AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS
Aquatic Conserv: Mar. Freshw. Ecosyst. **21**: 113–121 (2011)
Published online 14 January 2011 in Wiley Online Library
(wileyonlinelibrary.com). DOI: 10.1002/aqc.1164

*Rediscovery of the largest population of the freshwater pearl mussel (*Margaritifera margaritifera*) in the Leningrad oblast (north-west Russia)*

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ABSTRACT

1. An internationally important population of the freshwater pearl mussel (*Margaritifera margaritifera*) was rediscovered in a small river in north-west Russia.
2. A survey of visible mussels in 2008/2009 indicated an estimated population of 40 000 individuals. This is the largest population currently known in the Leningrad oblast and is comparable with the entire pearl mussel population of some western European countries.
3. The average density of visible mussels was 29.6 individuals m^{-2} in the middle part of the river. In the four largest mussel beds maximum densities of 1000+ individuals m^{-2} were recorded. Such densities are exceptional and have not been reported elsewhere in Europe during the last 100 years.
4. Live juvenile mussels were recorded, indicating that that this population is viable, although further investigation is required to establish its status.
5. Analysis of the population age structure, based on the measurement of empty shells, showed an age class distribution similar to those reported for other healthy *Margaritifera* populations.
6. Only two live juveniles were found. However, this is likely to be due to the survey being restricted to counts of visible mussels only, and the age structure being based on the analysis of dead shells.
7. The population's current status and possible reasons for its survival in this river are discussed. Conservation measures should include the construction of a fish ladder to make fish migration through the culvert possible, removal of a metal screen preventing fish migration from the upper reaches of the river to the lake, reduction of recreation activities, and providing the local children's camp with water treatment facilities.

Received 13 April 2010; Revised 17 October 2010; Accepted 27 November 2010

KEY WORDS: freshwater pearl mussel; endangered species; conservation; Russia

INTRODUCTION

Freshwater pearl mussel *Margaritifera margaritifera* (L.) was very abundant in many rivers in north-west Russia (Figure 1) up to the first third of the 20th century. It was distributed over a huge territory, being well known in the areas around Pskov, Novgorod, Tver, Smolensk, Saint-Petersburg, Petrozavodsk, Murmansk and Arkhangelsk (Zhadin, 1938; Golubev and Esipov, 1973; Korago, 1981; Makhrov, 2009; Makhrov *et al.*, 2010), and pearl fishing was an important traditional trade in some places (Vereshchagin, 1929; Vlastov, 1934; Saldau, 1940; Bespalaya *et al.*, 2007a). For instance, in 1788 the city of Kem

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Figure 1. Map of Russian Federation and the Leningrad oblast (given in red and in the insert), showing the major river systems (source: Wikipedia.org)

was granted arms with a pearl wreath on a blue field. The local people were reputedly skillful in recognizing a pearl-bearing mussel by its deformed shell and extracting the pearl without killing it (Oparin, 1976, Bespalaya *et al*., 2007a).

A number of large pristine populations of *M. margaritifera* still exist in a few rivers of the Kola Peninsula (Murmansk oblast) and Karelia, although some of them have declined considerably during the last 20 years. It seems that at least in some of these areas pearl mussel either drastically declined in number or became totally extinct (Ziuganov *et al*., 1993; Bespalaya *et al*., 2007a, b; Ziuganov, 2008; Golubeva and Golubev, 2009; Makhrov, 2009; Makhrov *et al*., 2009, 2010), a situation similar to that in Western Europe (Bauer, 1986, 1988; Young, 1991; Beasley *et al*., 1998; Moorkens, 1999; Araujo and Ramos, 2001; Cosgrove and Hastie, 2001; Young *et al*., 2001; Hastie *et al*., 2003a; Morales *et al*., 2004; Hastie, 2006; Moorkens *et al*., 2007). The major reasons for this decline are related to human activities, particularly eutrophication and pollution from agricultural and industrial run-off, siltation, timber floating, hydropower engineering and artificial change of the river beds, impact of invasive species, pearl fishing, decline of salmonid host numbers, deforestation and reforestation. As a result, *M. margaritifera* was included in both all-Russian and local Red Data books as an endangered species (Danilov-Danilian, 2001; Bogatov *et al*., 2004; Ivanter and Kuznetsov, 2007). However, information on pearl mussel is so scarce that its current status is unknown in many areas.

The Leningrad oblast (territorial unit of the Russian Federation around Saint Petersburg, former Leningrad) is a good example of such an area. It was recently realized that the pearl mussel populations have rarely been studied and virtually nothing is known about their current status in this area, although Saint Petersburg is a large scientific centre (Popov and Ostrovsky, 2010). The Leningrad oblast (Figure 1) is larger than some European countries and possesses a complex river network consisting of several large river systems. The largest of these are the Neva, Narva and Luga systems that run into the Gulf of Finland, and the Vuoksa, Volkhov, Svir and Sias systems that drain to Ladoga Lake. Salmonid fishes (*Salmo salar* and/or *Salmo trutta*) that are the hosts for pearl mussel larvae were recorded in the basins of all of these river systems (Khalturin, 1970; Valetov, 1999; Popov, 2003, 2010; Veselov *et al*., 2007; Makhrov, 2009). According to the scientific literature, archive data and the list of specimens in the Zoological Museum of the Russian Academy of Sciences, freshwater pearl mussel existed in at least 11 rivers, and was fished for pearls in some of them (Semenova *et al*., 1992; Bogatov *et al*., 2003, 2004; Makhrov, 2009; Makhrov *et al*., 2009). Recent surveys confirmed its presence in seven rivers (Ostrovskii and Popov, 2008a,b; Popov and Ostrovsky, 2010a,b, and unpublished data), however, most of these populations are very small.

In contrast, small River B[1] contains a surprisingly large and presumably viable population of *Margaritifera margaritifera*. The only research on it was undertaken by Semenova *et al*. (1992) who analysed the rates of shell growth in some distant rivers of northern Russia. The size and the status of the population in the River B has never been studied and described, although five specimens of dry shells from the River B kept in the Zoological Institute were collected on 24 May 1970, 9 June 1990 and 3 May 1992. This paper describes the status of this unique population and discusses possible reasons for its survival.

[1]According to widely accepted international practice to prevent illegal pearl fishing (Hastie, 2006; Hastie *et al*., 2010), river names, specific site details and map locations are not given. Further information is available from the authors.

Figure 2. River B. Typical biotope with mixed forest in the middle reach. This sector is shallow (0.25–0.35 m depth) with a superficial layer of small gravel and relatively low number of molluscs

STUDY AREA

River B runs from the large lake to the Bay of Finland, having a length of about 2.3 km. It often meanders having widths ranging from 1 to 6 m (3.5–4 m on average), and depths of 0.15–0.6/0.7 m during midsummer (low-water period). Flow velocity in midsummer ranges from 0.3–0.5 $m\,s^{-1}$. The main hydrochemical parameters (pH > 6.38, oxygen content 8.5 $mg\,L^{-1}$, permanganate oxidizability 7–16 mg $O_2\,L^{-1}$, water mineralization $< 50\,mg\,L^{-1}$) were detailed earlier (Semenova *et al*., 1992).

The river passes mainly through secondary mixed forest dominated by spruce, pine and birch (Figure 2). Sub-dominant tree species include ash, aspen, alder, maple and oak. In some places the river banks are covered with dense bushes and ferns. Distribution of all vegetation types is patchy and numerous dead tree trunks lay along the river banks. They also very often cross the river, either lying in the water, sometimes creating small 'artificial' rapids, or being above the water level forming 'bridges' (Figure 2). There are also large stones, separate or in small groups, sometimes forming rapid-like structures. Apart from a few small springs and two brooks, tributaries are absent.

The river was divided into three arbitrary reaches, separated by two road crossings.

Upper reach

The upper reach (*ca* 1.1 km) is between the lake and a motorway with a culvert beneath. There is also a metal screen separating the upper reaches and the lake. Its construction dates back to the early 1970s, and is connected with abandoned local fishery activities. A children's summer camp is located near the river, and its wastes run into the river with very little water treatment. Tourist paths and places to light fires for barbecues or for camping are common along the riversides. The bottom sediment consists of coarse sand with a high proportion of gravel and pebbles.

Middle reach

The motorway culvert separates the upper and middle reaches of the river. Below the culvert, the river runs through the forest approaching a deforested area *ca* 100 m wide with a high-voltage electric cable. The entire length of the middle reach is *ca* 0.5 km.

In the middle part of the river the bottom sediment consists primarily of a thick (> 0.5 m) layer of coarse sand with some patches of gravel and pebbles that often form large areas (up to several tens of square metres). Shingles and cobbles are relatively rare. The predominantly sandy bottom is characterized by numerous sand bars, patchy aquatic vegetation (both algae and higher plants), and low river banks.

Lower reach

In contrast, the river banks are up to 2 m high in the lower part of the river between the country road and the river inflow to the Gulf of Finland. This part of the river is *ca* 0.7 km in length. Higher proportions of small gravel and pebbles occur in the bottom sand layer. Shingles and cobbles are also common. Again, a large recreational zone with numerous pathways and places where fires are lit occupies the lower reaches of the river and surrounds its inflow.

River B is located within a protected area organized for general conservation of the lakes and surrounding forests; however, there are no special activities focused on the protection of freshwater pearl mussel.

MATERIALS AND METHODS

Field work was conducted in May 2008 and in July 2009. In spring 2008 a preliminary survey was made of the entire river, mainly focused on the potential suitability of the different parts of the river bed for pearl mussels, and on a visual search for juveniles (molluscs 6.5 cm in length or smaller: Cosgrove *et al*., 2000; Hastie *et al*., 2000b). River reaches were measured and mapped and a preliminary biotope description was made. In 2009 mussels were counted using aquascopes (glass-bottomed viewers) in the middle and lower reaches.

Distribution and density of visible mussels

The middle part of the river was arbitrarily divided into 28 sectors with fallen trunks used as markers (Figure 2). The length and width of each sector was measured, and sector size (area) was calculated. The total number of visually detectable mussels in each sector was counted, and an average density estimate was calculated (Table 1). In the places with high mussel densities, the river bed was divided into 0.25 m^2 quadrats using a wooden frame, and the total number of mussels was calculated for each site. Photographs of mussel beds at different densities were made using the aquascopes and underwater camera.

In the lower part of the river with much lower numbers of mussels, 10 sites (about 0.7 km in length) were randomly chosen at intervals of 50–70 m, and the total numbers of pearl mussels were counted in 1 m^2 at each site. The average density for these 10 sites was regarded as the average density of the mussels in the lower part of the river. Its area was calculated and the approximate number of mussels estimated.

Age structure

In order to evaluate age structure without damaging the population, empty shells were collected (Figure 4). The substrate was not searched for juvenile mussels in order to prevent shell damage and destruction of the river-bed habitat. This study was based on the assumption that the number of empty shells in each

Table 1. Number of individuals and average density in the sectors studied in the middle part of river B

Sector	Sector length (m)	Sector width (m)	Sector area (m^2)	Number of mussels	Mussel density (individuals m^{-2})
1	9.0	3.5	31.5	712	22.6
2	7.0	4.0	28.0	2367	84.5 (up to 1040)
3	8.0	5.0	40.0	1342	33.5
4	6.0	5.0	30.0	3128	104.2 (up to 1040)
5	7.0	4.0	28.0	2524	90.1
6	14.0	4.0	56.0	1757	31.3
7	10.0	3.0	30.0	787	26.2
8	4.0	4.0	16.0	425	26.5
9	12.5	4.5	56.25	531	9.4
10	7.0	4.5	31.5	510	16.1
11	5.6	3.0	16.8	883	52.5
12	13.0	5.0	65.0	2911	44.7
13	7.5	5.0	37.5	333	8.8
14	10.0	4.0	40.0	2360	59.0
15	5.0	3.0	15.0	442	29.4
16	5.0	3.0	15.0	1525	101.6
17	5.0	3.0	15.0	1867	124.4
18	6.0	6.0	36.0	36	1.0
19	10.0	4.0	40.0	3010	75.25 (up to 1000)
20	10.0	5.0	50.0	1207	24.1 (up to 1000)
21	20.0	4.0	80.0	742	9.2
22	12.0	5.0	60.0	452	7.5
23	8.5	4.0	34.0	675	19.8
24	5.6	4.0	22.4	1633	72.9
25	12.0	5.0	60.0	178	2.9
26	10.0	5.0	50.0	42	0.8
27	23.0	5.0	115.0	1444	12.5
28	15.0	5.0	75.0	981	13.0

Total length: 267.7 m. Total area: 1173.95 m^2. Total number: 34804. Average density: 29.6.

age class approximately corresponds to the number of live mussels with some correction for shell drift and dissolution (Hastie, 2006; see also Discussion). Altogether, 127 empty shells were collected and studied in the laboratory. Ages were estimated by counting the growth lines (annuli) on both valves (Hendelberg, 1961; Semenova *et al.*, 1992). The larger of the two numbers counted was regarded as an approximate age without a few early years because the corresponding part of the shell was eroded. The eroded part of the shell was measured and compared with the size of annuli on the shell of the youngest (6 years old) live juveniles found (Figure 5). This gave an approximate estimate of total age (Hastie *et al.*, 2010). The total number of annuli on the ligament was also counted, but this method was less useful since a large part of the ligament was destroyed. In addition, the length of the valves was measured for each shell collected using Vernier calipers.

In a search for juveniles several live individuals with their shells deeply buried in the sand were selected for making measurements and taking photographs and about 50 adult molluscs were randomly collected and measured without disturbing the sediment. All live mussels were carefully returned to their original river-bed locations.

RESULTS

Distribution and density

The observed mussel distribution was patchy in River B, and the population density varied considerably along the river bed (Table 1).

Figure 3. Part of one of the largest aggregations found with mussel density approaching 1000 individuals m^{-2}. Photograph taken on 18.07.2009 by A.N. Ostrovsky

About 30 old shells with almost dissolved valves were found on the river bed in the upper reach of the river, and in the middle reach below the culvert except the area deforested for a high-voltage electric cable. The rest of the middle reach contained the largest numbers of mussels in high densities. Mussels were distributed individually and in small and large groups at all depths (0.15–0.60 m), flow velocities and subsrate types including patches covered with gravel and pebbles, silt and plant debris (where the mussels were often numerous as well) and, sometimes, aquatic vegetation. Mussels were found in all channel gradients including the steeper areas. In one instance, a group of mussels covered with moss was observed. Large groups were also found underneath and behind the sunken trunks and snags. Mussels were less numerous in the shallow areas (<0.4 m) and in pools with reduced flow velocities.

Aggregations of mussels on the river bed ranged from small clusters of 2–10 mussels to large mussel beds containing thousands of individuals (Figure 3). The four largest aggregations had densities $\geqslant 1000$ individuals m^{-2}, at intermediate depths (~ 0.4 m), normally at some distance downstream from a river meander. It seems that these largest aggregations are not 'sink' beds because all of them occurred on straight parts of the river, with clean flat bottoms demonstrating a band-like pattern, 0.4–1 m wide and 2–5 m long. Also the mussels were not distributed chaotically as might be expected if they had been accumulated by current or floods. Shells were tightly pressed to each other with no space in between, forming a 'fish-scale' pattern. Mussels that were closer to the river side formed rows perpendicular to the current. In contrast, such rows were parallel to the current on the opposite side of the aggregation (close to the mid-line of the river bed) with a range of intermediate (diagonal) shell orientations in between. Most of the mussels in the dense aggregations were adults, with younger molluscs mainly concentrated on their periphery. Mussel density was usually higher on the near bank-side.

In most cases half to two-thirds of the shell was buried in sand, whereas in young mussels only the proximal tip of the shell with siphons was exposed. Two 6 year-old juveniles (Figure 5) were totally buried in sand except for their siphons. One of them was found on the edge of a large group, whereas the second was alone. In the four largest aggregations only one-third of the shell was buried in the sand.

The total number of mussels observed in the middle reach (1173.95 m^2) was 34804 giving an average density of 29.6

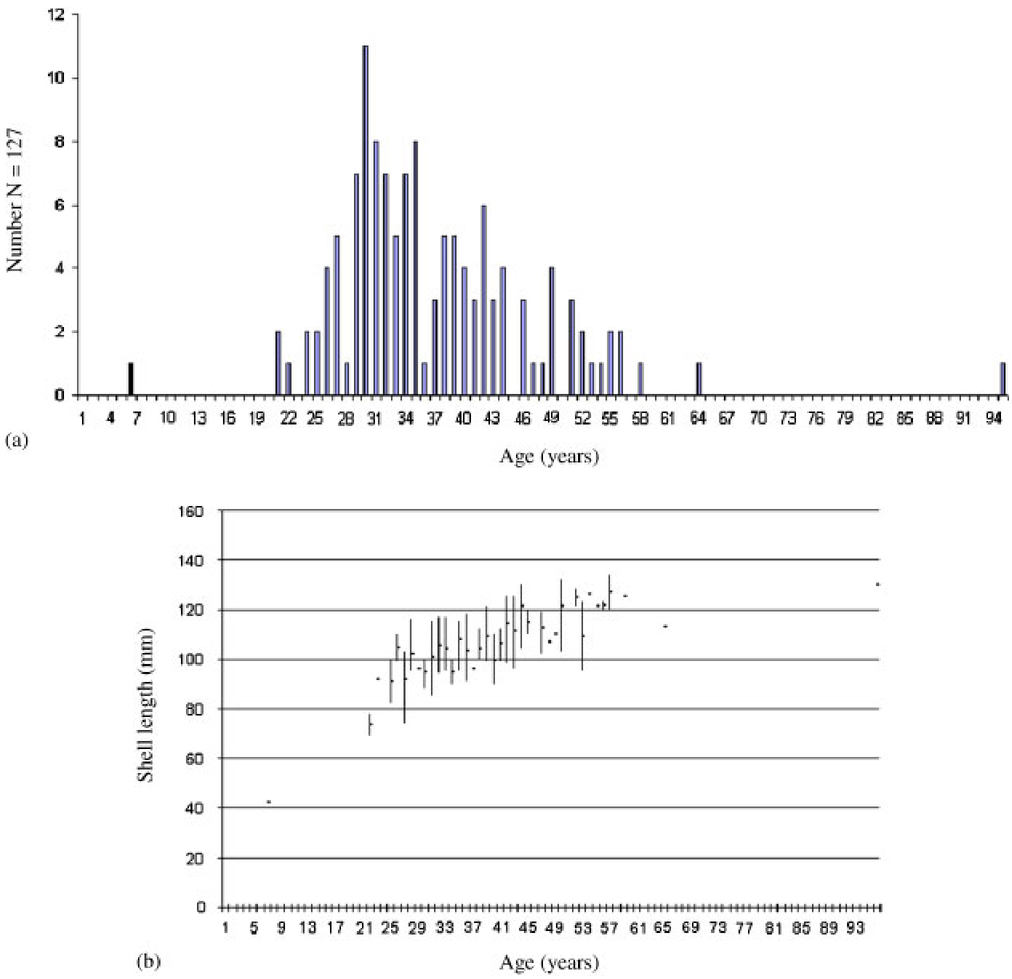

Figure 4. (a) Age (years) frequency distribution, and (b) scatter plot of length (mm) at age data of the sample of 127 empty shells studied. In (b) each bar represents the minimum and maximum length with a dot representing the average (algebraic mean). One youngest live individual was included in the histogram (black bar to the left) and the plot

Figure 5. Live 6 year-old juvenile pearl mussel and two adult empty shells. The size of the eroded parts of the empty shells is comparable with the size of the juvenile

individuals m^{-2}. The size of the sectors measured in the middle part, the number of individuals and the average density in each sector are shown in Table 1. In the lower part of the river the numbers of mussels fell abruptly together with the change in substrate type. Individuals living on the mixed river-bed (sand/gravel/pebble) substrates were buried in the substrate no deeper than one-half of the shell length. There were no large aggregations there, small dense groups (up to 40 individuals) were rare, and the vast majority of the pearl mussels were isolated. The average density in this part of the river was estimated to be 1.5–2 m^{-2}. Thus, the approximate number of mussels in the lower reach (length 0.7 km, area $\sim$2800 m^2) was estimated at about 5000, and the total number in River B was estimated at 40 000.

No live mussels or empty shells were found in the deforested areas between 100 m below the motorway and about 50 m above the river mouth (Bay of Finland).

Age structure

The younger live individual found was 6 years old (shell length = 4.25 cm: Figure 5). The second juvenile (detected by photograph) was similar in size. Most of the live mussels (with one-third to two-thirds of their shells exposed) that were randomly collected, had a length about 10.0 cm or more, thus being about 25–30 years old or older (Figure 4; Semenova *et al*., 1992). Those that were buried in the sand were generally smaller, having a size of *ca* 7.0–8.0 cm (i.e. 10–20 years old).

Live mussels of the larger size/age class were abundant, and of the smaller one common (and also in the largest aggregations). Mortality seems to be low: very few empty shells were found in contrast with the high number of live molluscs. Empty shells of the younger class were very rare: only three empty shells 21–22 years old were found (less than 3% of the sample), and ranging from 6.9 to 9.2 cm in length.

The age class 21–30 years old was represented by 35 mussels (27%). 41% of the shells in the sample (53 individuals) had an age between 31 and 40 years, and the age classes 41–50 and 51–60 years old contained 25 (19%) and 12 (9%) individuals, respectively (Figure 4). The oldest mussel found was estimated to be 95 years old (shell length 13.0 cm). The length-at-age variability observed was quite high (Figure 4) (Hastie *et al*., 2000a).

DISCUSSION

State of the population

This study shows that the *M. margaritifera* population in River B is the largest one known in the Leningrad oblast. Its size is comparable with the total pearl mussel numbers known for countries such as Austria (70 000), Estonia (40 000) and Latvia (25 000) (Moog *et al*., 1993; Araujo and Ramos, 2001; Gumpinger *et al*., 2002; Rudzīte, 2004), and may be much larger since juvenile molluscs were not assessed during the visual survey.

Average densities of mussels were 1.5–2 and 29.6 individuals m^{-2} within the lower and the middle parts of the river, respectively. These numbers are within the limits known for many other *Margaritifera* populations studied elsewhere in Europe. In contrast, we were not able to find any recent data in the literature comparable with the maximum density — 1000 individuals m^{-2} and more — found in the four largest aggregations in River B (Figure 3). This density is almost 2.5–5 times larger than in the world's largest populations known in Russia (194 individuals m^{-2}, Ziuganov *et al*., 1993) and Scotland (398 individuals m^{-2}, Hastie *et al*., 2000b), and comparable with those reported in the 19th century for some pristine European rivers (von Hessling, 1859; Israel, 1913; Riedl, 1928).

The small proportion of juveniles in the population overall is generally considered to be characteristic of the pearl mussel decline in Europe (Bauer, 1986; Ziuganov *et al*., 1993; Beasley *et al*., 1998; Araujo and Ramos, 2001; Moorkens *et al*., 2007; Hastie *et al*., 2010). In the case of River B it looks as if the small number of juveniles found contrasts markedly with the otherwise healthy state of the population. However, a visual search for juveniles is not very effective because of their small size and immersion within the substrate. It is well known that juvenile *M. margaritifera* are usually under-sampled during bottom surveys, even when using sieving (Hastie *et al*., 2000b, 2010; Hastie and Cosgrove, 2002; Hastie, 2006). The hidden life-style might be of special importance in the case of River B where the substrate is predominantly sandy. It is often heavily shaded in the places where pearl mussels aggregate making visual recognition of the siphons of the small mussels even more difficult.

The small number of the young empty shells found contrasted with the fact that living mussels with a shell length of 7.0–8.0 cm (10–20 years old) were common. Perhaps after death the smaller shells are removed during seasonal floods; the expected persistence of empty shells in the river calculated for shells of different sizes showed that the smallest shells should be removed by the current first (Hastie, 2006). Also, they tend to dissolve or to break up rapidly (Hastie *et al*., 2001). Another explanation is that juvenile shells stay deep within the substrate after mussel death, and could not be detected during visual survey. The presence of juveniles shows evidence of recruitment within the last 6 years. According to Cosgrove *et al*. (2000) such populations should be considered as 'functional' (viable).

The small number of shells available, the fact that these cannot be assumed to constitute a random sample, and the bias towards the collection mainly of adult shells (since juvenile shells are more likely to be buried, crushed or washed away, see above), mean that these data should be interpreted with a degree of caution. However, the preliminary results on population age structure show a distribution of the age classes similar to those for the large *Margaritifera* populations in the Kola Peninsula, where live individuals were measured (Ziuganov *et al*., 1993; Bespalaya *et al*., 2007b). It is also similar to the age structures reported for other large *Margaritifera* populations in Western Europe (Hastie *et al*., 2000b, 2001, 2004, 2010; Hastie and Cosgrove, 2002; Reis, 2003; Hastie, 2006), although local variations in age and size of the shells prevent direct comparison (Bauer, 1992). A general predominance of middle-aged (30–40 years old) mussels is apparent. Although there were only two empty shells 7.0–8.0 cm in length in the sample (both 21 years old), live individuals of that size are common; that, together with the presence of juveniles, presumably indicates that this population may be viable (Cosgrove *et al*., 2000; Hastie *et al*., 2010). Permanent monitoring is necessary, however, to show how stable it is.

River B as an optimal biotope for freshwater pearl mussel

We suggest that the survival of the River B population is a result of several factors. First, it is near to the so-called 'no entry' (border) zone that existed there until the mid-1990s. This could explain the lower human impact on the river. Also it is currently located in the territory of a protected area with a relatively low level of human activities, and their impact on the river apart from the upper part, has, until now, been rather moderate. There are no large deforested areas, drainage channels, agricultural fields or grasslands adjoining the riversides, and the biotopes (apart from signs of recreational activities) look natural.

Moorkens *et al*. (2007) defined *Margaritifera margaritifera* as 'a species of near natural conditions'. The size and, seemingly, state of the population described indicate that this river and its surroundings is an optimal (in this particular geographic zone) and almost undisturbed environment. This 'ideal' biotope is characterized by a substrate of coarse sand and small gravel (particle size 1–5 mm), relatively low current velocity (0.3–0.5 $m\,s^{-1}$), and depth 0.2–0.6 m. The two last parameters were calculated as optimal for an important, stable *Margaritifera* population in Scotland (Hastie *et al*., 2000c).

The optimal conditions are confirmed by the fact that many mussels survive even in those parts of the river with a substrate type that is commonly considered to be unfavourable (i.e. silted, with plant debris and aquatic vegetation) (Hastie *et al*., 2004; Moorkens *et al*., 2007). It appeared that mussels accumulate in such places during floods (Hastie *et al*., 2000c), but no signs of increased mortality of these mussels were seen during the survey. The low number of empty shells found elsewhere in the river, combined with rather low current velocity, suggests that only natural mortality occurs there.

The river flows out of a large mesotrophic lake, providing a year-round stable water regime (preventing both freezing to the bottom in winter and drying during summers) and, apparently, a food supply. The bottom is formed from a thick layer of large-sized sand and small gravel. Beasley and Roberts (1999) suggested that cobbles might be important for stabilizing the underlying gravel and sand during floods in some Irish pearl mussel rivers. Hastie *et al.* (2003b, 2004) considered a river bed of small patches of stable, clean sand between the cobbles and stones as an optimal microhabitat. Such a bottom type is characteristic for most of the rivers studied by the authors (Popov and Ostrovsky, 2010a), but it is predominantly sandy in River B. Since cobbles and large stones are generally uncommon there, perhaps the stability of the sandy bottom is due to the rather slow current velocity during most of the year, and the river profile. The river bends strongly, especially in the middle reaches with the largest mussel density. It is possible that this factor could stabilize the flow regime and lower the current velocity during floods. Meanders could also help to reduce the amount of suspended sediment in such periods, mainly accumulating in the zones of stagnation in which current abruptly changes direction. In its lower reaches the river bends much less; this, together with the change in substrate density, might reduce mussel numbers. River profile could also partially explain the patchy distribution of mussels, although other factors such as the substrate structure, depths and local flow regime should be considered too. Although substrate type is the most important factor influencing pearl mussel abundance in River B, it plays no obvious role in the patchiness, in contrast to rivers having a predominantly stony bottom (Hastie *et al.*, 2000c).

The riparian vegetation comprises mixed forest that reduces erosion by stabilizing the river banks, and also shades the river, lowering water temperature in summer and possibly preventing the microalgal growth at the bottom (Figures 2 and 3) (Hastie *et al.*, 2003a,b, 2004). For example, the part of the river that runs through the deforested area is devoid of mussels. Also, the fallen tree trunks create numerous microhabitats for a range of species, including young host fishes; this might explain the aggregations of pearl mussels underneath.

River B flows directly to the sea, and the host fish population consists of small brown trout, which were observed several times during the surveys. The substrate type necessary for Atlantic salmon spawning is absent. The trout population is apparently anadromous, i.e. consisting of two forms — resident and migratory. In the case of River B the migratory form obviously prevails. Because the river is short and shallow it does not provide habitats for the prolonged stay of large fish: in the area around Saint-Petersburg trout can migrate to the sea when 1–2 years old (Popov, 2001). If so, the trout population can rapidly repopulate, providing optimal conditions for successful mussel infection.

Despite its relatively good state, this unique population is very vulnerable, and urgent measures should be undertaken to protect it. Findings of empty shells in the upper part of the river show that mussels previously existed there too. Position, size and length of the culvert underneath the motorway show that it is a serious obstacle to fish migration to the upper reaches of the river. Free circulation of the host fish in the river is also hampered by the metal screen preventing fish migration from the upper reaches of the river to the lake. Thus, the main reason for pearl mussel disappearance in the upper part of the river could be an absence of host fish. In some oligotrophic systems, e.g. in north-west Scotland, the loss of migratory salmonid hosts may have had a serious impact on some *M. margaritifera* populations (Hastie and Cosgrove, 2001). The influence of the wastes from the children's camp is possibly of less significance. The camp itself is small, being mainly active during three summer months. If its negative influence was strong it would inevitably affect the main part of the pearl mussel population in such a small river.

The presence of the juveniles and large numbers of young mussels (10–20 years old) may indicate that the local pearl mussel population is regenerating. Also, based on the comparison of these data with those obtained by Hastie (2006) on large Scottish populations, we suggest that only natural mortality is occurring at present. Because of its size and state, this population should be considered internationally important (Cosgrove *et al.*, 2000; Young *et al.*, 2001), and very valuable for conservation.

Conservation measures required

In Russia, except for the formal inclusion of *Margaritifera* in the Red Data books, protection measures are virtually absent, and only a few breeding populations survive in the distant wild areas with minimal human impact. The same can be said about Leningrad oblast where the only measure for conservation of *Margaritifera* and reintroduction of the Atlantic salmon was the establishment of the sanctuary 'Gladyschevskiy' in 1996. Artificial reintroduction of salmonid parr from a local hatchery does not take into account the restoration requirements of *Margaritifera*, and the parr releases are not synchronized with the periods of pearl mussel reproduction. Recent efforts have led to the release of parr to the River Roschcinka at the beginning of August 2009, coinciding with larval release by female pearl mussel. Such work requires much more effort, however.

Because of the small size of River B, its pearl mussel population is highly vulnerable, and it has already been lost in part. In addition to further monitoring and scientific studies, urgent conservation measures are required, and at present we are trying to attract the attention of the local authorities to this problem. Illegal pearl fishing still exists in north-west Russia, including the Leningrad oblast. Similar to other countries (Young, 1991; Hastie, 2006; Hastie *et al.*, 2010), it is very difficult to prevent it, since the 'pearl rivers' are usually in remote areas that are difficult to control. However, the major potential threats are connected with industrial, agricultural and recreational activities. The main requirement for maintaining the conservation status of this population is to protect the natural state of the river and riparian vegetation. In the case of River B, a number of measures are urgently needed. Four major steps are required: (1) the culvert discussed above should be provided with a fish ladder to allow salmonid migration; (2) the metal screen preventing fish migration from the upper reaches of the river to the lake should be removed; (3) an appropriate management scheme for recreation activities should be implemented, possibly including restricting access to local country roads leading to the river in order to reduce the number of people visiting the site; and

(4) water treatment for the children's camp should be provided.

ACKNOWLEDGEMENTS

The authors thank Mrs O. Kotenko, Dept. of Invertebrate Zoology, St Petersburg State University, Russia, who helped to make measurements, Dr A. Makhrov, Institution of Ecology and Evolutionary Problems of the Russian Academy of Sciences, Moscow, for the archived information on pearl mussel and for literature; Dr L. Henriksson, WWF, Sweden, for assistance in getting the equipment for hydrobiological research; Dr A. Briguglio, Dept. of Palaeontology, University of Vienna, Austria, who helped to make plots; and Dr L.C. Hastie, University of Aberdeen, Scotland, for reading the early drafts of the manuscript and useful comments. Dr S. Cooksley, The Macaulay Land Use Research Institute, Aberdeen, Scotland, and an anonymous reviewer provided useful comments and suggestions. Rufford Small Grants (for Nature Conservation) is acknowledged for financial help.

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