Ecological state of aquatic biocenoses in the streams of the
Kola basin, Barents Sea

N V Ilmast\textsuperscript{1,2}, M Y Alekseev\textsuperscript{3}, N A Bochkarev\textsuperscript{4} and D S Sendek\textsuperscript{5}

\textsuperscript{1} Institute of Biology KRC RAS, Petrozavodsk, Russia
\textsuperscript{2} Petrozavodsk State University, Petrozavodsk, Russia
\textsuperscript{3} Knipovich Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, Russia
\textsuperscript{4} Institute of Systematics and Ecology of Animals SB RAS, Novosibirsk, Russia
\textsuperscript{5} State Research Institute on Lake and River Fisheries, St. Petersburg, Russia

ilmast@mail.ru

Abstract. The ecological state of freshwater ecosystems is essential because they are actively used in human economic activities. As the habitats of valuable commercial fish species deteriorate, their population decreases rapidly. Therefore, environmental monitoring of water bodies, markedly affected by human activities, contributes to efficient natural resources management. Thus, analysis of recent data on the state of river ecosystems in the Kola Bay basin is of great interest. It shows the current state of biocenoses in some of the streams flowing into Kola Bay of the Barents Sea, an environmentally unsafe area on the Kola Peninsula. Studies have shown that in spite of ongoing human activities in the Kola Bay watershed, the state of the ecosystems in local streams generally remains satisfactory. The distribution density of Atlantic salmon juveniles in the tributaries of the Nizhnetulomsky Reservoir varies from 20 to 70 juv./100 m\textsuperscript{2}. The distribution indices of trout in the River Bolshaya Lavna vary from 5 to 65 fish/100 m\textsuperscript{2} and those in streams from 10 fish/100 m\textsuperscript{2} (Goryachev Brook) to 18 fish/100 m\textsuperscript{2} (Tretiy Brook). The main factor which negatively affects the reproduction of diadromous fish species is hydric construction which results in the decrease of the Atlantic salmon, sea trout and whitefish stock. To efficiently maintain the ecosystems of the streams, the construction of fish-screening structures, the river channels should be recultivated and the artificial reproduction of valuable fish species should be launched.

1. Introduction

Northern water ecosystems are affected by climatic (changes in water regime and temperature) and anthropogenic factors. Therefore, assessment of various human economic activities is increasingly essential [1, 2, 3, 4, 5, 6, 7].

During World War I, Kola Bay of the Barents Sea and large adjacent areas were actively developed. The Russian Empire needed a sea port which does not freeze all year round. Wharfs and other port structures were built and Oktyabrskaya Railway to Petrograd was laid out. Murmansk, Severomorsk, Polyarny and other cities and towns arose on both bay shores. Several residential areas are located in the basins of Kola and Tuloma, two large rivers flowing into the bay. The Murmansk sea port, cities and towns are permanent sources of industrial and household wastes deleterious for the environment.
As a result, Kola Bay and its vast surroundings are considerably affected by human activities. The ongoing construction of loading facilities, railways, highways and electrical power lines in the bay area and on the adjacent shoreline aggravates the situation.

The ecological state of the bay has been thoroughly assessed [6, 7, 8]. However, no extensive studies of freshwater ecosystems, their economic value and biodiversity have been conducted. As the habitats of high water quality-demanding fishes of the salmon family deteriorate, the fish population decreases and the fish die. Therefore, environmental monitoring of water bodies considerably affected by human activities is essential for the efficient management of natural resources. It would be interesting to analyze recent data on the state of freshwater systems in some of the streams in the Kola Bay basin. This evidence could be used to assess changes in the biocenoses, to reveal the factors deleterious for the environment and to discuss necessary nature protection activities.

2. Materials and methods

The River Tuloma, an extensive water system with a regulated flow, the River Bolshaya Lavna and Goryachev and Tretiy brooks were used as models. All the four streams flow into Kola Bay of the Barents Sea (figure 1).

Benthos samples were taken from a depth of 0.5 to 4.0 m using Peterson’s bottom grabs with a grabbing area of 0.04 m² in the various parts of the study area. Zooplankton was sampled using a cone-shaped plankton net (Apstein’s net). When taking each sample, 50 l of water were strained through the filtering sieve of the net. All the samples were fixed in 70% ethanol solution. The samples were then treated using generally accepted hydrobiological methods [9, 10, 11].

Fish samples from the Tuloma River system were caught using 30 m long, 1.5-2.5 m high fixed gill nets with a mesh size of 20-50 mm. Two sets of nets were mounted simultaneously in the near-bank and deep-water zones of the river. The fish samples were exposed for 48 to 72 hours to catch the required amount of fish and to assess their species composition.

The presence of fish fauna in the River B.Lavna and in the brooks was detected with a special electrofishing device used to rapidly catch up to 98% of fish in a shallow-water zone and repeat the process three times. Therefore, assessing the quantitative and qualitative composition of fish fauna by electrical catching is the most reliable [12]. The distribution density of juveniles was calculated by removal [13]. The fish samples were treated using standard procedures [14, 15]. In addition, whitefish samples from the River Tuloma were taken for genetic analysis. Total genome DNA was removed from the whitefish liver and fixed in 96% ethanol using the phenol-chloroform method.
3. Results and discussion

The River Tuloma is the largest stream in the Barents Sea basin with a watershed area of 21140 km² and a mean annual water discharge of 235 m³/s. As a result of hydraulic construction, two reservoirs, Nizhnetulomskoye (1936) and Verkhnetulomskoye (1963-1965), were formed in the Tuloma River basin. Their water resources are used for power engineering and water supply. Hydraulic construction has exerted a strong impact on fish distribution in the river basin. As a result, Atlantic salmon cannot migrate to the spawning grounds located upstream from the Upper Tuloma hydraulic structure. The Tuloma Atlantic salmon population is now being reproduced in the Nizhnetulomskoye Reservoir (NTR) tributaries [16, 17]. Whitefish from NTR can migrate from the backwater to the tailwater of the Nizhnetulomskaya Hydropower Plant (NTHPP) dam. The whitefish inhabiting the Tuloma River sector between NTHPP and the river mouth, occurs in water that has turned brackish because of tides and cannot migrate to the backwater through the fishway.

The River Bolshaya Lavna flows from Lake Lavna into Kola Bay of the Barents Sea (Fig. 1). The river is 21 km long and its watershed basin area is 246 km². Slow river zones alternate with bars, rapids and waterfalls over 2 to 5 km from the river mouth. The hydrological characteristics of the river are favourable for rheophilic and limnophilic fish species. 1.6 km from the mouth, the river is cut by a dam. The pumping plant located upstream supplies water to the nearest residential areas [18]. As the dam has no fishway, producers and juveniles cannot migrate. Besides, the river morphology has changed as some of the spawning and growing areas were flooded. Until recently, Atlantic salmon used to enter the river for spawning, but in the past few years natural Atlantic salmon reproduction has ceased.

Goryachev and Tretiy brooks are minor streams of the same type flowing from raised bogs across a forested terrain. As they are markedly inclined, their flow speed is up to 1.2 m/s. The brook bottoms
consist dominantly of boulders and lesser shingle. The brooks do not freeze in winter. Their hydrological regime is favourable for rheophilic fish species.

The river water is poorly mineralized and xeno- oligosaprobic, as shown by tropho-saprobic indices. Heavy metal and oil hydrocarbon concentrations do not exceed maximum allowable values [18].

Zooplankton. Tuloma River zooplankton is dominated by the order Copepoda. The total abundance of organisms varies from 70 inds./m³ to 450 inds./m³, and their biomass ranges from 0.2 mg/m³ to 1.2 mg/m³. These values are due to the irregular distribution of the plankton community in various river sectors. The average abundance of zooplankton is 215 inds./m³ and its biomass is 0.6 mg/m³. Rotifers are scarce. They are represented by one species, Asplanchna priodonta. The order Cladocera consists of two families: Sididae and Bosminidae. It occurs in 80% of catches but in small numbers (20 to 70 inds./m³ and displays a biomass of 0.1 to 0.35 mg/m³). Crustaceans (Copepoda) are represented by three orders: Cyclopoida, Calanoida and Harpacticoida. In samples, they made up 77% of total abundance, varying from 30 to 430 inds./m³ and have a biomass of 0.09 to 1,075 mg/m³.

Planktonic communities in Bolshaya Lavna, Goryachev and Tretiy streams display low quantitative indices. Their total abundance varies from 215 to 520 inds./m³ and their biomass ranges from 0.6 to 8.84 mg/m³. Copepoda are most abundant and make the bulk of biomass in almost all the streams.

Benthos. Bottom fauna samples from the River Tuloma contain the larvae of organisms of 11 groups: Diptera, Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, Mollusca, Hydrachnidae, Amphipoda, Hirudinea, Nematoda and Oligochaeta. The samples analyzed were dominated by Chironomidae.

Most samples consisted of Diptera organisms. Oligochaeta are less common and Mollusca and Trichoptera are still less common. Other taxa were represented by single samples. The total abundance of benthos for the river sectors upstream from NTHPP is 5.200 inds./m², its biomass is 4 g/m² and the relative values for those downstream from NTHPP and biomass are 5.8 and 7.9, respectively. Differences in the qualitative composition of zoobenthos in the backwater and tailwater of NTHPP could be due to tides that result in a ~6% increase in water salinity downstream from the dam.

The benthic fauna of the River Bolshaya Lavna and the brooks consists of 8 taxonomic groups identical in composition in all stream sectors. The streams display similar zoobenthos abundance indices varying from 1067 to 1286 inds./m², while total biomass ranges from 3.71 to 7.13 g/m². Considerable variations in biomass are due to the abundance of Ephemeroptera and Plecoptera that make up 70% of all organisms.

The quantitative evolution of plankton and benthos in the streams, characteristic of a tundra zone, is consistent with an oligotrophic type of water bodies [19].

Fish fauna. The fish population of the River Tuloma is relatively diverse. Seventeen out of 38 fish species and subspecies inhabiting the water bodies of the Murmansk Region, 17 species from the Tuloma River basin belong to three faunistic complexes: 1) Arctic freshwater, 2) boreal plain and 3) boreal piedmont [20]. These are Kamchatka lamprey (Lethenteron camtschaticum), Atlantic salmon (Salmo salar), sea trout (Salmo trutta) and its forms, lake and brook trout, char (Salvelinus alpinus), vendace (Coregonus albula), whitefish (Coregonus lavaretus), grayling (Thymallus thymallus), pike (Esox lucius), minnow (Phoxinus phoxinus), burbot (Lota lota), perch (Percia fluviatilis), threespine stickleback (Gasterosteus aculeatus), ninespine stickleback (Pungitius pungitius), fourhorn sculpin (Triglops quadricornis) and fluke (Platythys flesus). Besides, pink salmon (Oncorhynchus gorbuscha), which has acclimatized in the seas of the region, and Omega smelt (Osmerus eperlanus), introduced from Karelia, have been migrating into the river since 1960.

Eleven species out of the entire fish fauna are being caught by amateur fishers and three species (Atlantic salmon, sea trout and whitefish) are recognized as valuable. Besides, vendace, pike, grayling and burbot are actively caught by anglers. Perch, smelt and char also occur in catches.

The fish distribution in the Tuloma River basin has been markedly affected by hydraulic construction which impeded the migration of Atlantic salmon to its spawning grounds located upstream from the Upper Tuloma hydraulic facilities. Besides, the flooding of Atlantic salmon’s
spawning grounds in the river channel as a result of Nizhne-Tulomskaya dam construction has led to a decrease in its abundance. Atlantic salmon, pink salmon and sea trout pass easily through the NTHPP fishway, but other fish species fail to do so.

The long-term control electrofishing of juvenile Atlantic salmon has shown that the distribution densities of juvenile Atlantic salmon in the NTR tributaries (Pecha, Konya, Shovna and Pak rivers) varied from 20 to 70 fish/100 m². Inter-annual variations of this index display a cyclic pattern and do not tend to increase or decrease. The long-term monitoring of the spawning migration dynamics of Atlantic salmon, conducted at the NTHPP fishway has shown that the mean annual abundance of the population after the regulation of the river by hydraulic facilities stabilized at about 6300 salmons with inter-annual variations of 2700 to 12700 salmons [16, 17, 21]. The state of the Atlantic salmon stock in the Tuloma River system is considered satisfactory, but it depends on the fishway, which should be permanently maintained and occasionally repaired.

The Coregonus family in the river system is represented by European vendace and whitefish. Analysis of the biological indices of Tuloma River whitefish has shown that it belongs to sparsely-rakered (Sp.br = 23.30±0.45) and medium-rakered (ll=87.2±0.7122) groups. Whitefish samples exhibit the following genetic parameters: the number of polymorphous (segregating) sites (S=3), the number of haplotypes (h=4), haplotypical diversity (Hd=0.733), nucleotide diversity (π=0.00093) and the average number of nucleotide differences (k=0.911). Whitefish from Lake Kamennoye, located in the Kem River basin, displays a lower haplotypic diversity (Hd=0.638) but a higher nucleotide diversity (π=0.00168) and more nucleotide differences (k=1.638) [22]. To assess genealogical relationships between haplotypes, median nets were designed. To reveal relationships, whitefish haplotypes from some water bodies in European Russia and Siberia were used (figure 2).

![Figure 2. A median network of whitefish haplotypes from some of Russia’s water bodies based on the gene sequence 16S-ND1 mtDNA](image-url)
(White circles indicate whitefish haplotypes from water bodies on Taimyr Peninsula. Grey circles indicate haplotypes from Ob River tributaries. Horizontal striated circles indicate those from the Baltic Sea basin. Vertical striated circles indicate those from Lake Kamennoye, Kem River basin. Black circles indicate those from the River Tuloma. The line length is proportional to the number of replacements. Circle size is proportional to the number of haplotypes. Small black circles indicate haplotypes that have not been revealed or have died off).

Two haplogroups in the median network are noteworthy. One group consists of several stellar whitefish structures from most European water bodies; the other is composed of chains of haplotypes from Siberian and Taimyr Peninsula water bodies. Whitefish haplotypes from the River Tuloma are part of whitefish haplotypes from the Baltic Sea basin. These are final stellar structures with their own minor haplotypes.

It is generally believed that the River Tuloma is inhabited by the sparsely-rakered and medium-scaled whitefish Coregonus lavaretus. It differs from Siberian pizhyan-like whitefish in having more perforated scales in the lateral lineage [23]. However, whitefish populations with a similar number of scales in the lateral lineage have also been reported from water bodies in the Baikal Rift Zone and in the rivers connected with Lake Baikal [23, 24]. The perforated scale distribution in the lateral lineage of Tuloma River whitefish displays two peaks, suggesting the incomplete hybridization of genetically different sparsely- and medium-scaled whitefish forms/populations.

Preliminary genetic analysis has shown that Tuloma River whitefish belongs to whitefish populations of Baltic origin (group I) which form their own structure directly related to Kamennoye Lake whitefish haplotypes and to one of the structures of Ob River basin whitefish. Thus, the study of Tuloma River whitefish has revealed discrepancies between the results of morphological and genetic analyses. We think, however, that these discrepancies could be eliminated by taking more morphological and genetic white fish samples.

No visible pathologies in the covers and internal organs of whitefish from the backwater and tailwater of NTHPP have been detected.

River Bolshaya Lavna. Until recently, Atlantic salmon has migrated for spawning into this river. In the past few years, natural Atlantic salmon reproduction has ceased because of human activities (dam construction near the river mouth). Valuable fish species in the River Lavna are represented by a wild freshwater form of trout. The trout distribution density varies from 5 to 65 fish/100 m². The highest densities were reported from shoals in the upper reaches of the river. Other fish species occurring in small quantities in catches are perch juveniles and sexually mature burbot individuals.

Goryachev and Tretiy brooks are inhabited by trout. Scarce trout individuals are short and have a small mass. They become sexually mature in a third year of life and do not seem to leave the brooks for feeding and growing in the sea. Fish aged 0+ to 5+ occurred in both brooks. The trout distribution density varies from 10 fish/100 m² (Goryachev Brook) to 18 fish/100 m² (Tretiy Brook).

4. Conclusions

Our studies have shown that in spite of the high urbanization of the Kola Bay watershed basin and a considerable impact of large-scale human activities, the ecosystems of local streams are in good condition. The main factor which has a negative effect on the reproduction of fish, mainly diadromous species such as Atlantic salmon, sea trout and whitefish, is hydraulic construction, even though fishways are available.

Industrial and household emissions, as well as airborne pollution, do not markedly affect the ecosystems located in the urbanized zones of the streams, as indicated by a good water quality, the quantitative evolution level of zooplankton and zoobenthos and the presence of safe environment-demanding rheophilic fish fauna in the streams. The density of juvenile Atlantic salmon in the Nizhne-Tulomskoye Reservoir tributaries varied from 20 to 70 fish/100 m². The trout distribution density in the River Bolshaya Lavna ranged from 5 to 65 fish/100 m² and that in the brooks from 10 fish/100 m² (Goryachev Brook) to 18 fish/100 m² (Tretiy Brook).
The whitefish occurring in the lower reaches of the River Tuloma, near Kola Bay, are of Baltic origin and show no visible pathologies indicative of the long-term effect of poor environmental conditions.

To efficiently maintain the ecosystems of the streams, the dams should be dismantled or fish-screening facilities should be built, the river channels should be recultivated and the valuable fish populations lost should be restored by artificial reproduction.

Acknowledgements
The paper is based on research carried out with the financial support of State Program (Project No 0218-2019-0081) and the Russian Foundation for Basic Research (Project No 18-04-00163).

References
[1] Pavlov D S and Striganova B R 2005 Biological resources of Russia and main directions of basic studies Basic grounds of biological resources management 4-20 (in Russian)
[2] Alimov A F et al 2013 Production hydrobiology (St. Petersburg: Nauka) p 343 (in Russian)
[3] Dgebuadze Y Y 2014 Invasions of alien species in Holarctic: some results and perspective of investigations Russian Journal of Biological Invasions 5 (2) 61–64 doi 10.1134/S207511714020039
[4] Ilmast N V and Sterligova O P. 2016 Results of introduction of new fish species into Lake Munozero (southern Karelia) Russian Journal of Biological Invasions 7 (4) 333–339 doi: 10.1134/S207511716040032
[5] Sterligova O P and Ilmast N V 2017 Population dynamics of invasive species of smelt Osmerus eperlanus in Lake Syamozero (South Karelia) Journal of Ichthyology 57 (5) 730–738 doi 10.1134/S0032945217050162
[6] Kudasov V I 2006 Characteristics of heavy metal pollution in the waters of the Kola Bay according to the 2001-2004 study Scientific Journal of Murmansk State Technical University 9 (5) 833-838 (in Russian)
[7] Shahverdov V A and Shahverdova M V 2016 Assessment of the current geoecological state of the Kola Bay by geochemical data Arctic: ecology and economy 4 (24) 22-31 (in Russian)
[8] Shavykin A A (ed) 2018 Kola Bay and oil: biota, vulnerability maps, pollution p 520 (in Russian)
[9] Zadin V I 1956 Methods of studying the benthic fauna and ecology of benthic invertebrates Life in fresh waters of the USSR 4 (1) 279-382 (in Russian)
[10] Shustov Y A 1983 Ecology of Atlantic salmon juvenile p 152 (in Russian)
[11] Alekseev V R and Tsalolikhin S Y (eds) 2010 Key to zooplankton and zoobenthos in freshwater in European Russia p 495 (in Russian)
[12] Veselov A E 2006 Ecological and behavioral bases of reproduction of Atlantic salmon (Salmo salar L.) in the rivers of East Fennoscandia. Abstract of doctoral dissertation p 50 (in Russian)
[13] Zippin C 1958 The removal method of population estimation J. of Wildlife Management 22 (1) 82-90
[14] Reshetnikov Y S 1980 Ecology and systematics of coregonid fish (Moscow: Nauka) p 301 (in Russian)
[15] Dgebuadze Y Y and Chernova O F 2009 Bony fish scales as diagnostic and recording structure p 315 (in Russian)
[16] Samokhvalov I V and Alekseev M Y 2011 Assessment of natural reproduction of salmon of the rivers of the basin of Nizhnetulomskoye Reservoir (Murmansk region) for the distribution of its juveniles Current problems and prospects of the fisheries sector Materials of scientific conference 109-112 (in Russian)
[17] Samokhvalov I V et al 2014 Some population characteristics of juveniles of Atlantic salmon (Salmo salar L.) of Tuloma river in the conditions of regulated runoff Fundamental study 6 72-77 (in Russian)
[18] Prishchepa B F (ed) 2011 Register of salmon rivers of the Murmansk region Barents Sea basin
[19] Kitaev S P 2007 *Basic of general limnology for hydrobiologists and ichthyologists* p 395 (in Russian)

[20] Nikolsky G V 1980 *Species structure and regularities of variability of fish* p 182 (in Russian)

[21] Alekseev M Y 2003 Study of the dynamics of the number of spawning populations of Atlantic salmon of the Tuloma River using a mathematical model *Fisheries issues* 4 (2) 246-263 (in Russian)

[22] Ilmast N V et al 2016 On the differentiation of the ecological forms/subspecies of the whitefish *Coregonus lavaretus* from Lake Kamennoye *Proceedings of Petrozavodsk State University* 4 (157) 42-53 (in Russian)

[23] Bochkarev N A et al 2011 Morphology and mitochondrial DNA variation of the Siberian whitefish Coregonus lavaretus pidschian (Gmelin) in the upstream water bodies of the Ob and Yenisei rivers *Evol Ecol* 25 557-572 doi 10.1007/s10682-010-9437-7

[24] Bochkarev N A et al 2013 Morphological, biological and mtDNA sequences variation of Coregonid species from the Baunt Lake system (the Vitim River basin). *Adv Limnol* 64 257-277 doi 10.1127/1612-166X/2013/0064-0025