southeast Europe such as Albania, Macedonia and Greece. More studies should therefore be conducted to fill knowledge gaps in order to improve the capacity to apply effective management methods and conservation measures.

As a first step, increased knowledge of limiting factors in the life cycles of all mussel species is essential, as even closely related species may have different habitat requirements. Those factors must be investigated for species, concerning which knowledge of suitable host fish is unclear or unknown, or for which there is little information regarding habitat preferences. There is also a need for more knowledge about the habitat requirements of European species. Preferably, such knowledge would be developed co-operatively via a comprehensive European strategy, instead of the current focus on separate conservation strategies at the national level. Ultimately, that could lead to the setting of priorities between and within mussel species on the European level, which would make the work of preservation more effective (Lopes-Lima *et al.*, 2016).

Despite dramatic population declines and the threat of extinction for several European species of freshwater mussel, there are reasons for optimism. For example, water quality has improved in Europe during recent decades, making it possible for mussels to return to more streams, rivers, lakes and ponds. Media coverage has drawn attention to the preservation needs of mussels, with the result that more people recognize them — an important component in the work of preservation.

In recent decades there has also been a large increase in the number of European scientists conducting studies of freshwater mussels. That has resulted in more knowledge about ecological aspects, and new methods for preserving these species are being developed.

Efforts to preserve both national and European diversity of freshwater mussels on a larger scale would benefit from an European action plan or the development of a strategy to increase collaboration among scientists, nature conservation authorities and, not least, the general public.
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“Return of the Thick-shelled River Mussel” Project
The project was conducted by the Skåne County Administrative Board in co-operation with Karlstad University and the administrative boards of Blekinge, Jönköping, Östergötland and Södermanland counties. The project budget was ca. SEK 50 million, of which half was financed by the EU Commission’s LIFE Programme and the remaining half by Karlstad University, the Swedish Agency for Marine and Water Management and the above-noted county administrative boards.