IDENTIFICATION AND AMELIORATION OF MAN-MADE HAZARDS TO THE SURVIVAL OF THE FRESHWATER PEARL MUSSEL, *MARGARITIFERA MARGARITIFERA* (L.)

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The importance of the river catchment area, and of different river habitats and their functions, to reproducing freshwater pearl mussel population has only been recognised recently. Based on this understanding, it has become possible to assess the degree of naturalness of rivers and the extent of change that has occurred within them. The results have also helped understanding of the hazards to *Margaritifera* populations from human activities in river ecosystems and how they function. Hazards include dams for energy production, various forestry and agricultural activities like land clearance and ditching and modifications to river channels for the fishing industry. These phenomena have a direct or an indirect effect on the naturalness of the river and the living conditions of the freshwater pearl mussel.

In Finland, surveys carried out by the Margaritifera working group from 1978 onwards have covered 3500 kilometres of river channel and established that freshwater pearl mussels are present in 70 rivers, with a total population of some 3 million mussels. Only 18 of these rivers are protected as part of the EU Natura-2000 network. Impetus to the activities of the Margaritifera working group was provided by the 1997-2002 EU Life-Nature project "The restoration of fluvial ecosystems containing pearl mussels", which resulted in considerable quantities of new information leading to innovative conclusions on the requirements of *Margaritifera* and on how rivers can be restored to sustain *Margaritifera* populations, both by identifying and eliminating hazards and by proactive management of the river channel and catchment basin. It is pointed out that any river restoration measure has to be carried out within an integrated management plan for the river in its totality, not in isolation. An integrated management regime should have the objective of re-establishing natural relationships between the various river habitats, so that a natural water-flow energetic continuum returns: rapids restored to rapids, stream-flow sections to streams, still water to still water. Natural erosion, drifting, sorting and accumulation all require re-instatement as long-term components of the river's flow. Natural conditions cannot be re-established in the presence of bottom dams that subdivide rapids into a series of short rapids separated by pools. Bottom dams destroy the fluvial bottom fauna and flora and, where there is need to raise the water level in some section of a river's length this should not be achieved using bottom dams, but by construction of partial barriers formed of groups of stones, through which the water can pass freely.

Key words: catchment area, continuum, Finland, fluvial habitats, freshwater pearl mussel, indicator species, hazards and risk assessment, river ecosystem, river habitat.

INTRODUCTION

Historical data show that the large freshwater pearl mussel, *Margaritifera margaritifera* (L.) was once frequent in many of Europe's rivers. That is not the situation today (Bauer, 1986; Woodward, 1996; Valovirta, 1998b; Araujo & Ramos, 2000; Larsen, 2005; Oulasvirta et al., 2006). Various of the human uses to which rivers and their catchments are subject have impacted adversely upon the mussel's developmental stages, the fish which host one of those developmental stages, the adult mussel and the mussel's habitats in the river channel. These adverse influences cannot be combated without understanding the mussel's life history and habitat requirements and knowing how man's activities are impacting. Once that is achieved it is necessary to design, test and then carry out practical remedial measures and to establish a legal framework that provides adequate control of human activities in rivers (and their catchments) selected for conservation of the species.

The main features of the freshwater pearl mussel's life history are now known. Freshwater pearl mussels are mainly unisexual (Bauer, 1987; Hansten et al., 1997). The male releases sperm into the water during the summer. With water taken in for respiratory purposes, the sperm reaches the gills of female mussels down-stream. The female mussel subsequently releases developed glochidial larvae into the water, where they attach to the gills of brown trout (or salmon). The life span of the glochidia depends strongly on water quality. In southern and central

Finland water quality frequently poses a risk to glochidial survival. During the reproductive period, the synchrony between mussel and trout should work in such a way that the fish host and the small glochidia meet. The glochidia then remain in the fish gills throughout the winter. The following spring the young freshwater pearl mussels become detached from the fish gills and let themselves drop to the river bottom (Larsen? 1999, 2002). If the trout happens to be swimming over a gravel bottom suitable for the mussel, the small mussels dig themselves into the porous and oxygen-rich bottom deposits and remain there three to six years (cf. Degerman et al., 2009) (Fig. 1). But, if the mussels drop on a solid mud bottom that doesn't allow pore flow, they will not survive. The risk to the survival of these young mussels is also increased if channel modification measures are being carried out in the same river section. The increase sediment deposition on the riverbed is often the most serious negative factor for young mussels (Hendelberg, 1960; Goudie, 1993; Geist, 2005; Österling, 2006; Stayer, 2008; Söderberg et al., 2008a, 2008b). Chance plays a very big role in the life cycle of freshwater pearl mussels, even in waters that are in a natural state. More than 99.99 % die before they reach the age of 5 years. If the burden of particulate matter being carried by the river doesn't suffocate the young mussels dug into its bed, or dirty water kills them, they will move up to the surface of the bottom deposits in about five years. At that point they will still require to grow for 12 – 15 years before reaching sexual maturity.

Fig. 1. Gravel and sand areas at the end of rapids and fast flowing rivers are places for young mussels

The freshwater pearl mussel grows very slowly compared to other large mussels (Bauer, 1992). It can live longer than any other invertebrate in the Finnish fauna, reaching over 170 years (Helama et al., 2007; Helama & Valovirta, 2007; Helama & Valovirta, 2008a; Helama & Valovirta, 2008b; Degerman et al., 2009) of age. As the water flows through the gills of the mussel, it separates organic particles for food and removes non-organic particles back to the river bottom. When abundant, a freshwater pearl mussel population is a significant water cleaner and simultaneously improves the environment of young salmonids (Ziuganov et al., 1994).

The freshwater pearl mussel is adapted both morphologically and physiologically to natural fluctuations in water volume and quality. The thick calciferous shell well endures mechanical stress. The thick shell also protects the animal from desiccation. In a location sheltered from the sun a mussel in a good condition can survive through seasons of low water, even if there is so little water that only the bottom gravel stays wet. A freshwater mussel population that has dug its way into the bottom of the river reflects a disturbance free state in the population. Dug into the river bed, they need to react with the environment only to the extent necessary to obtain oxygen and food.

Because of the random nature of the freshwater pearl mussel's life cycle, a population of 500 mussels present in a section of river channel 500 m long, providing appropriate habitat throughout, is taken as a naturally viable population and therefore very important in the protection of the species (Valovirta, 1995b). The smaller the population, the greater the risk that it will die out. If the mussels are scattered along the whole length of a river, the mussel has better possibilities of surviving than if the population is confined to a particular segment of the river's length. A reproducing freshwater pearl mussel population reacts many times more strongly to changes in the river environment than do trout populations and so is an excellent indicator of a natural state river (Valovirta et al., 2003). A reproducing freshwater pearl mussel population indicates that the river is in a natural, dynamic state in respect of the river bed, the water flow regime (bottom and surface water current, catchment area) and the intermediate fish host (trout). It also indicates that the position of dependence that has lasted for hundreds or thousands of years, between the mussel and its fish host still functions (Table 1). By contrast, a non-reproducing freshwater pearl mussel population is indicative of changes in the naturalness of the river, subjecting the mussel to various kinds of hazard, and of inadequacies in the level of protection provided for the affected sites. Very small changes in the bottom layer (stones, sand), removal of natural obstructions like rapids, increase of water temperature (synchrony with fish and glochidia) may form a serious risk to the early life stages of *Margaritifera* (Valovirta et al., 2003). The early stages of the life cycle of this mussel have been disrupted in many rivers of southern and central Finland and the remaining populations of freshwater pearl mussel are slowly dying (Fig. 2). The only population still successfully reproducing is in the river Ruonanjoki, near the town of Tampere.

Table 1. Requirements of the freshwater pearl mussel at different stages of its life cycle

- An evolved synchrony between reproduction (glochidia stage) and a population of the intermediate fish host (trout), genetically adapted to the river
- Neutral, oxygen rich and cool (spring/ground) water
- Biologically old, but perennially regenerating river bottom, created by the dynamic state natural to river habitats (young mussels dug into the bottom)
- Water flow regime typical for river habitats, especially bottom flow
- Biological and energetic flow continuum in the river
- An adult pearl mussel population dense enough to reproduce

Until the 1960s log-floating was a significant component of forestry practices in Finland. The channels suitable for log floating include 40,000 km of Finnish water courses and these rivers were essentially canalised to facilitate log-floating, by altering the cross-section of their channels, straightening meanders and using embankments to isolate shallow bays from the main channel (Valovirta & Yrjänä, 1996).

Such modification of river channels have caused loss of natural-state fluvial ecosystems in Finland and associated reductions in freshwater pearl mussel populations, or, in many places, their total destruction. The remaining natural or semi-natural rivers are extremely important to fluvial organisms, like Margaritifera. Indeed, the habitat and life history requirements of the mussel make a breeding population of the species an indicator of a natural river in peak condition.

Frequently, extensive projects has been implemented to restore modified river-sections to their natural state. But restoration projects can be carried out without an adequate knowledge of how they can affect aquatic organisms – poorly implemented restoration can cause irreparable damage to endangered species (Table 2). The necessary information is all-too-often only available to specialists not involved in these river restoration works.

In Finland, the freshwater pearl mussel became protected by law in 1955, and was categorised as a nationally endangered species. Collecting mussels and empty mussel shells is prohibited, as is damaging the mussel's environment. A natural resource value (confiscation value) has been determined to protected animals and plants in Finland. The value of a freshwater pearl mussel is set at 589 € (Väisänen, 1996; Valovirta, 1998a). The wildlife resource value of a river containing approximately 50,000 mussels (the averaged population size/river) is thus about 30 million €, making this endangered large mussel a considerable part of the total natural resource value of the river. WWF-Finland chose *Margaritifera margaritifera* as a species for special protection in 1978 and the "Margaritifera group" was established to support this work. The aim of the group was to do research on the Finnish pearl mussel populations and their environments and to improve protection of the species.

Fig. 2. Only some tens of elderly *Margaritifera* specimens remain in the river Pohjanjoki in SW-Finland

Table 2. The degree of understanding of the situation in Finnish rivers provides certain insights that require to be taken into account in developing a strategy for *Margaritifera* conservation:

- A breeding population of *M. margaritifera* can be considered as a top indicator of natural or semi-natural river status.
- If we have such a natural *Margaritifera* river, restoration work on the natural parts of the river, or drainage basin, can only be expected to disturb the life cycle of *Margaritifera*.
- Restoration of the catchment or channel of a semi-natural section of a *Margaritifera* river is possible if the risks are not too great for the *Margaritifera* population (e.g. changes in flow dynamics, in water quality or quantity).
- All or part of a river channel may be in a natural condition even if no *Margaritifera* population is present. Such rivers, or river sections, are also potentially of international significance for habitat protection.

The Habitats Directive (92/43/EEC) has the objective of ensuring the conservation of internationally important areas of natural habitats and populations of wild fauna and flora, throughout the EU (Rassi et al., 1992). Maintenance of the favourable status of natural habitats and wild fauna and flora based on scientific research, ensuring high biodiversity, and elimination of risk to Natura-2000 network sites are very prominent in the Directive. *Margaritifera margaritifera* is listed in Annex II of the Habitats Directive, which means that its habitat must be protected. Essentially, this means that Natura-2000 sites require to be established to protect populations of this mussel. The designation of a Finnish river as a site in the Natura-2000 network is mostly based on the occurrence of the freshwater pearl mussel in it.

Once the Habitats Directive was in place, the activities of the Finnish "*Margaritifera* group" expanded, under the EU Life-Nature project «The restoration of fluvial ecosystems containing pearl mussels» (Valovirta et al., 2003). By the end of that project divers of the Margaritifera group had carried out *Margaritifera* surveys all over Finland and in some rivers in Norway, Estonia, Latvia and in Russian Karelia (Valovirta, 1995b). Further during the project very comprehensive data were obtained on three Finnish river catchments, their rivers and their pearl mussel populations. One of the best rivers for large mussels in Finland is the river Mustionjoki in SW-

Finland (Fig. 3). There live all the seven mussel species occurring in Finland, including the three lake mussel species duck mussel (*Anodonta anatina*), swan mussel (*A. cygnea*), compressed river mussel (*Pseudanodonta complanata*); three river mussel species, thick shelled river mussel (*Unio crassus*), painter's mussel (*U. pictorum*), swollen river mussel (*U. tumidus*) and finally the freshwater pearl mussel (*Margaritifera margaritifera*) (Valovirta, 2005). It is doubtful that there are many cases in the EU, of a river that flows through a city, yet supports these seven mussel species in such quantities. In the rivers of northern Finland *M. margaritifera* is more common and it is often the only species of large mussel present, making inventory much more rapid and more easily carried out (Valovirta, 1980, 1984, 1997, 2006; Valovirta & Huttunen, 1997).

Fig. 3. All the seven large mussel species found in Finland live in the River Mustionjoki

Most of the rivers in Finland belong to the natural habitat category "small rivers and brooks". We now know that out of approximately 200 Finnish rivers containing populations of freshwater pearl mussels at the beginning of the 20th century, the mussel remains in less than 70 today. It is found in only eight rivers in the south and central Finland (south from town of Oulu 65 °N) (Valovirta, 2006). Moreover, it is currently able to reproduce in only one of these rivers, the Ruonanjoki in south-western Finland. The Ruonanjoki population was one of the most comprehensively researched *Margaritifera* populations during the Life-Nature project. However, the fact that mussel populations in other rivers are not breeding successfully at present does not significantly reduce their conservation value, because the mussel's longevity means that a population can restart reproducing even after a gap of 50 years, if conditions again become favourable. The population of freshwater pearl mussels in Finland is estimated to be about 3 million. Only 18 of the 70 Finnish *Margaritifera* rivers belong to the Natura-2000 network, suggesting quite strongly that a favourable conservation status for the species is not yet secured.

The Life-Nature inventory of freshwater pearl mussel populations in Finland has been comprehensive and to the highest level of accuracy attained in Europe (see Fig. 5). It has given a lot of new information about the optimum environment for *Margaritifera*. Moreover, in recognising the importance of the right water flow and the natural continuity of different river habitats, it provided new and significant data for the restoration of small rivers for freshwater pearl mussel, as well as for salmon and brown trout. It also gave answers to the question of why restoration work for salmon and *Margaritifera* rivers has so often failed (Valovirta, 2003).

The information in this article on risk assessment, protection measures and conservation perspectives is based on three main sources: the research and inventory results of the Finnish *Margaritifera* group in 70 rivers, between 1978 and now; The Life-Nature project "Restoration of Fluvial Ecosystems Containing Pearl Mussels" 1997–2002, and recent Finnish conservation innovations in river ecosystem management.

DATA REQUIRED TO ASSESS RISK TO *MARGARITIFERA* POPULATIONS AND IDENTIFY APPROPRIATE REMEDIAL MEASURES

One of the first requirements of any *Margaritifera* restoration project is to know the distribution and status of the mussel populations in the targeted stretch of river. There is also need for a lot of information concerning e.g. water quality, water flow, topography of the river, and the history of the river, its bottom fauna, its fish populations and pollution status. In restoration projects carried out by the Finnish *Margaritifera* group data on some 32 different variables are recorded, from every 100 metres of channel. Once these data are available it becomes possible to identify potential hazards to the sustainability of both the habitat type and freshwater pearl mussel populations.

Survey of freshwater pearl mussel populations

Underwater surveying is nowadays the main method for mapping Finnish rivers containing large mussels (Fig. 4). The number of individual mussels is estimated by using a cross line method, but also alongside methods with often three scuba divers swimming side-by-side at the same time, or zig-zag line track methods. The divers make an inventory of mussels observed on a 0.5–1 metre wide transect and simultaneously estimate the area of the river bottom suitable for the species.

When the density of mussels increases, the line transect method is replaced by a study carried out square metre by square metre. In northern Finland it is very rarely necessary to remove mussels from the bottom layer for identification. However, in southern Finland the underwater visibility can be so bad that it is necessary to collect all of the individuals found and, after determination, return them to the river bed. Survey locations are determined by GPS equipment and the diving areas are photographed. In all, about 25 divers have taken part in the large mussel inventories in Finnish rivers since 1978. Altogether, the *Margaritifera* group carried out over 3500 kilometres of one metre wide river-bed transects in surveying *Margaritifera* populations. The aim of survey and subsequent results analysis was to minimise risk to the riverine environment and organisms and to identify required protection and restoration measures.

Fig. 4. Underwater surveying is the main method for mapping the Finnish rivers containing large mussels

The Life-Nature project (1997–2002) obtained comprehensive survey data for three Finnish rivers, two small rivers in southern Finland and a much larger river in northern Finland. In one of the southern rivers, the Ruonanjoki, the freshwater pearl mussel can still breed, but not in the other, the nearby Pinsiö-Matalusjoki. Both rivers are 6-8 m wide and about 10 km long. Both of the southern rivers have been inventorised (SCUBA diving) very carefully by survey of 5x5 m quadrats (Fig. 5). In the river Pinsiö-Matalusjoki about 19000 mussels were recorded and in the river Ruonanjoki 26000 mussels. The confiscation value (natural resource value) of these two populations is all together about 2.5 million ECU. The northern river, the Korvuanjoki, is 10-30 m wide and c. 30 km long. In this river (an old pearl fishing river) half a million living specimens of pearl mussel were expected, but only 500 were found, which is only one thousandth (=1/1000). The apparent cause of this catastrophic population collapse was a thick layer of loose sand on the river bed. Reasons for the presence of the large amount of sand are numerous, but the ditching of wet forest is one of the worse (Valovirta et al., 2003).

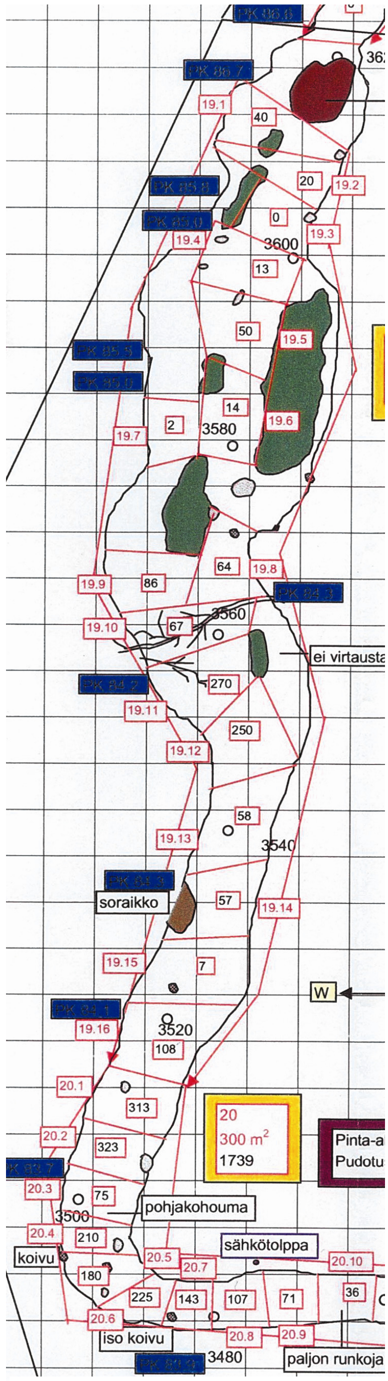


Fig. 5. Small scale mesohabitat inventory in the river Ruonajoki. The river basin (10 km) is divided into squares about 5 m long. The number of *Margaritifera* specimens is in squares (red) in the middle of the river channel (40, 20, 0, 13, 50….). Flow direction is downwards in the map

Water quality and flow

From 1997 onwards an extensive network of water quality sampling stations was established on watercourses, especially in the areas of southern small rivers. Because the water quality and water volume are dependent on the environment of the river, we also investigated restoration management of the river catchment. Continuous measurements of water flow, especially the surge flows of spring and autumn, are appropriate for monitoring of extreme habitat. The importance of water volume, especially cool ground water, for the breeding of *Margaritifera* and its fish host, the brown trout, is considerable in southern Finland. Active water quality parameters identified as being significant were recognised by comparison between sites with and without breeding mussel populations/without any mussels. To monitor water quality, or suspended solids content, during the Life-Nature project, we used not only standard water analysis, but also the water moss (*Fontinalis dalecarlica*) method. Water moss assay works as a continuous indicator method for checking the concentrations of inorganic material and toxic metals, in exactly the same surface layer level of the river bottom deposits that the freshwater pearl mussels inhabit. Therefore it is about 50 % more effective in demonstrating meaningful water quality levels.

Genetics of host-fish populations

There are differences between the brown trout populations of different rivers in the degree of success with which they may be used to host mussel glochidia (Buddensiek, 1995; Myllynen et al., 2000; Altmüller & Dettmer, 2006; Larsen, 2009). But, in a *Margaritifera* river where the brown trout population has at some time diminished, the river may have been restocked using trout from other rivers. So we found it necessary to carry out genetic tests to identify the original and introduced trout populations of the *Margaritifera* rivers. The risk to *Margaritifera* populations increases if the right age classes and host fish of a suitable origin are not available to the mussel.

Translocation of mussels and artificial breeding

As a last conservation method we have translocated freshwater pearl mussels from river sections that are undergoing restoration. To do this we have adapted a method used for transporting salmon fry (Valovirta, 1987). The level of success we achieved in translocating mussels from one part of a river to another location in the same river has been over 95 %, as assessed by checking survival of the translocated population 10 years after transferral, but only 50 % at maximum (0–50 %) in translocating specimens from one river to another river. The risk is particularly high in translocation of specimens to another river (Kleiven & Dolmen, 2008).

Table 3. Summary list of data-gathering and processing activities necessary to identify threats and provide a basis for designing practical measures to achieve the favourable conservation status of large mussels:

- General survey/inventory of the river ecosystem, which includes e.g. local history, local research data and general surveys of the river channel and its catchment area.
- Surveys in the river channel, of its flora and fauna, including endangered species, their distribution and status, river habitats and their state.
- Surveys within the catchment area and along the river banks, e.g. the state of naturalness and the effects of human activities.
- Analysis of the results from the surveys, to identify hazards and evaluate the risk to *Margaritifera* populations – what drawbacks/disadvantages and threats exist to the favourable conservation status of the freshwater pearl mussel in the targeted river.
- Production of an action plan on protecting and restoring the river ecosystem, with which it is possible to achieve the favourable conservation status required for the habitat types and species represented.

The most critical period in the life cycle of *Margaritifera* is one or two weeks in the late summer or early autumn, when the mother mussel releases larvae into the river water to hosts (salmon or brown trout). During this period good water quality is extremely important for the life cycle of *Margaritifera*. Artificial breeding, either in laboratory or field conditions, has also been used to maximise the opportunities for glochidia of *Margaritifera* to find the host fish. We found that the glochidia are not so sensitive to water quality once they are encysted in the gills of their fish hosts. However, there are many practical difficulties to overcome before artificial breeding can be used as an effective conservation method for *Margaritifera* (Table 3).

IDENTIFIED HAZARDS TO MARGARITIFERA POPULATIONS

A key element of the Habitats Directive, defined in article 6(2), is the principle of prevention of damage to habitats and species recognised as requiring protection at the international level. Under the Habitats Directive it is thus not acceptable to wait until damage or disturbance has occurred, before taking action. Member states are presumed to take all steps they reasonably can that would prevent the occurrence of significant damage or disturbance. Therefore it is important to identify hazards to *Margaritifera* before they cause damage or disturbance. Many human activities carried out in rivers and in their drainage basins change the natural state of rivers and brooks. The costs and benefits of these activities require to be established and the activities themselves controlled by authorities. Such activities include (Table 4):

Table 4. Human activities potentially hazardous to *Margaritifera*

- damming
- dredging
- clearing
- water abstraction

- waste water discharges
- ditching in forests, on bogs and in meadows
- cutting of trees along the river bank, in the riparian zone
- fish farming
- leisure activities

Such hazards impact on *Margaritifera* populations by causing:

- deterioration in or blocking of the bio-energetic continuum of water flow
- disappearance of fluvial habitats (change in the type of habitat represented)
- extensive oscillations in water flow volume, e.g. increasing occurrence of extensive floods and total freezing of the water column
- increase in the particulate matter content of the water
- increased sedimentation
- increased acidity of water
- eutrophication of water
- increased concentration of chemicals toxic to organisms in the river water and bottom deposits.

As a further consequence of the above-mentioned adverse effects, populations of the trout, that serves as host for the glochidial larvae of the freshwater pearl mussel, also regress or vanish.

Changes in the catchment water run-off regime

The drainage basin of the fluvial ecosystem, the river itself and its different habitats each have their own, characteristic capacity to delay water run-off (Valovirta et al., 2003). The magnitude of this delay is manifested in the time taken by water to pass through, e.g. a certain habitat type, or the water retention time of the drainage basin. The dynamic state, water flow conditions and water quality of the river channel combine to create a characteristic environment to which a range of animal and plant species have adapted – they have adapted to the *natural* variations in river conditions. Under these circumstances the species can survive, even though during periods of low water level some of the fluvial habitats (e.g. the rapids) almost cease to function. The surface and bottom-water currents characteristic of a river channel are vital to many organisms living in flowing water. In particular, the bottom-water current is important to, for instance, the juvenile stage of freshwater pearl mussels and the spawn of the trout, both of which develop in the interstices of the bottom sediments. All of these attributes of a natural river can be impacted by increases in water run-off rates in a catchment, and many of man's activities within a drainage basin can increase rates of run-off (Table 5).

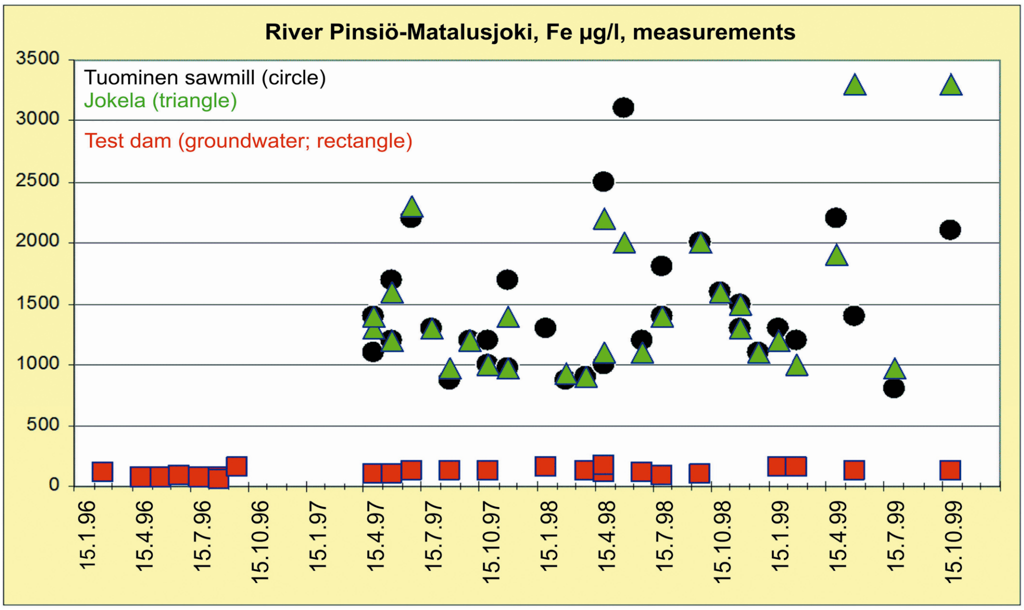
Table 5. The fauna and flora of different fluvial habitats are affected by decreasing water retention time via:

- rate of water-flow (surface and bottom currents)
- water temperature (temperature stratification)
- increased nutrient content of the water (serious for young mussels)
- increases in suspended solid content of the water column
- changes in water chemistry (e.g. pH)
- lowering of water oxygen concentration (especially during the low-water levels of summer)
- regulation of water volume (flood terrace)
- changes in species composition (caused e.g. by increases in strength of water currents)

Increased run-off rate thus represents a significant hazard to *Margaritifera* populations.

Changes in water quality

There are minimum and maximum values of water quality parameters between which the growth of the freshwater pearl mussel is possible (Valovirta, 1995a; Moorkens et al., 2000). For pH of the water these values are in northern Finland between 6 and 7.5, for electric conductivity between 2 and 10, and the maximum content of suspended solids ought to be less than 25 mg/l. The water quality requirements of adult mussels and glochidia proved to be different. The glochidia are sensitive to the concentration of iron in the water. If this is over 1.5 mg/l during the escape of glochidia in autumn the survival time of the glochidia, in which to find a host fish, is very short (Fig. 6). Often there are many substances in water which make survival impossible for *Margaritifera*.



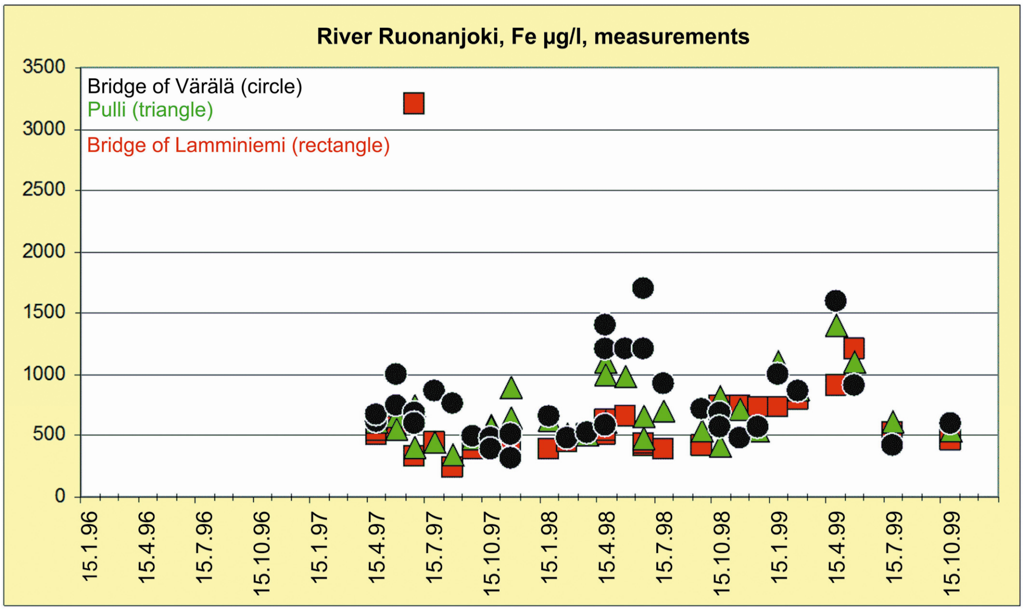


Fig. 6. Critical level of Fe content for *Margaritifera* is 1500 (µg/l). In the river Ruonanjoki the species can breed (above), but not in the river Pinsiö-Matalusjoki (below) (4.1997–10.1999). Red squares are from ground water area. (Life Nature project. Valovirta et al., 2003)

Catchment management operations hazardous to *Margaritifera*

Changes in the character and quality of a river and its habitats can be caused by a wide range of human activities within the river drainage basin and various of these activities can occur together (Bauer, 1988; Valovirta, 1990; Young, 1991). It would be difficult to produce a comprehensive list of the management operations involved, but any listing of them would include those in Table 6. Natural-state rivers and brooks in Finland have decreased notably in number due to human activities. But there may still remain sections of channel in a condition worthy of protection or restoration.

Table 6. Management operations hazardous to *Margaritifera* populations

Management operation	**Agriculture**	**Settlements**	**Forestry**	**Power supply**	**Fishing industry**	**Industry**	**Hazard**
Construction works			1	1		1	roads, bridges, buildings, fish farms, storage
Use of fertilisers			1			1	eutrophication, reduction in water quality
Regulation of water level and flow in summer			1	1			destruction of natural water flow, increase in water temperature
Tree felling			1			1	lack of shade and food for fish, water warming
Dam construction				1			lack of bottom current, water warming, siltation
Flood protection works			1	1			dredging, canalisation, construction of water-retention banks and walls
Installation of river bank shielding			1			1	reduction in natural erosion processes
Installation of domestic water supply systems				1		1	lack of water in river
Installation of refuse dumps					1	1	toxic effluents in river
Drainage of peat bogs			1			1	water quality reduction, siltation, water exploitation
Dredging and dredging walls				1			destruction of natural bottom conditions
Dredging walls of fish basins					1		increase in erosion, eutrophication, waste waters
Establishment of canoe and boat routes				1	1		changes in water fow, cracking of mussel shells
Ditching of fields			1				reduction in water quality
Peat cutting and harvesting			1	1		1	increased erosion, water level fluctuations, decreased water quality
Golf course management			1				eutrophication from fertilisers
Use of pesticides			1				poisoning effect
Afforestation of bogs			1				eutrophication from fertiliser use, siltation from ploughing
Deforestation			1				clear-felling
Disposal of waste waters and condensation waters		1				1	eutrophication, introduction of toxic effluent, reduction in general water quality, water warming
Ditching and ploughing wet forest			1				increase in erosion, fluctuations in water supply
Digging of draw channels for fish				1	1		erosion
Fish ladder				1	1		trout/mussel synchronisation differences
Irrigation e.g. in cultivation of potatoes		1					water abstraction, eutrophication
Landscaping		1			1		erosion, tree felling
Log storage areas			1				important previously
Mining of gravel and soil		1					alteration in bottom deposits, siltation
Other forms of tillage			1				increased erosion and thus siltation
Utilisation for recreation		1			1		docks, boat harbours, swimming beaches, fishing camps
Water exploitation				1		1	decreased water flow
Water level regulation and flow in winter				1		1	soft ice in bottom
Construction and use of reservoirs of hydroelectric power stations		1		1			water level regulation
Establishment of beaches for swimming		1					destruction of river bottom
Establishment of fish culture basins					1		waste waters, nutritive matter, diseases, genetic risk to indigenous trout population
Log floating			1				important previously
	23	21	17	13	13	11	

In the circumstance that it is intended that a natural-state section of a river or restored fluvial ecosystem should be subject to multiple use, such as contributing to the power supply, aiding in agricultural and forestry production, supporting the fishing industry or recreation, it cannot be supposed that it might also serve the purpose of maintaining the value of a natural-state area that is being conserved. In a multiple use regime, the economic advantages of different activities are seen as equal (Table 6). When valuation of the natural-state of small rivers becomes possible (as in the Ruonanjoki and the Pinsiö-Matalusjoki), through consideration of the confiscation values of threatened species (589 € for *Margaritifera* specimen), the economic costs of multiple use can be seen to be more than ten times as great as the economic gains. Or, to express this in another way, the economic value of the river in its natural condition can be seen to be many times as great as its economic value under a multiple-use regime. For instance, factors changing the characteristic water flow regime and the energy-flow continuum of the river greatly endanger the living conditions of the threatened freshwater pearl mussel, and thus trigger the risk of forfeit of millions of euro, calculated merely on the confiscation value of the numbers of freshwater pearl mussels that would be threatened by such changes (Ross, 1990).

Understanding of the value of a natural-state river, or a river returned to its natural-state, inhibits multiple use proposals for such a river. Such fluvial ecosystems are also protected by designation as Natura-2000 sites and by associated provisions of the EU Habitats and Species Directive and Water Framework Directive.

Hazards to *Margaritifera* engendered by river restoration work conducted in support of the fishing industry

It might be supposed that river restoration work carried out to benefit fishing interests might also be to the benefit of *Margaritifera*. Unfortunately, this is not the case. In restoration of rivers carried out for *Margaritifera*, the structures employed in river improvement for fishing (such as bottom dams, stony thresholds and other stair like constructs, thrown-down matter and other structures directing or changing the water flow, and other modifications aimed at influencing water flow) cannot be utilised, without changing the water flow regime characteristic of the river and causing several consequent adverse effects. Therefore, river improvement for fishing introduces hazards to survival of the natural fauna and flora resident in the river, and is not helpful in the restoration of the fluvial ecosystem.

The water volume in the river bed cannot be artificially increased with threshold-like, stair-like or dam-like structures, without changing the natural water flow regime in the fluvial habitats. In many cases the "ecological restorations" of a river for salmon, do not meet the criteria required for the protection of the pearl mussel and its environment (Table 7; Fig. 7).

Preservation of unnatural migration barriers (e.g. dams and bottom dams) prevents recovery of stretches of the river to their natural state and thus increases the risk of disappearance of species and populations of organisms resident in the fluvial system. At the same time the dams, by changing the water flow regime characteristic of a river, decrease the extent of the living area naturally suitable for both the freshwater pearl mussel and the trout.

Table 7. Hazards to *Margaritifera* introduced by river modification for purposes of supporting the fishing industry can be summarised as follows:

Bottom dams

- alteration in the fluvial habitat
- alteration in the water retention time
- alteration in flood volume and the level of the water surface

Thresholds

- alteration in the fluvial habitat
- alteration in the water retention time
- alteration in flood volume and the speed of water flow

Introduced soil and stones
- alteration in the natural or semi-natural water flow regime of the fluvial habitat
- alterations in turbulence
- alteration in the freezing kernel in the winter

Wintering excavations
- alteration in water flow regime, especially in shallow water habitats
- alteration in natural erosion processes

Conduct of repair works from upstream to downstream
- the natural water flow regime does not recover
- the process of restoration of the natural state does not start

Introduction of gravel
- alteration in the water flow regime
- alteration in natural erosion processes

Survey of fish populations (wading and electric fishing)
- crushing of freshwater pearl mussels

Making new river beds bypassing natural barriers to fish migration by more gentle sloping
- genetic risk to the indigenous organisms
- disappearance of the native strain of trout, followed by loss of the synchrony between the freshwater pearl mussel and the trout
- abnormal introduction of predatory fish

Fish introduction of captive-bred fish stocks
- genetic risk to the indigenous organisms
- disappearance of the native strains of trout, followed by loss of the synchrony between the freshwater pearl mussel and the trout

Maintenance of boat routes
- the natural water flow regime of the river does not recover, and thus the process towards recovery of the natural state of the river does not start
- poisonous fuel

Fig. 7. If the ecological restoration of fish includes removal of old slipways for timber floating, the result does not meet the criteria required for the protection of the pearl mussel and its environment

Hazards caused by Conservation Agencies

The independence of action enjoyed by the agencies responsible for planning, realisation and monitoring of nature conservation in fluvial systems has led in Finland to the present practice of recognising these agencies as themselves introducing hazards to the survival of *Margaritifera*. Their negative impact is manifested in various ways (Table 8).

Table 8. Hazards caused by Conservation Agencies

- Planning is often based on long established practice, which often impedes innovative conservation action in fluvial systems and renders possible repetition of mistakes, which hinder the conservation process.
- Responsibility for decision taking is transferred to persons (e.g. to land-owners) who cannot be expected to have expertise in this field of knowledge
- Utilisation of external specialists is minimal
- The "Consent of persons with joint interest" is used as the justification for reparation works, despite the fact that it can be predicted the works represent a hazard to riverine habitats and fauna in the affected area.
- The actions carried out in the field once the reparation works are agreed ignore the plans.
- Important factors threatening the natural state or recovery of the river can be excluded from consideration in the plans.
- In natural-state river sections, dilapidated or ruined structures that, when operational, change the natural water flow regime, are renewed by order of the authorities.
- When a river is subject to multiple use, agreements to protect and repair the natural or recovered state of the river are made, not only with the authorities, also with land-owners and the other interested parties involved in use of the river. Responsibility for conservation is then obscured and utilitarian points of view and normal business principles can affect the activities that are related to protection.
- Regular follow up activity is maintained only at a very low level, and is not financed.
- Scientific monitoring from outside is seldom directed towards the measures taken by another agency. This leads to a situation where the environmental hazards caused by such measures remain to a significant extent unrecognised and uninvestigated.

RESTORATION MEASURES

A river is a chain of habitats linked in an energetic continuum, from its source to the estuary. The links consist not only of rapids and pools, but also of turbulent stream sections, deep stream sections and slow flowing pools (Figs. 8-12). All of the links in this chain have considerable influence on the fluvial animals and plants of any one link, whether or not those organisms are confined to just that particular river habitat (Valovirta, 2001; Degerman et al., 2009). If conservation work on a semi-natural river concentrates only on rapids, only part of the body of the “patient” recovers its health. Moreover, restoration measures within the catchment area can be as important as restoration measures in the river channel itself. If man has influenced the volume of water naturally present in a catchment area, for instance by water abstraction or ditching, the consequent changes cannot be compensated for by structures built in the river bed. The water volume in the river bed cannot be artificially increased with threshold-like, stair-like or dam-like structures, without changing the natural water flow regime in the fluvial habitats. Modifications of the river channel have been so intensive in many rivers that the main channel of the river cannot be restored to a suitable environment for the freshwater pearl mussel unless the dams are removed.

The effects of restoration measures have to be considered both up and down stream of the restoration site because river habitats are interactive. If the estimated benefit from a restoration project is smaller than the risk to the river habitat and the organisms, the restoration should not be carried out.

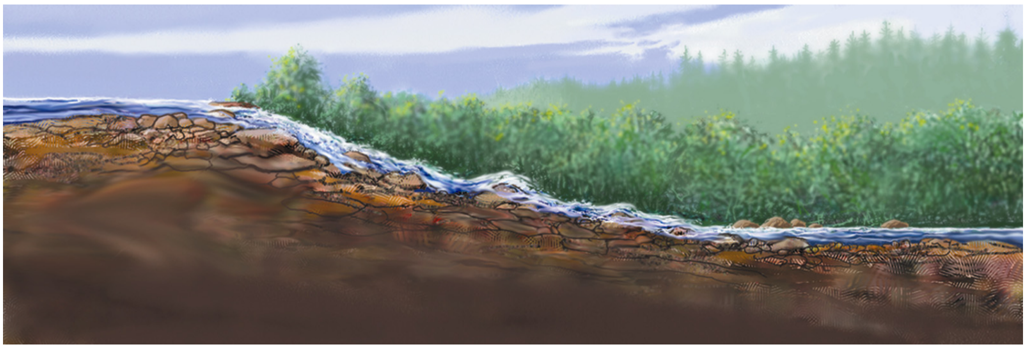


Fig. 8. Rapid. Rocky and spatey

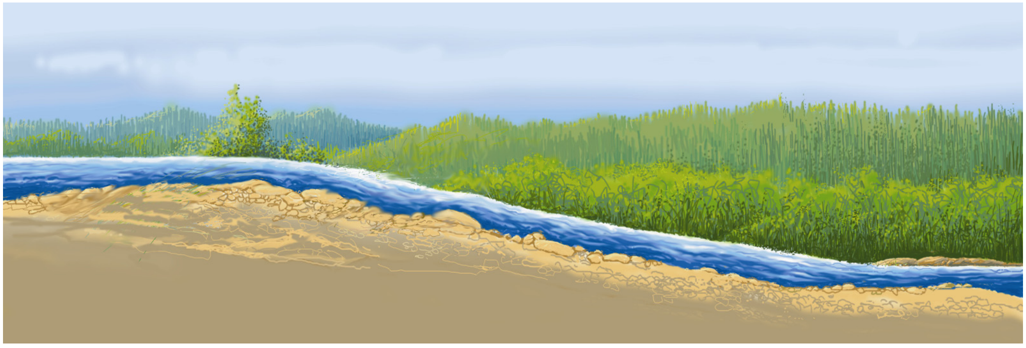


Fig. 9. Fast flowing stream section. Gravel and small stones, no spating

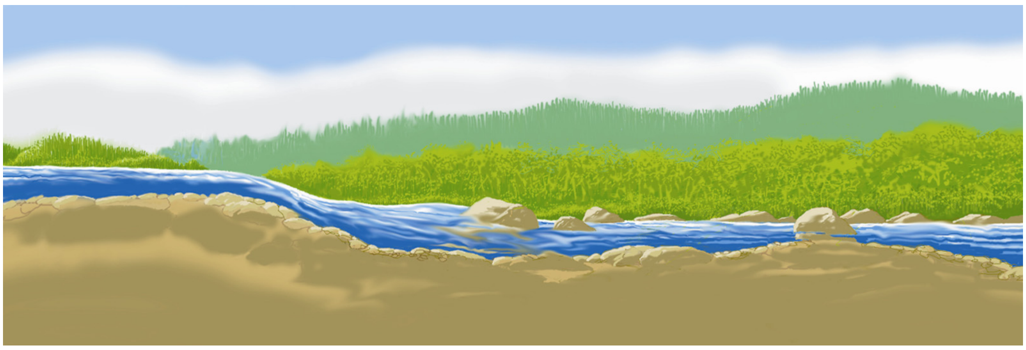


Fig. 10. Deep and turbulent stream section. Turbulence visible between boulders, gravel and sand bottom. The best habitat for *Margaritifera*

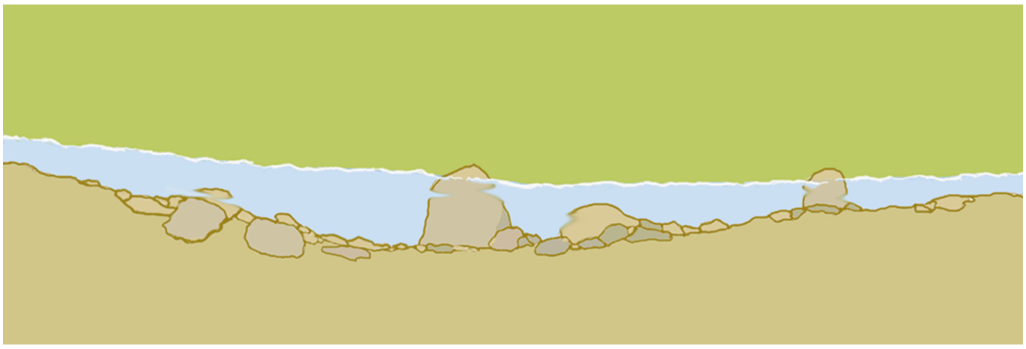


Fig. 11. Slow flowing stream section. Gavel, sand and soft bottom. Water flow regime can be deduced from hydrophytes

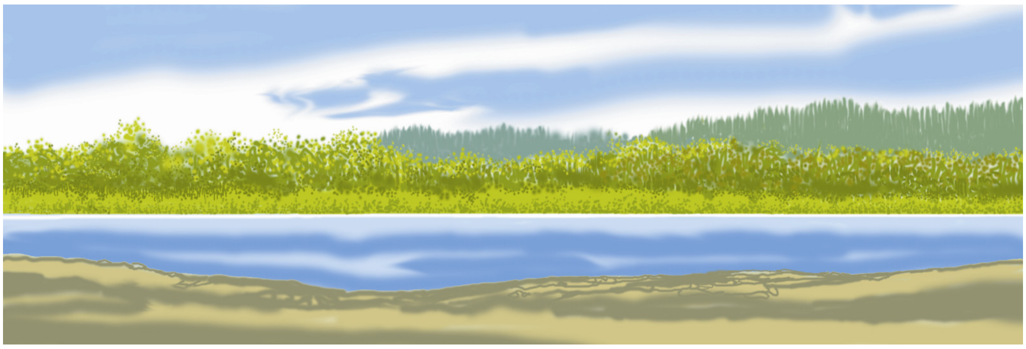


Fig. 12. Stagnant stream section. Soft, deep bottom. Functions as a water storage zone for the river

Restoration within the river channel

The river or brook channel can be divided into five major classes of fluvial habitats, defined by reference to its shape, bottom profile and water flow characteristics (Table 9). Acting both individually and together these five classes of habitat have a critical effect on *Margaritifera* populations, via the energy-flow continuum. Each major habitat class, like rapids, includes more than one macrohabitat category, a number of mesohabitats and thousands of dynamic microhabitats, depending on the type of organism targeted in the river ecosystem (Valovirta, 2003). The degree of success achieved in restoring a semi-natural river, e.g. for freshwater pearl mussels, depends basically on how well we recognise these habitats and how well we can provide appropriate levels of natural water energy for them, as determined by channel slope and friction typical for each habitat type.

Table 9. Major habitat classes

- *rapids (you can hear the water)*
- fast flowing stream sections (you cannot hear the water)
- deep and turbulent stream sections (turbulence visible between boulders)
- slow-flowing stream sections (you can deduce the direction of water flow from observation of bottom-rooting hydrophytes)
- stagnant stream sections (effectively zones of water "storage" for the river, where direction of flow cannot be deduced from observation of the vegetation)

It is important to restore what were originally rapids to rapids, streams to streams, etc. Management of a river for salmon, resulting in restructuring of a rapid into a series of short rapids and pools, by deepening some sections and installing bottom dams in others, introduces a considerable risk of causing a domino effect on the *Margaritifera* habitats, that results in breakdown of their natural progression and consequent reduction in the sustainability of their conservation value.

Particulate matter in the river channel

The river bed of a natural fluvial ecosystem is in a dynamic equilibrium state, maintained by natural fluctuations in water flow but influenced by the fluvial habitats. The fluctuations in flow influence the morphology of the river bed and the character of the bottom substrate. The consequences of this influence are observed as:

- erosion
- drifting
- sorting
- deposition

Any restoration of the river channel has to accommodate these processes. The measures to prepare a river for brown trout e.g. by adding gravel and sand, usually are much more extreme than the natural procedure, and so can impact severely on young mussels. For mussels, it is of paramount importance that, whatever restoration procedures are used, those procedures minimise the load of fine material entering the river water as a result of the restoration works, and leave the actual living area of the mussel untouched. The average suspended solids content we have recorded during "soft" restoration processes proved to be 6-15 times greater in the restoration areas than in control areas. The critical level for *Margaritifera* populations is >25 mg/l, should it continue for a couple of weeks. By contrast, where the "hard" restoration process was used (without any conservation methods) the average suspended solids content was at its maximum about 60 times greater than in the control areas. The average quantities were way beyond the capacity of mussels to tolerate.

Improving the effectiveness of conservation agencies

Significant impacts on the environment, river habitats and river catchments inhabited by the protected freshwater pearl mussel continue, driven by economic interests. The national authorities responsible for protection still do not have sufficient power or knowledge to maintain the favorable conservation status of this highly specialized species (Fig. 13). This situation could be greatly improved if data collection and planning of protection measures for the species mentioned in Annex II of the Habitats Directive (such as the freshwater pearl mussel and the thick shelled river mussel), were concentrated under one authority (Table 10).

Fig. 13. Information plays an important role in the protection of the freshwater pearl mussel. The press and TV are invited to a floating pontoon in the river Mustionjoki. White and blue flag signals the presence of divers in the water

Table 10. Improving the effectiveness of conservation agencies

- interpretation of directives would become easier
- consultation with experts would become more cost effective
- information gathering, terms and work methods would become standardised
- managing conflicts between socio-economical factors and conservation would become standardised
- determining natural and semi-natural river habitats would become standardised
- elimination of risk and controlling and monitoring of measures would become more effective
- the level of protection would be stabilised

FUTURE PROSPECTS

During the 30 years, we will lose most of the *Margaritifera* populations in southern and central Finland, because those populations are not reproducing. At the end of the 1970´s there was a non-reproductive sub-population of about 400 individuals in the river Mustionjoki, but in 2002 fewer than 10 remained. In the river Pinsiö-Matalusjoki one sub-population (in 30 m of river channel) has diminished from 1200 specimens to zero during 25 years, even though this river belongs to the Natura-2000 network. In northern Finland, in the river of Siika-Juujoki, we have lost 8 000 of the sub-population of 10 000 *M. margaritifera* individuals, because of an ecological modification of the river section for the purposes of supporting the fishing industry.

On the other hand, we now have good knowledge of the hazards to mussel populations. Nowadays it is not possible in Finland to restore or carry out any measures in a *Margaritifera* river without the mussel population of the river being inventorised. Considerable survey activity is necessary to keep one step ahead of all the measures which are going on in Finnish *Margaritifera* rivers.

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