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New Fish Species in Water Bodies of Northeastern European Russia

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Abstract—Changes in the composition of ichthyofauna of northeastern European Russia under the effect of biological invasions are analyzed. It is shown that alien invader fish species appeared in the water bodies of the region as a result of acclimatization measures (the Far Eastern pink salmon and Pechora peled in the White Sea basin, the Northern Dvina sterlet and Siberian sturgeon in the Pechora River), intentional (the pike perch) or accidental introduction (the Chinese sleeper), and expansion of species from the Caspian Sea (the white-eye bream and asp) or the Baltic Sea (asp). The results of analysis of long-term changes in the freshwater ichthyofauna show that the appearance of alien fish species in the water bodies of northeastern European Russia has led to an increase in the diversity of ichthyofauna, trophic competition with native species, deterioration of the fishery status an increased mortality risk for juvenile Atlantic salmon, and potential aggravation of the epizootic situation in the lower reaches of the Northern Dvina River. At the same time, the successful acclimatization of the Pechora peled in the White Sea basin has made it possible to develop a scheme for organizing full-cycle lake coregonid farms with the formation of peled brood stocks and local whitefish polyculture. Sturgeon species naturalized in the Onega and Pechora rivers may subsequently diversify the list of commercial fish species.

Keywords: northern freshwater ecosystems, alien fish species, species diversity, trophic competition, fishery status of water bodies, ecological consequences

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Changes in aquatic ecosystems due to natural and anthropogenic factors influence hydrobionts in different ways: some species become suppressed, some continue to maintain homeostasis, and others begin to expand the borders of their natural ranges under changing conditions. This can result both from the intentional introduction of species for their acclimatization in new areas and from their spontaneous expansion.

Biological invasions are understood as cases when a species colonizes ecosystems located beyond its original (usually natural) range. Invasive species, called *invaders* or *adventive* or *alien* species, can affect native populations, species, and communities, thereby causing irreversible changes. The term *invasive species* was defined in the Convention on Biological Diversity (1992), meaning naturalized species causing damage to native fauna and ecosystems. Alien fish species can cause severe damage to fisheries, acting as carriers or vectors of diseases or as active competitors displacing local commercial fish species. Thus, the Chinese sleeper *Perccottus glenii* Dybowski, 1877 has widely spread in Northern Eurasia and caused suppression of many populations of native invertebrate, fish, and amphibian species [1]. It has become a dominant species in some isolated water bodies of the Komi Republic, displacing the crucian carp [2], and populated the basins of all main rivers in Belarus [3]. The scientific literature provides a number of examples showing that the pike perch also has a negative effect on native fish species [4].

Therefore, the identification of invasive species and study of their effect on native communities and ecosystems are important tasks. The study of the current state and dynamics of fish communities in of northern water bodies under the effect of natural (climatic changes) and anthropogenic (technogenic load) factors is of considerable scientific and practical interest.

This study is an attempted to review new species (alien and invasive) that have appeared in the fresh water bodies of northeastern European Russia as a result of acclimatization measures, intentional and accidental introduction, and spontaneous expansion.

MATERIAL AND METHODS

The region of northeastern European Russia has its northern boundary along the coastlines of the western White Sea, southeastern Barents Sea, and southwestern Kara Sea, including the Kara River basin (Fig. 1). The eastern boundary of the region coincides with the Pechora–Ob watershed in the Urals, and its southern

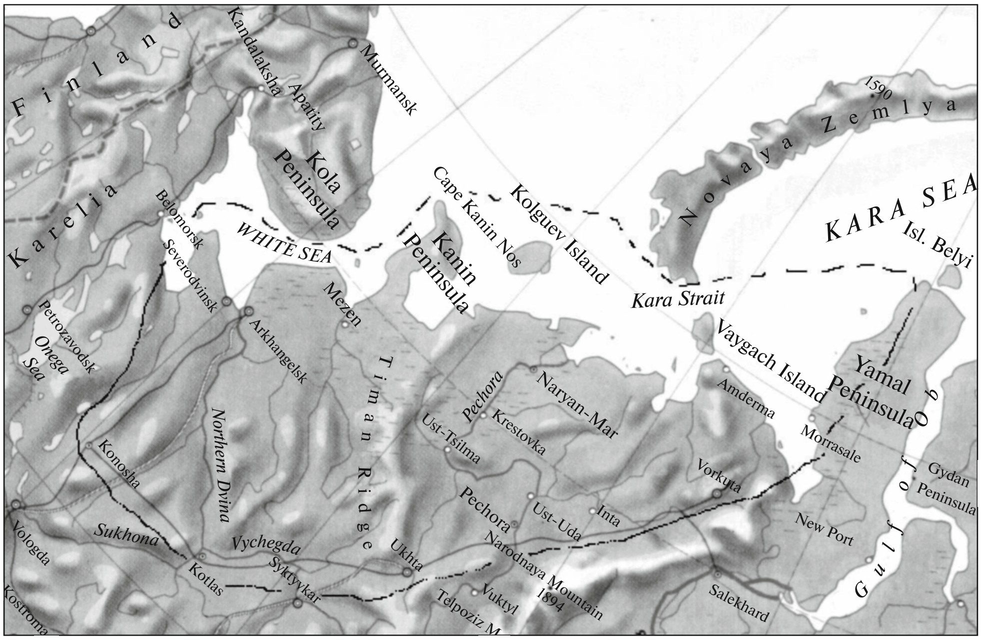

Fig. 1. Schematic map of watercourses in northeastern European Russia.

boundary is along the watershed of the Barents and Caspian seas. The western boundary passes along the western contour of the Omega River basin, i.e., almost in the same area where the Baltic crystalline shield borders on the Russian Platform plain. This region includes the coasts of the seas around Arkhangelsk oblast and the Yamalo-Nenets Autonomous Okrug and the basins of the Onega, Northern Dvina, Mezen, and Pechora rivers, the largest in northeastern European Russia.

The material for this study included the results of long-term research on the ichthyofauna of northeastern European Russia since the 1980s, as well as published data on the appearance of new species in the ichthyofauna of the region. The studied samples were collected in water bodies of the Onega Peninsula, lakes of Arkhangelsk oblast, and basins of the Northern Dvina and Pechora rivers (in the Yamalo-Nenets Autonomous Okrug and Komi Republic). The taxonomic status of fishes, presented according to [5] after verification with reference to [6].

New species were caught and studied during integrated ichthyological surveys using both active and passive fishing gears, namely, a haul seine 80 m long, with a cod-end mesh size of 16–20 mm, and a set of ten trap gill nets with a mesh size of 15 to 70 mm. The material was analyzed to evaluate the species ratio in control catches, the temporal (different years) and spatial (different water bodies) aspects of fish distribution, and biological parameters of alien species.

Biological analysis of fresh samples was performed by conventional methods [7], taking into account recommendations for studies on coregonids [8]. The captured fish were examined to measure standard body length (cm, from the tip of the snout to the end of the scale cover), body weight (g), and visually determine sex and stage of gonads maturity (in grades). The age of fish was determined by annual rings on scales taken from two–three rows above the lateral line anterior to the dorsal fin. The number of rings and their radii along the anterior scale margin were measured under an MBS-9 binocular microscope. The rate of the linear and weight growth of whitefish was analyzed by conventional methods [9] with regard to the guidelines by Mina [10], estimating the difference between the last body increment and the increment in the previous season.

The fish diet was analyzed according to [11]. The quantitative composition of food was expressed as a percent weight ratio of individual food items to the total gut contents. The feeding intensity was calculated as total indices of gut filling and expressed in prodecimille (‱).

The feeding (competitive) relationships between alien and native fish species were analyzed based on the degree of food similarity (FS) between the studied fish species [12] and using the food niche overlap index (C_λ) [13]. The food similarity index was calculated as the sum of the lowest values of the species composition of diets of the compared fishes (diets in %): the index was 100% for complete similarity and 0% for the absence of similarity. The degree of food niche overlap in different fish species was determine by calculating the Horn index:

$$C_\lambda = \frac{2\sum x_i y_i}{\sum x_i^2 + \sum y_i^2},$$

where x_i and y_i are the values of individual components in the food bolus, %.

The collected materials were analyzed based on the following generally accepted concepts [14]:

Introduction is a transfer of organisms for introducing them into a new area, water body, or culture. This is the first stage of the acclimatization process, but it does not always result in the acclimatization of the introduced organism. Introduction may be *intentional* (when an alien species is intentionally transported or released beyond its natural range) or *unintentional* (when a species is introduced for any other reason related to human activities) [15].

Acclimatization is the process of adaptation of introduced individuals and their offspring to new environmental conditions, including the formation of a new population in these conditions.

Naturalization is the final stage of the acclimatization process at which the invader has adapted to the new conditions, its niche and relationships with native species in the ecosystem of the water body have been established, a dynamic balance in the abundance of the new population is maintained, and it has become possible to use this population for feeding or commercial purposes.

Spontaneous expansion is self-introduction of aquatic organisms into a new water body followed by their acclimatization in it.

RESULTS AND DISCUSSION

Over the past 50 years, a number of new species have appeared in the ichthyofauna of fresh water bodies of the study region. Their appearance was due to the following factors: (1) acclimatization measures (the Far Eastern pink salmon in the basins of the White and Barents seas, the Pechora peled in the White Sea basin, the Northern Dvina sterlet and Siberian sturgeon in the Pechora River); (2) intentional introduction (the pike perch in the Onega and Northern Dvina river basins); (3) accidental introduction (the Chinese sleeper in the lake ecosystems of Arkhangelsk oblast and the Komi Republic); and (4) spontaneous expansion of Caspian (the white-eye bream and asp) or Baltic species (the asp) to the Northern Dvina River.

ACCLIMATIZATION

Pink salmon *Oncorhynchus gorbuscha* (Walbaum, 1792). The acclimatization of Far Eastern pink salmon in the northern European Russia has a history of over 50 years. During this period, pink salmon has widely spread in water bodies of the Kola Peninsula, Karelia, Arkhangelsk oblast, and the Nenets Autonomous Okrug; it has also been recorded off the coasts of Norway, Sweden, Iceland, and Spitsbergen, in the basin of the Pechora River, and expanded to the Taz River basin in the east [16]. Numerous naturally spawned odd-year stocks of pink salmon enter the rivers of the White Sea. The biological effect of acclimatization manifests itself in fairly high abundance of naturalized pink salmon as a fishing object [17].

The competition between pink salmon and native species (Atlantic salmon and sea trout) was an especially acute problem during organization and performance of acclimatization measures. To exclude this competition, Russia signed a convention in 2005 on the prevention of introduction of new salmon species into water bodies inhabited by Atlantic salmon *Salmo salar* Linnaeus, 1758.

Peled *Coregonus peled* (Gmelin, 1789). Measures to introduce the Pechora peled into water bodies of the White Sea basin began in 1972. Eggs collected in the Pechora River were incubated at the Onega Fish Hatchery, and various water bodies of Arkhangelsk oblast were stocked with peled larvae and juveniles. In total, about 60 million larvae and over 6 million current-year juveniles were released in the 1970–1980s, and this species successfully adapted to its new range [18–20].

Under the new conditions, the wide ecological plasticity of this species manifested itself in the development of three ecological forms: the lake, lake–river, and river peled. Typical lake peled, characterized by a deeper body, began to spawn and grow in lakes and did not enter the Onega River. Slenderer and small-sized lake–river peled grew in lakes and migrated to the river for spawning in autumn. Typical river peled with a slender body adapted to living in the lower reaches of the Onega River, where it changed to mixed feeding (including predation on juvenile perch) and was characterized by retarded growth, compared to the lake and initial (Pechora) forms [18].

The growth rate of peled depended mainly on the type of its diet. The typical zooplankton feeding of peled in lakes with a sufficient food supply led to the formation of the lake form with an increased growth rate, compared to peled from other water bodies of the new range and even from the Pechora stock. The growth rate of river peled, which began to feed mainly on benthos, became significantly lower than in the lake and Pechora forms. Under the new conditions, its age at maturity decreased by 1–2 years, but absolute fecundity became lower [18].

The diet of peled depends on food reserves of water bodies. In lakes with sufficiently developed zooplankton, peled fed mainly on copepods and cladocerans, while the role of benthos was insignificant. However, its role in the diet was dominant in lakes with low abundance of food and in rivers. Under the new habitat conditions, competition between peled and native species was weak owing to a high divergence of their food spectra [21].

Under river conditions, a planktonic diet was not characteristic for any of the studied fish species, including peled. However, competition for food was also lower, since peled consumed mainly mollusks, while local fishes fed on chironomid, dragonfly, caddis fly, and mayfly larvae. Migratory whitefish could be the only serious food competitor for peled, since both these species fed on mollusks. However, whitefish almost cease feeding during spawning run up the river, and their spring–summer stay in the lower reaches of the river is a periodic event; therefore, persistently strained feeding relationships between peled and whitefish are unlikely [10]. In lakes, peled did not compete with representatives of local ichthyofauna, since it occupied the trophic niche of a planktophage, which was incompletely utilized before its introduction. All planktophagous fishes fed on cladocerans, but peled consumed mainly bosmins, while local bleak, roach, and small perch fed exclusively on water fleas. Benthophages (whitefish and freshwater bream) and euryphage (ruff) consumed zooplankton only accidentally.

The results of introducing the Pechora peled into the diverse water bodies of Arkhangelsk oblast confirm its high adaptive potential and can be regarded as an example of acclimatization measures with positive results. The possibilities of using peled as an object of cultivation in full-cycle whitefish lake farms are currently limited only by socioeconomic rather than ecological factors [18].

Sturgeon species acclimatized in the water bodies of northeastern European Russia, in new habitat conditions, include the Northern Dvina sterlet and Siberian sturgeon.

Sterlet *Acipenser ruthenus* Linnaeus, 1758 is the only sturgeon species that is widespread in northeastern European Russia, in the Northern Dvina River basin. It was long believed that sterlet appeared in this area due to the construction of canals [22, 23]. According to this hypothesis, sterlet moved from the Vychegda River to the Dvina basin through the Catherine Canal after the sluice on the canal was broken by a high spring flood in 1810 [24]. At the same time, the remains of sterlet were found in sediments of the Onega River basin dating 2000–3000 years BC, which suggested its further expansion to the Northern Dvina, where it has survived to the present, unlike in the Onega [25, 26]. Sterlet currently occurs in the rivers Sukhona, Yuga (with Luza), and Vychegda (with Sysola), as well as in the Dvina itself and its tributaries, the Vaga and Pinega [27].

The Northern Dvina sterlet was repeatedly released into the Pechora (1933–1961), Mezen (1960–1963), Onega (1961–1968), and Shuya (1968–1982) in order to acclimatize it and expand its range. No effect was observed in the first years after acclimatization measures, since the released fish differed in age and were small in numbers. Only single juvenile sterlets were recorded in the stocked rivers (Pechora, Mezen, and Onega), and adult fish, including sexually mature individuals, occurred in catches even more rarely. At present, cases of sterlet catches in the Pechora River have become common; this species also occurs in its tributary, the Usa River. Sterlet in the feeding period concentrates in the lower and, partly, middle reaches of the Pechora, and its abundance is limited only by availability of natural spawning grounds [28]. A similar situation is also observed in the Onega River, where the catch of a sterlet weighing over 10 kg was recorded.

Siberian sturgeon *Acipenser baerii* Brandt, 1869. About 100 sturgeons of different ages caught in the Ob River were released into the Pechora River in 1956, and several fish were caught with different fishing gears in the Usa and Kolva rivers in the same year [29]. Despite active fishing and regular ichthyological studies in the Pechora River and its tributaries, sturgeon was not recorded there until 2005. In July 2005, two sturgeons weighing 19.6 and 2.0 kg were caught in different parts of the main Pechora channel. The age of the large sturgeon was 22 years, and that of the smaller one was 6 full years [30]. One more sturgeon was caught with a trap net in the lower reaches of the Pechora River in the autumn of the same year. In 2007–2019, cases of catching sturgeons aged 4–7 years in the lower reaches of the Pechora River became regular, and all these fish were identified as Siberian sturgeon (*Acipenser baerii* Brandt).

According to the chronology of the events, sturgeons captured in the Pechora River appeared there as a result of natural reproduction of the introduced adult individuals. This follows also from the fact of catching a current-year juvenile sturgeon during fishing for vendace near the village of Ust-Tsilma in 2006 [20]; i.e., this indicates that the process of naturalization of the species in the new habitat conditions has already been completed. In any case, the current presence of Siberian sturgeon in the Pechora River should be considered an established fact, which makes it reasonable to include it in the list of ichthyofauna of the Pechora River as a rare species [30, 31].

INTENTIONAL INTRODUCTION

Common pike perch *Stizostedion lucioperca* (Linnaeus, 1758). The natural range of pike perch in the water bodies of Arkhangelsk oblast is limited only to a series of lakes of the Baltic basin. It is known that pike perch was not part of the fish community of the Onega River water system either in the last century or during the period when fishes of the thermophilic complex lived in the Onega basin (until the 1st millennium BC) [25, 32]. Its current presence in the Onega River is a result of its introduction into Lake Vozhe (Vologda oblast adjacent to Arkhangelsk oblast) for improving the qualitative composition of the lake ichthyofauna

[33]. The openness of the lake–river system allowed the introduced pike perch to penetrate into Lake Lacha, a source of the Onega River (one of the large rivers of the White Sea basin), through the Svid River. After 2003, pike perch began to appear in catches from the middle reaches of the Onega River, where the main Atlantic salmon hatcheries are located. It was found that the peak of downstream migration of salmon smolts coincides with the end of the spawning period and the onset of intensive feeding in pike perch. In 2001, up to five specimens of salmon smolts were found in the guts of several pike perches. In our opinion, the impact of pike perch on native species will become stronger with increase in its abundance in the Onega basin [34].

There are known examples of this impact on native fish species. Thus, after pike perch introduction into Lake Balkhash, the local commercial species Balkhash perch (*Perca schrenki*), was included in the IUCN Red List [35]; in Norway lakes, its introduction and subsequent increase in abundance led to a significant decrease in the abundance of local roach.

The pike perch appeared in the Northern Dvina River as a result of its intentional introduction from Lake Kubenskoe into the Sukhona River and then spread almost throughout the river up to its delta part and the outfall offshore zone (Sukhoe More Bay). We can now state that pike perch has completed its naturalization in the Northern Dvina basin, since both spawners (weighting up to 4 kg) and juveniles of different ages are recorded in commercial and control fishing gears.

ACCIDENTAL INTRODUCTION

The introduction of fishes beyond their natural ranges can have negative consequences and lead to changes in aquatic ecosystems [4]. Northern water bodies are weakly resistant to the impact of natural and anthropogenic external factors [35].**Chinese sleeper *Percottus glenii* Dybowski, 1877.** In the late 1990s, this species was introduced by aquarists to Lake Plesetskoe located in the restricted area of the Plesetsk Cosmodrome (Arkhangelsk oblast) in the Northern Dvina River basin. It has also been recorded in the Komi Republic in isolated ponds near the city of Syktyvkar in the Vychegda River basin [2]. It is known that Chinese sleeper in new conditions shows a shift to predation and has a high growth rate [36]. According to the results of our earlier studies [37], the growth rate of Chinese sleeper in Lake Plesetskoe is really high. At a significant population density of the species, individuals of different ages had a body weight ranging from 1 to 469 g and fed mainly by predation. The main component of the Chinese sleeper diet was fish (including individuals of its own species), which comprised over 80% of gut contents.

SPONTANEOUS EXPANSION

In recent decades, new fish species have appeared in the Northern Dvina River; these are inhabitants of the Caspian and Baltic Sea basins, namely, the white-eye bream and asp. The migrants might appear in the Northern Dvina basin in two ways: through the Vychegda and (or) Sukhona rivers. In the first case, they reached the Catherine Canal through the Kama River and its tributaries (Vyatka and South Keltma rivers). The Catherine Canal is no longer navigated, but fish migrations along it are quite possible in high-water years. These species might then move along the North Keltma River to the Vychegda River and colonize the entire Dvina basin through the Malaya Northern Dvina River. The second possible way of spontaneous expansion of Caspian species is from the Rybinsk Reservoir and Sheksna and Parazovitsa rivers along the Parazovitsa canal to Lake Kubenskoe and then to the Sukhona River, from which the Malaya Northern Dvina River takes its source at the confluence with the Vychegda River. In addition, asp may also migrate from the water bodies of the Baltic basin through the Parazovitsa Canal. This route is from Lake Onega to the Volga–Baltic Canal through the Vytegra River and then, through the Kovzha River, to Lake Beloe, the Parazovitsa River, and finally to the Sukhona River according to the already mentioned scheme of Caspian species expansion [38].

White-eye bream *Abramis sapa* (Pallas, 1814) is a secondary commercial fish species in the lower reaches of the Volga River. It was first recorded in the Vychegda River in 1971 and then appeared in the Northern Dvina River, where its abundance rapidly increased. It was long recorded in the fishery statistics as juvenile freshwater bream or white bream. In the last decade, it has occurred almost throughout the Northern Dvina River, spreading to its delta and the outfall offshore zone. The situation seems to be problematic, since white-eye bream as a brackish-water species can create a serious competition for food with valuable commercial cyprinid species of the native complex (the freshwater bream) and also with the Northern Dvina whitefish in its forage biotopes in the river delta and outfall offshore zone [38].

Analysis of the diet of white-eye bream its food competition with local species showed that the relationships between them were really tense. The index of food similarity [12] between the white-eye bream and whitefish was 62.8% and the food niche overlap index (C_λ) [13] was 89.9%. This was due to the similarity of their diets, which consisted mainly of aquatic insect larvae (70% in the white-eye bream and 58% in the whitefish) with dominance of chironomid larvae (53 and 50%) and also included aquatic vegetation (21 and 10%, respectively). Mollusks were found in the guts of both species, but whitefish consumed them more actively than white-eye bream ((18 vs. 1%). The same picture is observed when comparing the feeding patterns of the white-eye bream and freshwater bream (FS = 57.8%, C_λ = 84.1%). This results from the feeding of both species on chironomid larvae (53 and 86%) and mollusks (1 and 10%, respectively) [39].

Asp *Aspius aspius* (Linnaeus, 1758). A predatory representative of cyprinid fishes that appeared in the Northern Dvina basin after the white-eye bream. The asp is a rare species in the Vychegda River [40, 31], and its abundance of asp in the Northern Dvina River is also low: single individuals occur in the middle and estuarine sections of the river and in the outfall offshore zone.

SOME ASPECTS OF TRANSFORMATION OF AQUATIC ECOSYSTEMS DUE TO THE APPEARANCE OF INVASIVE SPECIES

Having successfully adapted to the new habitat, adventive species are a real factor of the transformation of aquatic ecosystems and can affect the populations, communities and species of native faunas. It is difficult to predict the degree of impact from each alien species due to a large number of associated parameters [41]. Based on expert estimates, the following possible consequences can may be predicted for the water bodies of the region under consideration:

(1) *Changes in species diversity.* The spontaneous expansion of a number of fishes of the Caspian and Baltic complexes (the white-eye bream and asp) into the Northern Dvina River has enriched the species composition of ichthyofauna. Under stable environmental conditions, they can colonize vacant ecological niches without causing the depression of native ichthyofauna. However, further climate warming and consequent eutrophication of river basins may give reproductive advantage to thermophilic (and phytophilic) invaders, providing conditions for their population outbreak, and this may well lead to population depression in species of the salmon–whitefish complex due deterioration of conditions for their natural reproduction. In other words, the current expansion of invasive fish species into the basins of northern rivers poses a threat to the maintenance of natural biological balance in the species composition of ichthyofauna.

(2) *Aggravation of trophic competition.* Competition for food can be aggravated primarily between invasive fishes and commercial species of native fauna. Thus, the appearance of white-eye bream in the Northern Dvina basin resulted in its competition with freshwater bream and whitefish. The current state of whitefish is classified as depressed because of general pollution of the river basin and serious fishery pressure. Therefore, the food competition with self-introduced white-eye bream in the Northern Dvina River basin should be regarded as an additional negative factor that increases environmental risk for the Northern Dvina whitefish population.

(3) *Decline of the fishery status of water bodies.* The introduction of predatory fish species may impair the fishery status of a water body or cause a loss of certain species inhabiting the adjacent water bodies. Thus, the appearance of pike perch in the Onega River created an additional risk factor for juvenile Atlantic salmon, since the peak of downstream migration of smolts coincides with the end of pike perch spawning and the beginning of its intense feeding. Therefore, it is quite possible that fish productivity in the Onega River (salmon) and commercial lakes in its basin (vendace) will decrease with the ecological progress of pike perch and its spread farther along the Onega River system and its ecological progress.

(4) *Deterioration of the epizootic situation in water bodies.* The expansion of alien species to northern water bodies may also entail a sanitary and biological hazard. For example, tapeworm infection in cyprinids (freshwater bream, ide, and roach) from the Northern Dvina delta was very rare (single cases) only a decade ago but has already become common in this area. The specific role of invasive southern species in the spread of this infection has not yet been determined and needs further study.

CONCLUSIONS

Under new conditions, invasive species can exhibit their biological aggressiveness and be more viable and potentially more adaptive than native species, thereby suppressing or displacing them. Therefore, the emergence of new species in the northern water bodies is itself a serious problem. In the water bodies of northeastern European Russia, alien invader fishes appeared as a result of acclimatization measures (the Far Eastern pink salmon and Pechora peled in the White Sea basin and the Northern Dvina sterlet and Siberian sturgeon in the Pechora River), intentional (the pike-perch) or accidental introduction (the Chinese sleeper), and spontaneous expansion of the Caspian (the white-eye bream and asp) or Baltic species (the asp).

The appearance of adventive fish species in the fresh water bodies of northeastern European Russia has led to an increase in the diversity of ichthyofauna, development of trophic competition with native species, decline of the fishery status of salmon rivers due to increased mortality risk for Atlantic salmon, and potential deterioration of epizootic situation in the lower reaches of the Northern Dvina River. However, the appearance of new species does not always has negative consequences. As a result of successful acclimatization of Pechora peled in water bodies of the White Sea basin, a scheme was developed for organizing full-cycle lake coregonid farms with the formation of peled brood stocks and local whitefish polyculture. Sturgeon species naturalized in the Onega and Pechora rivers may subsequently diversify the list of commercial fish species.

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