From the history of pearl harvesting in Karelia

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Photo 1. (by I. Inha). *Pearl fishing in Northern Karelia. Source: I.V. Olenev. Karelian land and its future in the context of the Murmanskaya railway construction. Helsingfors, 1917.*

Pearl harvesting had been an old trade for peasants in Karelia. A document dated 1563 mentions pearl fishing in the Keret River with 1/10th of the harvest due to the State. Exhibits in the Moscow Kremlin museums evidence pearls from the Pomor area were used in making gala garments for the Russian Church hierarchs. Somewhat later than in the Pomor area the trade developed to a commercial scope also in Southern Karelia. By the early 18th century, pearl harvesting had become very extensive. Large batches of decorative items made of pearls (up to 11,000 pieces) were delivered from Karelia to fairs in Novgorod.

In 1721, Peter the Great prohibited individuals to fish for pearls, imposing state monopoly on the activity. In 1736, following complaints from Olonets Province peasants, Empress Anna restored the freedom of the trade. Karelian pearls regained their nation-wide fame. Two strings of select pearl grains from Karelia were presented to Catherine the Great as a gift. The pearls issue shows through the region's heraldry. The Kem' City coat-of-arts adopted in 1788 has a wreath of pearls in it. The pearls were delivered to the local and the national markets, and used by peasants to decorate women's holiday apparel. Pearl embroidery adorned headgear; necklaces and earrings were made of pearls.

In the 1870s-1890s, pearl fishing in Olonets Karelia continued only on some rivers in the Povenetsky Uezd (Kumsa, Oster, Povenchanka, etc.), but even that stopped early in the 20th century because of low profits. The core of pearl harvesting in the Pomor area still was the Keret' River. The harvesters were Karelians from Voknavolok. There, too, the trade was gradually dying out. Where in the 1870s best harvesters would gather a 1000 roubles worth of pearls within a season, the yield in the 1910s dropped to 300 roubles. The crisis had several causes to it. Uncontrolled harvesting of pearl shells had undermined the resources. Deterioration of the environment caused by timber floating was another factor. Peasants switched to more dependable trades - fisheries and logging. Goods with pearls remained in usage among peasants until the 1930s. They have now enriched museum collections.

Photo 2 *Elements of special occasions headdress – pearls-decorated crown and netting from the Pudozh Regional History Museum collection.*

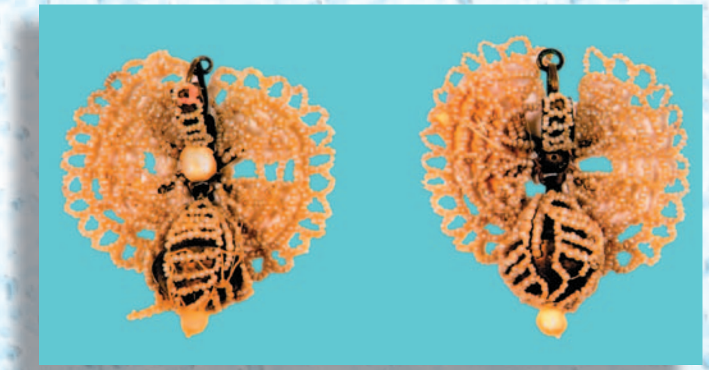

Photo 3 (by V. Golubev). *Butterfly earrings from the Karelian State Regional Study Museum collection.*

CONSERVATION OF FRESHWATER PEARL MUSSEL MARGARITIFERA MARGARITIFERA POPULATIONS IN NORTHERN EUROPE

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Institute of Biology
Karelian Research Centre
Russian Academy of Sciences

CONSERVATION OF FRESHWATER PEARL MUSSEL *MARGARITIFERA MARGARITIFERA* POPULATIONS IN NORTHERN EUROPE

Proceedings of the International Workshop

Petrozavodsk, Russia,
April 28–30, 2009

Petrozavodsk
2010

УДК 594.111(063)
ББК 28.69
М 34

”Conservation of freshwater pearl mussel *Margaritifera margaritifera* populations in Northern Europe”. Proceedings of the International Workshop. Edited by E.P. Ieshko, T. Lindholm. Petrozavodsk: Karelian Research Centre of RAS, 2010. 108 p.
ISBN 978-59274-0423-0

УДК 594.111(063)
ББК 28.69

The Proceedings were prepared and printed with financial support from the Finnish side of the Finnish-Russian Working Group on Nature Conservation

ISBN 978-59274-0423-0

FRESHWATER PEARL MUSSEL *MARGARITIFERA MARGARITIFERA*: COVERAGE BY STUDIES AND WAYS TO CONSERVE THE SPECIES IN RIVERS OF NORTHERN EUROPE

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The freshwater pearl mussel *Margaritifera margaritifera* (L.) used to be quite widespread in rivers and streams of Western and Central Europe, Baltic countries, Byelorussia, and the taiga zone of Northwest Russia, including waters in the White, Barents and Baltic Sea drainage basins. To people of the North, including the territory now belonging to Karelia, the pearl mussel was of great importance as the source of pearls, which were their favoured decoration applied to clothing, home utensils, cases of most venerated icons, and book binders. The biggest and most regular-shaped pearls were vigilantly kept in the national treasury.

Pearl fishing was the main source of income for many people in northern countries, and attempts have been made to start raising pearl mussels instead of fishing for them. For instance, pearl fishers, the Kelevaevs from Keret, successfully harvested pearls for centuries without killing the mussels, and even stocked them over to other streams on the Karelian Coast (Oparin, 1976). The importance of pearls for the local economy is stressed by the fact that a wreath of pearls is depicted in the coat of arms of the Karelian City of Kem.

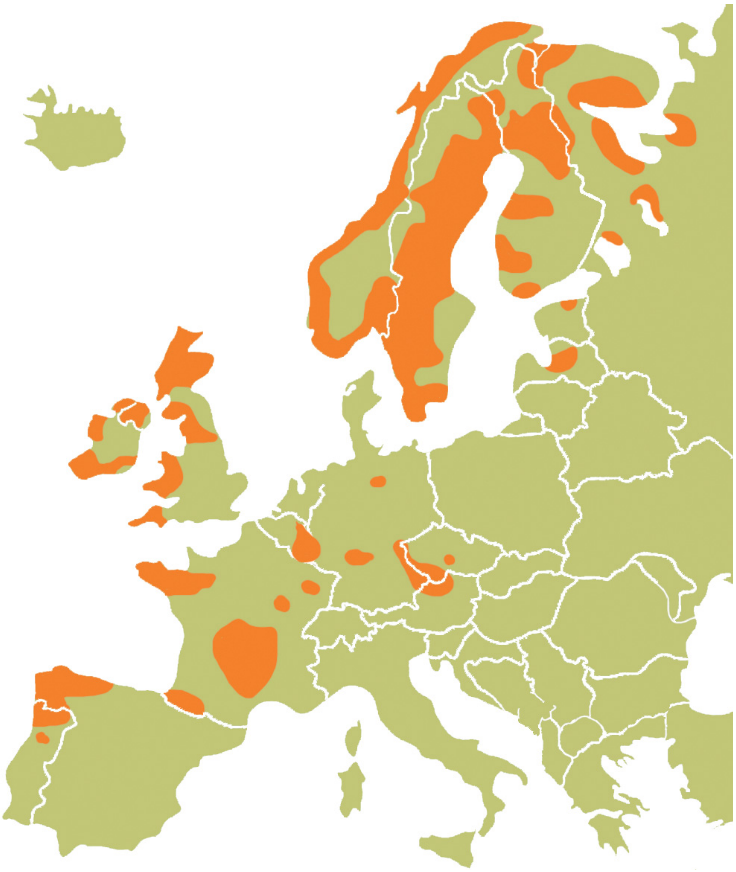

Fig. 1. Current distribution of the freshwater pearl mussel in Europe (Larsen, 2005).

The mollusk is protected under the Bern Convention (1979) and Annex II of the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Furthermore, the species is listed in the 1996 IUCN Red Data Book as being endangered, as well as in Red Data Books of East Fennoscandia (1998), Russia (2001), and Karelia (2007).

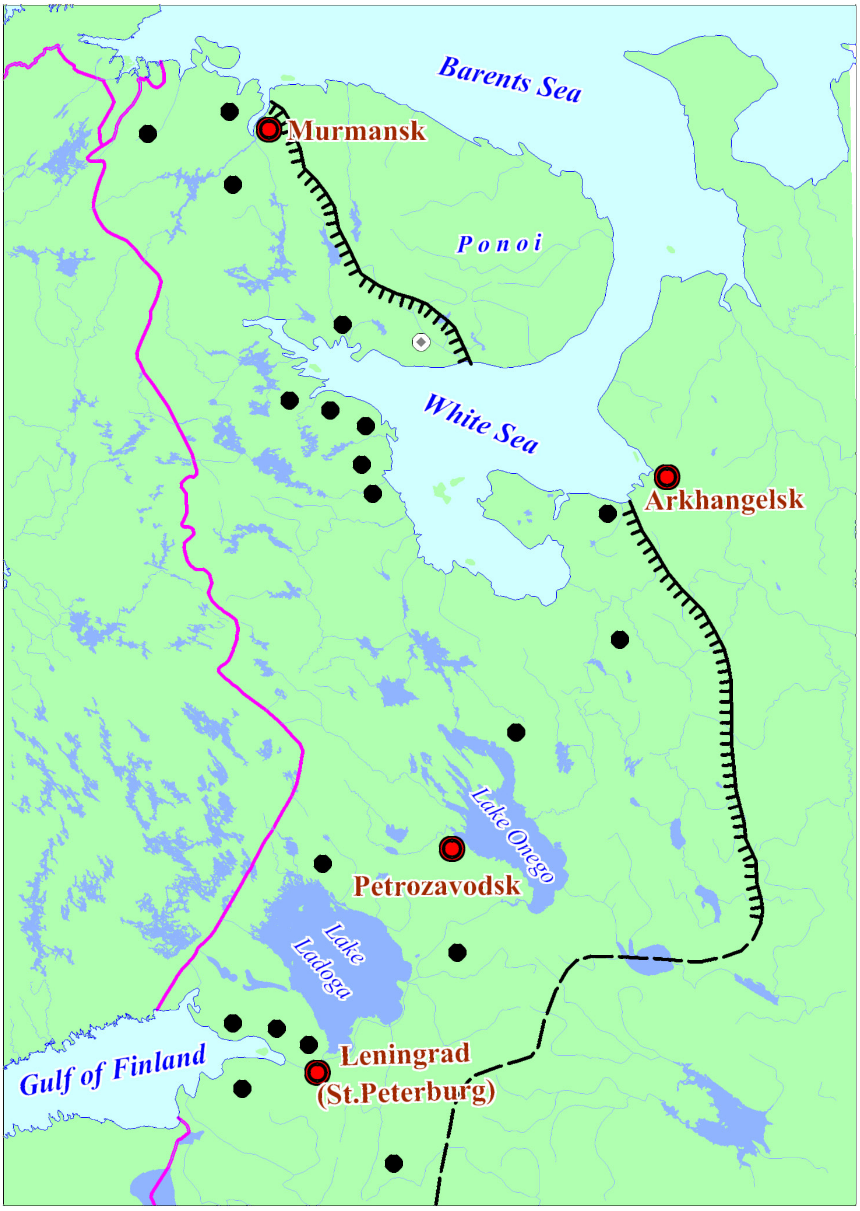

Fig. 2. Area of pearl harvesting (16th-20th centuries) in Russia. Dots mark rivers with surviving *Margaritifera margaritifera* populations (21th century) (Makhrov, ibid.)

In spite of all the protection measures, the pearl mussel *M. margaritifera* has over the past century gone nearly extinct from many regions of Central Europe (Araujo & Ramos, 2000). Numerous studies show the mussel abundance and occurrence have dropped abruptly in other regions as well, leaving fragmented declining populations behind (Fig. 1). The map below is a rather sketchy representation of the current distribution range of the pearl mussel in North European countries. However, even rough estimates of the mussel numbers (Geist, 2005; Larsen, 2005) lead to the conclusion that the principal role in the conservation of this endangered species in the near future would belong to rivers of the White and Barents Sea drainage basins (Fig. 2).

In view of this, the Finnish side of the Finnish-Russian Working Group on Nature Conservation and the Institute of Biology, Karelian Research Centre of the Russian Academy of Science have resolved to organize the international conference "State of freshwater pearl mussel *Margaritifera margaritifera* populations in Northern Europe" (Petrozavodsk, Russia, April 28-30, 2009). Specialists from Russia, Sweden, Norway and Finland assessed the current situation with the pearl mussel populations in rivers of Northern Europe, and outlined the ways to conserve this declining species.

The presentations made by invited specialists provided an insight into present-day problems and the results of the work for conservation of the pearl mussel in North European countries (Sweden, Norway, Finland, Russia). Special focus was on the human impact on communities in the northern rivers that play a crucial part in maintaining the mussel populations in Europe. Scientists from Russia reported the information characterizing the current state of the populations in Northwest Russia (Murmansk, Arkhangelsk, Vologda, Leningrad Regions, and Republic of Karelia). The trend there is for a heavy reduction in the pearl mussel numbers as the result of hydropower construction projects and declining populations of salmon, which is an essential part of the mussel's life cycle.

The participants have stressed in particular that the conference promoted Russian interregional and international integration, helped establish and strengthen scientific contacts between specialists and organizations from different countries aimed at conserving the unique natural heritage in northern rivers.

It was decided to publish the conference proceedings in the form of a volume of collected papers, which may help in the efforts for conservation and restoration of the pearl mussel populations in rivers of Northern Europe and Northwest Russia. The volume can also be used as the basis for developing joint research programmes, and working out practical guidelines on designation of new protected areas.

STATE OF *MARGARITIFERA MARGARITIFERA (L.)* POPULATIONS IN ARKHANGELSK REGION

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At present, freshwater pearl mussel populations in the Arkhangelsk Region have survived in the watersheds of rivers Solza (Rivers Kazanka and Solza) and Onega (River Kozha). The basic negative factor for the pearl mussel in the region is the decline in the numbers of host-fishes – *Salmo salar* (L.) and *S. trutta* (L). The dam blocks access of salmon to the upstream of Solza, which is the eastern limit of the pearl mussel range in Europe. Pearl mussel populations have survived only in the watercourses with artificial reproduction of Atlantic salmon. Thus, the activity of hatcheries secures steady reproduction and preservation of not only salmon, but also its parasite – the pearl mussel.

Key words: Arkhangelsk Region, freshwater pearl mussel, populations

INTRODUCTION

Available 19th – early 20th century publications about pearl harvesting indicate the pearl mussel had been quite widespread in rivers of the region (Bespalaya et al., 2007*a*). Museums and churches still feature items with pearl embroidery – rich peasants' clothes, icons casings, covers of church books, and other objects.

This paper provides information about pearl harvesting and the pearl mussel distribution in Arkhangelsk Region in the 16th–20th centuries (Bespalaya et al., 2007*a*). We know that the greatest resources of pearls have been concentrated in rivers Syuz'ma, Kazanka, Solza, Yaren'ga, Vajga, Hajno-ruchej, Onega (with tributaries), Kozha (with the tributary Syvtyuga), Somba, Nimen'ga, Maloshujka (Bespalaya et al., 2007*a*).

Presumably, the freshwater pearl mussel was a dominant and even the supra-dominant species in benthic communities of the region's fast-flowing small and medium-sized rivers with stony or sandy-stony bottom, rapids and riffles, where significant positions belonged to the main hosts of pearl mussel larvae – Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) (Veselov et al., 2001; Bespalaya et al., 2007*a*).

Below we summarize the available data on the state of the populations of the freshwater pearl mussel *Margaritifera margaritifera* (L.) in Arkhangelsk Region.

MATERIALS AND METHODS

Freshwater pearl mussel populations in the Solza River watershed were studied in 2005 and 2006 (Bespalaya et al., 2007). Surveys in 2007 included three locations in the Kozha River, Podsiman'ga rapid (Onega River watershed). The sample plots on Kozha were located near a station of the Onezhskiy hatchery, a division of Sevrybvod.

The Solza River watershed, 1400 km^2 in area, lies in the eastern part of the Onega Peninsula (Fig. 1, 2). The river originates from Lake Solozero and flows to the White Sea. It receives discharge from seven tributaries, and from numerous small streams. Solza is 109 km long, 10–20 m wide in the upper course, 20–45 m wide in the middle and lower course. The depth is 0.3–0.4 m in riffles and up to 1.5 m in still sections, the flow velocity averages 0.5–0.8 m/s. The river is mostly fed by wetlands and snowmelt, and annual discharge is variable. The riverbed is made up of crystalline bedrock; riffles and rapids are frequent (Fig. 2) (Bespalaya et al., 2007).

The Kozha River originates from Lake Kozhozero. It is a large left-bank tributary to River Onega. The length of the watercourse is 96 km, the drainage basin is 6210 km^2. The river has 36 tributaries, which are shorter than 10 km, and have a combined length of 75 km. Kozha is a semi-montane river (elevations in the upper course exceed 100 m) (Fig. 2). Most runoff comes from snowmelt. Discharge is the lowest in March (Novoselov et al., 2006).

Surveys of the pearl mussel population followed the procedure proposed by Zyuganov (1993), which has been tested at the Solza River (Bespalaya et al., 2007*b*).

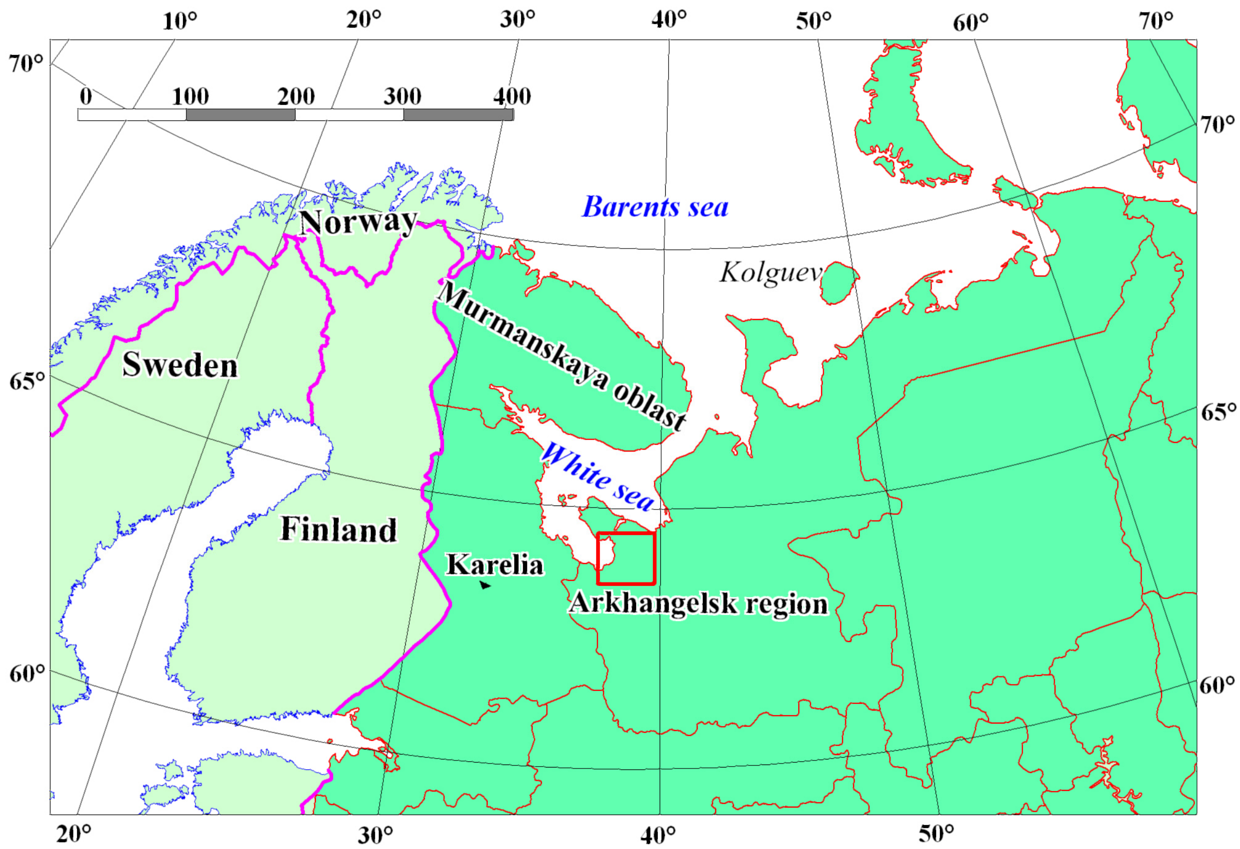


Fig. 1. Overview map of Northern Europe, showing field study areas

The study also included surveys of mollusc communities in the Kazanka River in order to assess the role of the freshwater pearl mussel in the structure of the mollusc fauna in the watercourse. Benthos samples were taken from the upper course of Kazanka upstream of Lake Krivoye, and from the lower reaches of the river downstream of Lake Rechnoye.

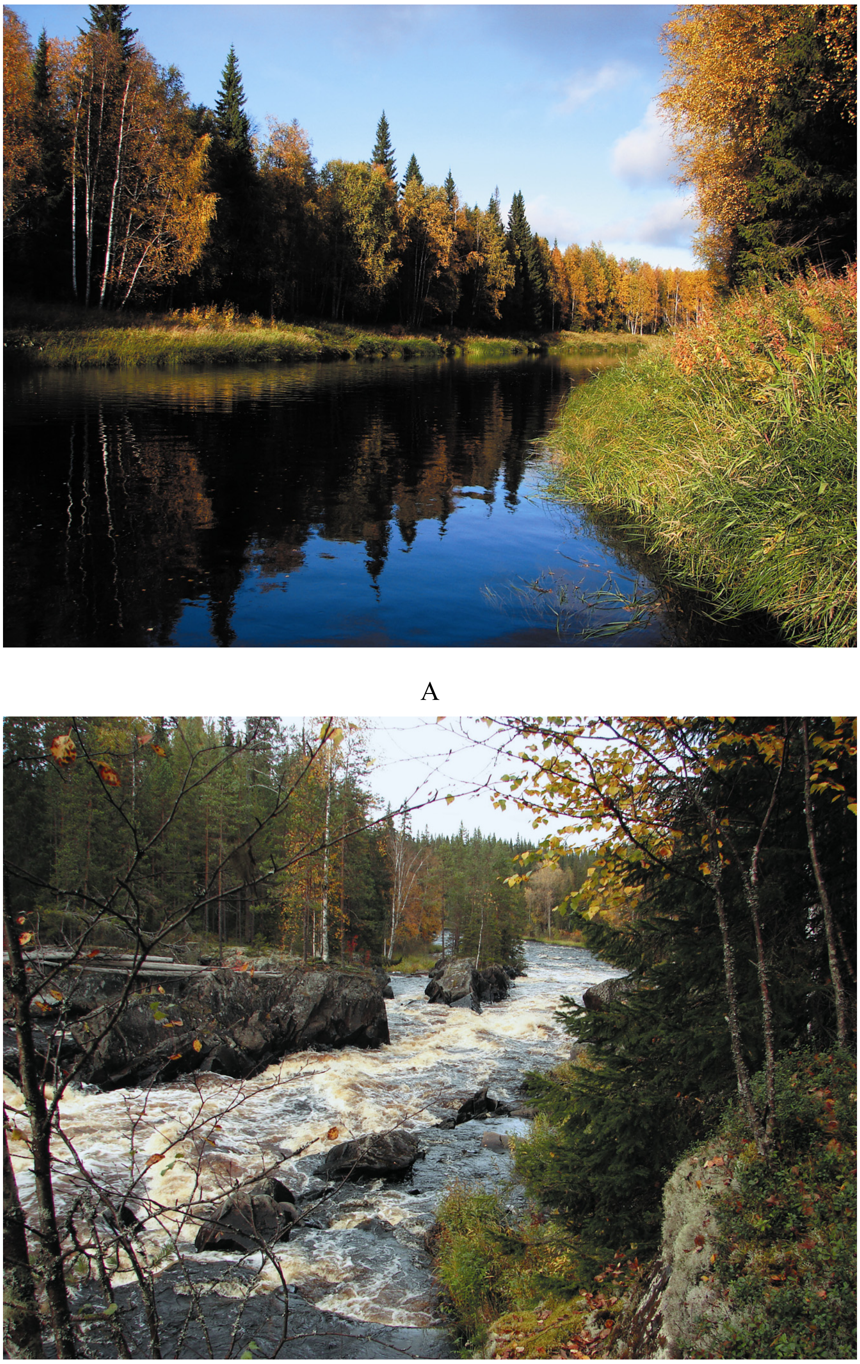
Hydrobiological work followed conventional techniques (Mordukhai-Boltovsky, 1975; Semyonova et al., 1992; Zyuganov et al.; 1993; Hastie et al., 2000). Qualitative sampling along the banks was carried out with a sweep net or manually, and a scraper was employed in the open littoral. Samples were also washed off rocks covered with silt or water moss (Mordukhai-Boltovsky, 1975).

Quantitative samples were collected randomly using an Eckman-Berge bottom sampler (1/40 m^2). The samples were washed in a hydrobiological sieve. The molluscs were preserved in 96 % alcohol, which was replaced a day later with 70% alcohol (Zhadin, 1960; Mordukhai-Boltovsky, 1975; Starobogatov et al., 2004). A total of 22 hydrobiological samples were collected. The total number of molluscs in the samples was 238.

The samples were examined in the laboratory under a MBS-10 stereoscopic microscope. Identification was carried out using tables by Starobogatov (1977, 2004), and keys by Kruglov and Starobogatov (1993), Kornyushina (1996), and Kruglov (2005).

The relative abundance of species was calculated as the share of specimens in the sample. The species richness of local groupings of molluscs was assessed using the computational technique of rarefaction followed by graph plotting and analysis (Smith, and van Belle, 1984).

Dominance was determined using the Berger-Parker index, which represents the proportion of the most abundant species (Magurran, 1992). The five point logarithmic scale was employed to determine the relative abundance of species (Pesenko, 1982). Species with an abundance of 4–5 points are considered dominant, with 3 points – common, with 1–2 points – scant.



A

B

Fig. 1. Habitats of the freshwater pearl mussel in Arkhangelsk Region
A – R. Solza, B – R. Kozha (Padun rapid)

RESULTS AND DISCUSSION

In the Solza River watershed, morphometric measurements were taken from 208 specimens from R. Kazanka and 185 specimens from R. Solza.

The average length of mussels in samples from R. Kazanka was 95.9 mm (from 49.5 to 136.3 mm), and that in the sample from the lower reaches of R. Solza was 89.2 mm (from 33.8 to 110.6 mm).

The proportion of juveniles with a shell length ≤70 mm in Kazanka was about 7%, whereas in Solza it was higher (11%). The average calculated age of 10 youngest specimens was 17 years in Kazanka, and 16 yrs. in Solza lower course; the youngest specimens were 13, and 9 years of age, respectively.

In the Kozha River, 4 mussels were found. The shell length in the sample ranged from 93.1 mm to 116.3 mm.

The pearl mussel population density in the Solza River varied from less than 1 ind./m^2 to 4 ind./m^2. The mussel density in different parts of Kazanka varied from 1 ind./m^2 to 68 ind./m^2 (Bespalaya et al., 2007a).

Pearl mussel abundance in the Kozha River has not been studied yet. Kozha is a big river, which abounds in deep pools and waterfalls. Thorough surveys were not possible because of the high water level and strong flow. We believe a promising technique for studying pearl mussel populations on such big rivers is remote sensing of the riverbed using underwater video camera.

Data about benthic communities, where pearl mussels coexist with other mollusc species, are so far insufficient. We have assessed the role of the freshwater pearl mussel in the structure of mollusc communities in small rivers of the Onega Peninsula. According to the studies, the mollusc fauna in R. Kazanka comprises 2 to 17 species in different parts of the channel (Table).

The upper reaches of the Kazanka River are inhabited by 16 mollusc species, which belong to 5 families and 12 genera. The family richest in species is Euglesidae.

The species prevailing in abundance is *Sphaerium westerlundi* (Clessin in Westerlund, 1873) (5 points on the abundance scale). It accounts for 71.3 % of the sample abundance. The only common species (3 points) is *Colletopterum anatinum* (Linnaeus, 1758), which contributes 7.4 % to the sample abundance. All other species are scant – their abundance is within 1–2 points. *Margaritifera margaritifera* is absent from the fauna of this area.

The mollusc species composition in the lower reaches of the river is made up of only two species – *Margaritifera margaritifera* and *Lymnaea intermedia* Lamark, 1822. The greatest abundance (5 points) is demonstrated by the freshwater pearl mussel, which accounts for 90 % of the sample. *L. intermedia* is common (3 points) in this coenosis, and contributes 10 % to the community. Thus, the species richness is the highest in the groupings inhabiting the upper course of Kazanka (Fig. 3).

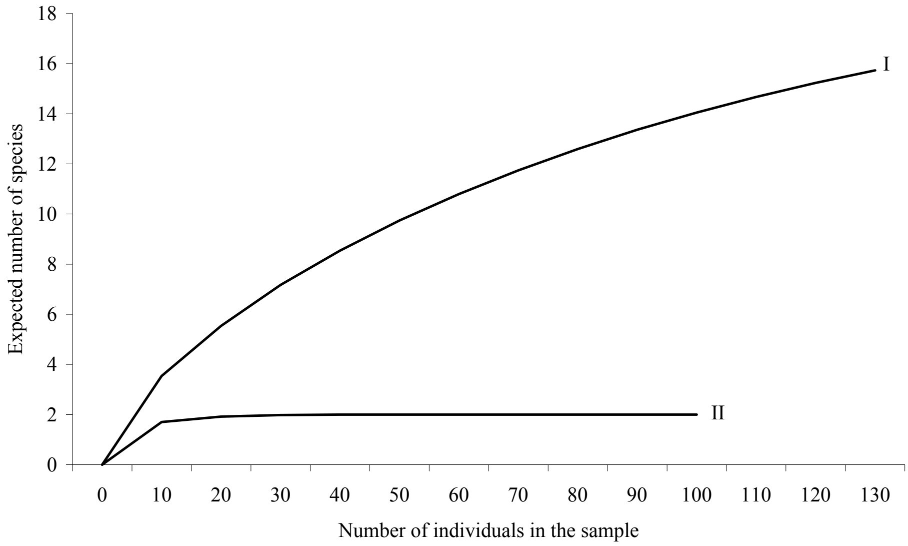


Fig. 3. Rarefaction curves for two variants of local groupings of molluscs in the Kazanka River.
I – headwaters of the river (upstream of Lake Krivoye, Lake Borovoye); II – lower course of the Kazanka River (downstream of Lake Rechnoye)

The structure of local groupings of molluscs in the investigated sites of the Kazanka River is predetermined, first of all, by the distribution of the freshwater pearl mussel through the watercourse, i.e. location of the species populations in Atlantic salmon spawning and nursery areas (Zyuganov, 1993). Apparently, salmon spawners do not reach the upstream of Kazanka. Secondly, being the super-dominant species, which shapes the ecological conditions for benthic communities (Zyuganov, 1993), *Margaritifera margaritifera* may supplant other species of bivalves, whether bigger or smaller in size (Protasov, 2006).

An interesting fact is that pearl mussel populations have survived in the watersheds of the rivers with operating hatcheries – Onezhskiy and Solzenskiy (divisions of Sevrybvod). They have lately considerably increased the release of salmon parr. In 2004, e.g., Onezhskiy hatchery stocked rivers Kozha and Onega with 66 500 salmon aged 2 years, and Solzenskiy hatchery – with 93 700 one- and two-year-old parr.

Activity of the hatcheries ensures regular supply of juvenile salmon, thus maintaining pearl mussel populations in the region.

CONCLUSIONS

Thus, no *M. margaritifera* populations were found in a number of rivers in the Arkhangelsk region that used to be inhabited by the pearl mussel. The main negative factor for the pearl mussel in the region is decline in the numbers of host fishes – *Salmo salar* (L.) and *S. trutta* (L.). E.g., a dam blocks access of salmon to the upstream of Solza, which harbours Europe's easternmost population of the pearl mussel (Bespalaya et al., 2007*b*).

Species structure and relative abundance of molluscs in the Kazanka River

No	Species	upper course of Kazanka (upstream of Lake Krivoye, Borovoye)			lower course of Kazanka (downstream of Lake Rechnoye)		
		N, ind.	I_d, %	*B*, number	*N*, ind.	I_d, %	*B*, number
1	*Margaritifera margaritifera* (Linnaeus, 1758)	–	–	–	91	89.2	5
2	*Colletopterum anatinum* (Linnaeus, 1758)	10	7.35	3	–	–	–
3	*Sphaerium westerlundi* (Clessin in Westerlund, 1873)	97	71.3	5	–	–	–
4	*Tetragonocyclas tetragona* (Normand, 1854)	3	2.2	1	–	–	–
5	*Roseana borealis* (Clessin in Westerlund, 1877)	2	1.5	1	–	–	–
6	*Pseudeupera subtruncata* (Malm, 1855)	6	4.4	2	–	–	–
7	*Cyclocalyx obtusalis* (C. Pfeiffer, 1821)	1	0.74	1	–	–	–
8	*Hiberneuglesa normalis* Stelfox, 1929	1	0.74	1	–	–	–
9	*Cingulipisidium nitidum* (Jenyns, 1832)	4	2.9	2	–	–	–
10	*Cincinna depressa* (C. Pfeiffer, 1828)	1	0.74	1	–	–	–
11	*Cincinna piscinalis* (Müller, 1774)	1	0.74	1	–	–	–
12	*Lymnaea fragilis* (Linnaeus, 1758)	1	0.74	1	–	–	–
13	*L. intermedia* (Lamark, 1822)	2	1.5	1	11	10.8	3
14	*A. acronicus* (Ferussac, 1807)	1	0.74	1			
15	*A. stelmachoetus* (Bourguigant, 1980)	2	1.5	1	–	–	–
16	*Anisus contortus* (Linnaeus, 1758)	2	1.5	1	–	–	–
17	*A. laevis* (Alder, 1838)	2	1.5	1	–	–	–
	Total	136	100		102	100	
	Quantitative sample/sampling area	10			12		
	Average density of molluscs, ind./m^2	56.9			8.5		
	Berger-Parker index	0.71			0.89		
	Simpson's index	0.52			0.81		
	Shannon index *(H')*	1.29			0.34		
	Margalef index	3.26			3.46		

N – total number of specimens in the sample; Id – proportion of specimens of a species in the sample, %; In – relative abundance points of the species on the five-point logarithmic scale (Pesenko, 1982): 1 – very rare, 2 – rare; 3 – common; 4 – abundant, 5 – dominant

Populations of the pearl mussel have survived in those watercourses where artificial reproduction of Atlantic salmon is maintained (Bespalaya et al., 2007*a*). Hence, the activity of hatcheries secures steady reproduction and preservation of not only salmon, but also its parasite – the pearl mussel.

The structure of local groupings of molluscs in the Kazanka River differs notably among sites, which may be due to the life cycle strategy of the freshwater pearl mussel, and its environment-shaping role in benthic communities related to its high biofiltration capacity.

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ABUNDANCE AND DENSITY OF THE FRESHWATER PEARL MUSSEL *MARGARITIFERA MARGARITIFERA* IN RIVERS OF NORTHWEST RUSSIA IN THE PERIOD FROM 1971 TO 1979

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The paper presents data from the studies of the distribution range of the mussel *Margaritifera margaritifera* carried out in 1970–1979. **Novgorod Region.** *M. margaritifera* still inhabited the upper courses of the rivers least affected by the industry, which originate from Valdai hills, for example, Polomet', Horinka. **Leningrad Region.** No *M. margaritifera* found in rivers of the Ladoga Lake drainage basin, such as Ojat', Pasha, Kapsha, although spawning of salmonids is common throughout. **Arkhangelsk Region and Karelia.** *M. margaritifera* was found in several rivers. In the Keret' River, which used to be a centre of pearl harvesting until the late 19th century, colonies of *M. margaritifera* were present only in the lower reaches. No mussels were found in another large river of the White Sea basin – Kem', although both rivers had been used for timber rafting up until the 1960s. Both rivers still contain salmon spawning areas. In the Arkhangelsk Region, colonies of the mussel with a density of up to 50 ind./m^2 were found in the Kazanka River, with hardly any pearl mussels present in the numerous tributaries of Severnaya (Northern) Dvina or on the southern coast of the White Sea. **Kola Peninsula.** Colonies of *M. margaritifera* were detected in the transboundary (Russia, Finland and Norway) Petsojoki River system. Extensive populations of *M. margaritifera* were found in many tributaries of the Tuloma River, which also originates in Finland. Examples of rivers with well-preserved pearl mussel populations are the Kola River (Barents Sea watershed), and the Varzuga River with its tributary Pana (White Sea watershed). Centuries of human pressure have resulted in near extinction of the mussel *M. margaritifera* from the majority of rivers of Northwest Russia.

Key words: Northwest Russia, freshwater pearl mussel, abundance

INTRODUCTION

The history of Russian pearls in the territory of Russia is mainly bound to the Northwest of the country. Peter the Great showed particular interest in northern pearls (Alopeus, 1787; Kazanskiy, 1891). In his decree issued on July 8, 1721 he prohibited both peasants and landowners to fish for pearls in Novgorod Province, Rzhev and Toropets provinces. Only state servants could harvest pearls. However, a new decree was issued just a year later. It allowed anyone to fish for pearls without restrictions under the condition that all the pearls collected were delivered to the Board of Commerce. Three quarters of the value of the pearls were paid to the fisher, and the state received the remaining quarter.

After the revolution of 1917, a few attempts were taken to investigate the populations of *Margaritifera margaritifera* in Northwest Russia. Thorough studies of the state of *M. margaritifera* populations in rivers of the Kola-Karelian region were carried out by Vereshchagin (1929).

Industrial development in the Northwest of the USSR, including logging and construction of numerous hydropower plants, has led to extinction of *M. margaritifera* from many waterbodies (Korago, 1981). One should note however that the surveys carried out in the Soviet period (Vereshchagin, 1929; Vlasov, 1934; Gaevskiy, 1926; Golubev et al., 1973; Golubev et al., 1974; Graevskiy et al., 1949; Zhadin, 1939) prove large colonies of *M. margaritifera* were present in many rivers of Northwest Russia.

Below we present data on the distribution range of *M. margaritifera*, and the state of its populations in specific rives of Northwest Russia in 1970–1979. The data remained unpublished for many years as they were property of the Ministry of Geology and the Jewelry Industry. We thought it wise to make data on the history of studies of the mussel's range more complete.

In 1969, the jewelry industry administration of the USSR charged one of the authors of the present paper with the task to assess the freshwater pearl mussel stocks in Northwest Russia.

The question was quite natural because rivers of the region have for several centuries (up to the 20^{th} century) supplied jewelry pearls to the imperial court and to the Church.

To fulfill the task, the following had to be done:

1. Determine current boundaries of *M. margaritifera* range.
2. Estimate the stocks in the watercourses where pearl mussel populations were in good condition.

MATERIALS AND METHODS

According to archival data, distribution of the freshwater pearl mussel *M. margaritifera* in Russia is bounded in the south by Valdai hills. In the north, the mussel's distribution is limited by the White Sea and the Barents Sea.

The following conventional subdivision of the range from south to north can be made:

1. Rivers of Lake Ilmen' drainage basin (Novgorod Region).
2. River systems of Lake Ladoga and the Gulf of Finland (Leningrad Region).
3. Rivers of Lake Onego drainage basin and transboundary water systems of Finland and Karelia, as well as rivers of the White Sea basin (Arkhangelsk Region).
4. Rivers of the Kola Peninsula.

The amount of factual material amassed over the 10 years of research is quite extensive, wherefore we shall limit ourselves to general data on the above zones, with some typical examples.

Most of the rivers were surveyed throughout, from source to mouth. The bottom of the rivers was examined from a boat through the «Korean window» (a box with glass). Every kilometre, the bottom was surveyed by divers for exact counts of mussels in sample plots (1 m^2). All sample plots were mapped, indicating the number and coordinates.

Sites of certain length and width were marked out in localities with the greatest numbers of mussels. E.g., length – 1 000 m; width (according to 6 measurements) – 50 m. Area S=1000x50=50 000 m^2. Mean density of *M. margaritifera* micropopulations within such sites averaged for 18 sample plots was 13 ind./m^2. Thus, the total number of mussels per site was 50 000x13 = 650 000 individuals.

DISCUSSION

According to historical data, *M. margaritifera* range is bound in the south by sources of the rivers Shelon', Lovat' and Msta of the Lake Ilmen' drainage basin. Watersheds of these rivers have for centuries been exposed to heavy human pressure: logging, timber floating, agriculture, etc. These activities could not but tell on the water chemical composition, reduce fish stocks, which are an obligatory phase in *M. margaritifera* life cycle, and, hence, reduce the mussel numbers.

Indeed, *M. margaritifera* has survived only in the headwaters of the rivers which originate from Valdai hills, and were least affected by industrial impact. These are small rivers – Polomet', Horinka (Fig. 1).

The surveys were rather unrewarding, given that less than one per cent of the thousand kilometres surveyed yielded some finds, and even there the state of the populations was far from optimal.

There remained either isolated colonies (Kulotina River – density up to 10 ind./m^2) or individual mussels (Rivers Reglinka, Yaryn'ya).

Another area where the pearl mussel may be present, judging by historical data, is rivers of the Ladoga Lake catchment, such as Ojat', Pasha, Kapsha (Fig. 2). The drainage basins of these rivers, including tributaries, were fully surveyed, up to the sources. No *M. margaritifera* was found, although salmonids spawned throughout the area. Intensive timber floating that had taken place there for most of the historical period could be the cause of the mussel's extinction. Drilling of the Ojat' riverbed showed silted tree trunks constitute the bottom sometimes up to several metres in depth. The map demonstrates how thoroughly the rivers were investigated.

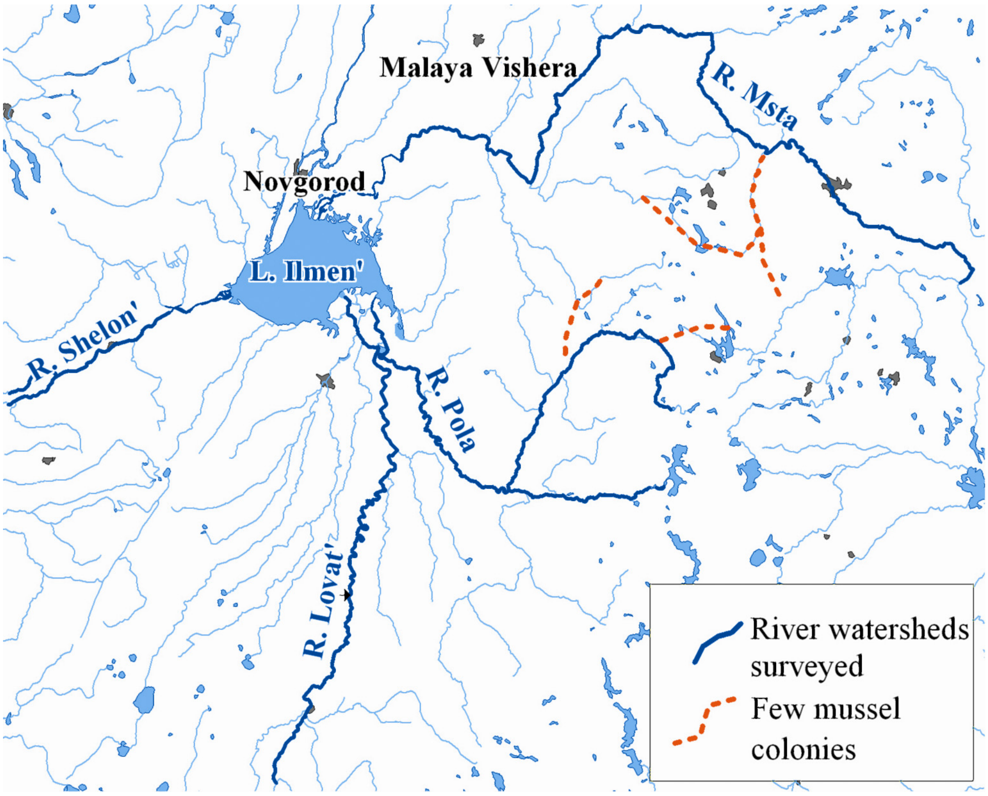

Fig. 1. Rivers surveyed in Lake Ilmen' drainage basin (Novgorod Region)

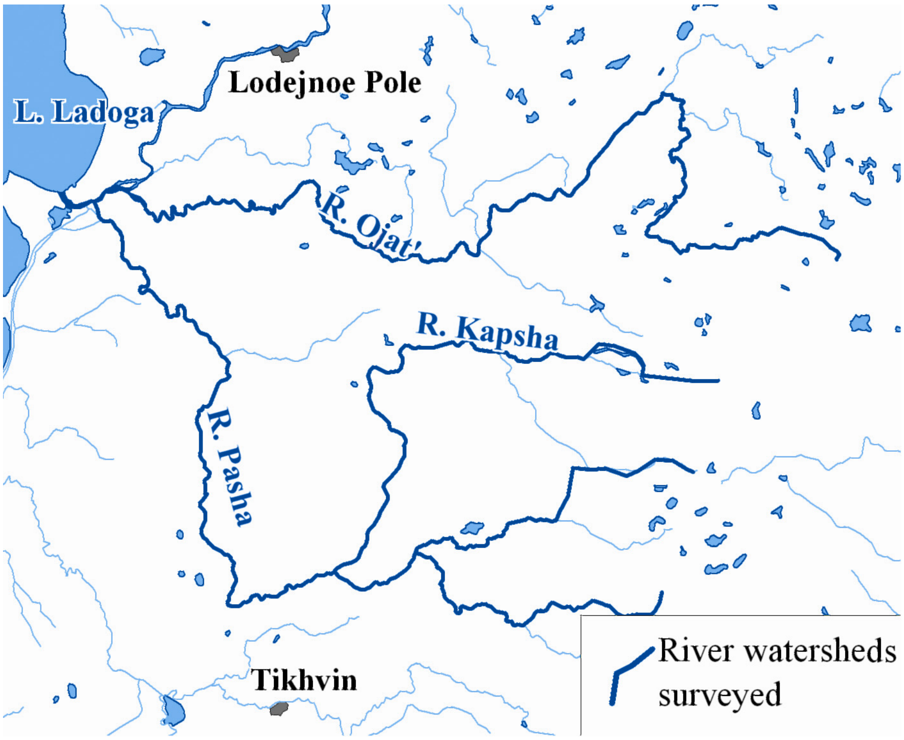

Fig. 2. Rivers surveyed in Leningrad Region *M. margaritifera* was found in the lower reaches of the Olonka River, where its density was 1–3 ind./m^2

The same zone includes small rivers flowing to the Gulf of Finland, and rivers of the Vuoksa system, which contained occasional mussel individuals.

River systems of Lake Onego and the White Sea used to be known for wide occurrence of *M. margaritifera*, and as natural spawning areas of salmonids.

The fate of forest stock in Karelia and Arkhangelsk Region is notorious. In the 1950s–1970s, in addition to conventional logging, the forests were chemically treated from the air. Quite expectedly, *M. margaritifera* populations in the region were severely affected. Only specialized studies can disclose the factors that have enabled survival of some populations. E.g., the Nemina River (Lake Onego): lower reaches (20 km surveyed) – no mussels; middle reaches (15 km surveyed) – *M. margaritifera* colonies with a mean density of 20 ind./m^2; headwaters (20 km surveyed) – no mussels.

The Keret’ River (White Sea) is an old pearl fishing area. No mussels were found in the headwaters (250 km stretch). *M. margaritifera* colonies in good condition (50 ind./m^2) were detected in the lower reaches, both in still and in rapid sites (Fig. 3).

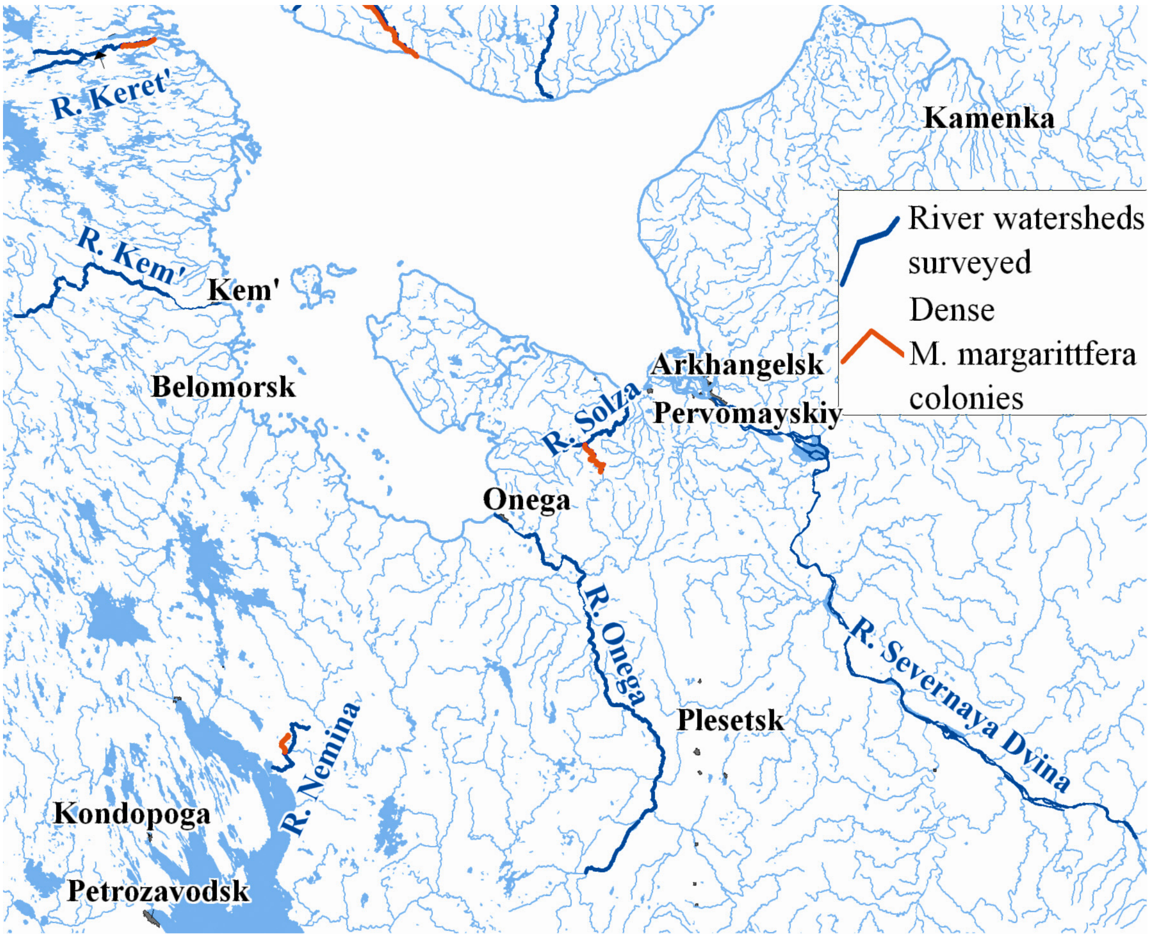

Fig. 3. Rivers surveyed in the drainage basins of Lake Onego (Karelia), and the White Sea (Arkhangelsk Region)

A well-known drainage basin south of Keret’ is the Kem’ River, which has a great number of tributaries. The combined length of the survey routes on the river and its tributaries was more than 500 km. No *M. margaritifera* was found. Note here that until the 1960s timber floating had been very intensive both on Kem’ and on Keret’. Salmonids still spawn in both rivers (Fig. 3).

In Arkhangelsk Region, mussel colonies with a density of up to 50 ind./m^2 were found in the Kazanka River. At the same time, hardly any mussels were present in the numerous affluences of the Severnaya Dvina River basin and the White Sea southern coast.

Kola Peninsula is the northernmost part of *M. margaritifera* distribution range. It all lies north of the Polar Circle. In contrast to southerner areas, there had been no agriculture or logging until the 19th century, whereas salmonids were widespread there.

Keeping these factors in mind, we assumed *M. margaritifera* populations have survived in their historical habitats in the region. These are rivers of the White Sea watershed: Umba, Varzuga, Olennitsa, Pyalitsa, Strel'na, etc., and rivers of the Barents Sea watershed: Jokanga, Voron'ya, Kola, Tuloma, Zapadnaya Litsa, Pechenga, etc. Sources of the Tuloma River, just like rivers Lotta, Iotta, etc. are also of interest as transboundary watersheds (shared with Finland).

Data from surveys of the Kola Peninsula rivers are presented in Fig. 4 and Tab. 1.

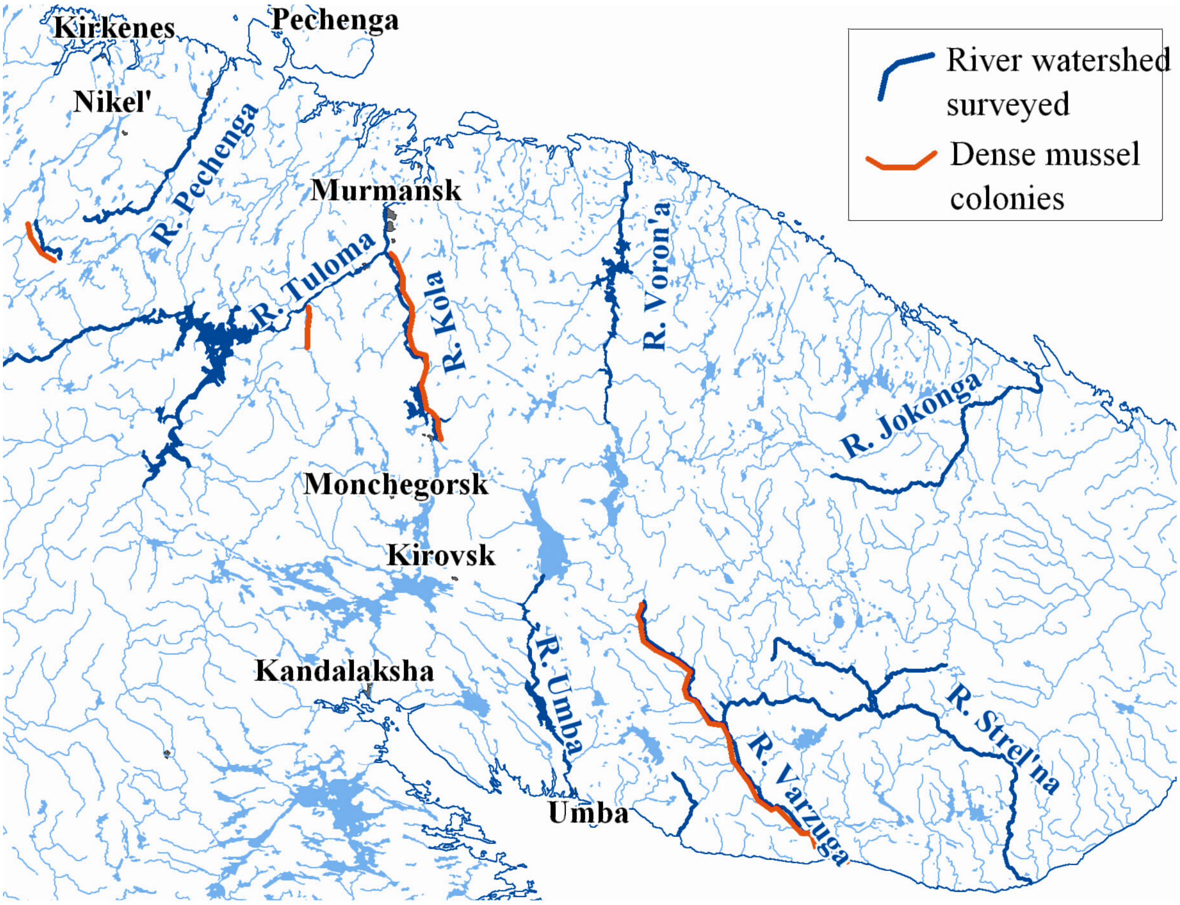

Fig. 4. Surveyed rivers of the Kola Peninsula

The Petsojoki River system is a water system of the lake-river type. It originates from Finland, from Lake Inari, and empties into the Barents Sea near the Norwegian city of Neiden. The right-side tributary of Petsojoki – the 36-km long River Nautsijoki, was surveyed. *M. margaritifera* was present in 30 km of the channel. The population density ranged from 1–5 to 17 ind./m^2 in the lower reaches; the size of the shells was up to 10–12 cm. The mussels were counted in a 100x50 m sample plot in the river downstream, and the result was 650 000 individuals.

Table 1. Surveys of the Kola Peninsula rivers for the mussel *Margaritifera margaritifera*

Drainage basin	Water system	River	Extent of survey routes, km	Presence of mussels
Barents Sea	**R. Pechenga**	**Bolshaya Pechenga**	**72**	absent
		7 tributaries	**130**	absent
	R. Petsojoki	**Nautsijoki**	**32**	Population in good condition
	R. Tuloma	**Malaya Kitsa**	**16**	absent
		Bol'shaya Kitsa	**21**	absent
		Kola	**66**	Population in good condition
		Pecha	**57**	Occasional mussels in the tributaries Kolna, Koodysh
		Nota	**138**	absent
		Yavr	**20**	absent
		Girvas	**14**	absent
		Lotta	**113**	Declining colonies with an average density of 1 ind./m^2, no young mussels
		Ulita	**31**	Population in good condition; the average density of a colony is 15 ind./m^2
White Sea	**R. Umba**	**Umba**	**50**	13 km in the headwaters populated with the mussel (1 ind./m^2); declining colonies
	R. Strel'na	**Strel'na**	**250**	absent
	R. Varzuga	**Varzuga**	**290**	Population in good condition
		Pana	**135**	Population in good condition

Tuloma River system.

The Kola River merged with the Tuloma in its mouth, near Murmansk. Mussels were present in 61 km of the river.

The Ulita River is a right-side tributary, which joins Tuloma in its middle reaches. The mussels were first noted at the confluence with its right-side tributary Gal'sha, and were then present throughout. The population density ranged from 1–2 to 12–15 ind./m^2.

The Umba River is a lake-type river 122 km long, originating from Lake Umbozero. The river has a step-wise profile typical of all rivers of the peninsula: still and rapid sections alternate. The water level is regulated by lakes; the river in general is shallow; it was used for timber floating. *M. margaritifera* began occurring 11 km from the source and was present for 13 km downstream. The population density was 1ind./m^2 – the colonies are declining.

River Varzuga. The channel is 290 km long. The headwaters flow across swampy plain; the channel width is 20–25 m, the depth is 1–1.5 m. After the tributary Pana empties into Varzuga, the channel broadens to 100 m and more, and many rapid sites appear. The number of rapids increases closer to the mouth, the river being confined by rocky banks sometimes for several kilometres. The mussels were found in a 30 km stretch from the Yuziya River to the Pana River. Adult mussels were counted in a 3000x80 m sample plot at the Kichisara River mouth. The resultant number was 2 160 000 individuals, including 17.4% of young mussels.

River Pana is the right-side tributary of Varzuga. Surveys covered 152 km (including tributaries). The river valley is flat, swampy, 10 to 70 m wide. The river is populated with mussels nearly throughout. The population density in the middle reaches was up to 50 ind./m^2. Young mussels contributed ca. 15% to the colonies. The mussels were counted in a 3600x50 m sample plot near the Purumvuej River, and the number of mussels there was 2 340 000 ind.

CONCLUSIONS

Ten years of surveys of river systems in Northwest Russia from the south of Novgorod Region to the Barents Sea coast for the freshwater pearl mussel *Margaritifera margaritifera* have led to the following conclusions:

1. *M. margaritifera* has practically disappeared from rivers of the Novgorod, Leningrad, Arkhangelsk Regions and Karelia. Either occasional individuals or isolated colonies have survived, representing historical samples.

2. Fairly abundant populations of *M. margaritifera* still inhabit several rivers of the White and the Barents Sea watersheds. Presumably, human activities have not yet produced their effect.

3. Older data need to be compared with the state-of-the-art, especially given that the most costly work of searching for mussel populations will not be needed. The mussel habitats have been identified, and the methodology has been tried out.

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CONSERVATION OF THE FRESHWATER PEARL MUSSEL *MARGARITIFERA MARGARITIFERA* IN SWEDEN BY AN EU-LIFE PROJECT

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During 2004-2009 WWF Sweden conducted a project "The freshwater pearl mussel and its habitats in Sweden". The project was financed by the EU LIFE Fund, Swedish Environmental Protection Agency and partners involved.

The overall objective was to improve the habitats for juvenile freshwater pearl mussel *Margaritifera margaritifera* and its host fish Brown trout *Salmo trutta* in 21 streams. The actions were improvements of the biotopes, re-introduction of mussels, information to the stakeholders, development of planning methods. The results of the actions could not be documented during the project period due to the difficulty to detect the juveniles. However, monitoring programmes will give data in the coming years. One output of the project is a manual for managing freshwater pearl mussel streams, based on experiences from the LIFE-project but also other projects in other countries.

Key words: Sweden; *Margaritifera margaritifera*; freshwater pearl mussel; conservation; restoration; LIFE

INTRODUCTION

Scandinavia and Scotland are the core areas for the remaining populations of threatened freshwater pearl mussel (freshwater pearl mussel) *Margaritifera margaritifera*. In Sweden there are approx. 550 streams with freshwater pearl mussel. However, the species has gone extinct in 1/3 of the streams and there is no recruitment in 3/4 of the remaining streams. The Swedish freshwater pearl mussel conservation strategy is based on (1) habitat protection and (2) habitat improvement.

Many Swedish freshwater pearl mussel streams are Natura 2000 sites, the European Union (EU) network of protected areas. Some of these streams and their surroundings are also nature reserves. However, this habitat protection does not guarantee real protection. Most of the Natura 2000 sites just include the stream, but not the riparian zone, and the reserves hardly ever include the whole catchment. Legal protection is not enough to save freshwater pearl mussel in Sweden.

There is great need for habitat improvements to create biotopes especially for juvenile mussels but also for the host fish – the Brown trout *Salmo trutta.* During the last decade some restoration projects focused on freshwater pearl mussel have been implemented in Sweden. In 2004, WWF Sweden initiated a project "The freshwater pearl mussel and its habitats in Sweden" with grants from the EU LIFE Nature Fund, the Swedish Environmental Protection Agency and the partners involved[1]. The partners were three county administrative boards, one city, Swedish Forest Agency, and Karlstad University.

PROJECT ACTIONS

The actions were:

(1) Improvements of the biotopes: establishing new "mussel beds" consisting of gravel and stone material to counteract siltation and to get a clean substrate where small mussels can survive, eliminating migration obstacles for host fish, and restoring river bottoms that had been cleaned to facilitate floating of timber, plugging ditches to eliminate input of fine particulate matter and thus prevent siltation.

(2) Re-introduction in one stream with just a few freshwater pearl mussel specimens left.

[1] EU LIFE Nature project "The Freshwater Pearl Mussel and its habitats in Sweden" (LIFE04NAT/SE/000231)

(3) Information to actors/stakeholders: in public and personal meetings with the actors (landowners, forestry operators, etc.) information and advice are given to achieve improved care for water in e.g. forestry.

(4) Development of planning methods: development of action plan at two levels – drainage area and biotope.

Fig. 1. A – Restoration of the stream bed by adding stones which had been removed to facilitate timber floating. B –Restoration of the riparian zone by eliminating planted spruce trees
Photo by *Lennart Henrikson*

RESULTS AND EXPERIENCES

The overall experience was that the actions were successful, but it was not possible to document any improvements of the recruitment of juvenile freshwater pearl mussel in the project streams during the project period. The reason is that it is very difficult to detect these small mussels. However, for each stream there is a monitoring programme, which will indicate whether the actions were successful.

One purpose was to decrease siltation, i.e. the clogging of the bottom substrate by fine particles. One action was to measure the degree of siltation. This was done by Martin Österling. Together with co-workers he found a correlation between the amount of fine particles and the occurrence of young mussels (Österling *et al.,* 2006). This study will be repeated and included in the monitoring programme.

The project is described in a "layman' report" (Anonymous, 2009). The practical experiences of the Swedish project, but also from other projects in Europe were summarized in the handbook "Restoration of freshwater pearl mussel Streams" (Degerman *et al.,* 2009). A travel report describing other European freshwater pearl mussel projects was published (Henrikson, 2009).

An international conference "Aquatic Conservation with Focus on the freshwater pearl mussel *Margaritifera margaritifera*" was held in Sundsvall on August 12–14, 2009. Proceedings from the conference will be published in spring 2010. More information and project publications are found at www.wwf.se/fpm.

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RIVER VARZUGA AT KOLA PENINSULAR, NW RUSSIA – A FRESHWATER PEARL MUSSEL RIVER WITH CONSERVATION VALUES OF GLOBAL INTEREST

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River Varzuga has the world's greatest (known) population – 140,000,000 specimens – of the Freshwater Pearl Mussel *Margaritifera margaritifera*. It also probably hosts the largest population of Atlantic Salmon *Salmo salar* in the world. The reason for that is that the river itself and the catchment are little affected by human activities, i.e. it is a pristine river.

Studies of water quality, bottom fauna and fish were made by Swedish scientists in 1995 and 1997. They concluded that River Varzuga (1) has very high conservation value, due to a high degree of naturalness and rarity, (2) is a pristine river and can be used as an unaffected reference for affected rivers in the northern part of Scandinavia, (3) is utilised for commercial as well as recreational fishing in a sustainable way.

In 2006, WWF Russia and Kola Biodiversity Center compiled data on the catchment. They concluded that the River Varzuga catchment: (1) can be divided into three large and uniform areas with different vegetation and human impact, (2) has areas of high terrestrial conservation value, e.g. old-age spruce forest, (3) the human impact is low or moderate, being most pronounced in the western part, mainly due to forestry.

This means that not just the river itself but also the whole catchment is of conservation interest. The potential threats are increased exploitation of natural resources like forest and minerals, and, perhaps, the salmon parasite *Gyrodactylus salaris* and the introduced salmon *Oncorhyncus gorbusha*.

River Varzuga and its catchment have extremely high conservation values not only in Russian but also in an international perspective. The river is of global interest concerning aquatic biodiversity. Therefore, a strategy for management and/or protection ought to be developed as soon as possible.

Key words: Russia; *Margaritifera margaritifera*; freshwater pearl mussel; status; conservation, pristine river

INTRODUCTION

The Varzuga River originates from the central part of the Kola peninsular, Russia, crosses the Arctic Circle, and empties into the White Sea (Fig. 1). The catchment is very little affected by human activities: limited forestry and agriculture; no alteration of the main river channel; unaffected water flow, minimal effects by air pollution, restricted fishing. The river is of international interest because of its great populations of the Freshwater Pearl Mussel *Margaritifera margaritifera* and Atlantic Salmon *Salmo salar*. In addition, there are a lot of historical and cultural monuments, as wells as venerated springs.

The Varzuga River was studied by a Russian-Swedish expedition in 1995 and 1997 (Bergengren et al., 2004). The objectives were (1) to study the Freshwater Pearl Mussel population, fish population, bottom fauna and water quality, (2) to assess the value of Varzuga as an unaffected reference for affected Swedish rivers. The results may also be used if protection measures are taken. In 2006, WWF Russia and Kola Biodiversity Center compiled data on the catchment (Belkina et al., 2006).

The objective of this paper is to present Varzuga and its conservation values.

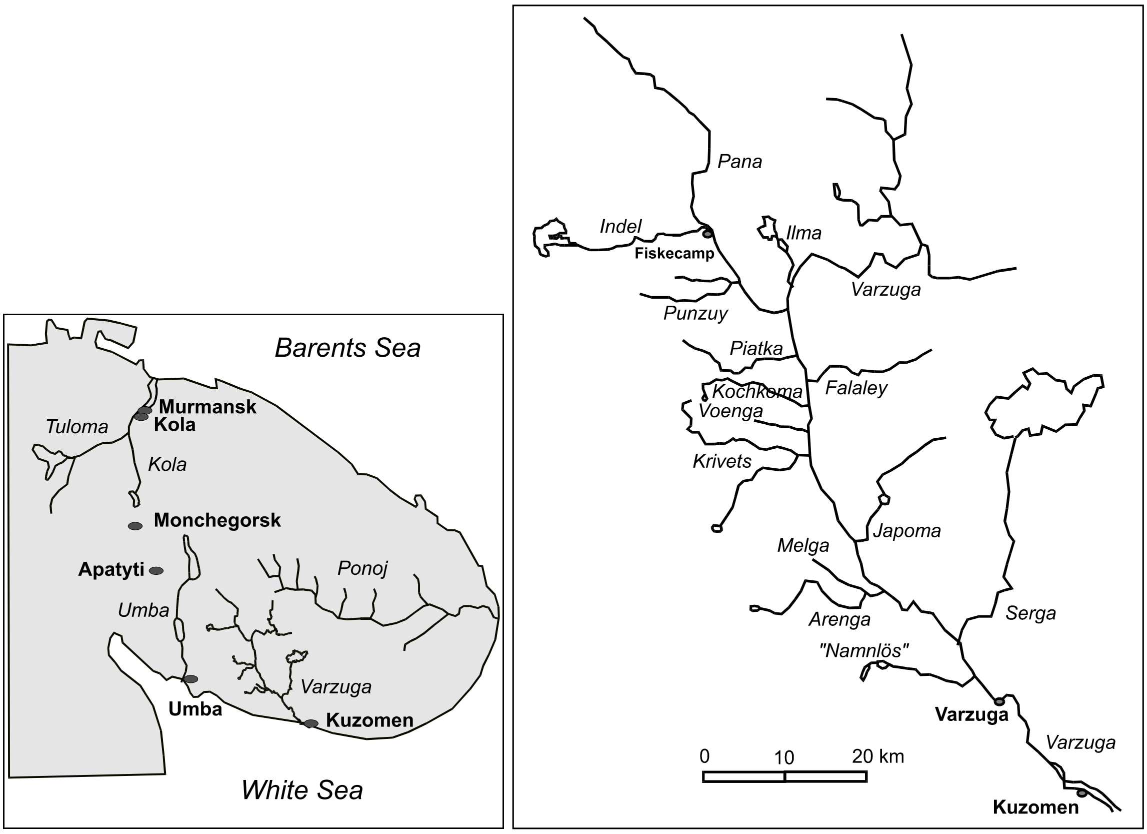

Fig.1. Maps showing River Varzuga on the Kola Peninsular (left) and the water system (right) (from Bergengren *et al.,* 2004).

DESCRIPTION OF THE RIVER AND ITS CATCHMENT

The river length is 254 km and the drainage area is 9 885 km^2. The width is around 80 m on average (300 m at max) and the depth is 0.2–2.5 m. The annual mean water discharge is 85 m^3/s with a peak in May. The water flows rather slowly (0.2–1.5 m/s), and there are no waterfalls in the main channel. There are more than two thousand lakes, occupying 3 % of the catchment area. There is a dam in the upper part of the tributary Indel, and a man-made canal built for timber floating leads from this dam to the adjacent Umba catchment.

The bedrock mainly consists of Proterozoic rocks and Quaternary deposits moraine. The catchment belongs to the boreal taiga subzone and is covered with forest (birch, pine, spruce) in dry sites and plenty of mires. Natural fires are important "processes" forming the forests. One third of the catchment is old-age forests where rare and red-listed species can be found (Table 1). The uppermost/northern part is tundra, and here the highest site, 629 m a.s.l., is found. The climate is warmer than in many other areas at the same latitude due surrounding sea. The annual precipitation is 500–600 mm. The average annual temperature is -0.6 ^{o}C.

Table 1. Vegetation types in the Varzuga River catchment (from Belkina *et al.* 2006)

Vegetation type	Percentage cover
Old spruce forests	32.5
Old pine forests	5.1
Old birch forests	0.6
Wetlands	212
Cleared and burnt-over areas, 50 years	19
Other communities	21.8

The land use is forestry, agriculture, tourism and prospecting/exploration for minerals. However, these human activities apparently affect the catchment and the river to a minor extent.

One hundred species red-listed in the Murmansk region live in the area. The most spectacular ones are the White-tailed Sea Eagle *Haliaetus albicilla*, Grey Wolf *Canis lupus*, Brown Bear *Ursus arctos*, and the Freshwater Pearl Mussel. The Muskrat *Ondatra zibethicus* is an alien species that may predate on the Freshwater Pearl Mussel.

Fig. 2. River Varzuga and the beautiful church at the Village of Varzuga
Photo by *Lennart Henrikson*

WATER QUALITY

Bergengren et al. (2004) conclude from the analysis of the water quality that the water in the Varzuga catchment is brown coloured due to humic substances from the mires, the content of anthropogenic sulfate and a small difference in the hardness and alkalinity indicate a very low impact of acidification, low or moderate content of total phosphorus and the lack of pollution indicate low impact of eutrophication. This is supported by data from Belkina et al. (2006).

AQUATIC BIOLOGY

The fish fauna comprises 18 species, of which one – pink salmon *Onchyrhynchus gorbuscha*, is introduced. The Atlantic Salmon reach a size of 5–6 kg. Brown trout *Salmo trutta* are found as "brook trout» and "sea trout" but the stronger competitor – the Atlantic salmon dominates. Atlantic salmon densities are very high in the main channel as well as in the tributaries. The Varzuga River has very large areas (2,000,000 ha) suitable for salmon production, and the river probably hosts the largest population of Atlantic salmon in the world. Infection by the salmon parasite *Gyrodactylus salaris* is found.

Bergengren *at al.* (2004) found 14 benthic species listed in Scandinavian red lists. The water colour may explain differences in e.g. species composition between different streams in the Varzuga system. The bottom fauna of the Varzuga system has more taxa sensitive to acidification or pollution than Swedish streams. The bottom fauna indicates minor impact by human activities.

The Freshwater Pearl Mussel population is the largest in the world (approx. 140 millions specimens) (Ziuganov *et al*., 1994). The population is viable, as indicated e.g. by a great proportion of young mussels. The conservation value of the mussel population is very high.

HUMAN IMPACT

The catchment is generally used in an extensive mode, for example in the lower parts around the Varzuga village. Today, there are only few local forestry companies operating in the western part. The hydromorphology is also little affected, but the dam in Indel prevents fish passage. The water quality, as well as air quality, is very good. The waters are used for canoeing, sport fishing and commercial fishing. The latter is practiced at the Varzuga village, and can be regarded as sustainable fishing. An overall conclusion is that the human impact is very low.

SYNTHESIS AND CONCLUSIONS

Based on Bergengren *et al.* (2004) and Belkina *et al.* (2006) the following conclusions can be drawn:

- The River Varzuga and its catchment have very high conservation value, due to a high degree of naturalness and rarity.
- The conservation values and the naturalness values are extremely high in the Russian as well as in the international perspective.
- Present-day land and water use do not severely affect the aquatic ecosystem.
- The fish population is utilised for commercial as well as recreational fishing in a sustainable way.
- The main threat to River Varzuga is exploitation of natural resources like forest and minerals in the catchment. The potential threats of the salmon parasite *Gyrodactylus salaris* and the introduced salmon *Oncorhyncus gorbusha* must be evaluated.
- A strategy for management incl. protection ought to be developed as soon as possible. The catchment basin is heterogeneous, and differentiated approaches to nature management and nature protection should be employed, with the variety of natural conditions and different history of nature management in different sites within its area being taken into account.

In conclusion, River Varzuga and its catchment is of very high conservation value not only in Russian but also in an international perspective. Most rivers in the world are strongly or moderately affected by human activities, such as fragmentation, regulation by dams, and pollution. Especially in Europe only a few rivers may be regarded as pristine – River Varzuga is one of these. The river is of global interest in terms of aquatic biodiversity but also as an unaffected reference for affected rivers in the northern part of the world. Therefore, a strategy for management and/or protection ought to be developed as soon as possible.

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FRESHWATER PEARL MUSSEL IN KOSTOMUKSHSKY STRICT NATURE RESERVE AND ADJACENT AREAS

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The freshwater pearl mussel *Margaritifera margaritifera* has been registered from several places in the Kamennaya River within the Kostomukshsky reserve and in the Liva River in Kostomukshsky District. The population is in fairly good condition.

Key words: Freshwater pearl mussel, Kostomuksha, northwest Russia.

INTRODUCTION

There are several species registered from the territory of Kostomukshsky strict nature reserve that are listed in Red Data Books of various levels: there grow 15 species of plants and 3 species of fungi, and 39 species of vertebrates and 10 species of invertebrates reside there or were noted on migration. Among these, the European freshwater pearl mussel (*Margaritifera margaritifera*) has the highest protection status, being listed in the IUCN Red Data Book as an endangered species.

In 1995, the pearl mussel was noticed for the first time in the River Kamennaya, which originates from the lake of the same name. In the next year 1996 two new inhabited sites were found (Kashevarov and Nikitin, 1998; Nikitin and Kashevarov, 1998). Both sites are situated downstream from rapids and have sandy bottom. The depth is 1–2 m. The distance between them is around 5 km. Mussel population density in one of the sites is 1–2 specimens per sq. m, and in the other site 0.1–0.2 specimens only.

MATERIALS AND METHODS

In July 2009, a repeated inspection of one of the inhabitancies on the Kamennaya River together with Finnish specialists P. Oulasvirta and J. Heikkilä was arranged (Fig. 1). Diving equipment, including scuba and waterscope, was used for the inspection.

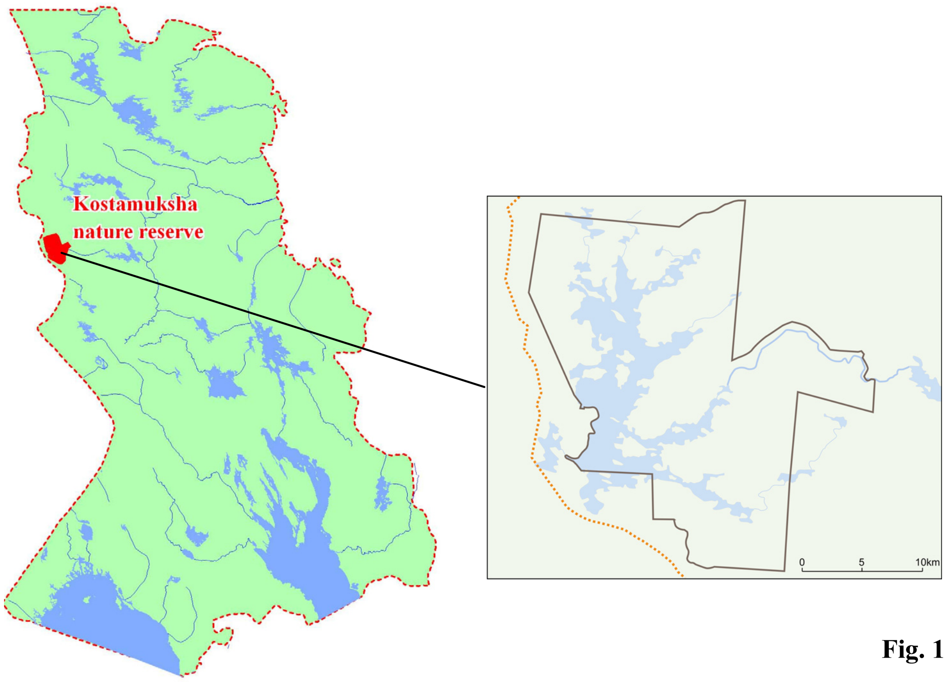

Fig. 1. Kostomuksha nature reverse

RESULTS

In 2009, dwelling of the species was confirmed in a pool downstream of Saarikoski, where more than 100 specimens of the mollusc of various sizes were found. The survey results are reported in more detail in the paper by Oulasvirta in this volume. Let us just note that the water level in the Kamennaya River during the survey was unusually high for that season (Fig. 2).

Fig. 2

One should add that in 2000, shell valves of the pearl mussel (in all appearance, recently eaten by an animal) were found on the shore of a small lake connected to the River Kamennaya by a 1 km long stream. This point is 2 and 5 km away from the sites found earlier.

Also, during the summer of 2009 an earlier suggestion was confirmed about the possibility of the pearl mussel dwelling in another watercourse in Kostomukshsky District: in the system of the Liva River, which empties into Lake Upper Kuito. Several specimens were found in a shallow place in the upper reaches of the river (oral communication and a photo by the Kostomukshsky reserve guard A. Astakhov). Previously, a numerous population of another bivalve (*Anodonta anatina*) was registered from lower reaches of the Liva River (R. Tollojoki).

CONCLUSIONS

Thus, dwelling of the freshwater pearl mussel in reservoirs of Kostomuksha has been confirmed, but is not yet reflected in the Red Data Book of Republic of Karelia (Ivanter and Kuznetsov, 2007). One may assume the pearl mussel population in Kostomukshsky reserve is in good condition, and that the species inhabits suitable places throughout the Kamennaya River downstream of Saarikoski rapid and in some of its tributaries. Thus, studies of the freshwater pearl mussel in reservoirs of the Kostomuksha area should be continued, the newly found places of its habitation should be carefully examined, and measures for their protection should be taken.

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ASSESSMENT OF THE HABITAT CONDITIONS FOR THE FRESHWATER PEARL MUSSEL *MARGARITIFERA MARGARITIFERA* (L.) IN THE HEADWATERS OF MAJOR RIVERS OF MURMANSK REGION

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Surveys to assess habitats of the European pearl mussel *Margaritifera margaritifera* (L.) in upper reaches of the major rivers of Murmansk Region were carried out. The main aim was to investigate the upper reaches of the main rivers with the "salmon-inhabited" status – the area around the deposit proposed for mining – as a potential habitat of the pearl mussel. It was found that the distribution of *M. margaritifera* depends on the hydrological and hydrochemical parameters of waters and the availability of river sites suitable for spawning and growth of salmonids. On the whole, the conditions in the very upstream of the rivers surveyed are not favorable for the mollusk because of heavily silted channels and the absence of host-fish species. Among-year variation of the water level in rivers was found to be one of the key factors for mollusk finding.

Key words: pearl mussel, headwaters, habitat conditions, water quality

INTRODUCTION

The freshwater pearl mussel *Margaritifera margaritifera* (L.) has become endangered as the result of growing anthropogenic pressure. Very high water quality requirements and peculiarities of the life cycle, which is strongly dependent on symbiotic relations with salmonids – *Salmo salar* L. and *Salmo trutta* L., make this species unique. The freshwater pearl mussel is widespread in the biggest salmon rivers of Murmansk Region, but there is little information about potential habitats of *M. margaritifera* in the headwaters of these watercourses, although quite a number of papers deal with its biology in their middle and lower courses (Prokhorov, 1995, 1996; Zyuganov et al., 1993, 1998, 2000, 2001). However the existing populations of mussels are exposed to human impact and their abundance it therefore decreasing. More detailed information is needed on the population abundance and the spatial limits of its extension upstream. As a rule, habitat conditions in the headwaters of so-called "salmon" rivers are not favorable for *M. margaritifera*, but any human activity there would be a serious threat to the mussel populations downstream. The main aim of this study was to monitor potential habitats of the freshwater pearl mussel in the area of the planned mining and ore processing enterprise (headwaters of the Murmansk Region major rivers: Umba, Varzuga, Voron'ya).

MATERIALS AND METHODS

The study area is situated in the vicinity of the planned mining and ore processing enterprise right in the middle of the Kola Peninsula, where its three main river systems originate (Fig. 1). Three river sites were investigated: Kitsa–Umba river system – the 5 km long stretch upstream of the Kitsa River mouth; Tsaga–Voron'ya river system – from the source to the point 2 km downstream of Lake Nizniy Tsagajavr; Pana–Varzuga river system – from the source of the Pana River to the point 1 km downstream of its confluence with the Chernaya River.

Hydrochemical analysis. Water sampling was carried out in the rivers during the year in the period of 2004-2008. Chemical analyses were performed in the laboratory. The samples were analyzed for pH, total mineralization, organic matter, water color, P, N, Fe, oxidation characteristics. All the analytical methods applied to determine the above hydrochemical parameters conformed to international standards (Lurje, 1984; Standard method…, 1975).

Analysis of water mosses. Samples were collected from the river sections with the highest percent cover of mosses: 70–100%. Determination of the species composition and description of the ecological characteristics of the mosses were carried out following Garibova et al. (1978), Abramova et al. (1961), Abramova &Volkova (1998), Ignatov & Ignatova (2003, 2004).

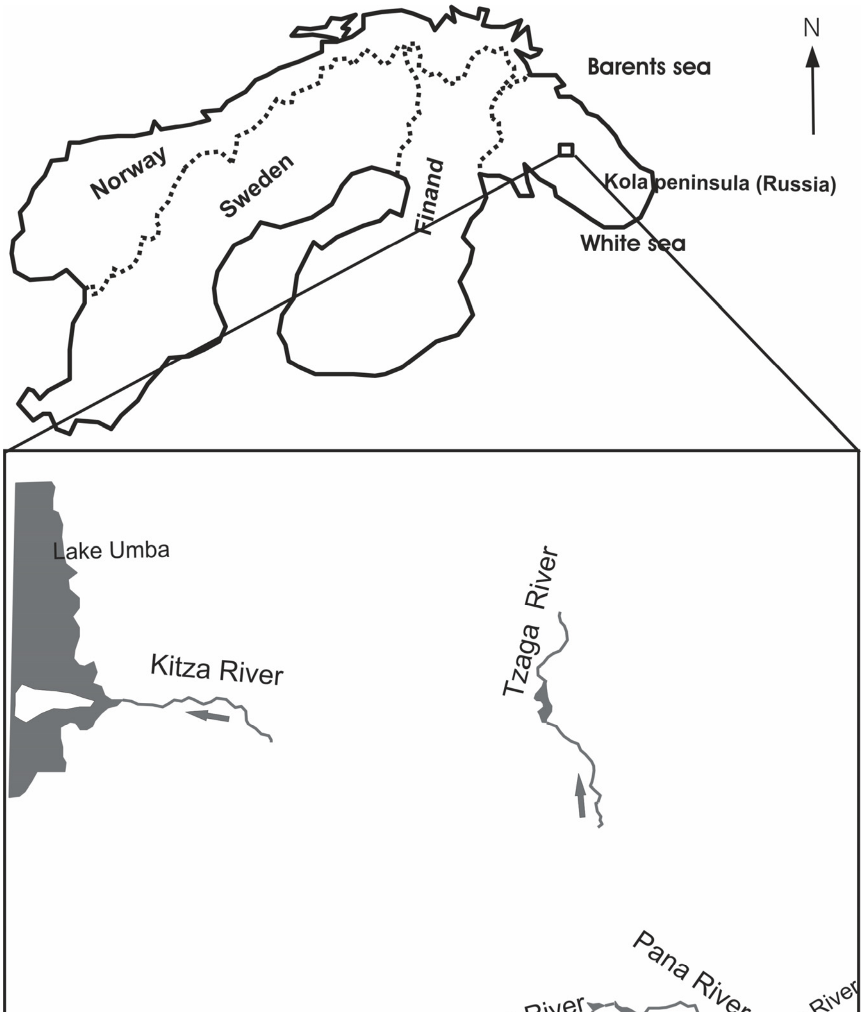

Fig. 1. Locations of the surveyed sections in the headwaters (Kitsa River – Umba River basin; Tsaga River – Voron'ya River basin; Pana River – Varzuga River basin)

Ichthyological surveys. Determination of the fish species composition was conducted in August–September of 2008. Special focus was on detailed assessment of potential spawning and nursery areas of *S. salar* and *S. trutta.* The surveys were conducted using portable equipment manufactured by Ing. S. Paulsen FA-3 (Trondheim, Norway) as in Amundsen et al. (2004), Bohlin et al. (1989), Reynolds (1996), Young and Schmetterling (2004). The density of salmon and trout parr was estimated through electrofishing following the technique by Zippin (1956) and Karlstrem (1976). Each individual was analyzed for weight, length and age (by scales).

Mussel surveys. The presence of *M. margaritifera* in the rivers was estimated by visual examination of the bottom and by findings of shells on the banks. The mussels were analyzed for weight, length and age (Semyonova et al., 1992; Prokhorov, 1995, 1996; Zyuganov et al., 1993, 1998, 2000, 2001).

RESULTS

Hydrochemistry. The river sites surveyed have the following hydrochemical characteristics: Tsaga River (pH – 5.93-7.26, mineralization –9.8-43.8 mg/l, oxygen content – 8.87 mg/l, oxidation capacity – up to 8.63 mgO/l, water colour – 16-96°); Kitsa River (pH – 6.33-7.21, mineralization – 14.1-54.0 mg/l, oxygen content – 8.03 mg/l, oxidation capacity – up to 12.12 mgO/l, water colour – 30-144°); Pana River (pH – 6.04-7.16, mineralization –5.15-51.1 mg/l, oxygen content – 8.02 mg/l, oxidation capacity – up to 8.12 mgO/l, water colour – 24-58°).

Analysis of P, N, Fe and organic matter content in the investigated river sites demonstrated a similar pattern during the period of 2004-2008, but the values of these elements in the Kitsa River and the Tsaga River were higher than in the Pana River. P, N and Fe content showed high variation in all the rivers studied (Fig. 2).

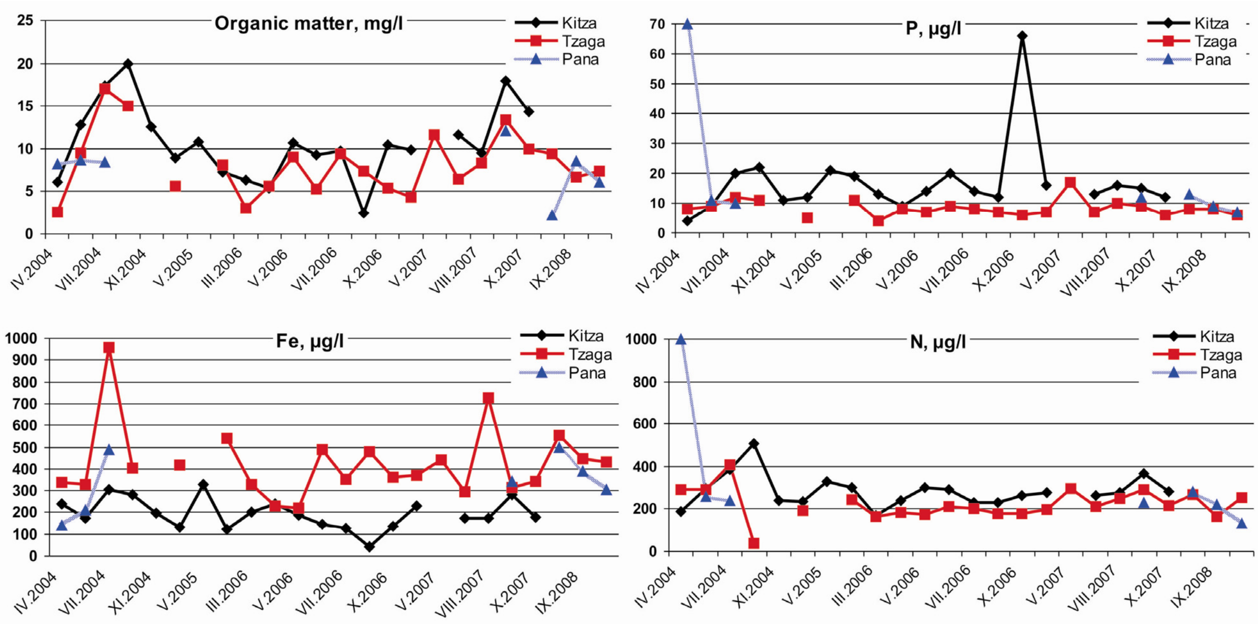

Fig. 2. Long-term data on some hydrochemical parameters (organic matter, P, Fe and N) in the surveyed river sections

Water mosses. Seven moss taxa were found in the investigated river sites: Pana River (*Fontinalis antipyretica* Hedw., *Fontinalis dalecarlica* B.S.G.); Tsaga River (*Warnstorfia fluitans* (Hedw.), *Campilium sp.; Ochyrea alpestris* (Sw. ex Hedio), *Bryum sp.*); Kitsa River (*Hygrohynella ochracea* (Turn. Ex Wils.)). These mosses are widespread arctic and polar taxa typical of oligotrophic waters.

Fish fauna. On the whole, the most common fish species in the headwaters of the rivers are: *Thymalllus thymallus* (L.), *Lota lota* (L.), *Perca fluviatilis* L., *Esox lucuis* L. and *Phoxinus phoxinus* (L.). The most favorable conditions for spawning and growth of salmonids were found in the Chernaya River (Pana River tributary) and in the Pana River (at the confluence with the Chernaya River), where *S. salar* parr were registered (Fig. 3, Tab. 1). Downstream of where the Chernaya River empties, Pana has all the characteristics needed to maintain salmon spawning, as well as salmon parr and the freshwater pearl mussel.

The total density of *S. salar* parr in the spawning and nursery areas is high (Tab. 2), with the age class 1+ prevailing. These data are in conformity with previous results obtained for the Pana River (Kalyuzhin, 2003).

The Kitsa River was found to have *S. trutta* spawning areas and juveniles in all riffle sites of the investigated section. The total density of trout parr in the spawning and nursery areas ranged within 18.4-48 individuals per 100 m^2, which corresponds to the moderate level, with domination of the 1+ age class (Fig. 4, Tab. 3).

Table 1. Size-at-age characteristics of salmon parr in the Chernaya River

Age class	Length AB, cm	Length AC, cm	Weight, g
0+ (n=6)	3.3±0.09	3.13±0.07	0.33±0.02
1+ (n=12)	5.78±0.07	5.48±0.07	1.5±0.05
2+ (n=8)	8.3±0.04	7.85±0.06	4.2±0.07

Table 2. The density of salmon parr in the spawning and nursery areas of the Chernaya River in 2008 (ind./100 m^2) (N = 26)

Density in different age classes			
0+	1+	2+	Total
31.5	63.0	42.0	136.5

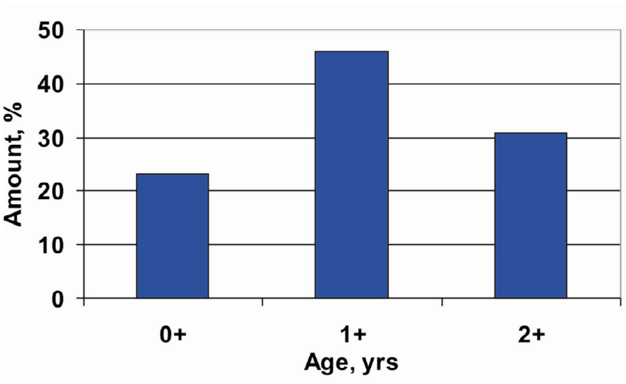

Fig. 3. Age composition of Atlantic salmon parr in the surveyed sections of the Pana River in 2008 (N = 26)

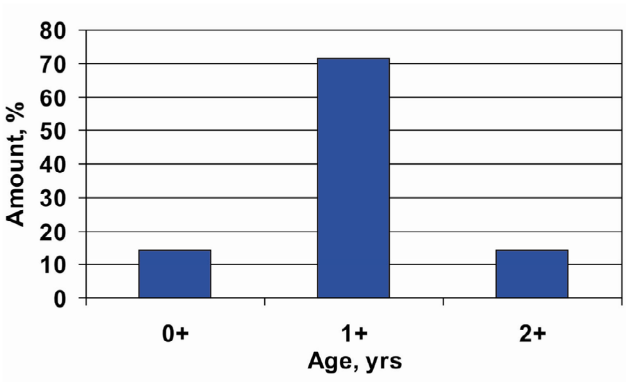

Fig. 4. Age composition of trout parr in the surveyed sections of the Kitsa River in 2008

Table 3. Size-at-age characteristics of trout parr in the Kitsa River (N = 7)

Age class	Length AB, cm	Weight, g
0+ (n=1)	1.2	5.5
1+ (n=5)	9.6±0.3	6.6 ±0.6
2+ (n=1)	11.2	11.4

The surveys of the Tsaga River upper reaches revealed no sites potentially suitable for trout spawning and growth because of unfavorable riverbed characteristics, but presence of suitable trout spawning sites in the river lower reaches cannot be excluded.

Benthic fauna and the European pearl mussel. The benthic community in the studied rivers comprises 12 groups (*Oligohaeta, Hirudinea, Gastropoda, Bivalvia, Chironomidae, Ceratopogonidae, Thrihoptera, Coleoptera sp, Ditiscidae, Ephemeroptera, Odonata, Plecoptera)*. All the invertebrate groups detected are included in the diet of salmonids (Shustov, 1983). Indicator-species of high water quality (*Ephemeroptera, Plecoptera*) were recorded in all rivers surveyed.

Among-year variation of the water level in rivers is one of the key factors for finding mollusks. E.g., the exceptionally high water level in all studied rivers in 2008 made the survey results on potential mussel colonies unreliable. Further surveys of the Pana River in 2009 yielded more accurate results. The average length of the mussels (N = 30) found in the Pana River upstream of the confluence with the Chernaya River is 54.4 mm (ranging from 47 to 65 mm), average weight is 18 g (13–-28 g), height – 28.8 mm (27–

33 mm). The age of the mussels ranged from 12.7±0.25 to 17.7±0.25 years, averaging 17.9 ± 2.5 years. The corresponding parameters of mollusks from the Chernaya River were as follows (N = 31): length – 93.4 mm (56-101 mm), weight – 71 g (15–93 g), height – 44 mm (28-50 mm). The age of the smallest mussels was 15±0.25 years. Bigger specimens were older than 45 years. Although the density of mussels in the Pana River is low, the presence of relatively young individuals presumably testifies to ongoing reproduction of the *M. margaritifera* population in the upper reaches of the river.

The low flow rate and riverbed characteristics in the upstream of the Tsaga River are unfavorable for pearl mussel habitation.

DISCUSSION

Some authors argue that water oxidation capacity of more than 15 mgO/l is a limiting factor for mussel populations (Zyuganov et al., 1993). Hydrochemically, the localities surveyed are favorable for the mollusk, especially the riffles, where salmonid juveniles were found, but at the very source of the rivers the flow rate is low, the bottom is silty, and host-fish are absent.

It is common knowledge that, being natural adsorption agents, mosses play an important role in self-purification of water ecosystems. The species composition of mosses in the region evidences good condition for *M. margaritifera*: oligotrophic, cold, transparent, fast-flowing waters.

Analysis of the *S. salar* size-at-age structure in the Pana River shows relatively slow growth as compared with salmon from the other rivers. Besides, these values in 2008 were much lower than those previously recorded for the Varzuga River salmon. The reason for that could be negative hydrometeorological conditions during the year. A similar relationship was noted for trout parr in the Kitsa River.

Surveys of the Tsaga River upper reaches did not reveal presence of pearl mussel populations either, but the river also lacked potential trout spawning and nursery areas. Low flow rate and riverbed characteristics in the upstream of the Tsaga River are unfavorable for pearl mussel habitation. Yet, one cannot exclude the mollusk may be present in the river lower reaches. It has to be mentioned that reliability of a study is strongly dependent on the water regime, as has been demonstrated by two-year studies. Thus, no definite conclusion can be drawn about the absence of the pearl mussel from the Kitsa River. Although the density of mussels in the Pana River in 2009 was very low, the presence of young individuals presumably testifies to ongoing reproduction of the *M. margaritifera* population in the upper reaches of the river.

Special attention should be paid to the Pana River ecosystem as a significant salmon watercourse and to the Tsaga River, which will be exposed to serious impact after operation of the mining and processing enterprise begins. Its activities may jeopardize reproduction and spread of salmonid and mussel populations. Further control of the water quality and pollution, and study of the distribution of potential mussel habitats are needed.

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DISTRIBUTION AND STATUS OF THE FRESHWATER PEARL MUSSEL (*MARGARITIFERA MARGARITIFERA*) IN NORWAY

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All available records on the occurrence of the freshwater pearl mussel *Margaritifera margaritifera* in Norway have been collected, and we have information about 504 streams or localities. The freshwater pearl mussel is still found all over the country. In the central parts of Norway there are many and large populations, while in south-eastern and southern parts of the country many populations have become extinct. The total number of streams include some unsubstantiated information (39 localities) and 124 localities (about 25%) where the mussels are believed to be extinct. In spite of several intensive surveys carried out in the country in 2006–2008, there is still incomplete knowledge about the distribution and occurrence of the freshwater pearl mussel in many parts. We have extensive information and population estimates from 56 streams, including various types of habitat – from small creeks with populations of less than 100 individuals to large rivers with more than 6 million individuals. The total number of visually counted mussels in these localities is 22.3 million individuals. Based on this, and assuming that we have 360 streams with living mussels, we may estimate the total number of freshwater pearl mussels in Norway to be 143 million individuals. Based on length distribution and recruitment in 74 streams, recruitment was described as good (mussels less than 20 mm present) in 26 of the streams investigated. There was weak or unsure recruitment in 23 streams with the smallest individuals ranging within 20–50 mm. If we assume that the streams are representative for the situation of the mussels in Norway, two thirds of the populations have some level of recruitment. The calculations above indicate that Norway contains a relatively high portion of the sustainable European populations.

Key words: Norway; freshwater pearl mussel; distribution; status; reproduction

INTRODUCTION

The freshwater pearl mussel is known from major parts of Europe and eastern North America. In Europe, the former distribution was from Portugal/Spain towards the Alps through Eastern Europe and northward through Northwest Russia to the Barents Sea. Currently, this region contains approximately 1250 populations of freshwater pearl mussels (Geist, 2005), of which about 100 populations are sustainable. The estimated number of mussels in all European populations is 130–135 million individuals (Geist, 2005). It has to be noted, however, that there is a lack of reliable information from some geographical regions due to no recent surveys. Norway was one of the countries where the actual numbers of populations remained unclear. Geist (2005) noted 340–350 mussel populations with a total number of individuals estimated in the "millions".

Historical data can be an important and reliable source in any project mapping the freshwater pearl mussel. We have reliable historical information on the freshwater pearl mussel and mussel-rivers in Norway from the 17th and 18th century. There is information available both in written sources as well as in the oral tradition. Examples are maps, nature descriptions, travelogues, juridical documents, and even folklore songs, poems, anecdotes and tales. Finally, there is information on freshwater pearl mussel rivers and historical distribution data in scientific reports and literature from the late 1800s up to the 1950s and 60s (e.g. Esmark, 1886; Taranger, 1890; Rost, 1952; Økland, 1961).

The main sources of more recent distribution data on the freshwater pearl mussel in Norway are two main mapping projects carried out in the 1970s (Økland, 1975, 1976) and in the late 1980s (Dolmen & Kleiven, 1997, 1999). Professor Jan Økland at the University of Oslo carried out a mapping project under the European Invertebrate Survey (European Molluscs Survey) in the mid-1970s (Økland, 1975, 1976). The resulting distribution map was based on modified 50 km squares and the occurrence was indicated by different symbols for records prior to 1950 and records from 1950 and later (Økland, 1976, 1983). A total of 189 squares cover Norway, and occurrence of the freshwater pearl mussel was reported from 78 (41%) squares. Eleven squares had only records prior to 1950 (Økland, 1983).

The second mapping project was initiated by Assistant professor Dag Dolmen at the University of Trondheim and researcher Einar Kleiven at the Norwegian Institute for Water Research (NIVA). This project was based on a questionnaire which in 1988 was sent to all county governors' offices and all municipal administrations. In addition, they published articles and roll calls in newspapers, radio programmes and even performed telephone interviews. This resulted in a total of more than 270 existing and 100 former localities (Dolmen & Kleiven, 1997, 1999). This covered 96 of the 189 modified 50 km squares in Norway.

By the end of the 1990s, the Norwegian Institute for Nature Research (NINA) initiated a research programme on the biology of the freshwater pearl mussel, and studies of the infection of mussel larvae on the host fish. This brought new information from many rivers and localities all over the country. The national monitoring programme was established in 2000 (Larsen *et al.*, 2000). Finally, in 2001, a project to compile and systematize all old records on distribution was initiated within a national database project on distribution of freshwater fish and invertebrates (VannInfo) (Larsen, 2002).

The freshwater pearl mussel is on the Norwegian red list of threatened species ("vulnerable") (Kålås *et al.*, 2006), and designated as a "responsibility species" for Norway (Larsen, 2005). Consequently, an Action plan for the freshwater pearl mussel was published in 2006 (Direktoratet for naturforvaltning, 2006). Among the measures proposed in the action plan were monitoring, public information, habitat improvement, and improvement of management routines according to acts and regulations relevant for the freshwater pearl mussel. Additional mapping and extended work to establish a database with information on the distribution and status of the freshwater pearl mussel was also proposed.

The County Governor in Nord-Trøndelag has a central role in implementing the action plan in Norway. Anton Rikstad and Kristian Julien at the County Governor's office are responsible for the project, and the main goal is to collect all available records on the occurrence of the freshwater pearl mussel in Norway. In 2006-2008, areas all over the country were picked out for more thorough investigations. The mapping project continued through 2009 and will continue in the years to come.

Geist (2005) stated rightly that "exact distribution, total numbers and juvenile status remains unclear" in Norway. This paper intends to draw together all the available information on the current distribution, and the primary data are analysed to assess a preliminary status of the freshwater pearl mussel in Norway.

MATERIALS AND METHODS

The distribution data presented here are based on several sources, such as the original work of Økland (1975, 1976) and Dolmen & Kleiven (1997, 1999), supplemented with my own records from field work in 1995-2008, and any relevant information on pearl mussel rivers was gleaned from notes, reports and other literature. Finally, data collected in 2006–2008 during the mapping project associated with the Action plan for the freshwater pearl mussel are included. However, the distribution data presented are still preliminary, and more information will be added in the years to come.

Norway's national catchment database, REGINE, is established and maintained by the Norwegian Water Resources and Energy Directorate (NVE). REGINE divides Norway into major and subordinate reference units along the coastline, rivers and catchments. The definition of main rivers and sub rivers in REGINE is used to count the number of streams with freshwater pearl mussel in Norway.

The abundance of the freshwater pearl mussel is shown by a distribution map using the 10 x 10 km units based on the national grid. A dot within a square indicates that the species has been recorded at least once somewhere within that square.

Information on the length distribution and recruitment of mussels is available from 74 streams from all over the country. Data originate from my own field work (32 streams) and 29 reports (covering 42 streams) by several authors (e.g. Lande & Storesund, 1999; Dolmen, 2003; Berger & Lehn, 2008). We distinguish between 1) good recruitment (smallest mussel <20 mm), 2) weak recruitment (smallest mussels ≥20 – <50 mm) and 3) no recruitment (smallest mussel ≥50 mm).

Good population estimates are available from 56 streams from all over the country covering various habitat types. Data originate from my own field work (28 streams) and 19 reports (covering 28 streams) made by several authors (e.g. Lande & Storesund, 1999; Berger & Lehn, 2008). The calculated mean number of individuals in these streams was used to estimate the total number of mussels in the country.

RESULTS

Data from earlier surveys, my own field work and the mapping projects in 2006-2008 have revealed information about 504 streams with present or historical freshwater pearl mussels. The mussels are still found all over the country.

The results indicate that we still have living populations of pearl mussels in 380 streams, while it is extinct in 124 streams. The existing populations are located within 378 10 km squares (Fig. 1), and include uncertain information from 39 streams.

The living populations are found in 18 of 19 counties, and are most numerous in coastal streams in the central and northern parts of the country. Nearly half of the localities are located within the counties of Sør-Trøndelag, Nord-Trøndelag and Nordland (Figs. 2 and 3).

The 124 extinct pearl mussel populations were located within 105 10 km squares, mainly in the south-eastern and southern parts of the country (Fig. 4). The freshwater pearl mussel is totally extinct in 76 10 km squares spread all over the country, in 17 of the 19 counties. Nearly 60% of the localities with extinct populations are located in the counties of Aust-Agder, Vest-Agder, Rogaland and Hordaland (Figs. 2 and 5). In addition, we notice that a higher number of extinct populations is found close to the largest cities in southern Norway – especially near Oslo.

The recruitment is good in 35% of the investigated streams (N = 74; Table I). Weak or uncertain recruitment was found in 31% and no recruitment in 34% of the streams. If we assume that the streams are representative for the situation of the mussels in Norway, two thirds of the populations have some level of recruitment.

The recruitment seemed to be poorer in south-eastern Norway (the counties of Østfold, Hedmark, Oslo, Akershus, Oppland, Buskerud, Vestfold, Telemark and Aust-Agder; 57% of the streams with no recruitment) compared to the central part of the country (the counties of Sør-Trøndelag, Nord-Trøndelag and Nordland; 24% with no recruitment) (Table 1).

The population estimates from 56 streams vary from less than 100 to more than 6 million individuals. The estimated sum of individuals based on visual counts within these streams is 22.3 million freshwater pearl mussels. Assuming that these streams are representative, and that we have 360 streams with living mussels, the total number of freshwater pearl mussels in Norway may be estimated at 143 million individuals (Table 2). However, this number may even be too low as we have preliminary estimates from two large mussel rivers with 15–25 million individuals each (Dolmen, 2003; unpublished data).

Based on the estimates available from the rest of Europe, Norway has about 25% of the remaining streams with freshwater pearl mussels in Western Europe. Including Sweden, the total number of populations on the Scandinavian peninsular constitutes nearly 65% of the living populations in Western Europe. Counting individuals, it may seem that Norway has more than two thirds of the total number of freshwater pearl mussels in Western Europe. Adding Sweden, this proportion increases to nearly 90%.

DISCUSSION

The freshwater pearl mussel has declined significantly in Norway in the last 100 years. In spite of this the mussel remains widespread and is obviously not in danger of extinction in the country as a whole. We have so far information about 504 streams or localities, and the freshwater pearl mussel is believed to be extinct in about 25% of the known localities in Norway. One hundred and thirty new localities have been found during the last ten years (cf. Dolmen & Kleiven, 1999), and presumably there are still mussel populations which are so far undiscovered.

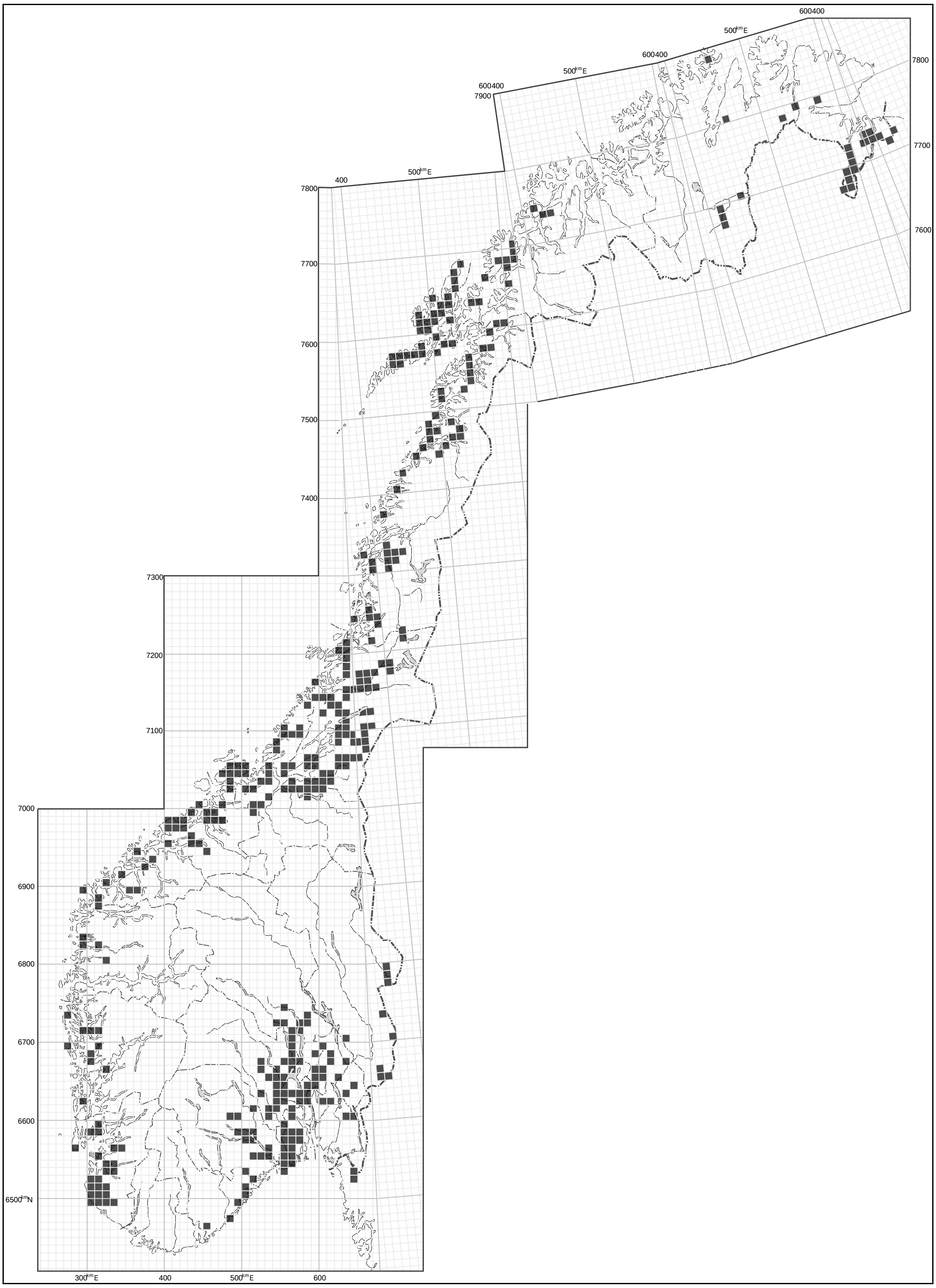

Fig. 1. Distribution of streams with living populations of freshwater pearl mussel in Norway plotted on 10 km squares

Fig. 2. Norway is divided into 19 counties. The map shows the names of the counties given in the text and on Fig. 3 and 5

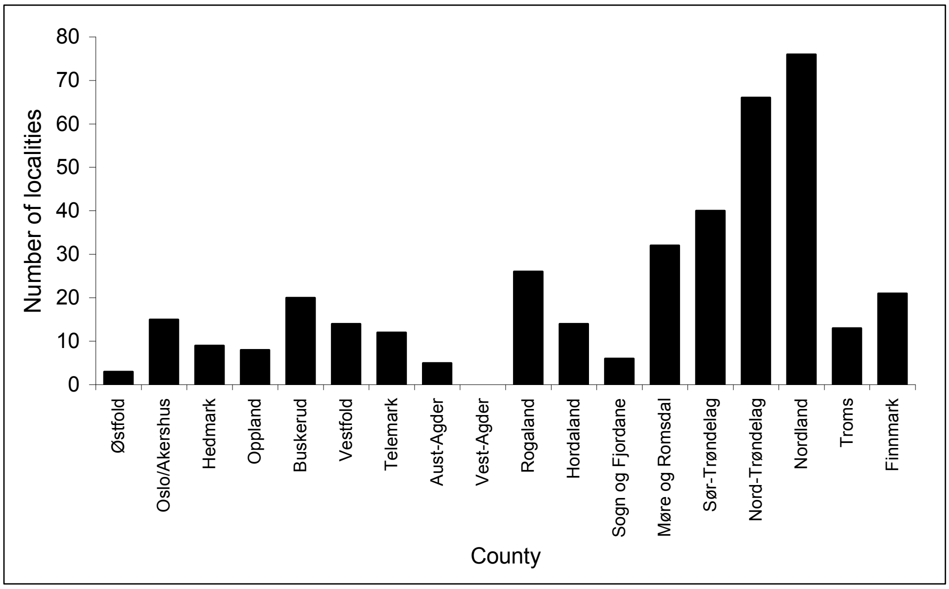

Fig. 3. The number of streams or localities per county with living populations of the freshwater pearl mussel in Norway (N = 380). Cf. Fig. 2

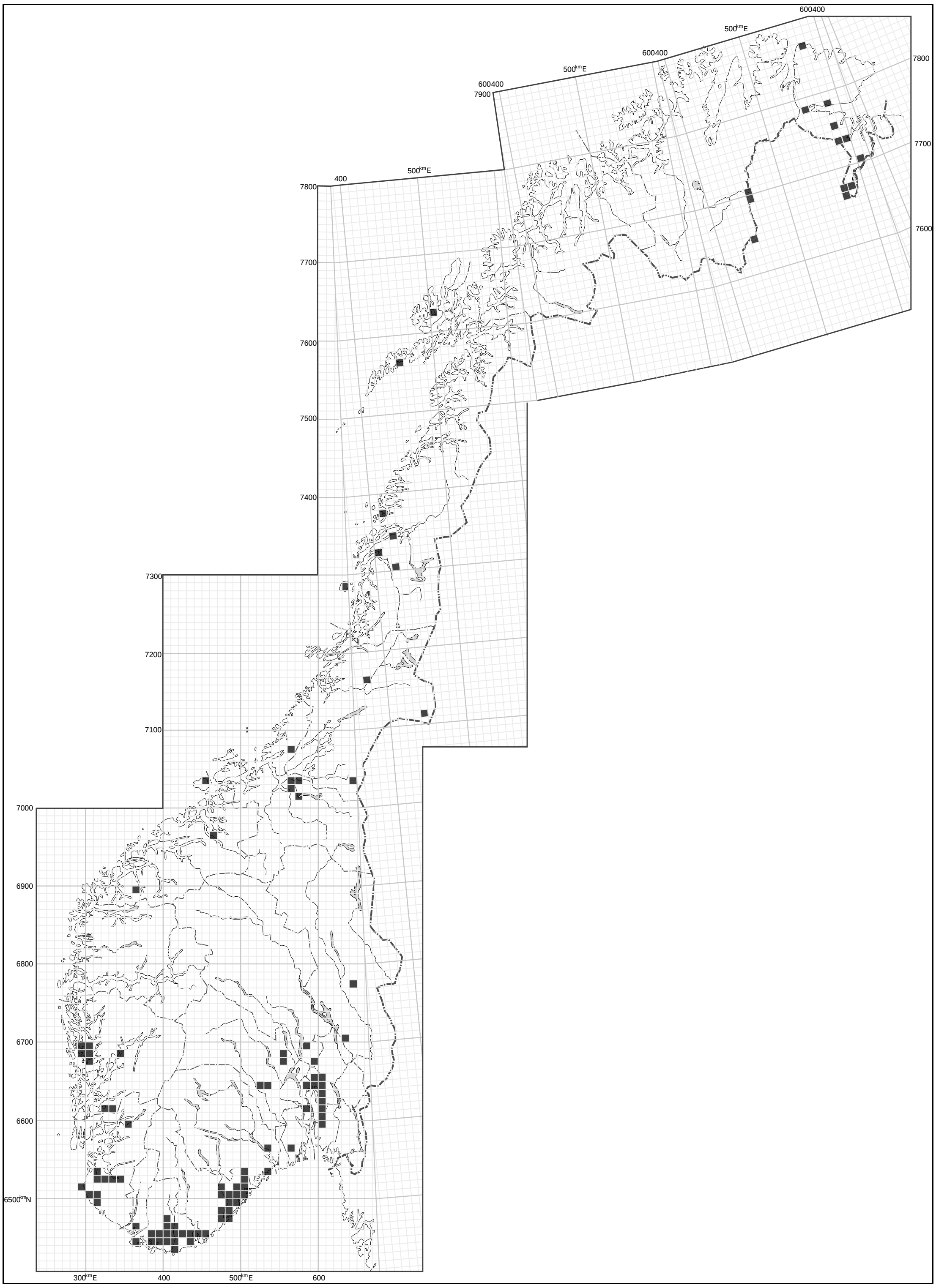

Fig. 4. Distribution of streams with extinct populations of freshwater pearl mussel in Norway plotted on 10 km squares

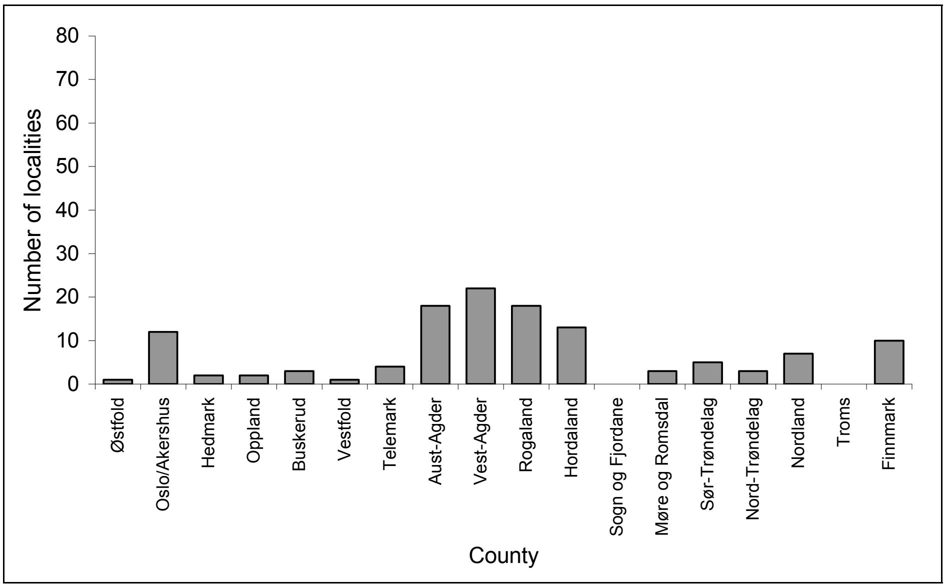

Fig. 5. The number of streams or localities per county with extinct populations of the freshwater pearl mussel in Norway (N = 124). Cf. Fig. 2

Table 1. Information about recruitment in freshwater pearl mussel rivers in Norway (N = 74)

Recruitment	Norway (all streams)	Streams in south-eastern part of Norway	Streams in central part of Norway
No	34%	57%	24%
Weak	31%	29%	31%
Good	35%	14%	45%
No. of streams	74	28	29

Table 2. Revised estimates of current population status of the freshwater pearl mussel in Norway, Sweden and the rest of Europe. The large Russian populations are excluded from the total European estimates due to lack of updated data

Country	Norway	Sweden[1]	Russia[2]	Rest of Europe[3]	Total[4]
Estimated numbers of streams/populations	c. 360 (341–380)	551	>8	495–496	c. 1407 (1387–1427)
Part (%) of the total number of streams/populations	26	39		35	100
Estimated number of individuals, millions	143	39 (35–40?)	>100	25	c. 207 (203–208)
Part (%) of the total number of individuals	69	19		12	100

[1] From Söderberg et al. (2008) and Eriksson et al. (1998)
[2] From Geist (2005). Uncertain estimates. Both number of streams and number of individuals are considerably underestimated
[3] From Geist (2005)
[4] The large Russian populations are excluded

Occurrence and distribution of mussels is normally presented either as number of populations (Geist, 2005) or as number of localities or streams (Söderberg *et al.*, 2008). It is important to notice that the number of populations often differs from the number of streams or localities. In small streams we will normally find only one population. However, in rivers with Atlantic salmon *Salmo salar* L. and sea trout *Salmo trutta* L. in the lower part and resident brown trout in the upper part we may expect to find more than one population due to the differences in the suitability of the host fish (Larsen, 2006). It may also be possible to distinguish different populations in watercourses which include large lakes.

We observe a substantial decline in the number of populations of freshwater pearl mussel in Norway. The mussels are highly susceptible to acidification, and in addition, acidification has reduced host fish populations in large areas in southern part of Norway (Hesthagen & Hansen, 1991). The freshwater pearl mussel has disappeared from 44 localities in Aust-Agder and Vest-Agder counties, and acidification was assumed to be the main reason (Dolmen & Kleiven, 2004). Threats to the freshwater pearl mussel are more diverse in other parts of the country. Larsen (1997) indicates that, in the past, fishing for pearls had a deleterious effect. Recently, however, factors like river engineering and hydroelectric regulation, erosion and siltation due to drainage and logging, and eutrophication, all have been major causes of decline, especially of juvenile mussels.

Still we have recruitment (smallest mussel less than 50 mm) in approximately 66% of the localities in Norway. But the watercourses are sensitive to several threats in an environment affected by human activities. In acidified rivers liming has been an important mitigation measure benefitting the mussels (Larsen, 2009), and all actions to reduce the leakage of nutrients from farm land and agricultural activities has been shown to be beneficial. The fact that 26% of the freshwater pearl mussel streams and 69% of the individuals in Western Europe are found in Norway means that Norway must take even greater responsibility for this species. The development and implementation of the action plan (Direktoratet for naturforvaltning, 2006) for the species is one important component, but we will also need a more extensive mapping and monitoring programme, and development and implementation of concrete conservation and restoration actions.

ACKNOWLEDGEMENTS

The mapping project on the freshwater pearl mussel in Norway is financed by the Directorate for Nature Management. Thanks are due to J. Økland, K. A. Økland, D. Dolmen and E. Kleiven for their extensive work on earlier mapping projects on the freshwater pearl mussel in Norway. Thanks also to A. Rikstad and K. Julien for all information on new data resulting from the mapping project in the Action plan for the freshwater pearl mussel in Norway. O. T. Sandlund has given valuable comments on the manuscript and improved my English.

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DISTRIBUTION OF THE FRESHWATER PEARL MUSSEL IN RUSSIA

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The review provides information about pearl harvesting (16th–20th cent.) and distribution of the freshwater pearl mussel *Margaritifera margaritifera* (L.) in North-West Russia; special focus is on the Kola Peninsula. In the Russian Federation at large, 157 rivers and streams are either known to have had pearl harvesting or/and reported to harbour pearl mussel (species affiliation of the mussels in 65 of them was confirmed by experts). The number of pearl mussel streams is strongly underestimated since both pearl harvesting and pearl mussel distribution have been insufficiently studied. State-of-the-art of pearl mussel populations is also poorly known, but it is safe to say there now (21st cent.) exist at least 24 populations. Freshwater pearl mussel abundance in Russia is higher than elsewhere in the world.

Key words: pearl mussel, nature protection, distribution, Kola Peninsula

INTRODUCTION

Freshwater pearl mussel *Margaritifera margaritifera* (L.) used to be quite widespread in rivers of NE North America and western Europe (reviews: Ziuganov et al., 1994; Geist, 2005). It is present is countries bordering Russia in the west. Large pearl mussel populations have survived in Norway and Finland (Oulasvirta, 2006, 2008; Larsen, this volume). In Estonia and Latvia, this mussel is rather scant (Timm, 1994; Rudzīte, 2004). In Lithuania, Byelorussia and Poland, the pearl mussel used to occur, but has apparently gone extinct (Dutkiewicz, 1960; Jankevičius, 1981; Kozlov, 1981).

Information about Russian pearls and the pearl mussel can be found in over 300 publications, but they have never been properly summarized. The ecology of Russian pearl mussel populations has been studied (Ziuganov et al., 1994). *Margaritifera margaritifera* was proven to be the only pearl mussel species living in North-west Russia (Sergeeva et al., 2008). However, distribution of the species in Russia is still largely understudied. Two papers (Vereshchagin, 1929; Yakunina, 1955) contain lists of rivers known for pearl harvesting, but the lists are incomplete. Furthermore, many of the rivers mentioned in these lists cannot be located in modern maps.

Intensive research into the pearl mussel distribution in Russia has only just begun. This work is underway in Arkhangelsk Region (review: Bespalaya et al., 2007a), western Leningrad Region (Ostrovskii and Popov, 2008), Karelia (Makhrov et al., submitted); a review of data on pearl mussel populations in southerner regions has been prepared (Makhrov, 2009).

Data on the pearl mussel occurrence in the Murmansk Region have not been summarized before (Pavlov et al., 2007). Such a summary is given in the present paper. In addition, we have synthesized published and archival information on the pearl mussel distribution in different regions of Russia.

PROBLEMS OF METHODOLOGY

Pearl harvesting had been practiced in Russia for several centuries, and pearls were widely used to decorate icon cases and costumes (let us mention only a few books: Khrebtov, 1897; Romanchenko, 1912; Yakunina, 1955; Donova, 1962; Oparin, 1976; Korago, 1981; Srebrodol’skiy, 1985; Vishnevskaya, 2007). However, the locations where the pearls were treated and worked into decorative items were often far away from the harvesting site (Vilkuna, 1980; Bernstam, 1983; Storå, 1989), wherefore it is hardly ever possible to locate the pearl rivers relying on information about the circulation of goods with pearls.

Some information about pearl harvesting was gathered by the few travellers, or found in archives. Often, the information about “pearl” rivers the researcher got hold of was second- or third-hand, which resulted in fallacies. Pearl fishers themselves tried to keep information about harvesting sites secret, passing it only to their sons. Top secret was information about small taiga rivers rich in pearls (Oparin, 1976).

More problems arise because changes in national borders and administrative borders between regions of Russia need to be taken into account. E.g., River Nyadema has been mentioned as a Russian river where pearls were harvested (Stukenberg, 1849; Bartenev, 1902; Vereshchagin, 1929; Yakunina, 1955). Since 1826 however, the watershed has been Norwegian territory, and the river now has the name Neiden (Chulkov, 1901).

To avoid such mistakes, we used modern maps to locate the rivers mentioned in old sources. Newspaper publications about pearl fishing were excluded from consideration because of low reliability of the information (in the future, it may become possible to verify the information through surveys of the rivers mentioned in the doubtful sources). A similar procedure was applied in other reviews (Bespalaya et al., 2007a; Makhrov, 2009; Makhrov et al., submitted).

Unfortunately, there have been hardly any studies of the pearl mussel distribution in Russia. The few scientific expeditions for pearl mussel study that were held mostly headed for the rivers with pearl harvesting. During general benthos surveys, the pearl mussel often evades the frame hydrobiologists use.

Thus, both information about pearl harvesting sites and data on pearl mussel distribution in Russia are rather limited. There is no doubt rivers with pearl mussel populations are much more numerous than it is stated in the literature. E.g., thorough surveys (Graevskiy and Baranov, 1949; Golubev and Esipov, 1973) helped find pearl mussel populations in six streams flowing to the relatively small Lake Vadozero.

PEARL MUSSEL DISTRIBUTION IN MURMANSK REGION

Pearl fishing was practiced in many rivers of the Kola Peninsula and adjacent part of the Karelian Coast, which now belong to the Murmansk Region, Russian Federation (Tab. 1). The pearl mussel is widespread in the western part of the region (Fig. 1). No findings of the species are known from rivers of the Kola Peninsula northern coast east of Tyuva (Tab. 1). No pearl mussel is to be found on the southern coast of the peninsula east of Varzuga (A. Zotin, pers. comm.).

Some information indicates pearls used to be harvested in the easternmost Kola Peninsula, in the Ponoi River (Tab. 1). As reported by Popov (1914) however, people from Varzuga failed to find pearls in the river early in the 20th century. The idea about pearl fishing in the river must have appeared because earlier sources claimed people of Ponoi "for this pearl fishing had the greatest habit" (Fomin, 1805; Molchanov, 1813).

Several rivers reported to have had pearl fishing could not be found in modern Murmansk Region maps and in the vocabulary (Voshchinin, 1939): streams emptying into Lake Permo (Kuznetsov, 1930) – the reference may be to Lake Permusozero in the Imandra Lake watershed; River and Lake Pil'ma (Kuznetsov, 1930; Makarov, 1934) – this may be a misprint, and the Nil'ma River in Karelia was meant; River Kol'cha (Zimmerman, 1853; Kuznetsov, 1930) – may be a distorted variant of Kolvitsa. Ukhanova (1966) mentioned Chernaya Umba (presumably River Chernaya in the Umba River watershed), Puzreka (apparently stands for Kuzreka), Povda (probably Kovda was meant).

On some occasions, rivers in different regions may have the same name, and it is unclear which one of them is the right one. E.g., a Valas River (Kuznetsov, 1930) can be found both in Murmansk Region and in Karelia. Also, both these regions have rivers named Shomba, consonant with Sombo, which was mentioned by Ukhanova (1966).

In the Umba River, pearl mussel glochidia were found on pink salmon gills (Grozdilova, 1974). In several fish hatcheries in Murmansk Region, glochidial infection was detected in Atlantic salmon parr (Bogdanova, 1967); the presumable infection agent was pearl mussel larvae.

Little is known about the human impact on pearl mussel populations in the Kola Peninsula. Several of the watercourses inhabited by the species (Paz, Tuloma, Niva, Zhemchuzhnyi Ruchei, Kovda) are affected by hydropower engineering. A number of populations in streams flowing to Lake Imandra had died out, and the Umba River population was heavily impaired by industrial pollution (Ziuganov et al., 1994). However, sulphur and nitrogen concentrations in shells of pearl mussels from other parts of the Kola Peninsula are low (Carell et al., 1995).

The pearl mussel was stocked into some rivers in SE Kola Peninsula: Chavan'ga, Chapoma, Strel'na, Yugina. The mussels survived, but nothing is known about further results of the stocking activities (Ziuganov et al., 1994).

Table 1. Water systems of the Kola Peninsula, where pearl harvesting had been carried out earlier or live mollusks were found (Bold type)

Water system	18th century	19th century	20th century	21st century
Paz river drainage basin		Reineke, 1830; Stukenberg, 1849	Fersman, 1923	**Polikarpova, Makarova, 2009**
Pechenga	Blagoveshchenskiy, 1902			
Western Litsa*				**Oulasvirta, 2006**
Ura*				
Tuloma drainage basin (6 streams)*		Reineke, 1830; von Middendorff, 1845; Stukenberg, 1849; Nemirovich-Danchenko V.I. 1877; Bartenev, 1902	**Collection of V. Soldatov (July 28, 1906), in Zoological Institute of Russian Academy of Science;** Fersman, 1923; Kupletskiy, 1925; Kuznetsov, 1930; Zorich, 1931	**M. Kaukoranta, pers. comm.**
Kola drainage basin (3 streams)	le Brun, 1718	Reineke, 1830; von Middendorff, 1845; Stukenberg, 1849; Slutchevskiy, 1897; Slezkinskiy, 1898; Bartenev, 1902	Kupletskiy, 1925; **Collection of V. Kapustin (June 12, 1926) in Zoological Institute of Russian Academy of Science;** Zorich, 1931; Valkov, 1934; **I.L. Shchurov, V.A. Shirokov, pers. comm.**	
Tyuva		von Middendorff, 1845		
Ponoi		Stukenberg, 1849; Bartenev, 1902; Oparin, 1976	Kupletskiy, 1925	
Varzuga drainage basin (9 streams)	le Brun, 1718; Blagoveshchenskiy, 1902; Ukchanova, 1966	Stukenberg, 1849; Zimmerman. 1853; **Rippas, 1899**; Bartenev, 1902; Kolpakova, 1937; Oparin, 1976	Popov, 1914; Regel, 1914; Fersman, 1923; Kupletskiy, 1925; Kuznetsov, 1930; Zorich, 1931 Valkov, 1934; **Saldau, 1939; Zhadin, 1939; Golubev, Esipov, 1973; Ziuganov et al., 1994, 1998; Kazakov et al., 1992; Prokhorov, 1995, 1996**	**Machordom et al., 2003; Bergengren et al., 2004**
Kuzreka			Kuznetsov, 1930	
Thurma			**A.A. Zotin, pers. comm.**	**Machordom et al., 2003**
Umba drainage basin (4 streams)*	Blagoveshchenskiy, 1902	Stukenberg, 1849; Zimmerman. 1853; Bartenev, 1902; Oparin, 1976	**Vise, 1912**; Regel, 1914; Kupletskiy, 1925; Kuznetsov, 1930; **Saldau, 1939; Zhadin, 1939; Grozdilova, 1974**	
Porja	Blagoveshchenskiy, 1902	Stukenberg, 1849	**I.G. Murza, O.L. Khristoforov, pers. comm.**	
Kolvitsa			**Anonymous, 1928**	
Niva and Imandra Lake drainage basins (15 streams)	Blagoveshchenskiy, 1902	Oparin, 1976	Kuznetsov, 1930; **Graevskiy, Baranov, 1949; Semyonov-Tjan-Shanskiy, 1960; Golubev, Esipov, 1973; Gilyasova, 2000**	
Luptche-Savino (Lupija)			Kuznetsov, 1930	
Kanda		von Middendorff, 1845; Zimmerman. 1853; Bartenev, 1902	Kozhin, Novikov, 1937	
Virma (Vuruma)			**Anonymous, 1928**	
Ostrechija			**Anonymous, 1928;** Kuznetsov, 1930; **Graevskiy, Baranov, 1949**	
Zhemchuzhnyi brook			**Makarov, 1934**	
Kovda		Stukenberg, 1849; Bartenev, 1902; Oparin, 1976	Kozhin, Novikov, 1937	

* There are data about pearl harvesting in Ura and Western Litsa during the 16th century (Andreev, 1920) and in Ura, Western Litsa, Tuloma and Umba during the 17th century (Anonymous, 1936; Ushakov, 1998)

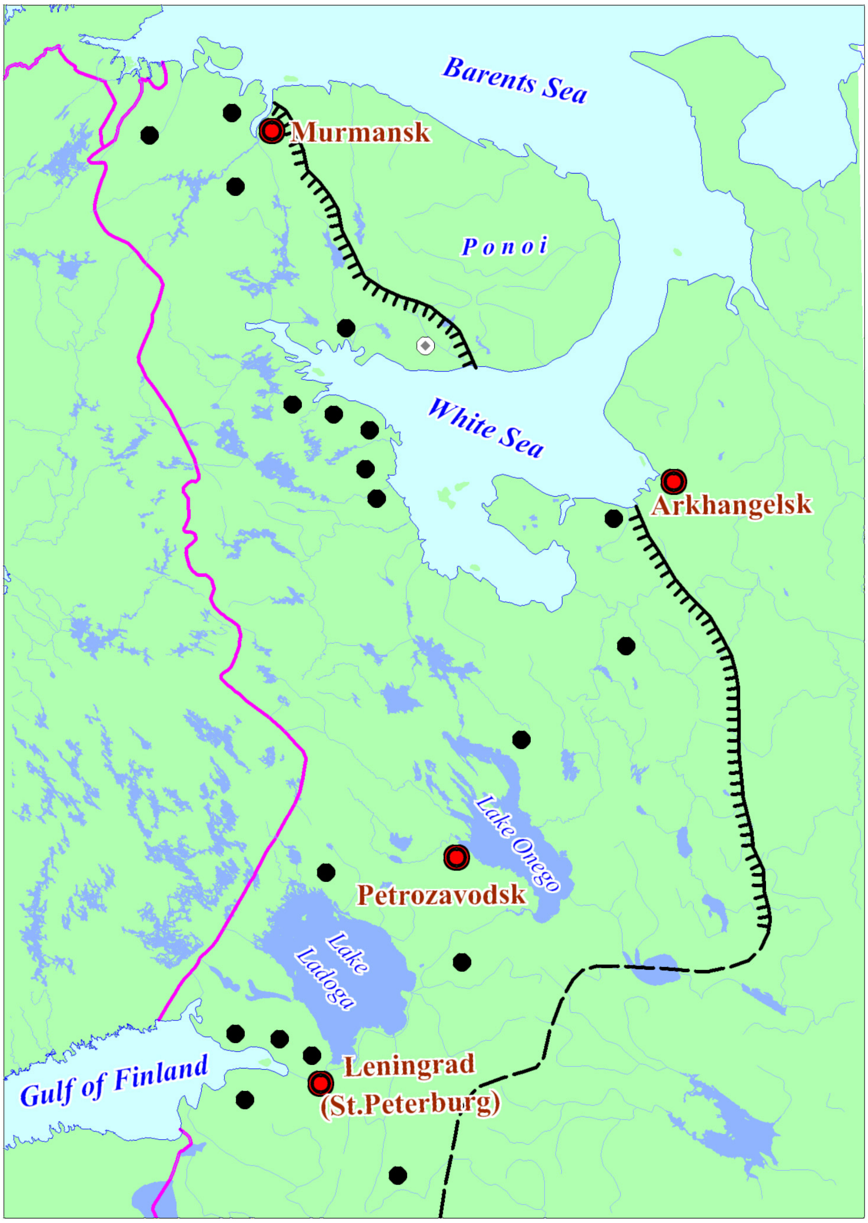

Fig. 1. Area of pearl harvesting (16th-20th centuries) in Russia. Dots mark rivers with surviving *Margaritifera margaritifera* populations (21st century)

PEARL MUSSEL DISTRIBUTION RANGE IN RUSSIA

In addition to rivers of the western Murmansk Region, the pearl mussel distribution range comprises the western part of the White Sea watershed, which administratively belongs to Republic of Karelia (overview: Makhrov et al., submitted). The mussel lives also in the southern part of the watershed, which belongs to the Arkhangelsk Region (Fig. 1). There are no reliable data on any pearl mussel findings east of the Solza River, including the Northern Dvina watershed (overview: Bespalaya et al., 2007a).

Pearl mussel used to be widespread also in the Russian part of the Baltic Sea watershed – in streams flowing to Lakes Onego and Ladoga, rivers on the Gulf of Finland coast (Anonymous, 1752; Maksimovich, 1788; Pallas, 1809; Anonymous, 1834; Kessler, 1868; Esipov, 1879; Semyonova et al., 1992; Ostrovskiy and Popov, 2008; Makhrov, 2009; Makhrov et al., submitted; inventory of the RAS Zoological Institute's Collection, pers. comm. by I. Popov). Administratively, these areas belong to the Leningrad, Vologda, Pskov, Novgorod Regions and Republic of Karelia.

Pearl fishing has been reported also from the upstream of Zapadnaya Dvina – now belonging to Tver Region (Romanchenko, 1912). However, no findings of pearls or pearl mussel in the territory that is now Kaliningrad Region (former East Prussia) have ever been mentioned in the literature.

Table 2. Number of Russian water systems with pearl mussel populations and number of Russian streams with pearl mussel populations (in parentheses)

Region	Number of rivers where pearl harvesting was carried out/**Number of rivers where live pearl mussels were found**	Including:		
		Number of extinct populations	Number of living populations (21st century)	Number of populations with unknown status
Murmansk Region (Barents Sea drainage basin)	7 (14)/**4 (6)**	0 (0)	3 (3)	4 (11)
Murmansk Region (White Sea drainage basin)	13 (39)/**9 (25)**	0 (0)	2 (2)	11 (37)
Karelia (White Sea drainage basin)	18 (20)/**10 (11)**	3 (3)	5 (5)	10 (12)
Arkhangelsk Region	13 (18)/**2 (3)**	1 (1)	2 (3)	10 (14)
Lake Onego drainage basin	15 (19)/**3 (3)**	4 (6)	1 (1)	10 (12)
Lake Ladoga drainage basin	8 (36)/**3 (9)**	(1)	3 (5)	5 (30)
Gulf of Finland drainage basin	7 (10)/**6 (8)**	0	4 (5)	3 (5)
Western Dvina drainage basin	1 (1)/**0**	0	0	1 (1)
Total	82 (157)/**37 (65)**	8 (11)	20 (24)	54 (122)

Data on the number of watercourses where pearls used to be harvested in different parts of Russia are summarized in Table 2. The table does not include information about pearl fishing (Anonymous, 1780; Lovetzky, 1830; Stukenberg, 1849) or pearl mussel findings (Pallas, 1771; Gorodtsev, 1902; Gogulina, 1998) in the Volga River watershed – many of the accounts are fragmentary and need to be verified.

STATUS OF PEARL MUSSEL POPULATIONS IN RUSSIA

Before the 20th century, the main reason for a decline in pearl mussel stock was rapacious harvesting. E.g., late in the 19th century, all pearl mussels were collected from the Karelian river Pista, as reported by local people (Potakhin and Kapitonova, 2008). At that time, agriculture must have also affected the pearl mussel, but this impact was not studied then.

In the 20th century, pearl mussel extinction was triggered by timber floating and deforestation as well as by changes in the hydrology: impoundment, and water uptake for utility purposes (Makhrov et al., submitted). As mentioned above, some pearl mussel populations were affected by industrial pollution.

Today, one of the principal reasons for decline among the surviving pearl mussel populations is poor condition of the populations of glochidia hosts – Atlantic salmon and brown trout (Bespalaya et al., 2007b, Zyuganov, 2008; Ostrovskii and Popov, 2008; Makhrov, 2009; Makhrov et al., submitted).

Instead of these species, great numbers of the introduced pink salmon (*Oncorhynchus gorbuscha*) ascend rivers of the White Sea watershed. Glochidia attach to pink salmon gills (Grozdilova, 1974; pers. comm. by E. Ieshko), but die together with the fish before they can complete the development stage. The stream carries dead pink salmon into gaps between rocks, where adult pearl mussels live. Attacks on freshwater pearl mussels by introduced muskrats (*Ondatra zibethica*) have been reported in the Varzuga river drainage basin (Bergengren et al., 2004).

In spite of the environmental problems mentioned above, the numbers of the freshwater pearl mussel in Russia are higher than elsewhere in the world. River Varzuga alone has a population of about 140 million mussels (Ziuganov et al., 1994; Bergengren et al., 2004), i.e. nearly as much as in all rivers of Norway taken together (Larsen, ibid.).

FURTHER RESEARCH

Detailed and large-scope research into current distribution of the pearl mussel in rivers and streams of Russia has to be set up, similar to the work done in our neighbor countries (Rudzīte, 2004; Oulasvirta, 2006, 2008; Larsen, 2009). It would be expedient to organize international studies of pearl mussel populations, first of all in transboundary river watersheds.

Simultaneously, study of the fish hosts of the mussel glochidia should be continued. The distribution of Atlantic salmon in Russia is quite well known (monographs: Kazakov, 1998; Kaliuzhin, 2003; Martynov, 2007), but Russian rivers with brown trout populations have not yet been listed (overview: Makhrov, 1999). It is also important to assess current condition of the fish populations in the rivers inhabited by the pearl mussel, and such studies have begun in Karelia (Makhrov et al., submitted).

To properly organize pearl mussel culture and reacclimatization, one needs to investigate its parasites, bacteria and viruses, analyze genetic diversity of *Margaritifera margaritifera*. Hardly any studies of this kind have been implemented, and only data on the genetic structure of several pearl mussel populations are available (Machordom et al., 2003; Artamonova and Bukhanova, unpublished).

Genetic data can also be used to investigate the pathways of the pearl mussel dispersal. Study of dispersal pathways in combination with analysis of environmental factors can help identify the factors restricting pearl mussel distribution in Russia.

It would also be interesting to study former pearl fishing activities as a social phenomenon of high significance for people in the north of Russia. Researchers from different countries would need to cooperate to learn more about pearl fishing in the territories that had drifted from one country to another. Furthermore, until the beginning of the 20th century, pearl fishers from Finland used to harvest pearls on the White Sea coast (Khrebtov, 1897; Nikol'skiy, 1927); and vice versa, Karelians went to Finland for pearls (Vilkuna, 1980; Storå, 1989). These practices may become a topic for international research.

ACKNOWLEDGEMENTS

This paper would have been unthinkable without the help of the colleagues, who have taken part in joint field work and generously shared literature and information: V. Artamonova, P. Aspholm, Yu. Barskaya, Yu. Bespalaya, I. Bolotov, D. Dirin, A. Helm, L. Henrikson, E. Ieshko, M. Kaukoranta, O. Khristoforov, P. Kijashko, K. Kuzishchin, D. Lebedeva, I. Murza, O. Novokhatskaya, A. Ostrovskiy, P. Oulasvirta, I. Popov, M. Rudzīte, I. Shchurov, I. Sergeeva, V. Shirokov, B. Shulman, E. Voznesenskaya, S. Znamenskiy, A. Zotin, V. Zyuganov.

The author thanks the staff of the libraries of the Moscow State University White Sea Biological Research Station, Kartesh Biological Research Station, Russian Federal Research Institute of Fishery and Oceanography, State Inland Fisheries Research Institute, Russian Academy of Science Zoological Institute, RAS General Genetics Institute, RAS Karelian Research Centre, RAS Biological Sciences Division, Polar Research Institute of Fishery and Oceanography, Northern Fisheries Research Institute, Northern Research Institute of Fishery and Oceanography, as well as Arkhangelsk, Vologda, Murmansk, Novgorod and Pskov Regional Scientific Libraries, and Republic of Karelia National Library for assistance in finding the literature.

The study was carried out within the RAS Presidium Programme "Biodiversity: Inventory, Functions, Conservation" (projects 2.3.1 and 23-P) and Russian Foundation for Basic Research (grant 10-04-01605-a).

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FRESHWATER PEARL MUSSEL: DISTRIBUTION AND STATE OF THE POPULATIONS IN FINLAND

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Information on the present distribution and status of the threatened freshwater pearl mussel (*Margaritifera margaritifera*) populations in Finland was gathered. The data from the populations are based both on the available results of the recent field investigations and on the written and oral information on the historical pearl fishing. The records of *M. margaritifera* were classified into three categories: A. Rivers with confirmed populations and recruitment of young mussels, B. Rivers with confirmed populations but no recruitment, and C. Rivers with expected, but not confirmed populations. Altogether 91 category A and B rivers were recorded, out of which 31 contained breeding mussel populations. In addition, 83 rivers were classified as category C rivers. Most of the present *M. margaritifera* rivers are located in the northern part of the country. In southern Finland, freshwater pearl mussel is known only from seven rivers at the moment, and recruitment of young mussels takes place only in one river. In northern Finland, the state of the populations varies between catchment areas. In some areas, the species is near extinction, while in other areas abundant and viable populations are still found. However, disturbances in recruitment are common in many of the northern Finland rivers, too.

Key words: Finland; *Margaritifera margaritifera*; distribution; status; recruitment

INTRODUCTION

The freshwater pearl mussel (*Margaritifera margaritifera*) has been protected in Finland under the Nature Conservation Act since 1955. The species is also listed in Annex II of the European Union Habitats Directive as a species whose habitat must be protected for its survival. Despite the protection, the freshwater pearl mussel populations have been declining almost everywhere in its original range. According to some estimates, the decline of known populations in central and southern Europe is as high as 90% (Bauer, 1988). In Finland, the decline of the populations was estimated to be ca. 70 % vs. the situation at the beginning of the 20th century (Valovirta, 2006a). Indeed, the 1955 Act protected *M. margaritifera* in Finland from pearl fishing but not from destruction of its habitat. Since the era of pearl fishing, the reasons for the declining populations have included the clearing of rivers for timber floating, the construction of hydropower plants, eutrophication and pollution of the rivers, the building of forest roads, and other forestry operations such as drainage of forest and peatlands, which have led to silting of the rivers.

Although there is general awareness of the negative development of freshwater pearl mussel populations in Finland, the knowledge of the state of the populations is scattered, and the comprehensive picture from the whole country has been missing. The most complete record of freshwater pearl mussel populations in Finland is probably in the Museum of Natural History in the University of Helsinki. In addition, at least some of the Regional Environment Centres and the Metsähallitus Natural Heritage Services Lapland have their own databanks. These databanks have been complemented by the results of recently conducted investigations, both those I have been involved in (Oulasvirta et al., 2006 and 2008; Oulasvirta, 2004, 2005 and 2006), and the surveys carried out by Metsähallitus Natural Heritage Services Lapland, Regional Environment Centres and the joint research team of WWF Finland and the Museum of Natural History (unpublished data). The objective of this paper has been to summarize all these new data as well as older records of the distribution and state of the freshwater pearl mussel populations in Finland.

MATERIALS AND METHODS

The distribution of the freshwater pearl mussel presented here is based both on the results of field investigations and on the historical data on pearl fishing. Pearl fishing in Finland, and especially in the northern part of the country Lapland, has been documented for example by Itkonen (1948), Keltikangas (1977), Fellmann (1906, 1910), Montonen (1985), Storå (1989, 1995), Heikkinen (1999), and Oulasvirta et al. (2006). Information on the old time pearl fishing was obtained also from the archives of the Finnish Museum of Hunting, Finland.

Much of the data concerning Lapland were received from two Interreg mapping projects carried out in 2003-2005 and 2007 (Oulasvirta et al., 2006; Oulasvirta, 2006 and 2008). These projects provided updated information on the distribution and state of the freshwater pearl mussel populations in five big catchment areas, the Tana, Neiden, Pasvik, Lutto (Tuloma) and Tornionjoki, which flow in the cross-border areas of Finland, Sweden, Norway and Russia. The information from other river catchments in Lapland is based mainly on the findings of the joint research team from WWF Finland and the Museum of Natural History (Valovirta and Huttunen, 1997), and on the unpublished data of the Metsähallitus Natural Heritage Services, Lapland and Lapland Regional Environment Centre. Also, the data concerning southern and central Finland are based mainly on the findings of the joint research team from WWF Finland/ Museum of Natural History. Updated information from the Iijoki River and Oulujoki River catchments, in central parts of Finland, was obtained also from the Kainuu Regional Environment Centre/ Friendship Park Research Centre and Metsähallitus Natural Heritage Services, Ostrabothnia.

I have classified the freshwater pearl mussel rivers into three categories. Category A contains those rivers where the presence of freshwater pearl mussel population has been confirmed by field investigations, and in which the population is reproducing. The actual rate of recruitment in freshwater pearl mussel populations has been studied in few rivers in Finland. However, I have generally classified into this category almost all the rivers where small mussels (< 50 mm) were detected. Thus, although a certain river may be classified as a category A river, the level of recruitment in the population would not necessarily be adequate in the long run. In the category B rivers, the presence of freshwater pearl mussel has also been confirmed by field studies. In these rivers, however, there is either no recruitment or we have no information about it. In some cases, I included into this group also such rivers where small mussels can occasionally be found, but the population is clearly aged, and the level of recruitment is far from sustainable. Category C contains rivers where we have reliable knowledge of freshwater pearl mussel populations, but the presence of the mussels has not beenconfirmed after 1990. Reliable knowledge on them is, for instance, well documented historical pearl fishing in the river or a sample of an empty shell. Also, such rivers in which the population has been confirmed in field surveys, but it has been more than 20 years since the last inspection are included into this category. I made some exceptions, however. For instance, if the environment in the river has been drastically changed since the pearl fishing era, I did not include the river into this category. Such are most of the renowned pearl fishing rivers in southern Finland. On the other hand, in more pristine areas like Lapland, category C contains rivers where we still can expect to find populations not currently registered.

RESULTS

Today, there are altogether 91 freshwater pearl mussel rivers in Finland (categories A and B, Table 1). Recruitment of juvenile mussels (category A) is underway in 31 rivers. In addition, the number of rivers with reliable, but not confirmed data on freshwater pearl mussel (category C) is 83 (Table 1). Most of the present-day freshwater pearl mussel rivers in Finland are located in Lapland, i.e. the northern part of the country (Fig. 1). South from Lapland, freshwater pearl mussel is known only from 27 rivers in 10 different catchment areas (Table 1, Fig. 2). However, most of these rivers are located in the Iijoki River area, central Finland, and only seven freshwater pearl mussel rivers are known from southern Finland. Moreover, freshwater pearl mussel has not been reproducing for decades in southern Finland, except in one small brook in the Kokemäenjoki River basin. In some rivers however the populations have probably become extinct quite recently. For example, the Pyhäjoki River in Ostrabothnia was known to contain freshwater pearl mussels in the 1980s, but the inspection ca. 10 years ago detected no mussels there anymore (E. Mäenpää, West Finland Regional Environment Centre, personal communication). The freshwater pearl mussel may have disappeared recently also from the middle and lower courses of the Karvianjoki River: during the investigations in 2004–2005, no freshwater pearl mussel was observed in the sites where the species had existed in the 1980s (Oulasvirta, 2005). The population in the Ähtävänjoki River is also declining rapidly: where in the 1980s the population contained ca. 50000 mussels (Valovirta, 1987), it is now roughly half of that (J. Pakkala, West Finland Regional Environment Centre, personal communication). The southernmost population in Finland is in the Karjaanjoki River, where an aged population of ca. 1000 mussels lives (Valovirta, 2006b).

Table 1. Number of *M. margaritifera* rivers in different catchment areas in Finland at present. Class A. Confirmed freshwater pearl mussel rivers with recruitment of young mussels. Class B. Confirmed freshwater pearl mussel rivers with no recruitment, or recruitment level very low, or recruitment not confirmed. Class C. The presence of *M. margaritifera* has not been confirmed after 1990. Catchments located in southern and central Finland are with grey background. The numbers of the catchment areas are as in Figures 1 and 2

	Catchment area	**Class A**	**Class B**	**A+B**	**Class C**	**A+B+C**
1	Karjaanjoki		1	1		*1*
2	Kiskonjoki		1	1		*1*
3	Kokemäenjoki	1	1	2		*2*
4	Karvianjoki		1	1	*2*	*3*
5	Lapväärtinjoki		1	1		*1*
6	Ähtävänjoki		1	1		*1*
7	Pyhäjoki			0	*1*	*1*
8	Oulujoki		2	2	*10*	*12*
9	Iijoki	1	17	18	*3*	*21*
10	Kem (Karelia)			0	*2*	*2*
11	Simojoki		1	2		*2*
12	Kemijoki	12	21	33	*35*	*68*
13	Tornionjoki	2		2		*2*
14	Teno	2	1	3	*1*	*4*
15	Näätämö		1	1	*3*	*4*
16	Lutto (Tuloma)	13	9	22	*21*	*43*
17	Koutajoki		1	1	*5*	*6*
	TOTAL	**31**	**60**	**91**	***83***	***174***

Iijoki catchment area in central Finland is the only area outside Lapland where freshwater pearl mussel still exists in several rivers. Juvenile mussels were found at least from one river (P-L. Luhta, Metsähallitus Natural Heritage Services, Ostrabothnia, personal communication), but most likely there are also other reproducing populations. For instance, in the Livojoki River, which probably contains the biggest population of freshwater pearl mussels in the whole Iijoki river system, the youngest mussel detected in 1989 surveys was 12-13 years old (Valovirta, 1990). Thus, it is possible that the population in River Livojoki is still reproducing, but no confirmed information was available on that.

In Lapland, the range of the freshwater pearl mussel covers almost all the main catchment areas. The species is missing only from the Pasvik and Uutua (Munkelva) catchments. In Pasvik, the absence of the freshwater pearl mussel may be natural, although it is interesting, since the parts of the Pasvik catchment in Norway and Russia contain several freshwater pearl mussel rivers with viable populations (Oulasvirta et al., 2006; Oulasvirta, 2006). However, from the Finnish part of the Pasvik catchment, there is not a single finding of the freshwater pearl mussel? and neither does the documented history of pearl fishing know of pearl fishing practiced there. By contrast, the Uutua River has been mentioned as a pearl fishing river (e.g. Storå, 1989). However, during the field surveys conducted by the Metsähallitus Natural Heritage Services Lapland in 1998, no mussels were found (Mela, 2006). Thus, it is obvious that the freshwater pearl mussel population has vanished from the Uutua River.

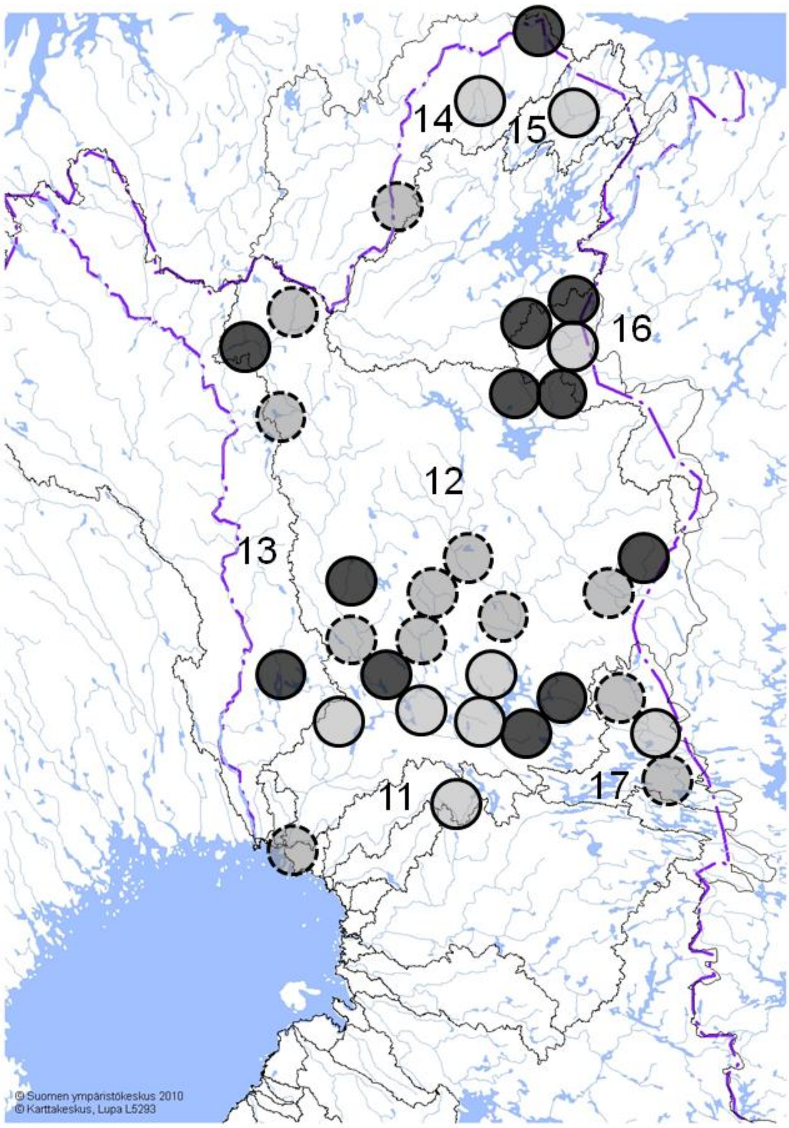

Fig. 1. Current distribution of the freshwater pearl mussel in Finnish Lapland. Black circles indicate class A rivers, grey circles – class B rivers, and dash-line grey circles – class C rivers (see Table 1). Note that each circle (diameter 35 km) may include several rivers. The catchment areas are delineated with black borders. The numbers of the catchments are as in Table 1

Most of the freshwater pearl mussel rivers in Lapland are located in the catchments of the Kemijoki and Lutto Rivers (Table 1, Fig. 1). At the moment, the most comprehensive knowledge of populations is from the Lutto and Tornionjoki river catchments (Oulasvirta et al., 2006 and 2008; Oulasvirta, 2006). The Lutto River and its tributaries represent the upper courses of the big Tuloma River, which flows to the Barents Sea. From Lutto area, 22 freshwater pearl mussel rivers are known today. Recruitment is known to take place in 13 rivers (Table 1). However, in the Lutto main channel, the level of recruitment is very low. Most likely this is due to the hydropower dam built in lower courses of the Tuloma, Russia, in the 1960s, which prevents the Atlantic salmon (*Salmo salar*) from ascending the Finnish part of Tuloma. Golubeva and Golubev (2009) have reported about the state of the freshwater pearl mussel populations in the Tuloma catchment in Russian territory. Populations in good condition are found, for example, from the Ulita and Kola Rivers, while the state of the population in the Lutto River on the Russian side is the same as or even worse than in Finland. Both Ulita and

Kola are located downstream from the Upper Tuloma hydropower plant, i.e. in the area where Atlantic salmon can still reach. This fact supports the hypotheses that the dam is the reason for the breeding problems in the freshwater pearl mussel population in the upper courses of Tuloma. In the tributaries of Lutto, the host fish for the freshwater pearl mussel is the local brown trout (*Salmo trutta*).

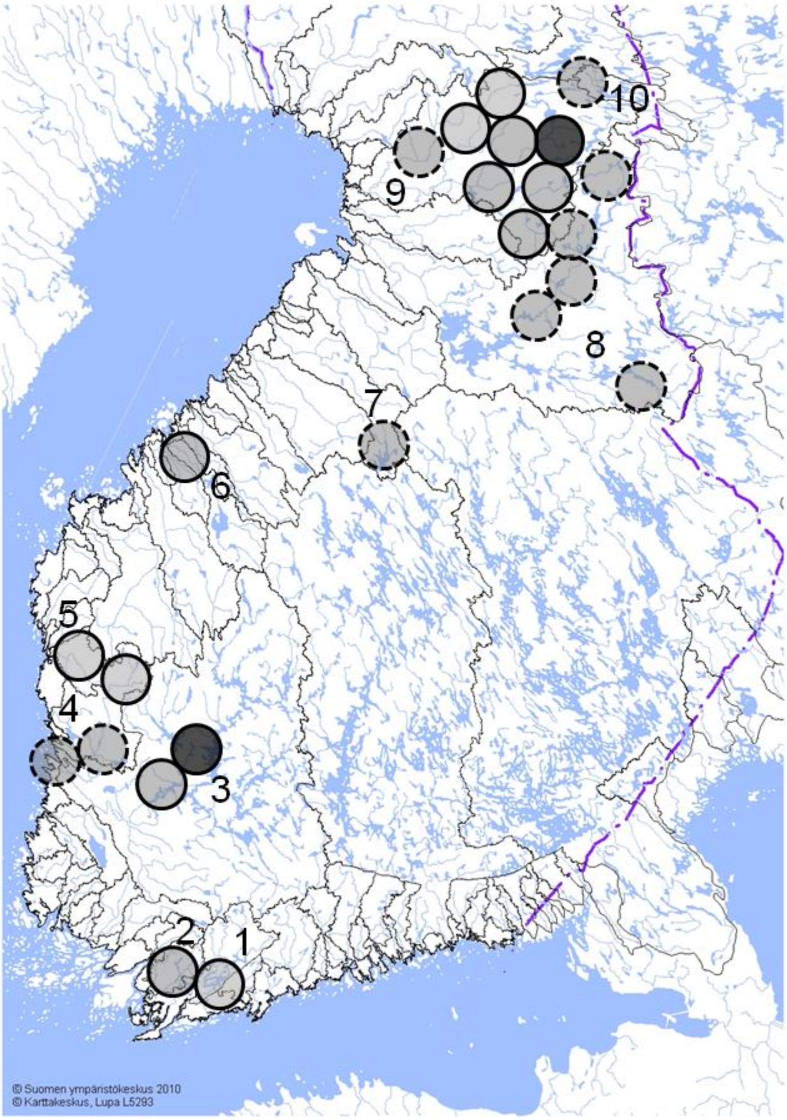

Fig. 2. Current distribution of the freshwater pearl mussel in southern and central parts of Finland. Black circles indicate class A rivers, grey circles – class B rivers, and dash-line grey circles – class C rivers (see Table 1). Note that each circle (diameter 35 km) may include several rivers. The catchment areas are delineated with black borders. The numbers of the catchments are as in Table 1

In the Tornionjoki river basin, the known distribution of the freshwater pearl mussel is restricted to three small brooks, two of which are located in Finland and one in Sweden (Oulasvirta et al., 2008). Both rivers in Finland contain viable freshwater pearl mussel populations. In one of the rivers, the maximum density of the freshwater pearl mussel exceeded 1000 specimens m^{-2}, which is probably one of the highest densities ever reported (Oulasvirta et al., 2008).

In the Neiden River, the state of the freshwater pearl mussel population is critical. During the investigations conducted in 1998 and 2004-2005, only 14 specimens were found in the main channel and none in the tributaries (Oulasvirta et al., 2006; Oulasvirta, 2006; Metsähallitus Natural Heritage Services, Lapland, unpublished data). All the specimens in the main channel are old and located far from each other.

In the Finnish part of the Teno catchment, only three rivers are now known to contain the freshwater pearl mussel. Two rivers, belonging to the same sub-catchment, were found during the Interreg project in 2005 (Oulasvirta et al., 2006). These populations, located near Lake Pulmanki, are the northernmost populations in Finland, and probably among the northernmost populations currently known in the world as well. In 2009, freshwater pearl mussel was found also from the Utsjoki River, tributary of Teno (Juho Vuolteenaho, University of Helsinki, personal communication). On the other hand, old pearl fishing sites in the Inarijoki River turned out to be empty in the surveys conducted in 1999 (Metsähallitus Natural Heritage Services, Lapland, unpublished data).

Kemijoki river catchment covers more than half of the Finnish Lapland. Currently, 33 freshwater pearl mussel rivers are known there, out of which 12 populations are known to contain juvenile mussels (Table 1). However, especially here, in the Kemijoki catchment, we have large areas not yet investigated (Fig. 3). Thus, it is possible that in the future more populations will be found. Like in Lutto, hydropower engineering has prevented salmon from ascending the Kemijoki River. As a consequence, the freshwater pearl mussel populations in Kemijoki catchment today are entirely dependent on brown trout, and are found in tributaries only.

In Finland, the freshwater pearl mussel has become totally extinct at least in the Kymijoki, Porvoonjoki, Eurajoki, Perhonjoki, Lestijoki, Kalajoki and Siikajoki river catchments, which had, according to the archives of the Museum of Hunting, been earlier renowned for their pearl fishing. Besides these, freshwater pearl mussel has most likely disappeared from many other river basins in southern Finland as well. For example, an empty shell of the freshwater pearl mussel was found in the Mankkaa River in 2008, indicating that the mussel had probably existed very close to the city of Helsinki less than 50 years ago (Laaksonen et al., 2008). As already mentioned, freshwater pearl mussel may have disappeared recently also from the Pyhäjoki River, and from the middle and lower courses of Karvianjoki river catchment.

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DISCUSSION

During the last decades the freshwater pearl mussel has declined dramatically in Finland. Valovirta et al. (2003) have reported that at the beginning of the 20th century, the species was found in more than 200 rivers, and in the modern time only in ca. 70 rivers. The updated information of this study supports the earlier estimates. We must remember however that the number of freshwater pearl mussel streams (91) presented in this paper, contains also the new findings not reported earlier. The state of the freshwater pearl mussel is critical, especially in southern Finland, where the last remaining populations are quickly vanishing. It is clear that only immediate and extensive restoration efforts, including measures in the catchment areas, can save the species in southern Finland.

Besides southern Finland, also most of northern Finland's populations are threatened in one way or another. The reasons for the negative development are multitudinous. The pearl fishing practiced before 1955 has certainly had negative influence on certain populations. However, since the pearl fishers collected mainly big sized old mussels and left juvenile mussels in the river, pearl fishing alone rarely destroyed the whole population. In such rivers where successful recruitment takes place rarely – once a decade or even more rarely – pearl fishing may have been the original and principal reason for the process leading to the extinction, however. For example, the conditions in the Neiden River could be suitable for the freshwater pearl mussel, but, perhaps because of the earlier pearl fishing, the number of mussels today is too low for them to survive.

After the protection of freshwater pearl mussel against pearl fishing was introduced in 1955, the reason for the decline of the populations has been the destruction of the river environment. This has included dredging of rivers for timber floating, construction of hydropower plants, eutrophication, building of forest roads, and other forestry operations such as drainage of forest and peatlands, which have led to silting of the rivers. In Finland, where drainage operations have been extensive, they are probably the major single cause of population extinction or decline. These same activities are still threatening the remaining populations, also in the remote wilderness areas in Lapland. For example, the last two freshwater pearl mussel rivers in the Tornionjoki river basin are extremely valuable in terms of protection, but still threatened and already partly affected by the forestry operations in the surroundings.

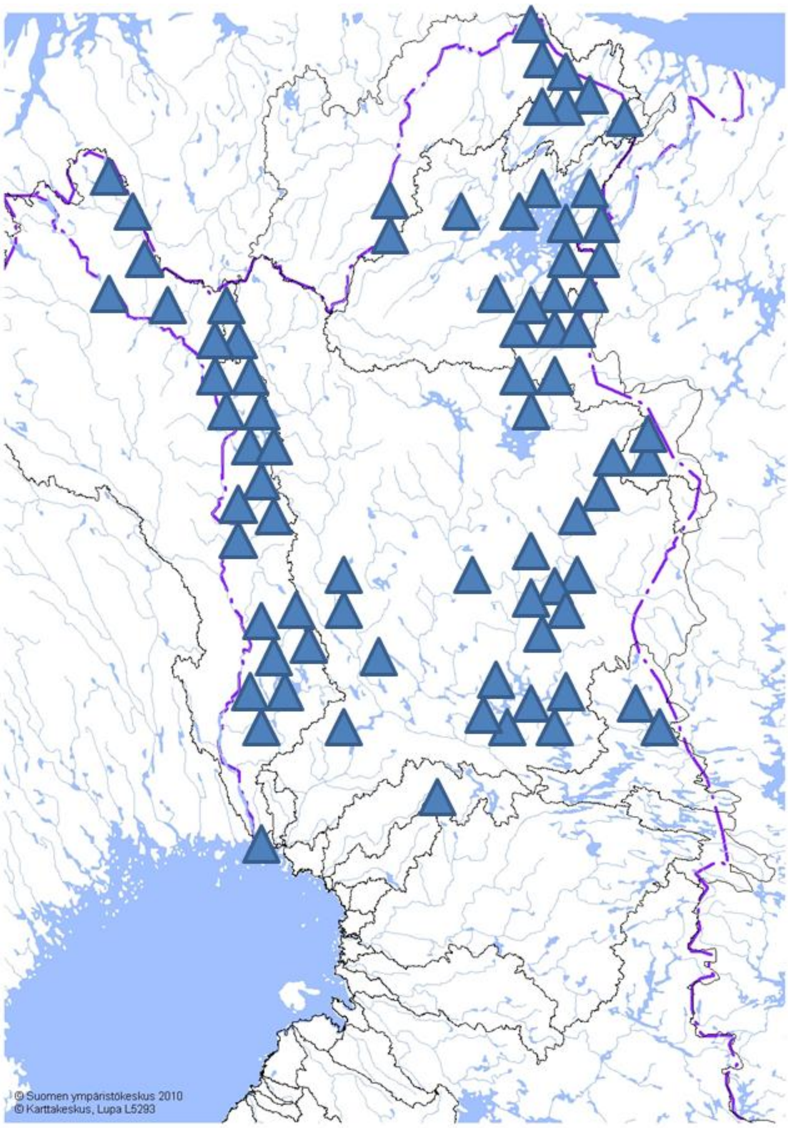

Fig. 3. Location of the sites where the distribution of the freshwater pearl mussel has been investigated in the field in Lapland. The map is based on the data of Valovirta and Huttunen (1997), Oulasvirta et al. (2006), Oulasvirta et al. (2008), Oulasvirta (2008), and on unpublished data of the Lapland Regional Environment Centre and the Natural Heritage Services, Lapland

In Table 2, I have summarized the main threats for the freshwater pearl mussel populations in different catchment areas in Finland. Also, the estimated numbers of mussels in different catchments are presented in Table 2. One should note that the mussel numbers presented in Table 2 are only rough estimates based on the available, quite inadequate data on the populations. The actual population size surveys have been conducted only in a couple of rivers in Finland. Moreover, possible findings of new populations in the future may change these figures greatly. As seen from Figure 3, especially the Kemijoki and Teno catchments still contain large unsurveyed areas. Still, the number of freshwater pearl mussels is small compared to the estimated freshwater pearl mussel numbers in Sweden (>8 million specimens) and Norway (143 million specimens) (Geist, 2005; Larsen, 2005; Direktoratet for naturforvaltning, 2006). Also, the number of known freshwater pearl mussel rivers or rivers with breeding populations is much higher in Sweden (550 rivers/ ca. 140 breeding populations) and Norway (485/ ca. > 300 breeding populations) (Henrikson, 2009; Larsen, 2009). From Russia, the available knowledge of the populations is not as good as from Norway or Sweden. However, according to Ziuganov (1994) the population in the Varzuga River in the Kola Peninsula alone contains a viable population of more than 100 million mussels. During the Interreg project in 2003-2005 viable and abundant populations were found also from the Pechenga area, Russia (Oulasvirta et al., 2006; Oulasvirta, 2006).

Table 2. The estimated numbers of living pearl mussels in different catchment areas in Finland, and a summary of the state of the populations and the factors threatening them. The data on the mussel numbers is partly based on the articles of Oulasvirta et al. (2006), Valovirta (1984, 1987) and on personal communications with Ilmari Valovirta (Museum of Natural History) and Eero Mäenpää (West Finland Regional Environment Centre)

Catchment	No of mussels	State of the populations, main threats and other remarks
1. Kiskojoki	?	No recruitment; vanishing, threats/reasons for decline [2,3,5]
2. Karjaanjoki	ca. 1000	No recruitment; vanishing, threats/reasons for decline [2,3,5]
3. Kokemäenjoki	ca. 50000	Recruitment in one brook, elsewhere vanishing; threats/reasons for decline [2,3,5]
4. Karvianjoki	> 500	No recruitment; vanishing, threats/reasons for decline [2,3,5]
5. Lapväärtinjoki	< 500	No recruitment; vanishing, threats/reasons for decline [2,3,5,7]
6. Ähtävänjoki	10000–50000	No recruitment; vanishing, threats/reasons for decline [2,3,5]
7. Pyhäjoki	?	Extinct (?); reasons [2,3,5]
8. Oulujoki	?	Populations threatened [2,3,5]; Large uninvestigated areas
9. Iijoki	>10000	Recruitment at least in one brook; Populations threatened [3,4,5]
10. Vienan Kemi	?	State of the populations unknown
11. Simojoki	>1000	Populations threatened [3,4] ; Large uninvestigated areas
12. Kemijoki	>100000	Populations threatened [3,4,5,6]; Large uninvestigated areas
13. Tornionjoki	50000–100000	Populations threatened [3]
14. Teno	?	Large uninvestigated areas; Reasons for decline [1(?)]
15. Näätämö	<100 (?)	No recruitment; vanishing; threats/reasons for decline[1(?), 7]
16. Lutto (Tuloma)	500000–1000000	Vanishing from the main channel, threats/reasons for decline [3,5,6]
17. Koutajoki	?	State of the populations unknown

1. Pearl fishing before 1955
2. Agriculture
3. Forestry (including drainage operations, building of forest roads and clearing of rivers in the past)
4. Peat harvesting
5. Hydropower
6. Gold and other mining
7. Small population size

CONCLUSIONS

The threatened species freshwater pearl mussel will be largely vanishing from Finland in the next few decades. In order to save the remaining populations, a management plan for saving the species is required. The management plan should include step-by-step program of how to protect the species in Finland. This would involve surveys in the yet uninvestigated areas, monitoring of the key populations and prohibition of all the activities, both in the river and in its catchment, which may threaten the freshwater pearl mussel populations.

ACKNOWLEDGEMENTS

I am grateful to Paul Aspholm, Jari Heikkilä, Marko Kangas, Taina Kojola, Pirkko-Liisa Luhta, Matti Mela, Eero Mäenpää, Jukka Pakkala, Ilmari Valovirta and Juho Vuolteenaho who all have generously helped me to collect all the data presented in this paper.

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FRESHWATER PEARL MUSSEL IN KAMENNAYA RIVER - EXPEDITION TO KOSTAMUKSHA NATURE RESERVE, NW RUSSIA

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The objective of our expedition was to find out whether the freshwater pearl mussel (*Margaritifera margaritifera*) exists in the Kamennaya River, Kostamuksha Strict Nature Reserve, NW Russia. There were some earlier observations about the species in the Kamennaya River made by the staff of the Nature Reserve (Kashevarov & Nikitin, 1998). Our aim was to verify these findings and confirm that the mussel species in the river really is *Margaritifera margaritifera*. Also, we wanted to get a picture of the state of the mussel population. Our expedition was a preliminary study for further, more thorough investigations.

The expedition took place on 20–23.7.2009 and was accompanied by Jari Heikkilä (Friendship Park, Finland), Boris Kasherov (Kostamuksha Nature Reserve, Russia) and the author (Alleco Ltd, Finland), who was responsible for searching for and identifying the mussels. The expedition headquarters was a Nature Reserve´s wilderness hut, which is situated by the Kamennaya River, ca. 10 km downstream from Lake Kiitehenjarvi. Searching for the mussels was carried out in three locations: in a river pool in front of the hut, and in one location upstream and one downstream of the hut (see Fig. 1).

FRESHWATER PEARL MUSSEL

The freshwater pearl mussel (*Margaritifera margaritifera)* is the longest living species in Europe´s fauna, and can attain an age of at least 150 years. The species exists only in rivers and can be recognized by its kidney shaped shell and gold or dark brown colour. The fully grown freshwater pearl mussel is 10–15 cm long, the maximum being 16–17 cm.

Because of its complex and vulnerable life cycle, the freshwater pearl mussel is considered a top indicator of a healthy river ecosystem. A vital population with stable recruitment of young mussels always indicates clean water and good salmon or trout populations. On the other hand, if a population consists only of adult mussels, it indicates that negative changes have taken place in the environment.

An abundant and vital freshwater pearl mussel population does not only indicate clean water; it also produces it. An adult mussel filters around 50 litres of water per day through its body at the same time as it purifies the water. Indeed, dense mussel populations play an important role in maintaining the health of the ecosystem. By purifying the water, they benefit the spawning success of many fish species, including their host fish, salmon and brown trout. Such species, which maintain the diversity of the ecosystem and create habitats for other species, are known as key species of the ecosystem. If these key species are destroyed, the function of the whole ecosystem suffers.

The freshwater pearl mussel is protected at both national and international levels. In Finland, it has been protected by the Nature Conservation Act since 1955. In Russia, it is a red-listed species as well. The freshwater pearl mussel is also listed in Annex II of the European Union Habitats Directive as a species whose habitat must be protected for its survival.

METHODS

Searching for the mussels was done by diving. Depending of the depth of the location, either skin (snorkel) diving or SCUBA diving (diving with an aqualung) was used. Locations 1a and 3 were examined by skin diving and locations 1b and 2 with SCUBA. Location 3 was surveyed by two divers (Boris Kasherov and the author) doing parallel transects.

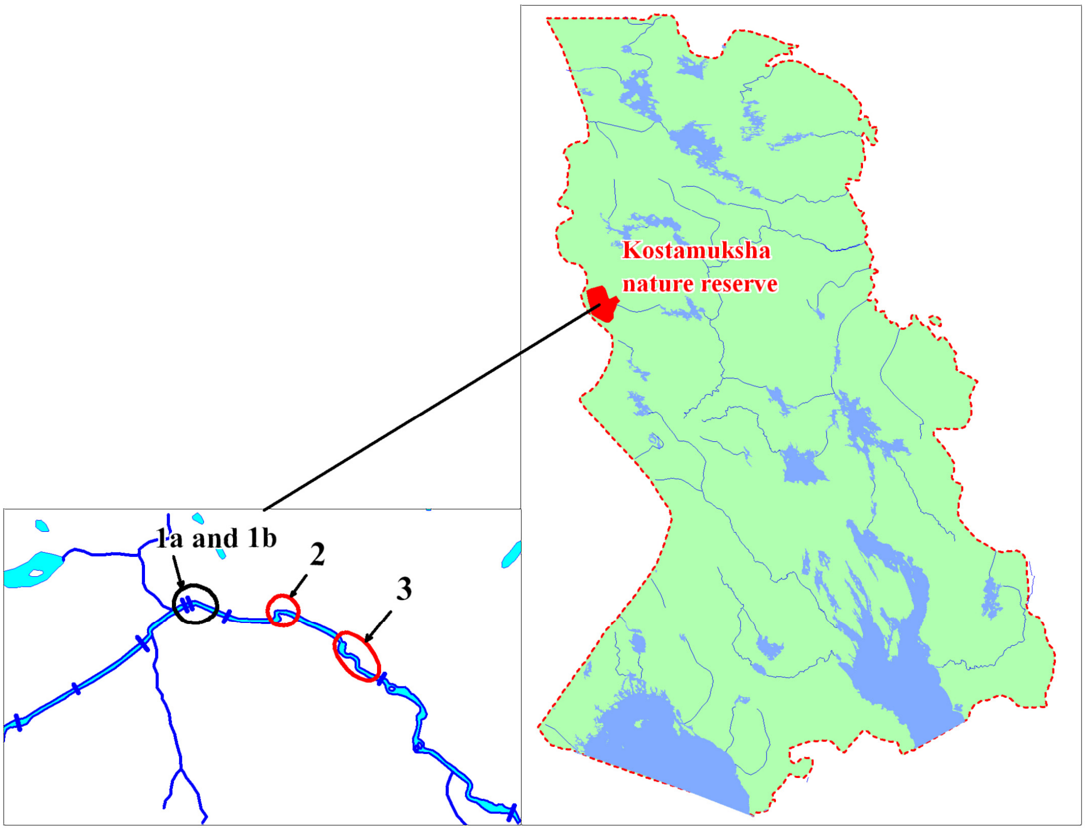

Fig. 1. Kostamuksha nature reserve and investigated locations (1a, 1b, 2 and 3). Freshwater pearl mussels were found from sites 2 and 3 (red circles)

RESULTS

Freshwater pearl mussels were found at locations 2 and 3. Location 1b in the upstream was a very deep site (max 7 m) just downstream of a powerful rapid. No mussels were observed there. Neither were the mussels found from location 1a, which was the upper part of the same rapid.

A majority of the mussels were found just opposite the hut in the river pool (location 2). The mussels were mainly located immediately downstream of the rapid in an area where the current became weaker and where the depth was around 4 metres (Fig. 2). The bottom substrate was mainly sand with few bigger stones here and there. I counted well over one hundred mussels in the ca. 100 m^2 area. The highest densities were 5-10 mussels per square metre. The smallest mussels found were ca. 5 cm long, which indicates that the population is breeding. However, to confirm this, and to estimate the rate of the recruitment, we need to carry out more detailed studies. This time the limited amount of air in the diving cylinder prevented any longer search for juvenile mussels. Besides this area, individual mussels were observed also in some other parts of the river pool.

Location 3 downstream from the river pool was ca. 1 km long. The river habitat there was mainly strong current with small rapids in some places. Altogether 13 freshwater pearl mussels were found. All the observed specimens were adult mussels.

Fig. 2. The river pool in front of the Nature Reserve´s wilderness hut (location 2). The red circle indicates the area where more than one hundred mussels were observed.
Photo by *Jari Heikkilä*

Fig. 3. Location 3 downstream from the river pool at location 2. Thirteen mussels were detected in the 1-km long river stretch
Photo by *Jari Heikkilä*

Fig. 4. Location 1b is a deep river pool downstream of a strong rapid. The bottom in this area is rocky, and the maximum depth is ca. 7 metres. No mussels were detected
Photo by *Jari Heikkilä*

Fig. 5. Location 1a just upstream of the rapid in Fig. 4. Boris Kashevarov standing on the stone and Panu Oulasvirta skin diving in the water. No mussels were detected
Photo by *Jari Heikkilä*

CONCLUSIONS

Our expedition proved that the Kamennaya River is a *Margaritifera* river. It is also obvious the mussel population in the river is breeding. However, due to limited time for our field work the rate of the recruitment and the vitality of the population could not be estimated during this expedition. Although well over one hundred mussels were found we still cannot say for sure that the population in the Kamennaya River is remarkable. Considering the fact that investigations were carried out only in three areas, it is, however, quite likely. Most probably, the main habitats of the mussels are elsewhere in the river. Further studies will give us more information on that. According to the previous observations made by the staff of the nature reserve mussels exist also a couple of kilometres downstream from the sites we surveyed.

A majority of the mussels observed were in an area where the depth was ca. 4 metres. Such a significant depth is not very common a habitat for the freshwater pearl mussel. Although even deeper findings are known, freshwater pearl mussel is normally found in much shallower water. Moreover, a river pool is not a very common surrounding for the freshwater pearl mussel, which always requires flowing water. This was the case also this time, because the mussels were in the area just downstream of the rapid, where the current was still notable. In fact, the water in the whole river pool at location 2 was constantly moving, thus providing a suitable habitat for the freshwater pearl mussel in the area which resembles a small lake rather than a river.

According to my earlier observations on freshwater pearl mussel populations I would have expected to find more mussels from location 3, where both the depth and current conditions were typical for *Margaritifera* rivers. However, only a couple of specimens were found. Our surveys showed, however, that the distribution of the mussels continues downstream from the river pool. We can expect to find more mussels further downstream.

At locations 1a and b, upstream from the river pool, the bottom consisted mainly of big boulders. Especially at location 1b beneath the rapid the boulders were really big, several metres in diameter. Thus, it is theoretically possible that there are still mussels between and under the boulders, which were invisible to the diver. The same uncertainty applies also to location 1a, upstream of the rapid, where the bottom was also stony.

Thus, since no mussels were found from locations 1a and 1, it is still uncertain whether the distribution of the freshwater pearl mussel continues to the upper reaches of the Kamennaya River. This is also a matter to be investigated in further studies.

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PEARL MUSSEL IN THE NAUTSIJOKI RIVER VALLEY, PASVIK – INARI AREA (KOLA PENINSULA, BORDER BETWEEN RUSSIA, NORWAY AND FINLAND)

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Reliable information about the presence of the freshwater pearl mussel in NW Kola Peninsula in the early 21st century is available from the Pasvik-Inari area, on the border between three countries – Russia, Norway and Finland. The study area was the Nautsijoki River – a tributary of the Paz River. The pearl mussel population density varies from the source to the mouth of the river. The highest density was 17 ind./m^2 (1977–1978) and 50 ind./m^2 (2003–2004). No definite conclusions regarding the population dynamics can be drawn. Studies of the population in the Nautsijoki River and other parts of the Paz River watershed, particularly within the Pasvik Reserve, should be continued. The main limiting factor is uncontrolled salmon fishery. Detailed study of the population, recovery of the numbers of salmonids – hosts of pearl mussel larvae, regulation of fisheries, and establishment of a protected area in the Nautsijoki River valley would promote conservation of the species.

Key words: pearl mussel, population, density, distribution, Pasvik-Inari area, the Nautsijoki River, Kola Peninsula, Pasvik Reserve.

INTRODUCTION

The bivalve freshwater pearl mussel (*Margaritifera margaritifera L.)* is an indicator of the water ecosystem status. This species, formerly widespread in freshwaters bodies in the north of European Russia, was barbarically exterminated by so called “Russian pearls” harvesting (Kazanskiy, 1891; Vereshchagin, 1929). By the late 18th – early 19th century already, the harvesting practice had locally declined because of the lack of the mollusks. In the Pasvik-Inari area however (Fig. 1), it continued until World War II, when pearl mussels were fished both by Eastern Sámi and by professional pearl fishers (Oulasvirta et al., 2006).

There existed also other reasons for the decline in one of the world’s northernmost populations of the pearl mussel – the Pasvik-Inari area population. After the War, industry in the region was rapidly developing. The mining and smelting enterprise Pechenganickel was built. It generates air-borne pollution and discharges wastewaters in the Paz River watershed. Seven hydropower plants have been operating on the river since the 1950s. The flow is now regulated, and natural development of salmonid populations is hampered. Also, some settlements and frontier posts have been built. Uncontrolled fishing for salmonids by local people and visitors in the Paz River watershed in the second half of the 20th century and at the beginning of the 21st century sharply reduced their numbers. As the result, the freshwater pearl mussel nearly disappeared from most waterbodies where it used to be common.

The pearl mussel is included in the IUCN Red List (IUCN, 1996), Red Data Books of East Fennoscandia (1998), Murmansk Region (2003), and others. It is recognized as a rare vulnerable or endangered species in need of protection and comprehensive study nearly everywhere. The main limiting factors are rapacious harvesting, water pollution and reproductive problems related to the decline in salmonid numbers (Red Data Book..., 2003).

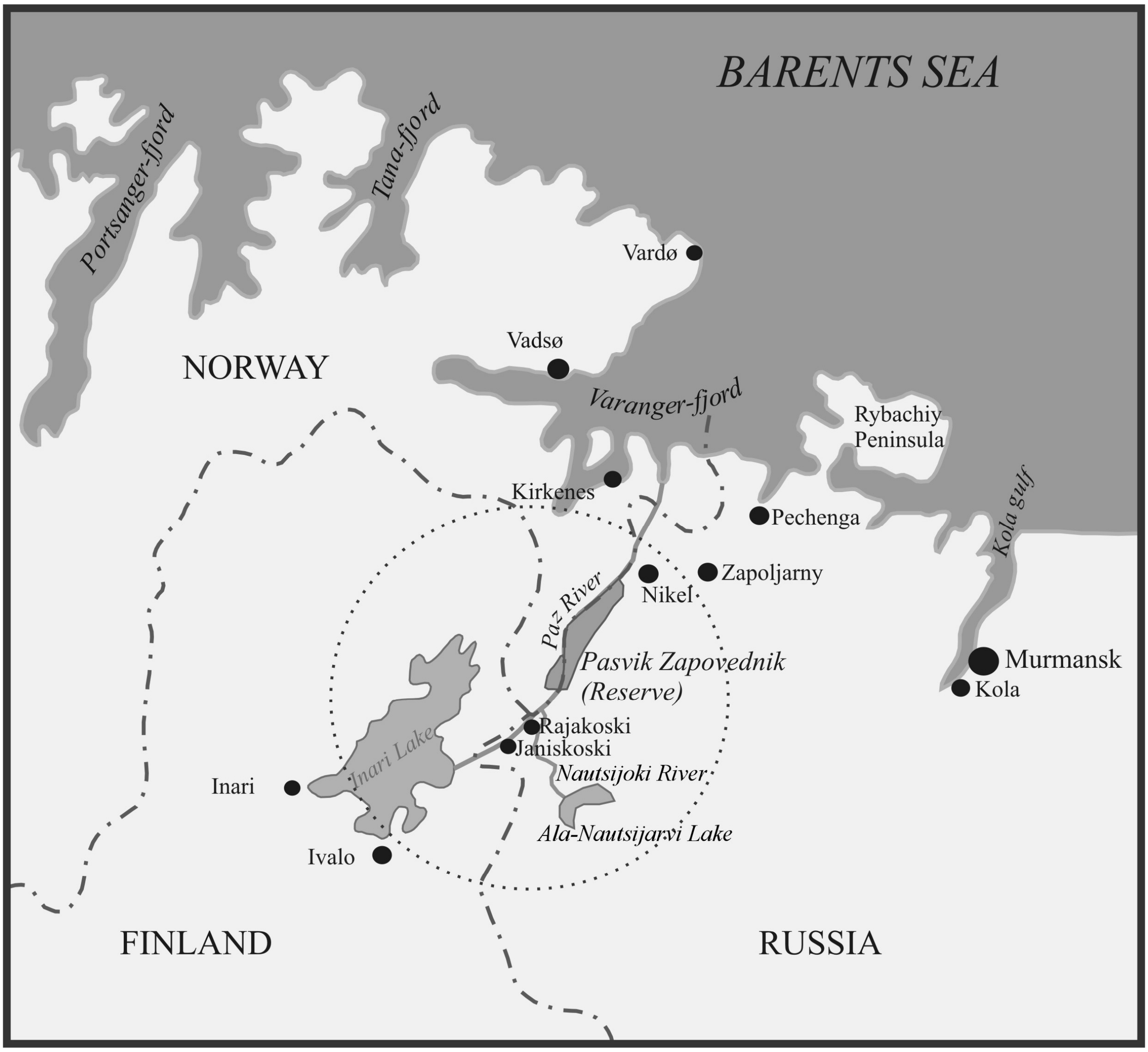

Fig. 1. Map of the Pasvik-Inari area

Pearl mussel studies in the Kola Peninsula began early in the 20th century (Zhadin, 1939; Graevskiy and Baranov, 1949). They became more extensive in the late 1980s and early 1990s, when they mostly covered the watershed of rivers Varzuga and Umba (Zyuganov et al., 1993; Prokhorov, 1995). In the past 20 years, the species has been actively studied in Europe (Larsen et al., 2000; Oulasvirta, 2006) and the European part of Russia (Zyuganov, 2005; Bespalaya et al., 2007). Presence of the freshwater pearl mussel has been confirmed for the Lapland Reserve (Gilyazova, 2000; Red Data Book..., 2003).

The first post-war surveys for pearl mussel populations in NW Kola Peninsula were carried out in rivers Nautsijoki and Pechenga. They were implemented by Primorskaya geological party (directed by B.F. Golubev) under the Ministry of Geology (SeverQuartzSamotsvety Division) in 1977 and 1978 (Golubev, 1978). The materials of the report are published for the first time.

Much later, in 2003–2006, the international project "Presence and status of pearl mussel populations in the north-east of North Calotte" was carried out within the Interreg III A Kolarctic programme. Its aim was to investigate some rivers in the border area of Finland, Russia and Norway with known historical habitats of the pearl mussel (Oulasvirta et al., 2006; Oulasvirta, 2006). In the summer periods of 2003-

2004, the international team surveyed the Russian side of the Pasvik-Inari area, namely the Nautsijoki River in the Paz River watershed.

The Paz River (Paatsjoki in Finnish, Pasvikelva in Norwegian) originates from Lake Inari in Finnish Lapland, and then flows through Russian territory. The middle course of the river is the national border between Russia and Norway. Finally, the river empties into the Barents Sea in Norway. Thus, the Paz River is common for the three countries. The river drains an area of 20 890 km^2. Nearly 70% of the drainage area is in Finland, 25% is in Russia, and 5% is in Norway. The river is 147 km long, its drop is 119.6 m, and its slope is 80 cm/km, wherefore the streamflow is high. In the Paz River mouth, mean annual streamflow is 187 m^3/sec, and mean annual runoff is 11.57 km^3 (National Water Cadastre, 1989). Such high flow rate and the presence of rapids that remain ice-free even in heavy frost had prompted the construction of a series of hydropower plants. Paz has many tributaries, of which the longest and the most full-flowing ones are Nautsijoki, Kornetijoki, Seigijoki and Laukkujoki.

The Nautsijoki River has its source in Lake Ala-Nautsijärvi and discharges into the Paz River in its upper course north of Rajakoski, close to the southern end of the Russian-Norwegian border (Fig. 2). Nautsijoki is 36 km long. It is a meandering river with low swampy banks. Closer to the mouth, the banks may be high, up to 2.5 metres. A few nameless streams join the river. The river is mostly still-flowing with some rapids: in its upper course, 4 km from the source, and 0.5 km downstream of its left-side tributary Kohisevanjoki. The channel is on average 35 metres wide and 2–3 metres deep. The flow rate varies from 0.5 m/sec in still sections to 1.5 m/sec in the rapids. The riverbed is mainly sand and pebbles, with a lot of boulders. The water is yellowish; the visibility is up to 1.5 metres. Most runoff is from snowmelt. Some rapids are ice-free all year round.

The territory surrounding Nautsijoki is mostly covered with lakes and forest, with a high proportion of wetlands. The ridges and chains of hills in the predominantly hilly-ridge terrain (abs. elevations 120–200 m) mainly stretch from north-east to south-west; their height varies from 10-60 m to 180 m. The ridge crests are undulating, and the hilltops are either flat or dome like. The slope gradient of the ridges and hills is up to 10°. Flat swampy lowlands separate the ridges and chains of hills. Strings of lakes cross many of the lowlands. The lakes are connected by channels, forming a line of successive water barriers (Oulasvirta et al., 2006).

Human pressure on the area is moderate. Nautsijoki valley used to be covered in old-growth pine forest, but in the second half of the 20th century the forest was cut down by Verkhnetulomskiy logging company. Some small fragments of the pine forest with lichen in the ground cover have survived, but most of the forest today is mixed birch-pine stands with few spruce trees. There is a road from Nikel to Virtaniemi close to the mouth of the Nautsijoki River. The settlements of Rajakoski and Janiskoski with a population of about 400 people, and three hydropower plants (Kajtakoski, Janiskoski and Rajakoski) are within a distance of 10 km from it. The settlement of Nikel, which comprises the Kolskaya GMK industrial premises, is 100 km NE of it. At present, the main human impact on the Nautsijoki drainage basin is connected with fishing and picking of berries and mushrooms in summer and autumn. These activities result in littering of the river banks and the bottom.

Pasvik Strict Nature Reserve lies to the north of Nautsijoki, in the middle of the Paz River valley, at the border between Russia and Norway. Its area is 147 km^2, of which over 20% is water – the Paz River, other rivers and streams, lakes. Surveys of several sites on the Norwegian side of the Paz River failed to find any pearl mussels there. A number of reasons, first of all border regulations on the Russian side, have made thorough surveys of the Paz channel and its tributaries within the reserve impossible.

MATERIALS AND METHODS

The 1977–1978 expedition explored the Nautsijoki River from the source to the mouth. The tributaries were not surveyed except for the place where Kokhisevanjoki joins Nautsijoki. The bottom was examined from the boat through a «Korean window» (a box with glass). The number of molluscs per square meter was counted, the length of the shells was measured, the substratum was assessed, and flow velocity was determined. Every other kilometre, divers examined the bottom to more accurately count the mussels in the sample plots. Every sample plot (1 m^2) was numbered and mapped; places with different densities of molluscs were marked (Fig. 2).

In 2003-2004, the international team interviewed local people in Finnish Lapland who remembered or knew something from their ancestors about pearl fishing in Pasvik-Inari area. Locations for the field work were chosen using results of the interviews and analysis of the literature.

The researchers either went snorkelling in wetsuits or used an aquascope to count the number of the pearl mussels along and across the river/stream. Cross-sectional counts were usually done in pairs, one diver moving from the left-side bank, the other one – from the right-side bank. The counts in small rivers and streams were carried out by one diver. Information on the staring point and the end point of the transects was recorded in the survey form. The length and width of the river and the transect were measured, the number of pearl mussel specimens found was indicated, the flow rate was determined, the riverbed topography and the substratum were assessed.

The mussels found were grouped into several classes by size: less than 3 cm, 3-7 cm, 7-10 cm, and bigger than 10 cm. Three samples ten mussels each were taken for the analysis from different parts of the river (sampling points 1, 3, 5; Fig. 3). The sampling was random. The mussels were returned to the river once measured and weighted. Only adult and mature individuals were treated because juveniles stayed in the bottom sediments, and were therefore not used in the assessment of the population status (Oulasvirta et al., 2006; Oulasvirta, 2006).

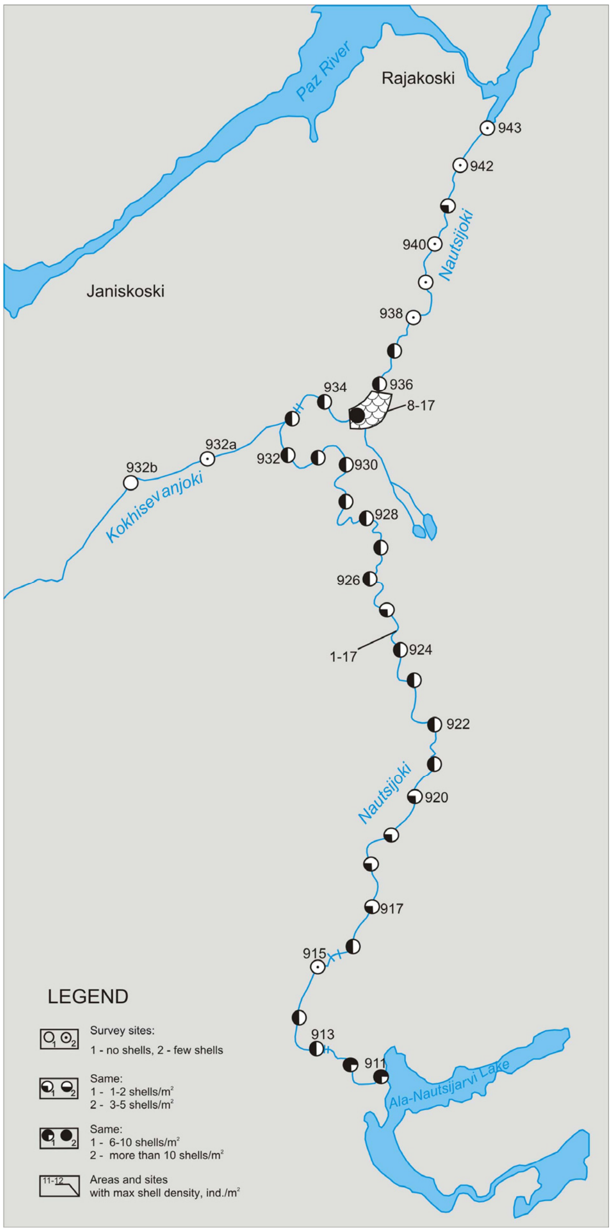

Fig. 2. Distribution of the pearl mussel in the Nautsijoki River watershed in the period from 1977 to 1978 (Golubev, 1978)

RESULTS AND DISCUSSION

Colonies of *Margaritifera margaritifera* were found throughout Nautsijoki when the river was surveyed for the first time in 1977-1978. No pattern could be distinguished in the distribution of the colonies. Mean density of the pearl mussel population in the river was 1-5 ind./m^2. A 50 000 m^2 area (1000 m long, 50 m wide, with a mean depth of 2.5 m) with a maximum density of the micro population – 13 ind./m^2 (data from 18 sample plots), was distinguished 7 km upstream of the river mouth. The density was quite even throughout this area, so that the mussel abundance there was about 650 000 individuals. Also, sites with a higher density – 17 ind./m^2, were found in the lower course of the river (Golubev, 1978). The population status was assessed as good.

The age composition of the population was not evaluated; only adults were counted; average shell length was 100–120 mm.

Surveys carried out in 2003–2004 also revealed the presence of the pearl mussel in the Nautsijoki River; the best population was found in its tributaries.

Population with the highest density – more than 50 ind./m^2, was found in a nameless tributary in the middle of the Nautsijoki River Valley – site 14 (Fig. 3). The number of the molluscs varied from the source to the mouth of the river in the following way: 30 ind. per 500 metres of the river (upper course, site 5), 21 ind. per 100 m (middle section, site 2), 520 ind. per 350 m (lower reaches, site 3). The number of pearl mussels found in the tributaries was the following: 812 ind. per 700 m (site 14), and 429 ind. per 300 meters of Kohisevanjoki – site 3 (Oulasvirta et al., 2006).

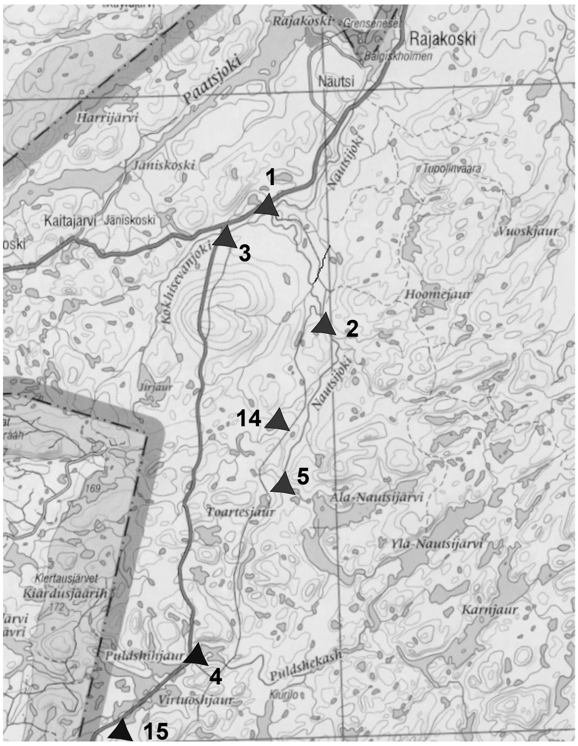

Fig. 3. Nautsijoki watershed coverage by 2003–2004 surveys (Oulasvirta et al., 2006). Sites 1, 2, 3, 5, 14 – pearl mussel found, 4, 15 – not found

According to the information based on three samplings, average shell length was 105 mm (min – max 80-124 mm) in the Nautsijoki River (main stream, site 1), 100 mm (82-110 mm) in Kohisevanjoki (site 3) and 98 mm (65-130 mm) in the nameless tributary of the Nautsijoki River (site 14). Judging by these parameters, the age of the populations in these three rivers may vary from 20 to 150 years or more. The smallest pearl mussel was 1.8 cm (Oulasvirta et al., 2006). This fact evidences ongoing reproduction of the population in the Nautsijoki system.

The main aim of the two expeditions was to get general information about the presence of *Margaritifera margaritifera* in the Nautsijoki River watershed. Therefore, these results alone do not allow for a reliable estimate of the population abundance in the river at large.

No pearl mussels were found in the Paz River. This does not mean however *Margaritifera* is absent also from other parts of its watershed.

CONCLUSIONS

Habitation of the pearl mussel *Margaritifera margaritifera* has been ascertained in the Nautsijoki River basin in the Pasvik-Inari area. The populations there occupy the species' typical High North habitats. The population density varies significantly from the source to the mouth, as indicated by the data received in1977–1978 (17 ind./m^2) and in 2003–2004 (50 ind./m^2). The dynamics of the species numbers could not be traced because the later surveys did not cover the whole river, data on mean density are missing, and so on. Further detailed surveys are needed to get more complete information on the present day status of the pearl mussel population, its abundance and biological characteristics, particularly reproduction. The issue is of international importance and can be dealt with within bilateral or trilateral projects. Human pressure has not yet destroyed the population. One cannot definitely conclude that its numbers have decreased under human impact because this would take specialized research.

It is obvious that the lack of information about the pearl mussel as well as selective surveys of only a few streams where pearl fishing used to be practiced could not provide us with a comprehensive picture. It would be rather difficult to do the job in the future not only for the lack of money but also for the lack of qualified divers-researchers in Russia. Since this fact hampers the study of this rare species, special courses should be organized for Russian researchers.

It is necessary to proceed with the research, especially given that there now exists a close international cooperation network on this issue in the Pasvik-Inari area, and exchange of experience would create a more comprehensive image of the pearl mussel life in its northernmost habitat. This is first of all important for the watercourses where the pearl mussel has already been found, as well as for the unsurveyed rivers and streams, e.g. in Pasvik nature reserve and for other watercourses in the border area.

An issue to be seriously addressed is the industrial impact on the pearl mussel population in the Pasvik-Inari area (Kolskaya mining and smelting company, hydropower plants). Measures should be taken also to restore the population of salmonids – typical hosts of pearl mussel larvae.

Unregulated fishing and poaching are still a big problem in the region. One should take care to conserve the brown trout population lest it becomes irrecoverable. This would not only benefit nature conservation but also help local people use natural resources sustainably. Awareness raising should therefore go along with active research and conservation measures. A useful step would be to publish a book in English to widely disseminate information among local people, specialists and authorities, and to design a website.

Setting up of a fishery- or integrated protected area in the Nautsijoki River valley would promote recovery of brown trout (host of pearl mussel larvae), further research into the status of the population, as well as enable some other studies, e.g. on post-felling successions.

The research was funded by the Ministry of Geology of the USSR in 1977–1978, Interreg III A Kolarctic project KA 0042 "Presence and status of the pearl mussel population in the north-east of Northern Calotte", and Pasvik Reserve (Ministry for Natural Resources of RF) in 2003–2004.

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SURVIVAL OF THE EUROPEAN PEARL MUSSEL *MARGARITIFERA MARGARITIFERA* UNDER HEAVY ANTHROPOGENIC PRESSURE AROUND THE CITY OF SAINT-PETERSBURG

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A survey of the European pearl mussel *Margaritifera margaritifera* around one of the largest Russian cities – St. Petersburg, revealed five populations in the rivers flowing to the Gulf of Finland, Baltic Sea. Population in River Peypia comprises about 40 000 individuals, which makes it one of the biggest in Russia. Four other populations are represented by a few individuals, although both adult and young. We believe such populations can survive even being very small, and discuss the conditions required for that. We also compare the circumstances of the pearl mussel survival in Russia and in Western Europe.

Key words: freshwater pearl mussel; St. Petersburg; conservation; arboreal vegetation; anthropogenic pressure

INTRODUCTION

St. Petersburg is one of the largest megalopolises in the world with about 6.5 mln residents in the city and its suburbs. Industry, communications, agriculture and tourism are well developed in the city and the surrounding territories, resulting in strong pressure on the environment. Despite that, a few populations of some rare animals still exist in close proximity to the city. Among those is the freshwater pearl mussel *Margaritifera margaritifera* (L.), which is currently considered to be one of the most endangered animal species.

In 2006–2009, we undertook a survey of *Margaritifera* populations over the area around St. Petersburg, and discovered some surprising facts: (1) although the territory is densely populated, the pearl mussel still lives in some rivers, even though no special actions for its conservation have ever been taken (except for formal local red-listing); (2) pearl mussel populations have hardly been studied at all in this area, although St. Petersburg is a big scientific centre (at least, we failed to find any published results or personal information); (3) in one of the rivers surveyed we rediscovered a large population with a total of about 40000 mussels and a density of 1000 individuals per 1 m² and in some places even more. Such abundance and density are significantly higher than in many rivers of the European countries where special measures are taken to restore mussel populations (Moog et al., 1993; Moorkens, 1999; Araujo and Ramos, 2001). This situation gives us a chance to discuss various factors causing pearl mussel decline in Europe. Here we describe newly discovered or rediscovered populations of *Margaritifera margaritifera* around St. Petersburg, and analyze the conditions for the pearl mussel survival under heavy anthropogenic pressure.

STUDY AREA, MATERIALS AND METHODS

Our study of the pearl mussel began in 2006 with compilation of the map of salmonid-inhabited rivers in St. Petersburg surroundings and Leningrad Region (St. Petersburg was renamed to Petrograd in 1914, then to Leningrad in 1924, and back to St. Petersburg in 1991, but the area around it still holds the Soviet name of “Leningradskaya oblast” meaning “Leningrad Region”). At the moment, it includes the territory around the Russian Gulf of Finland, Baltic Sea, and the southern part of Lake Ladoga, and is bigger than, for example, Austria and some other European countries. The present paper focuses on the western part of this territory, i.e. the rivers flowing to the Baltic Sea (data on the rivers of the Ladoga Lake catchment are under preparation).

Using the map mentioned above, as well as museum and archival data, those rivers were selected for the survey where the presence of the pearl mussel was assessed as probable. Direct observations were conducted during field seasons of 2006–2009. In each river, 500–1500 m² of the riverbed were examined using bathiscopes. The numbers of mollusks, their age and size were recorded. The main elements of vegetation covering the banks were described.

All we managed to find in the literature was two references to studies of pearl mussels in this territory. One of them dealt with the size of dead mussel shells collected in the Peypia River, and their comparison with some remote northern populations (Semyonova et al., 1992). The other (taxonomic) study was based on the collections of the Russian Academy of Science Zoological Institute. Three pearl mussel species – *Margaritifera margaritifera* (Linnaeus, 1758)*, M. elongata* (Lamarck, 1819) and *M. borealis* (Westerlund, 1871) were distinguished in the Leningrad region rivers relying on differences in the shell form (Bogatov et al., 2003; Bogatov et al., 2004; Bogatov, 2009). Recent partial revision of this collection did not support this division, showing only one pearl mussel species was present there – *M. margaritifera* (see Sergeeva et al., 2008). However, Russian Red Data Books and nature protection documents still include all three species mentioned above. In any case, since the pearl mussel in the area around St. Petersburg has never been properly studied, we aimed first to check those rivers where the species had been known before and, using the map of salmonid-inhabited rivers, look for previously unknown populations.

RESULTS

Seventeen rivers and numerous small streams empty into the Russian part of the Gulf of Finland, where salmonids have been caught. Some rivers have several tributaries where Atlantic salmon (*Salmo salar*) or brown trout (*Salmo trutta*) can reproduce. The total number of salmon and trout rivers exceeds 30. We failed to find the pearl mussel in the majority of these rivers and brooks, and there are no indications of its former habitation there. Several small rivers remain unexplored. *Margaritifera* has been found in five rivers only – Sestra, Peypia, Okhta, Gladyshevka and Roshchinka, and the latter two belong to the same river system. All these rivers flow across the territory where human population density and anthropogenic pressure are especially high. The distance from the centre of the megalopolis to these populations is within 100 km, and the habitats of two populations partially lie within the administrative borderline of the city.

The five rivers mentioned above have some features in common. They all originate from lakes, and are additionally fed by numerous small brooks and springs. The depth at rapids rarely exceeds 1 m, being usually ca. 0.7 m. Originally, the riversides had mostly been covered by spruce forest, which has by now been to different extents transformed by logging and agriculture. As the result, the forests contain a big share of small-leaved trees such as birch and alder. Some fields and villages lie along the rivers, but pearl mussel habitats are normally surrounded by arboreal riverside vegetation.

Differences between the “pearl rivers” mainly concern the riverbed composition, distribution of rapids and current velocity. In the rivers Sestra and Okhta, rapids are mainly located in their upper reaches. Stony bottom prevails, and boulders are numerous. In the rivers Roshchinka and Gladyshevka, rapids occur throughout the river. The bottom in the rapids is made up of boulders (0.5-1.5 m in size) with a thick layer of sand and fine gravel between them. The current velocity in all four rivers is up to 1 m/s. In the fifth river (Peypia), the bottom is sandy with some gravel and very few boulders. Rapids are hardly discernible, and the current velocity is about 0.3-0.5 m/s over the entire river.

Below we present more detailed information on each river mentioned and data on the pearl mussels found.

(1) River Gladyshevka (Finnish name “Vammelsuunjoki”) is about 10 km long, and 6 m wide on average. There are 6 rapids with a total area of 15000 m². *M. margaritifera* has been found in three of them, and incidentally on the sandy bottom outside the rapids. In 2006, two young mollusks (5 years old) and three adults (30–50 years old) were found. Similar results were obtained in 2009: three adults (30–50 years old) and one juvenile (4 years old). Additionally, two dead shells of old mollusks were seen.

The territory around Gladyshevka belonged to Finland up to World War II. It was intensively exploited for timber rafting at that time. Some parts of the river were straightened, and several weirs were built in the rapids. In the 1940s, these activities ceased, and since that time the main factor affecting the local pearl mussel population has obviously been a dramatic decline in host fish numbers. In 1950-60s, commercial and "scientific" fishing by means of the counting fence resulted in extermination of the local Atlantic salmon population and a heavy reduction of the brown trout population (Khalturin, 1970). According to the State Fisheries Inspectorate, trout regularly gets caught in Gladyschevka, however. We also saw some brown trout juveniles there.

Spruce and mixed forests cover most of the riverside. There are several small villages, abandoned fields and grasslands. Today, pollution of the river from agriculture and settlements seems to be insignificant, although construction of a new settlement started last year close to the river source. It is sure to increase the pressure on the river. The main human impacts on the river now are tourism and overfishing. Although Gladyshevskiy nature reserve was established in 1996 to protect salmon and pearl mussel, its work has for a long time been ineffective (mainly because of the lack of the scientific background and facilities).

Since 2000, attempts have been made to restore the salmon population in Gladyshevskiy. Atlantic salmon parr were released in some rapids. Some cases of natural salmon spawning were recorded after 2003 (Popov, 2003; Ostrovsky and Popov, 2008a-b), but stable reproduction has not been achieved yet. Before our studies began, there had been no agreement between salmon releases and the needs of mussel restoration. Usually, salmon yearlings were released in May, and almost all of them migrated to the sea soon after the release. Moreover, salmon YOY were released several times in late autumn. Hence, the host numbers during the period when the pearl mussel larvae leave the mollusks in August were low. Only in 2009 some young salmon were released in the rapids with *Margaritifera* in July, i.e. they can contribute to the mussel restoration.

(2) River Roshchinka (Finnish name "Raivolanjoki") is about 10 km long and 7–10 m wide on average. It joins Gladyshevka to form one river system. There are 3 rapids in this river with a combined area of about 14000 m². The rapids are located close to each other in the middle course of the river. Adult pearl mussels were found in all rapids, and a few specimens were found on the sandy bottom outside the rapids: 23 mollusks in 2006, and eight more in 2009. Most of them were 30-50 years old. No living young pearl mussels were found, but they probably exist in Roshchinka: three shells of recently dead young individuals (3-5 years old) were collected from the lower part of the rapids in 2009.

Most of the riverside is covered with mixed forest (spruce, pine, birch, aspen, rowan, and alder). For a distance of 3 km the river flows through one of the oldest protected forests in the area around St. Petersburg – a larch plantation founded in the 18th century.

Like Gladyshevka, Roshchinka greatly suffered from overfishing of salmonids. The last catch of Atlantic salmon was registered in 1949 (Khalturin, 1970). Brown trout still lives there, but is rare. The major source of pollution is effluents from the cottage community in the upper reaches of the river, but it is far away from the rapids. Thus, the main human impacts on the river are tourism and overfishing.

Following our advice, salmon parr were released in the rapids of Roshchinka in the beginning of August of 2007 and 2009.

(3) River Okhta is 99 km long. Rapids occur in a stretch of 8 km in the upper reaches, where the width of the river is about 3 m. Only three adult mollusks were found there (2009), and one of them was relatively young – about 15 years old. No dead shells were found.

The riverside in the area where pearl mussels have been found is covered with spruce and mixed forests. The territory is partially deforested in the middle course of the river and totally deforested in its lower course. The mouth of Okhta is located within the industrial part of St. Petersburg. Close to the mouth, the river is blocked by a dam, as well as crossed by several highways with concrete water-pipes underneath. During seasonal low water periods, such pipes become an insuperable obstacle for fish migration. Brook trout has occasionally been caught in the upper course of the river over the past decade (D. Dirin, pers. comm., 2005).

(4) River Sestra is 85 km long. Most rapids are situated in the upper reaches of the river, extending for 5 km, and reaching 6-8 m in width. Only two old mollusks and no dead shells were recorded.

Sestra is similar to Okhta in having its upper reaches surrounded by spruce and mixed forests, and being crossed by roads with concrete water-pipes underneath. The river is also blocked by a dam close to its mouth, which is located within the city boundaries. According to local fishermen, brown trout 20-30 cm long would sometimes be caught in the upper reaches of Sestra. During our survey, we also noted one such fish.

(5) River Peypia is 2.5 km long, and 3-5 m wide. The total number of pearl mussels there is about 40 000. In the middle part of the river the average density counted was 29.6 individuals per square metre, reaching up to 1000 mollusks per 1 m² and even more in four largest congestions. The bulk of the population (35 000 individuals) is concentrated in a small section of the river about 250 m long. Mollusks of different age were found, including few young ones (6 years old); 7 cm long mollusks (about 10 years old, according to Semyonova et al., 1992) were common. Dead shells were quite abundant too. To estimate their age and measure the size, 124 such shells were collected. Most of them were 30-40 years old, while the oldest one reached an age of 95 years. When counting the mollusks, we noted some trout, but they were rather few.

A power line and a highway with a concrete water-pipe underneath cross the river. No living pearl mussels were to be found upstream of these structures. Only a few large dead shells covered with sand were noted. Among the additional factors affecting the river is effluents from a summer children's camp. Also, the river mouth is a popular recreational site with numerous fire circles, trampled vegetation, and litter scattered around. Peypia is located within Kotelsky nature reserve, founded in 1996, but no special measures are taken to protect *Margaritifera*.

Almost all along the banks there grows spruce forest with some birch, aspen and alder. Locally, the riverside is covered with pine forest. In contrast to the other four rivers, one can encounter also broad-leaved trees – maple, oak and ash. Such trees are rare in natural forests around St. Petersburg, and would typically grow along rivers, where the soil is rich in carbonates.

Comparing the rivers surveyed, we agreed that Peypia represents an "ideal" habitat for the pearl mussel in possessing the following features:

– the river bed is composed of a thick layer of coarse sand and fine gravel with a particle size of 1–5 mm. This type of bottom is especially favorable for young mussels, which live between its particles. Most of the Peypia population was found in the river section with exactly this bottom type, while the section with a higher proportion of gravel and small stones had considerably fewer pearl mussels;

– Peypia originates from a large lake (Kopanskoe), which provides stable water supply in summer and accumulates detritus, which serves as nutrition for *Margaritifera*. The lake is mesotrophic, and eutrophication is relatively weak there;

– natural arboreal vegetation is conserved along the riversides, and the land use is slight;

– the hosts available are mostly young brown trout. In rivers that have connection to the sea, brown trout population usually exists in two forms – resident and migratory. In the case of Peypia the migratory form obviously prevails. This river is short and shallow (0.2–0.6 m), and cannot provide habitats for prolonged stay of big fish. A known fact is that in the area around St. Petersburg, brown trout can migrate to the sea when 1–2 years of age. Such data were obtained for the Luga River, which is close to Peypia (Popov, 2001). Thus, the trout population rapidly renovates, which is important for the pearl mussel, since its larvae infect young fish more successfully than adults, who acquire immunity to the infection.

DISCUSSION

Survival of small Margaritifera populations

As our study proceeded, more and more interesting facts showed up. Actual rediscovery of the very big pearl mussel population in a very short section of a small river is the most remarkable one. For a comparison, the entire Austria has 27 mussel populations with a total number of mussels estimated as 50 000 individuals (Moog et al., 1998), which is comparable with the Peypia population.

Another intriguing fact is that most of the populations surveyed seem to be still reproducing, although represented by only a few individuals. Referring to a statistical chance to infect a fish host by glochidia, Moorkens (1999, p. 18) regarded 500 reproducing individuals within 0.5 km of a river as the minimum number "within a unit of mussel population below which it becomes unviable". Our data suggest that, at least sometimes, populations of the pearl mussels can reproduce even being much less numerous. Findings of young mollusks in rivers Gladyshevka and Roshchinka, low numbers of adults and the absence of piles of dead shells suggest that the *Margaritifera* populations have been quite small there during past years. Recruitment does take place however. It is possible that such a situation can last a certain period of time (some years or even decades), and the adult mollusks found in our study could have also been born under the same circumstances (i.e. when the mussel population was small). Noteworthily, the mollusks manage to survive even in spite of overfishing and very low numbers of the host fish. One knows from the archives that about a century ago the rivers under consideration were already exposed to heavy anthropogenic pressure – logging, timber rafting, and agriculture. The pressure in those times was probably even stronger than today, because timber rafting had ceased a long time ago, and agricultural activities in this area are now minor.

Except for the upper part of the river Peypia, which was cut off the lower part of the river by a concrete water-pipe, and is exposed to pollution from the summer camp, we were unable to find any evidence of complete extinction of the pearl mussel from the St. Petersburg area rivers mentioned as pearl-inhabited in the archives and collection lists. Populations of *Margaritifera* have survived, although obviously declined to a very minimum.

The assumption is made that the pearl mussel is preadaptated to reproduction in low density populations (Bauer, 1987). First of all, in addition to gonochoristic individuals, its populations comprise a considerable amount of hermaphrodites. Moreover, mussels can change their sex from females to hermaphrodites if the chances to be fertilized are low. These factors are coupled with very long life-span and high fertility, which is independent of age (Bauer, 1987). In the remote past, such mussels could colonize northern rivers during glacier recession. The founders of new populations could reproduce without or with few sexual partners. Nowadays, after prolonged direct or indirect extermination, they find themselves in a similar situation. Hence, there still exist chances for the restoration of the pearl mussel, and we try to activate this work by delivering the materials on the current state of *Margaritifera* and recommendations to the local administration.

Circumstances for the pearl mussel survival in Russia and Western Europe

In the central and northern parts of Western Europe, where the conditions are similar to those in the area around St. Petersburg in many respects, pearl mussel populations are continuously declining. Many populations have become extinct, whereas many others are represented exclusively by old individuals, with no signs of successful recruitment (Bauer, 1986, 1988; Young, 1991; Moog et al., 1993; Moorkens, 1999; Araujo and Ramos, 2001; Moorkens et al., 2007). The main factors believed to lead to *Margaritifera* decline are the following:

– eutrophication;

– siltation;

– pollution;

– artificial modification of the river beds, dam and road construction;

– lack of host fish;

– impact of invasive (American) species: muskrats can eat mussels; rainbow trout can substitute European trout, whereas European pearl mussel cannot use rainbow trout as a host species;

– pearl poaching;

– erosion of the riversides after removal of the vegetation, with the following increase in the amount of sand and other particles in the water;

– forest plantation (especially artificial spruce monoculture) (Bauer, 1988; Young, 1991; Moog et al, 1993; Araujo and Ramos, 2001; Moorkens et al., 2007).

Obviously, eutrophication, siltation and water pollution do take place in St. Petersburg surroundings as inevitable effects of the activity of very large human population. Roads with water-pipes and, in some instances, dams cross all the rivers studied, preventing fish migration. Host fish populations are decreasing.

Invasive species are present as well. However, rainbow trout, which often escapes from farms, never becomes abundant in the natural environment, and does not reproduce. Muskrats are numerous around St. Petersburg, but they have never been noted on the “pearl rivers”, preferring to live on lakes.

Both poaching and official pearl fishing haveexisted in Russia for a long time, but over the past decades they have been minor around St. Petersburg because of low profits. Moreover, professional pearl collectors do not kill mollusks in large numbers, since they can easily distinguish pearl-bearing mussels by their deformed shell. Mollusks smaller than 8 cm are of no interest to them either. During Soviet times, so-called All-Union Jewelry Industry Research Institute looked for raw materials of organic origin to be used in jewelry. Pearl mussel was within the scope of this activity together with mammoth tusks and some fossils. The Institute’s staff estimated stocks of the pearl mussel with view to its further commercial exploitation (Golubev and Yesipov, 1973). The five mussel populations in question were not found, since the Institute was more interested in remote areas of the Russian North and Far East. Thus, the impact of pearl collecting is insignificant in terms of the state of the mussel populations, although such a conclusion does not mean this factor can be just neglected.

Poaching and overfishing of salmonids clearly have more significant consequences, because they continuously reduce the host fish populations. Violations of local fishery regulations and illegal fishing are common in Russia. Over the past decades, illegal fishery of salmonids was mainly recorded in two of the rivers studied – Gladyshevka and Roshchinka (we participated in several raids of inspectors). They traditionally attract fishermen, and are therefore more often patrolled by the State Fisheries Inspectorate. Legal fishing of salmon and trout is prohibited in all the rivers studied, as well as in most others in the region.

One of the most important factors influencing the pearl mussel is the land use pattern, and its consequences for the state of the riverside and water quality. These patterns differ greatly in Western Europe and Russia. Judging by our excursions through some European countries (Austria, Finland, France, Germany), not only trunks, but also all branches are removed from the forest after felling. In Russia, even around St. Petersburg, forests are being managed extensively rather than intensively. After clearing, heaps of stumps, branches and small trees remain in the glades. The branches are partly burnt in the site. As the result, a great amount of nutrients remains in the forest. In Western Europe, grasslands and pastures often stretch to the very water edge. Private property to land allows doing that without any serious restrictions. In Russia however, forest cannot be private property. It can be rented, but there are some regulations concerning its use. For instance, restrictions concern the logging area, and forest must always be left around clearings. Also a strip of arboreal vegetation has to be left along roads and waterbodies. Grasslands, fields and pastures rarely adjoin riversides (at least in the territory studied) since Russian law requires leaving so called “water protection zones”. The same holds for build-up. Watersides cannot be private property, and no houses should be built at the water edge. As the result (although violations are many), the stripe of natural vegetation is usually maintained along rivers even within settlements. That is why erosion and transformation of the riverbed are not so intense.

Trees growing at the riverside often fall into the river. In all five rivers surveyed, fallen trunks and branches were abundant. In Peypia, e.g., such trunks cross the river each 3-5 m, creating numerous microhabitats for a variety of aquatic organisms. In some sites that are especially popular among tourists, they try to clean the riverbed from the fallen trees, but this is fairly uncommon.

Another important difference that has to be discussed is spruce plantations that are widespread in Western Europe. Natural spruce forests, which cover riversides in North-west Russia, differ greatly from the planted spruce monoculture in Europe. They always contain a considerable proportion of deciduous trees and shrubs. Such a forest produces more detritus than pure spruce, wherefore natural spruce forests provide nutrition for aquatic organisms more effectively than planted monoculture.

The correlation between forest composition and the state of pearl mussel populations has been reported for Sweden (Jensen, 2007). It turned out that mussel populations are better-off in rivers surrounded by young forest containing broad-leaved trees, obviously because the latter produce more detritus. As trees grow, foresters sparse them out, remove everything “unnecessary” and gradually transform a «mixed» forest into a coniferous plantation. The rivers surrounded by such relatively old forests provide poorer conditions for pearl mussels, being inefficient suppliers of nutrients, and causing water acidification. Moreover, coniferous plantations often have a system of drainage canals, which carry great amounts of sediment to rivers (Moorkens et al., 2007, T. Ofenböck, pers. com., 2008). Since there are no artificial spruce forests around St. Petersburg, this negative factor is also absent.

CONCLUSIONS

Despite the high anthropogenic pressure, the European pearl mussel has survived in St. Petersburg surroundings, although mainly in very low numbers. Our assumption is that it can however exist and reproduce in low numbers for a long time: even being very small, three such populations have shown signs of recruitment. This is especially interesting since this reproduction takes place in the situation when host fish numbers are very low. Hence, there still is a chance for restoration.

We argue that one of the most important factors for the survival of *Margaritifera* is preservation of the natural vegetation on riversides, together with the extensive forestry practices in Russia. If this presumption is correct, then one of the most important negative factors affecting mussel populations in Europe is the loss of natural arboreal vegetation along rivers.

River Peypia with the mollusk density reaching a thousand individuals per square metre represents an “ideal” pearl mussel habitat. Its bottom is composed of coarse sand and fine gravel (the particle size is 1–5 mm); the flow velocity is 0.3–0.5 m/s, and the depth is 20–60 cm. Peypia originates from a big mesotrophic lake and flows through ‘mixed’ forest. Accumulating water and detritus, the lake provides a stable water regime all year round and sufficient amount of nutrients for the mussels. Peypia flows to the sea, and the host fish population is mainly anadromous. It rapidly renovates, providing optimal conditions for successful mussel infection. Although its abundance is high, this unique population is very vulnerable, and urgent measures should be undertaken to protect it.

ACKNOWLEDGEMENTS

The research was supported by the Rufford Small Grants Foundation (in 2008–2009). The authors express gratitude to Dr Alexander Makhrov (Severtsov Institute of Ecology and Evolution) for the archival information on the pearl mussel distribution and to Dr Lennart Henriksson (WWF) for assistance in getting equipment for hydrobiological research.

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DISTRIBUTION AND NUMBERS OF THE FRESHWATER PEARL MUSSEL *MARGARITIFERA MARGARITIFERA* IN SWEDEN

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The freshwater pearl mussel *Margaritifera margaritifera* is widely spread in Sweden from the southernmost to the northernmost part. According to an enquiry, it is present in 551 streams. The mussel streams are more common in large catchments than in small ones. All streams are situated below 600 m a.s.l. Densities are mostly less then 5 specimens/m^2. Approx. 1/4 of the populations have less than 5,000 mussels and the largest population comprises 1.4 million mussels. Recruitment, i.e. smallest mussel < 50 mm, has been reported from 234 streams, but mussels shorter than 20 mm were present only in 60 streams. Lack of small mussels indicates poor recruitment which may be a great problem for the survival in the long run. Most mussel streams, greatest population size, highest population density and small mussels are found in the north of the country, probably due to lower human impact.

Key words: Sweden; *Margaritifera margaritifera*; freshwater pearl mussel; distribution; status.

INTRODUCTION

Scandinavia and Scotland are the core areas for the remaining populations of threatened freshwater pearl mussel (freshwater pearl mussel) *Margaritifera margaritifera* in Europe. Modern documentation of freshwater pearl mussel in Sweden started in the 1980s, and today the knowledge of the occurrence and distribution is quite good, apart from some parts of northern Sweden.

The objective of this paper is to give a short overview of the distribution of freshwater pearl mussel in Sweden. More details are found in Söderberg *et al.* (in press).

METHODS

An enquiry was sent to all county administrative boards in areas with freshwater pearl mussel. The objective was to get answers on locations for freshwater pearl mussel, smallest mussel found, population size, population density and methods used. The time deadline was 2006.

The studies were made with different objectives, from just documentation of occurrence to more advanced studies. All inventories and more detailed studies were made by visual observation of the mussel. In addition, length measurements of some of the individuals were done. All numbers and sizes refer to visible mussels, i.e. no digging for hidden mussels was done.

RESULTS

Geographical distribution

Freshwater pearl mussel occurs from the southernmost to the northernmost part of Sweden, a distance of approx. 1,500 km, according to the enquiry. It is present in 551 streams. Most of freshwater pearl mussel streams are situated in the northern 2/3rds of Sweden (Fig. 1).

Freshwater pearl mussel streams represent 52 % of the 118 main catchments (larger than 200 km^2 and ending in the sea), and 7 % of 128 coastal catchments (smaller than 200 km^2). Among the smaller main catchments (< 1,000 km^2) the percentage of records is 34 vs. 80 among the larger ones.

All freshwater pearl mussel streams are situated below 600 m above sea level. In most (approx. 80%) of the streams freshwater pearl mussel populations occur in less than 6 km of the stream, according to data from 123 streams. Ten streams (8%) hold mussels in more than 10 km, the longest distribution being 29 km.

Population size

Judging by 126 streams, the populations size is less than 5,000 specimens in 29 % of the streams, 5,000–10,000 – in 11%, 10,000–50,000 – in 27%, 50,000-100,000 – in 13%, 100,000–200,000 – in 11%, and >200,000 – in 9%. The largest population is 1,400 000 specimens. All but one streams with >200,000 mussels are situated in northern Sweden.

Population density

Judging by 123 streams, the mean population density is less than 5 specimens/m^2 in 70%, and higher than 10 specimens/m^2 in 14% of the streams. The highest density found is 40 specimens/m^2. Most of the streams with highest densities (90%) are situated in the northern part of Sweden.

Size of the mussels (age)

In 60 of 465 streams the smallest mussel found was <20 mm, in 174 streams it was 20-50 mm, and in 234 streams the smallest mussel was >50 mm. There is a tendency that more streams with small mussels are found in the northern part of Sweden. Mussels <10 mm were found in 10 streams, all but one in northern Sweden.

DISCUSSION

The inventories and studies show that Sweden has quite many, at least 551, freshwater pearl mussel streams. This is more than what is known from other countries, compared to most other countries. However, the species was even more common 100 years ago. Eriksson *et al.* (1998) estimated that freshwater pearl mussel had gone extinct from approx. 1/3 of the streams known to hold freshwater pearl mussel around 1900 (cf. also Fig. 1).

Fig. 1. The distribution of freshwater pearl mussel in Sweden. Red dots = localities with living mussels after 1980, white dots = no mussels found after 1980. Map by Ted von Proschwitz, Natural History Museum, Gothenburg.

Although freshwater pearl mussel is still found all over Sweden, it seems obvious that the northern 2/3rds of Sweden hold most freshwater pearl mussel streams, feature the largest in-stream distribution, the greatest populations, the highest densities, and the smallest (youngest) mussels. The reason for that is probably that northern streams in general are less affected by human activities than southern ones.

The coastal catchments and the smallest main catchments have a lower percentage of freshwater pearl mussel streams. Once again, the likely reason is more human activities in these areas.

No freshwater pearl mussel streams are found above 600 m a.s.l., probably because the temperatures there are too low.

In most streams, only large/adult mussels are found. Only in 13% of the streams there are mussels smaller than 20 mm, corresponding to an age of approx. 10 years. Of course, the presence of small mussels is underestimated as only visible mussels have been counted, not the mussels within the substrate. However, the studies indicate that recruitment in general is very poor.

In conclusion:

- Sweden has fairly many freshwater pearl mussel
- Most of the streams are situated in the northern part, due to lower human impact
- Lack of small mussels indicates poor recruitment, which is a huge problem for the survival in the long run.

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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).

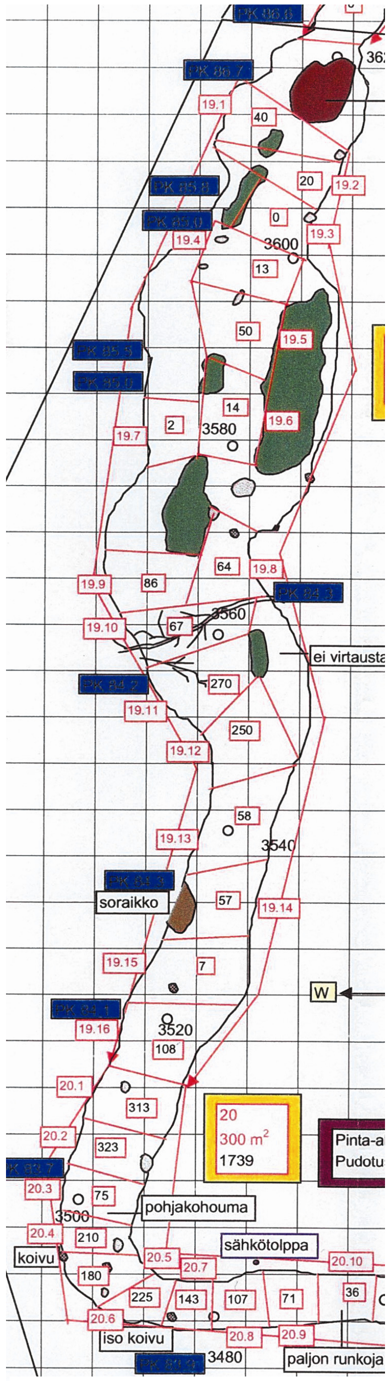


Fig. 5. Small scale mesohabitat inventory in the river Ruonajoki. The river basin (10 km) is divided into squares about 5 m long. The number of *Margaritifera* specimens is in squares (red) in the middle of the river channel (40, 20, 0, 13, 50….). Flow direction is downwards in the map

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).

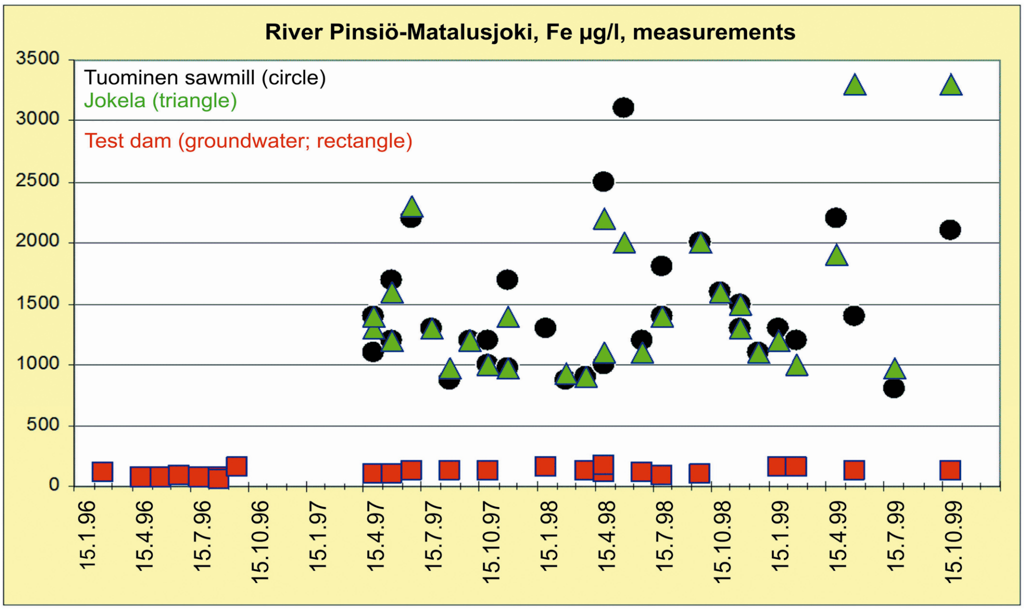
Table 5. The fauna and flora of different fluvial habitats are affected by decreasing water retention time via:

- 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*.



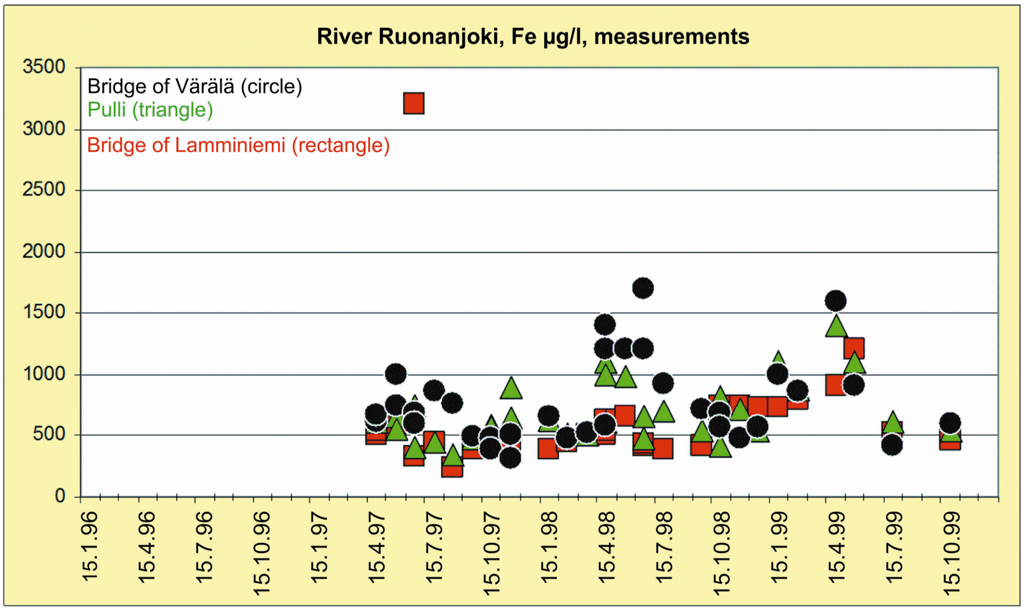


Fig. 6. Critical level of Fe content for *Margaritifera* is 1500 (µg/l). In the river Ruonanjoki the species can breed (above), but not in the river Pinsiö-Matalusjoki (below) (4.1997–10.1999). Red squares are from ground water area. (Life Nature project. Valovirta et al., 2003)

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

<u>Introduced soil and stones</u>
- 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

<u>Wintering excavations</u>
- alteration in water flow regime, especially in shallow water habitats
- alteration in natural erosion processes

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

<u>Introduction of gravel</u>
- alteration in the water flow regime
- alteration in natural erosion processes

<u>Survey of fish populations (wading and electric fishing)</u>
- crushing of freshwater pearl mussels

<u>Making new river beds bypassing natural barriers to fish migration by more gentle sloping</u>
- 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

<u>Fish introduction of captive-bred fish stocks</u>
- 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

<u>Maintenance of boat routes</u>
- 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.

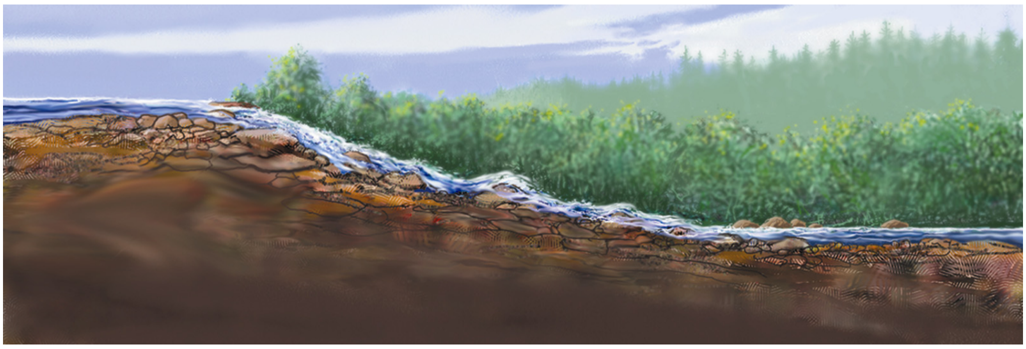


Fig. 8. Rapid. Rocky and spatey

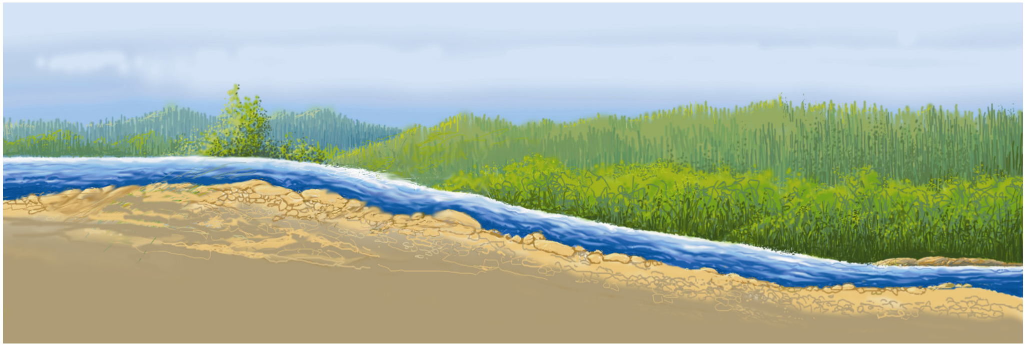


Fig. 9. Fast flowing stream section. Gravel and small stones, no spating

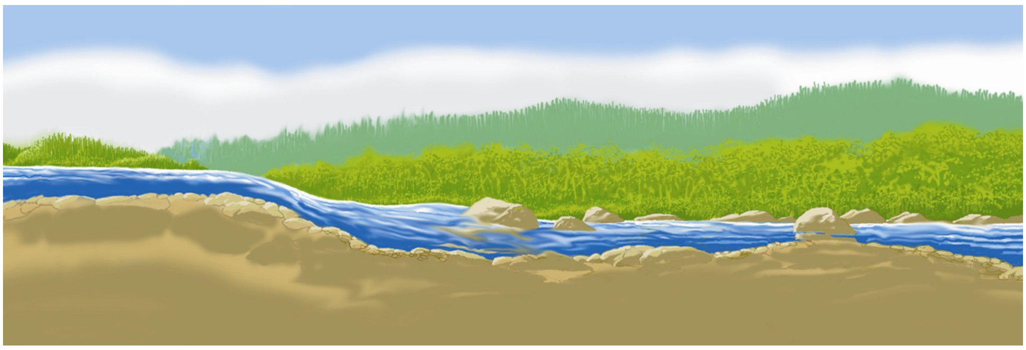


Fig. 10. Deep and turbulent stream section. Turbulence visible between boulders, gravel and sand bottom. The best habitat for *Margaritifera*

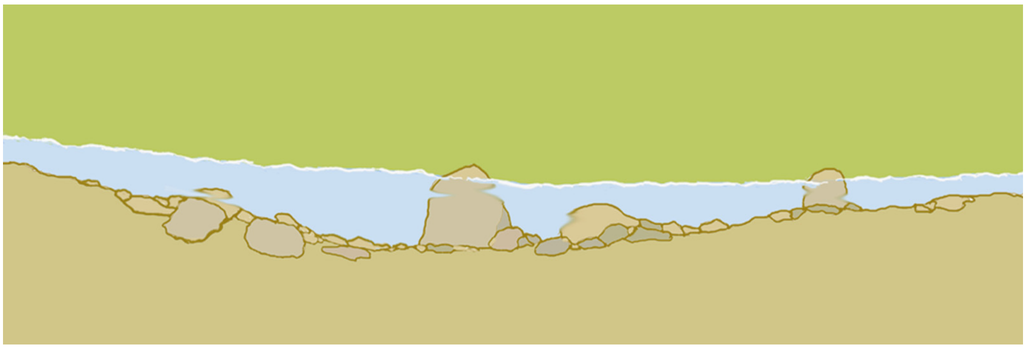


Fig. 11. Slow flowing stream section. Gavel, sand and soft bottom. Water flow regime can be deduced from hydrophytes

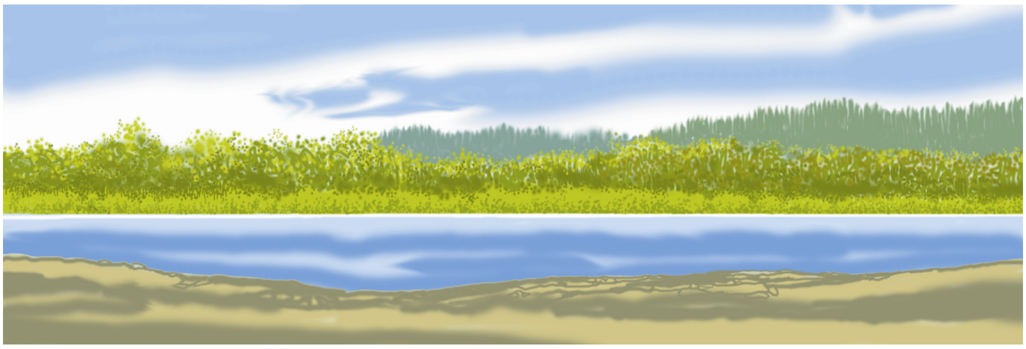


Fig. 12. Stagnant stream section. Soft, deep bottom. Functions as a water storage zone for the river

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.

ACKNOWLEDGEMENTS

I am most indebted to Dr. Martin Speight (Ireland, Dublin) for his patient reading of and comment on the manuscript and for checking the English text. My sincere thanks are also due to all the scuba divers, who have taken part in the field work, and to WWF-Finland, which has supported the Margaritifera projects. Mr. Markku Bussman has kindly drawn the habitat diagrams. Dr Evgueni Ieshko (Institute of Biology, Karelian Research Centre of RAS) and Dr Aimo Saano and Dr Tapio Lindholm (Finnish-Russian Working Group on Nature Conservation) are greatly acknowledged by the author. It was great pleasure to take part in the International workshop on "Conservation of freshwater pearl mussel *Margaritifera margaritifera* populations in Northern Europe" in Petrozavodsk on 28.-30.4.2009.

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Proceedings of the International Workshop

Petrozavodsk, Russia,

April 28–30, 2009

Cover: Freshwater pearl mussel distribution map after *Larsen* (2005) with modifications by *Oulasvirta* (2006).
Background photo by *Panu Oulasvirta*, trout photo by *Sauli Vatanen*,
graphics and picture processing by *Sanna Saari*

English translation and editing by *Olga Kislova*, Karelian Research Centre of RAS

Submitted to press on 07.12.2010. Format 60x84⅛.
Offset paper. Times typeface. Offset print.
13.1 conventional printer's sheets. 350 copies. Ed. # 133. Order # 922

Karelian Research Centre of RAS
Editorial and Publishing Department
185003, Petrozavodsk, str. A. Nevsky, 50