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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