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State of the Population of the European Pearl Mussel *Margaritifera margaritifera* (L.) (Mollusca, Margaritiferidae) at the Northeastern Boundary of Its Range (Solza River, White Sea Basin)

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Abstract—Only two river basins in which the European pearl mussel has survived to date are known in Arkhangelsk oblast. These are the Solza and Kozha basins. The northeastern boundary of the European range of this species passes along the watershed between the basins of the Solza and the Shirshema (the Onega Peninsula) and then along the Onega–Northern Dvina watershed. The population density and the proportion of juveniles widely vary in different parts of the Solza Basin, and, therefore, the previously conclusion concerning the ageing of the population in the Kazanka River (Bolotov and Semushin, 2003) applies only to certain parts of this river. The highest density of the pearl mussel in the Solza Basin is 68 ind./m^2. Fish cultivation contributes to the conservation of this pearl mussel population, as the release of Atlantic salmon juveniles ensures reproduction of the mollusk under conditions of regulated river flow.

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The European pearl mussel (*Margaritifera margaritifera*) is a species with a range in Europe and America (Ziuganov et al., 1993), which covers the margin of Eurasia from Arkhangelsk and Murmansk oblasts in the north to the Alps in the south, together with adjacent large islands (Great Britain, Ireland, and Iceland), and the Atlantic coast of North America from Newfoundland in eastern Canada to Delaware in the United States (Wells et al., 1983; Ziuganov et al., 1993; Ouslavirta, 2006).

Up to the early 20th century, the pearl mussel in northwestern Europe was regarded as an important biological resource providing the basis for traditional pearling (Vereshchagin, 1929). In this area, the pearl mussel was apparently a dominant and even an edificator species in benthic communities of small and medium-sized rivers with rapid flow, stony or sandy–stony bottom, and rapids. In fish communities of such rivers, classified by ichthyologists as salmon rivers, significant positions belonged to the main hosts of pearl mussel larvae, the Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) (Veselov et al., 2001). According to some data (Ziuganov et al., 1993; Ziuganov, 2005), the populations of pearl mussel and salmonids flourished in such rivers due to their symbiotic relationships.

The 20th century was marked by deterioration of *M. margaritifera* populations and reduction of the species range, which were apparently explained by increasing anthropogenic load. These processes were so rapid that 99% of all pearl mussel populations in the world disappeared by the turn of the 21st century (Ziuganov, 2005). This species is included in the Red Data List of the IUCN (Wells et al., 1983; *IUCN…*, 1996), the Appendix to the Bern Convention (*Bern Convention…*, 1979), and in the Red Data Lists of Eastern Fennoscandia (*Red Data…*, 1998), Arkhangelsk oblast (1995), Karelia (1995), Murmansk oblast (2003), and other regions.

Data on the present-day state of European pearl mussel populations are available for most regions of Northern Europe, including Norway (Dolne and Kleiven, 2001), Finland (Oulasvirta, 2006), Scotland (Hastie et al., 2000), Murmansk oblast (Ziuganov et al., 1993; Prokhorov, 1995a, 1995b, 1996; Gilyazova, 2000), Karelia (Ziuganov et al., 1993), and Leningrad oblast (Semenova et al., 1992). In Russia, populations of pearl mussel were investigated in detail in the Varzuga River on the Kola Peninsula (Ziuganov et al., 1993, 1998; Prokhorov, 1995a, 1995b) and in the Keret' River in Karelia (Ziuganov et al., 1993). These populations comprise 140 million and 6 million individuals, respectively, and are considered to be the largest within the present-day range of this species (Ziuganov et al., 1993). At present, several dozens of large self-reproducing *M. margaritifera* populations exist only in Russia, Scotland, and Fennoscandia (Hastie et al., 2000; Ziuganov, 2005; Oulasvirta, 2006).

Data on the current state of pearl mussel populations in the northeastern peripheral part of its European range, in the rivers of Arkhangelsk oblast, are virtually absent. Some early studies (Vereshchagin, 1929; Evdokimov, 1936; Guttuev, 1930, 1936; etc.) provide original data and a review of relevant publications over the period before the beginning of the 20th century. According to them, this species was widespread in rivers of the White Sea basin west of the Northern Dvina River, including the Solza, Kazanka (its tributary), Syuz'ma, Yaren'ga, Vauga, Khaino-Ruchei, Onega with tributaries (including the Kozha with its tributary Syvtyuga), Somba, Nimen'ga, and Maloshuika. The recent literature is limited to our brief communication (Bolotov and Semushin, 2003) on the state of the pearl mussel population in the Kazanka River as of 1998.

This study, based on original field data, deals with assessment of the state of European pearl mussel population in the Solza River basin.

STUDY REGION, MATERIAL, AND METHODS

Region. The basin of the Solza, 1400 km^2 in area, is in the eastern part of the Onega Peninsula (Figs. 1, 2). The river has its origin in Solozero Lake and flows to the White Sea. Among terrestrial biocenoses, spruce forests and upland bogs prevail. The river has seven tributaries, and many small streams flow into it. The Solza is 109 km long, its width is 10–20 m in the upper reaches and 20–45 m in the middle and lower reaches, depth is 0.3–0.4 m on rapids and reaches 1.5 m in pools, and flow velocity averages 0.5–0.8 m/s. Water supply to the river is accounted for mainly by bogs and snowmelt, and the annual water discharge is nonuniform. The bottom consists of crystalline rocks; bars and rapids are frequent. Water temperature is very low during the greater part of the year (below 10°C for eight months and ≤1°C or lower for four to five months), and small and medium-sized tributaries often freeze to the bottom in winter. Anthropogenic load is moderate: in the lower reaches of the river, there are several automobile roads, the dam of water intake for the city of Severodvinsk, a reservoir, the Solza fish hatchery, and country houses. The whole basin of the river upstream of the water intake is in an uninhabited forest area without any pollution sources.

Material and methods. Field studies were performed in autumn (September). In 1998, five areas in the Kazanka were investigated (Boltov and Semushin, 2003) (Fig. 2). One more part of this river was studied in 2006 using a diving suit. In the lower reaches of the Solza, a 2-km stretch downstream from the bridge carrying the Severodvinsk–Onega motorway was studied in 2005. In the same period, a 1-km stretch of the Pelezhma, another tributary of the Solza, was surveyed, but no mollusks were found.

Sampling areas in the stretches of interest varied in size (10–30 m long, 1–3 m wide, 10–90 m^2) depending on the river flow rate, bottom grounds, and depth. They were divided into squares using a 1 × 1-m frame, and each square was searched for mollusks. On the whole, we collected 149 ind. (1998) + 208 ind. (2006) from the Kazanka and 185 ind. from the Solza. The shell length in collected mussels was measured with slide calipers to an accuracy of 0.1 mm, and the mussels were returned to the river. Hydrological measurements were made, and water samples (two from the Kazanka in 1998 and two from the Solza in 1998 and 2005) were taken by standard methods. The type of ground was estimated according to the classification developed for salmon rivers (Veselov et al., 2001). Hydrochemical analysis of samples was performed in certified laboratories of PO Sevmashpredriyatie and the Center of State Sanitary and Epidemiological Inspection for Arkhangelsk oblast.

The age of the youngest mussels in samples was determined by the equation $y = (0.275x - 0.206) \pm 0.254$, where y is age (years) and x is shell length (≤74.5 mm) (Semenova et al., 1992). Its applicability to the material from the Solza basin was confirmed earlier (Bolotov and Semushin, 2003).

In addition to original results, we used the data of FGU Sevrybvod (Northern Basin Administration for Conservation and Reproduction of Aquatic Biological Resources and Organization of Fisheries), including archive data (*Report on Conservation and Reproduction of Fish Stocks and Regulation of Fishing*, Arkhangelsk, 1965).

RESULTS AND DISCUSSION

Distribution. The northeastern boundary of the European part of the pearl mussel range passes along the watershed between the Solza and Shirshema rivers (Fig. 1) and then along the watershed between the Onega and Northern Dvina river basins. On the map of pearl mussel distribution in a recent review (Oulasvirta, 2006, p. 25), the lower reaches of the Northern Dvina and small rivers of Zimnii Bereg (Winter Coast) of the White Sea are included in the pearl mussel range. This is an error, as this species is absent in the Northern Dvina basin and does not occur farther east. The *M. margaritifera* population from the Solza basin may be regarded as marginal (peripheral) in the structure of the species range. The factors delimiting this range in the east are beyond the scope of this study. It may be assumed here only that its northeastern boundary reflects specific features of the postglacial distribution of the pearl mussel and its hosts, salmonids of the genus

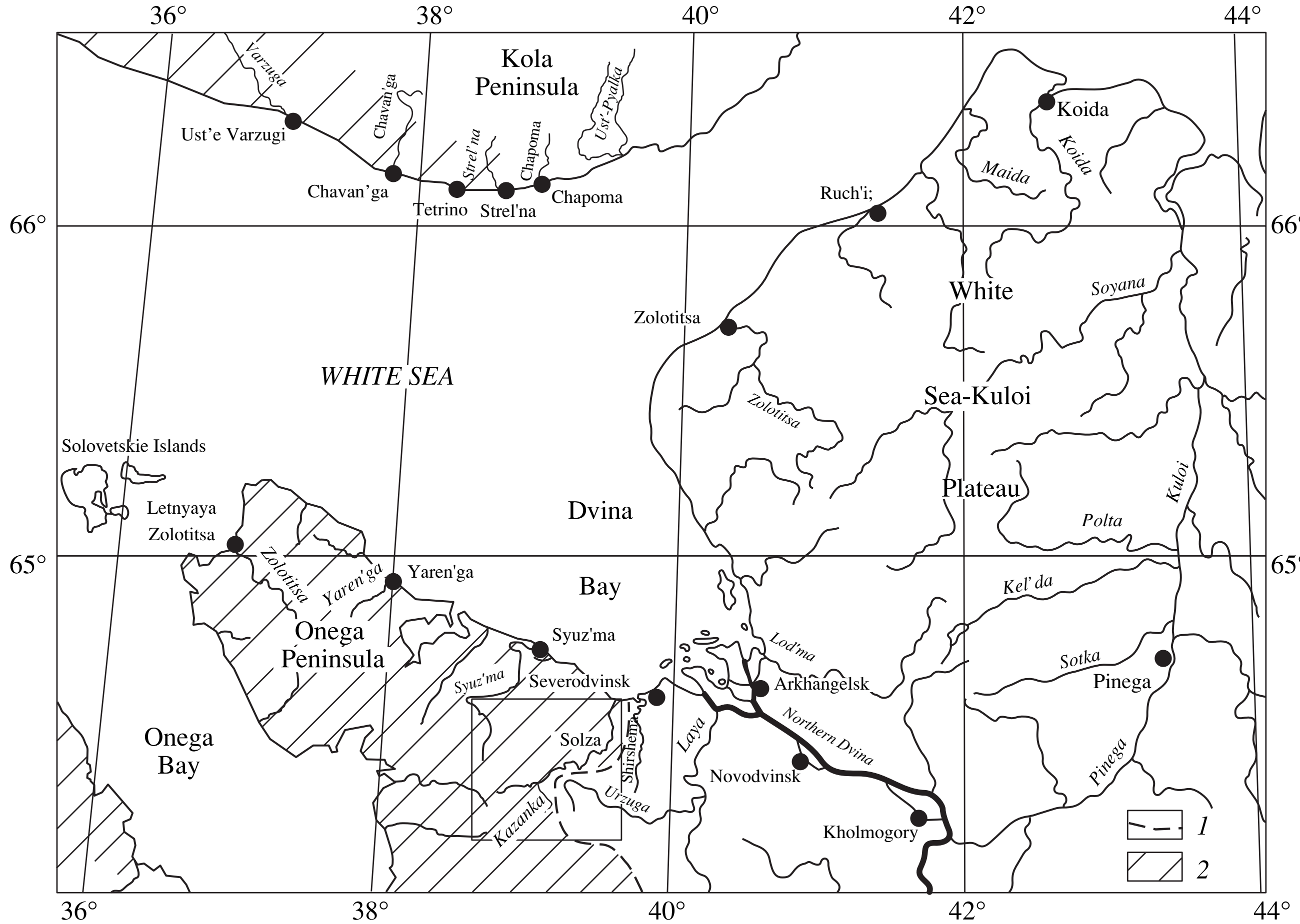

Fig. 1. Map of the eastern White Sea region (the rectangle outlines the Solza basin, see Fig. 2): (*1*) the northeastern boundary of the species range; (*2*) the range of European pearl mussel in the 19th and early 20th centuries (Vereshchagin, 1929; Guttguev, 1930, 1936; Evdokimov, 1936; Ziuganov et al., 1993; *Red Data…*, 1998);

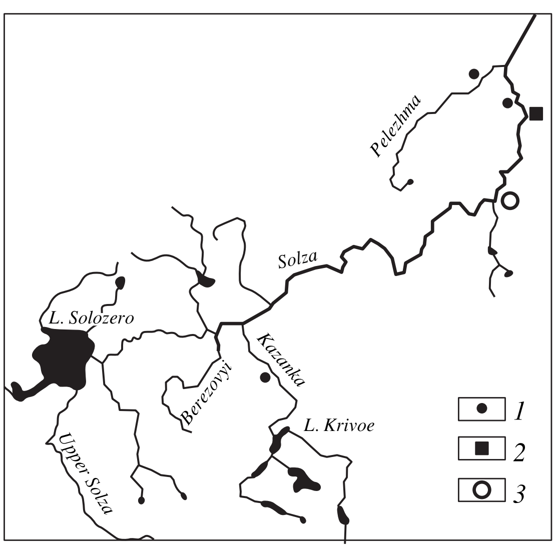

Fig. 2. Map of the Solza basin: (*1*) river stretches surveyed, (*2*) the Solza fish hatchery and the dam of water intake, and (*3*) approximate place were juvenile salmon from the hatchery are released to the river.

Salmo, in the north of Europe. In addition to the Solza, the pearl mussel in Arkhangelsk oblast is reliably known to occur also in the upper reaches of the Kozha River (in the Podsiman'ga Rapids in 2005; material kindly provided by V.N. Mamontov).

Habitats. In the Kazanka and Solza, the pearl mussel populates both pools and rapids. In the stretches studied, the Kazanka is 10–18 m wide, not deep (0.3–1.2 m), and has a moderate flow velocity (0.4–0.8 m/s in the low-water period). Bottom grounds are mostly pebble or boulder–pebble, with sand or silt–sand areas. The Solza in its lower reaches is 20–30 m wide, with its depth averaging 0.3-0.5 m and reaching 1.5–2.0 m in pools. Flow velocity in the low-water period ranges from 0.1 m/s in pools to 0.3 m/s on rapids. Boulder–sand, pebble, and boulder–pebble grounds prevail. They are slightly silted and overgrown by green algae. The Pelezhma is about 5 m wide, with rapids. Pebble and boulder–sand grounds are silted in places. The depth averages 0.2–0.3 m but reaches 1 m in some river bends. The absence of mollusks in this stretch may be explained by the small size of the river, which dries in

Table 1. Main hydrochemical parameters of some rivers in Northwestern Russia and growth rates of European pearl mussels in these rivers

River	pH	O_2, mg/l	Permanganate oxidizability, mg O/l	Growth rate of mussels
Peipiya*	6.1–6.6	8.6–12.8	4.5–6.3	Maximum
Keret'*	6.4	8.5	7.0–16.0	Average
Zhemchugovaya*	5.9–6.7	7.8–11.2	27.0–37.0	Minimum
Kazanka (upper reaches)	6.3	8.5	42.2	Minimum (tentatively)**
Kazanka (lower reaches)	6.3	8.9	37.4	″
Solza (lower reaches)	6.6–6.7	8.9	12.0–45.0	″

Notes: * According to Semenova et al. (1992).
** Substantiated in previous study (Bolotov and Semushin, 2003).

summer and freezes in winter. In the Solza basin, the pearl mussel populates mainly habitats that are typical of this species in other parts of its range (Zhadin, 1938; Ziuganov et al., 1993; Hastie et al., 2000).

Hydrochemical parameters. Waters of the Solza basin are very soft, weakly acid to neutral, with a high content of oxygen and a low concentration of suspended matter (Tables 1, 2). As the basin is swampy, the water is rich in dissolved allochthonous organic matter and its color index and oxidizability are high. Among other parameters, attention should be paid to a relatively high iron content, which exceeds the corresponding MAC for fishery by a factor of 1.2–1.4.

A comparison of hydrochemical parameters of water in the Solza basin with those in other rivers (Table 1) suggests that the growth rate of the pearl mussel in it should be low due to a high content of dissolved organic matter: the growth of mollusks is already inhibited in waters with oxidizability below 37 mg O/l (Semenova et al., 1992). Some authors consider that even oxidizability above 26 mg O/l is the main limiting factor for *M. margaritifera* populations. For example, the pearl mussel is absent in tributaries of the Varzuga, where the water is dark and humified (Ziuganov et al., 1993). Our data provide evidence that the upper limit of pearl mussel tolerance to water oxidizability is apparently higher than it was considered previously, on the one hand, and shed some doubt on the limiting role of this factor in the distribution of pearl mussels (at least in some rivers). In addition, changes in hydrochemical conditions in rivers are variable and the content of dissolved organic matter also varies within wide limits. For example, oxidizability in the lower reaches of the Solza reached 45 mg O/l in October 1998 but was only 12 mg O/l in August 2005.

Population density. The population density of the pearl mussel in the Kazanka is rather variable. In 1998, the average density in all plots was below 1 ind./m^2 (Table 3). In 2006, however, a river stretch with a much higher density was found: it averaged 11.12 ind./m^2 and had a maximum of 68 ind./m^2. In the 1920s, the density of pearl mussels in the same area reached 20 ind./m^2 (Evdokimov, 1936). In the Solza, the highest density of 4 ind./m^2 was recorded in a small channel about 40 m

Table 2. Additional hydrochemical parameters of the Solza basin

Parameter	Kazanka		Lower reaches of the Solza
	upper reaches	lower reaches	
Color index, degrees	220	220	270
Suspended matter, mg/l	2.5	1.4	2.1
Total hardness, meq/l	0.33	0.40	0.33
Alkalinity, mg/l	0.22	0.25	0.24
Chloride, mg/l	5.20	4.50	5.64
Total iron, mg/l	1.40	1.30	1.16–1.26
Manganese, mg/l	0.036	0.054	0.030
Nitrate, mg/l	0.19	0.15	0.21
Nitrite, mg/l	0.025	0.024	0.040
Ammonia and ammonium salts, mg/l	0.20	0.22	0.43

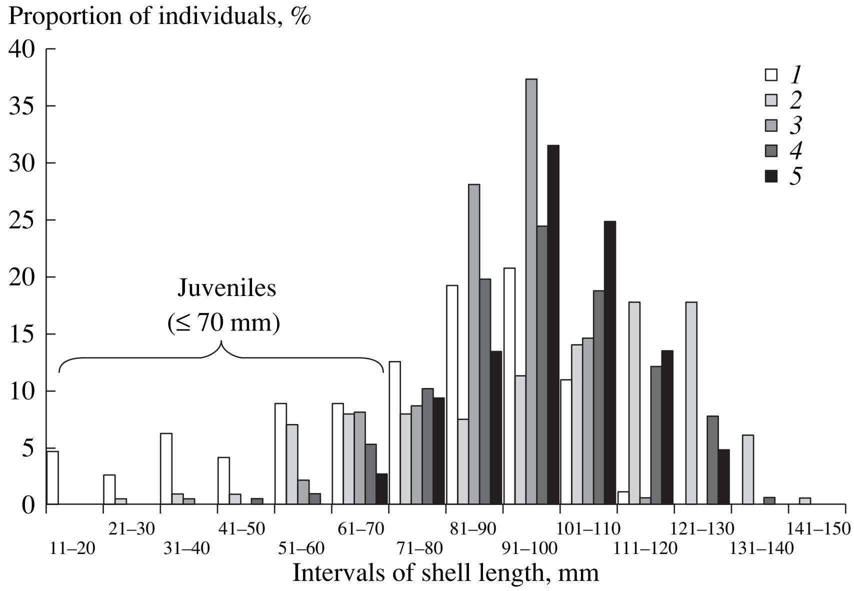

Fig. 3. Size structure of European pearl mussel samples from some rivers of the White Sea basin: (*1*) the Varzuga, $n = 192$ (Ziuganov et al., 1993); (*2*) the Keret', $n = 214$ (Ziuganov et al., 1993); (*3*) lower reaches of the Solza, 2005, $n = 185$; (*4*) the Kazanka, 2006, $n = 208$; (*5*) the Kazanka, 1998, $n = 149$.

long and 10 m wide, behind an island. In other plots, the density was below 1 ind./m^2. The maximum density of pearl mussels in the Varzuga reaches 194 ind./m^2, and that recorded in the Keret is 30 ind./m^2 (Ziuganov et al., 1993).

In contrast to the Kazanka (rarely visited by people), the plot on the Solza is near the bridge carrying a motorway, 2 km downstream from the dam of water intake. There are villages and roads along the river and

Table 3. Population density of the European pearl mussel in the Solza basin

River, biotope	S, m^2	N, ind.	p, ind./m^2
Kazanka, 1998			
Stretch between rapids, sand ground	15	5	0.33
Stretch beyond rapids, pebble ground	50	28	0.56
Stretch between rapids, silt–sand ground	40	22	0.55
Stretch beyond rapids, pebble ground	50	29	0.58
Stretch beyond rapids, pebble ground	90	65	0.72
Kazanka, 2006			
Stretch between rapids, boulder–sand ground	19	211	11.12
Total and average density	264	360	1.36
Lower reaches of the Solza, 2005			
Channel behind an island, boulder–sand ground	46	164	3.57
Rapids, boulder–pebble ground	10	7	0.70
Rapids, boulder–pebble ground	29	8	0.28
Stretch in front of rapids, pebble ground	19	3	0.16
Total and average density	104	182	1.75

Note: S is area, N is number of individuals, p is density.

popular recreational areas on its banks, and these factors account for a high degree of recreational digression in forests. The local population of pearl mussels exists under moderate anthropogenic load.

Size and age structure of mussels in samples. The average length of mussels in samples from the Kazanka was 97.9 mm (from 63.0 to 127.7 mm) in 1998 and 95.9 mm (from 49.5 to 136.3 mm) in 2006, and that in the sample from the lower reaches of the Solza was 89.2 mm (from 33.8 to 110.6 mm). Histograms of the size distribution of mussels in both samples from the Kazanka are shifted to the right, compared to the sample from Solza (Fig. 3). Thus, approximately half of the specimens from the Solza had a shell 81–100 mm long, and those from the Kazanka had a shell 91–110 mm long in 1998 and 81–110 mm long in 2006. The proportion of juveniles with a shell length ≤70 mm in the Kazanka was about 3% in 1998 and 7% in 2006, whereas that in the Solza was higher (11%) (Fig. 4).

In the sample from the Kazanka, the average calculated age of the ten youngest specimens was 19 years in 1998 and 17 years in 2006; in the lower reaches of the Solza, this age was 16 years; the youngest specimens were 17, 13, and 9 years of age, respectively (Table 4).

The samples of pearl mussels from the Varzuga and Keret' are characterized by a large proportion of juveniles (16–40%) and fairly uniform distribution of individuals by size and age classes (Figs. 3, 4). Individuals of older age classes prevail in the samples from the Solza and Kazanka (Fig. 3), especially in the latter (Fig. 4). In the 1920s, the proportion of young pearl mussels in the same area was about 8–10% (Evdokimov, 1936), which is comparable with recent data.

Due to the large proportion of juveniles, the populations of pearl mussels in the Varzuga and Keret' are regarded as successfully reproducing (Ziuganov et al., 1993). The sample from the lower reaches of the Solza also provided evidence for successful reproduction, but the age and size parameters of the 1998 sample from the Kazanka characterized the corresponding population as senescent. Previously, we proposed a hypothesis (Bolotov and Semushin, 2003) that the small proportion of juvenile pearl mussels in the Kazanka is explained by the cessation of natural spawning migration of Atlantic salmon upstream in the Solza. According to FGU Sevrybvod, disturbances in spawning migrations of Atlantic salmon began in 1961–1962 due to construction and subsequent reconstruction of the dam of water intake for Severodvinsk. The fishway in the dam was made near the bank, and most Atlantic salmon migrating for spawning in the mainstream were incapable of overcoming this barrier. The fishway in the dam on the Solza was closed in 1984, when an Atlantic salmon hatchery was built there. However, a site with a much higher density of pearl mussels and a large proportion of juveniles was found in the Kazanka in 2006.

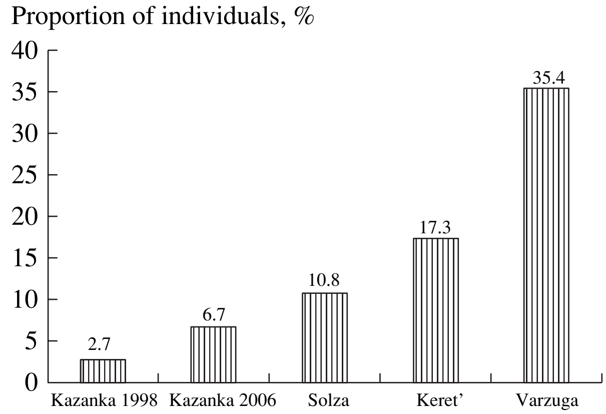

Fig. 4. Proportion of juveniles (≤70 mm) in European pearl mussel samples from some rivers of the White Sea basin (for initial data, see Fig. 3).

This fact indicates that the state of the pearl mussel population in this small river in not uniform.

Juvenile Atlantic salmon from the hatchery are regularly released to the middle reaches of the Solza. This usually occurs in March, about 10 km above the dam (Fig. 2), and juveniles then disperse over the river system. In September 2005, for example, a fairly high abundance of juvenile Atlantic salmon was observed in the lower reaches of the Solza. Some juveniles appar-

Table 4. Calculated age (years) of juvenile European pearl mussels in samples from the Kazanka ($n = 357$) and the Solza (2005, $n = 185$)

Age rank	Kazanka		Lower reaches of Solza
	1998	2006	
1	17.1	13.4	9.1
2	17.8	15.6	15.7
3	17.9	16.1	15.9
4	18.6	16.4	16.1
5	19.2	17.0	16.2
6	19.2	17.3	16.8
7	19.3	17.4	17.2
8	19.5	17.9	17.6
9	20.0	18.1	17.7
10	20.0	18.3	17.8
Average	18.9	16.8	16.0

ently ascend to the upper reaches of this river. At least, this was the case in the early 1990s, as the oldest age of mussels in the 2006 sample from the Kazanka was 13–16 years.

The state of the pearl mussel population in the middle reaches of the Solza, above the dam, is unknown and needs special study.

CONCLUSIONS

The European pearl mussel population in the Solza basin occupies habitats that are typical of this species in other parts of its range. A moderate impact of economic activities did not result in disappearance of this species from the lower reaches of the river. Cultivation of the Atlantic salmon is favorable for the conservation of the pearl mussel population in the Solza basin, as the annual release of juvenile fish ensures relatively successful reproduction of mussels under conditions of river damming. The density of pearl mussels and the proportion of juveniles noticeably vary in different parts of the river system. Therefore, the previous conclusion concerning senescence of the pearl mussel population in the Kazanka (Bolotov and Semushin, 2003) is true only of certain parts of this river. The maximum density of mussels in the Solza basin is higher than in the Keret', although the latter is inhabited by one of the largest populations of this species in Europe.

Data on the present-day state of pearl mussel population in Arkhangelsk oblast are fragmentary, in contrast to those on other regions of Northern Europe. Only two river basins currently inhabited by this species are known. These are the Solza and Kozha basins, and no quantitative studies in the latter basin have been performed as yet. There are also no data on the absolute numbers of pearl mussels in the rivers of this region. Such data are important for the monitoring and conservation of this endangered species included in Red Data lists of all categories, from regional to international. On the other hand, there are some fundamental problems that may be solved only on the basis of comprehensive information on the European pearl mussel from different parts of the species range, including reconstruction of its postglacial dispersal in the northeast of Europe (together with salmonids) and analysis of factors delimiting the European part of the species range in the east.

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