Трансформация экосистем
Ecosystem Transformation

ISSN 2619-0931 Online
www.ecosysttrans.com

Article

Monitoring of invasions of family Percidae in the Volga-Caspian fishery basin

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Received: 07.06.2022
Revised: 24.06.2022
Accepted: 25.06.2022
Published online: 12.04.2023

DOI: 10.23859/estr-220607
UDC 597.556.331.1-169
(282.247.41+262.81)

Translated by S.V. Nikolaeva

Abstract. This paper presents long-term data on the occurrence of parasites of commercially valuable fish species, the common zander (*Sander lucioperca* (Linnaeus, 1758)) and the perch (*Perca fluviatilis* Linnaeus, 1758). The parasitofauna of perch fish was characterized by low species diversity, dominated by Nematoda. The component parasitic community was formed of host specific and euryxenic species with direct and complex development cycles. Species of epizootic and/or epidemiological significance common to perch and zander included *Apophallus donicus* Skrjabin & Lindtrop, 1919, *Anisakis schupakovi* Mosgovoi, 1951; *Eustrongylides excisus* Jägerskiöld, 1909; *Corynosoma strumosum* Rudolphi, 1802; *Achteres percarum* Nordmann, 1932; *Argulus* sp., and *Piscicola geometra* Linnaeus, 1761. The dynamics of infection of fish with most parasites showed seasonal variability. The larvae of the nematode *E. excisus* and the crustacean *A. percarum* caused a pathological response in the body of their host, whereas other species were asymptomatic parasites. The changes revealed in the occurrence and intensity of infection are due to the biological characteristics of the parasites and their hosts, as well as the means of transmission of the invasion. The annual presence and low levels of parasite infestation suggest stability of parasite-host relationships in perch fish. However, the presence of pathogens of invasive diseases indicates the maintenance of natural foci of parasitosis in the Volga-Caspian fishery subarea. Parasitic diseases being at the subclinical level suggest that the parasitological state of perch fish is satisfactory.

Key words: parasite fauna, perch, zander, intensity of invasion, level of infestation, ectoparasites, nematodes, trematodes

To cite this article. Voronina, E.A. et al., 2023. Monitoring of invasions of family Percidae in the Volga-Caspian fishery basin. *Ecosystem Transformation* **6** (2), 9–18. https://doi.org/10.23859/estr-220607

Научная статья

Мониторинг инвазий окуневых рыб (Percidae) Волго-Каспийского рыбохозяйственного подрайона

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Поступила в редакцию: 07.06.2022
Доработана: 24.06.2022
Принята к печати: 25.06.2022
Опубликована онлайн: 12.04.2023

DOI: 10.23859/estr-220607
УДК 597.556.331.1-169
(282.247.41+262.81)

Аннотация. Приведены многолетние данные встречаемости паразитов ценных промысловых видов – обыкновенного судака *Sander lucioperca* L., 1758 и речного окуня *Perca fluviatilis* L., 1758. Паразитофауна окуневых рыб характеризовалась невысоким видовым разнообразием с преобладанием представителей класса Nematoda. Компонентное паразитарное сообщество формировали специфичные и эвриксенные виды с прямым и сложным циклами развития. Общими для окуня и судака являлись виды, обладающие эпизоотической или эпидемиологической значимостью: *Apophallus donicus* Skrjabin, Lindtrop, 1919; *Anisakis schupakovi* Mosgovoi, 1951; *Eustrongylides excisus* Jägerskiöld, 1909; *Corynosoma strumosum* Rudolphi, 1802; *Achteres percarum* Nordmann, 1932; *Argulus* sp. и *Piscicola geometra* L., 1761. Динамика зараженности рыб большинством паразитов характеризовалась сезонной изменчивостью. Личинки нематод *E. excisus* и рачки *A. percarum* вызывали патологические изменения в организме своего хозяина, остальные виды находились на уровне бессимптомного паразитоносительства. Выявленные изменения встречаемости и интенсивности заражения обусловлены биологическими особенностями паразитов и их хозяев, а также путями передачи инвазии. Ежегодное присутствие и невысокие числовые показатели зараженности паразитами свидетельствуют об устойчивости паразито-хозяинных отношений в паразитарной системе окуневых рыб, однако наличие возбудителей инвазионных заболеваний указывают на сохранение природных очагов паразитозов в Волго-Каспийском рыбохозяйственном подрайоне. Выявление болезней паразитарной природы на субклиническом уровне позволяет оценить паразитологическое состояние окуневых рыб как удовлетворительное.

Ключевые слова: паразитофауна, окунь, судак, экстенсивность инвазии, уровень зараженности, эктопаразиты, нематоды, трематоды

Для цитирования. Воронина, Е.А., и др., 2023. Мониторинг инвазий окуневых рыб (Percidae) Волго-Каспийского рыбохозяйственного подрайона. *Трансформация экосистем* **6** (2), 9–18. https://doi.org/10.23859/estr-220607

Introduction

The Volga delta is the shaped of an irregular triangle with one of the vertices facing northwest. The beginning of the delta is near the village of Verkhnelyabyazhye (Russian Federation, Astrakhan Region) where the Buzan distributary extends eastward, and together with the Kigach channel, forms the eastern border of the delta. The Bakhtemir distributary which is a continuation of the main channel of the Volga (Main Bank) forms the western boundary of the delta. The terrestrial part of the delta consists of numerous islands of various sizes, cut through by a dense network of branched channels. The relief typically includes oxbow lakes on the islands and small depressions located on the islands, occupied by lakes ("ilmens"). Water masses in the Volga delta (level regime, water and sediment runoff) are subject to long-term and seasonal changes, caused by fluctuations in the Volga runoff and the level of the Caspian Sea (Katunin, 2014).

Commercial species of the family Percidae: common zander (*Sander lucioperca* (L., 1758)) and river perch (*Perca fluviatilis* L., 1758) are widely used in the fishing industry of the Astrakhan region, and zander is the most desirable catch for many amateur fishermen. Populations of zander, one of the main predators of the delta of the Volga River, for a long time remained unstable. At present, its commercial stocks remain at a low level, as they comprise smaller generations. The low number of generations is due to unfavorable conditions for reproduction, feeding of juveniles and adult fish in the delta of the Volga River and in the Northern Caspian (Levashina, 2018). Unlike zander, perch have more stable stocks and catches in the fishing areas of the Volga delta. The high efficiency of the natural reproduction of perch and the low commercial exploitation of its populations have led to stabilization of the biological parameters of perch and the growth of its stocks (Abbakumov et al., 2015). Organisms associated with their development, including parasites, which can affect not only the health of the fish themselves, but also of humans, play an important role in the study of perch fishes.

The taxonomic diversity of parasites can serve as an indicator of the biocenotic mosaicity of the Volga delta. The species composition and quantitative indicators of host invasion at all levels reflect the processes taking place in the aquatic ecosystem (Kalmykov et al., 2017); therefore, some species may disappear or be replaced by other, more plastic species. Parasites take part in the regulation of the size of the host population and sometimes determine the direction of microevolutionary processes (Tsyganova and Drozhdina, 2011).

The study of the parasitic community of perch fish began as early as the 1930s. In the early 1960s, 40 species of helminths were found in perch, of which 10 were not identified to species (Zablotskaya, 1964). A characteristic feature was the complete absence of highly specific species of parasites. In the early 2000s Semenova et al. (2007) showed a high similarity between the parasites of river perch and common zander (22–23 species of nematodes and flatworms). According to other sources (Ivanov et al., 2012; Kalmykov et al., 2017), the nematode and trematode fauna of perch and zander was represented by 28 and 30 helminth species.

The purpose of this work was to conduct parasitological studies of perch fish and assess the state of the population of the Volga-Caspian fishery subarea, as industrial and recreational fishing increases.

Materials and methods

Seasonally, between 2016 and 2020, the sexually mature part of the population of common zander and river perch was studied based on 866 and 1188 specimens respectively, caught in the fishing areas of the Volga delta, included in the boundaries of the Volga-Caspian fishery subarea (Table 1).

The study of fish was carried out using generally accepted methods (Bykhovskaya-Pavlovskaya, 1985; Metody sanitarno-parazitologicheskoy ekspertizy..., 2001; Musselius et al. 1983). Species identification of the identified helminths was performed using MBS-10 stereoscopic microscopes and "Olympus" biological microscopes, and using the manuals "Key to parasites of freshwater fish of the USSR" (Bykhovskaya-Pavlovskaya et al., 1962) and "Key to parasites of freshwater fish of the fauna of the USSR" (Bauer, 1987).

In parasitological studies, generally accepted indicators were taken into account. Extensiveness of invasion (EI), or occurrence, is the number of infected fish of one species as a percentage of the number of studied individuals of this species. The intensity of invasion (II), or infestation, is the minimum and maximum numbers of parasites of one species per fish. The abundance index (AI) is the average number of parasites of one species per one examined individual of each studied species.

Statistical processing of the results was carried out using the standard Microsoft Excel 2010 software package.

Results and discussion

The parasitic fauna of perch fish included 14 species of parasites of various taxonomic groups: *Sphaerospora* sp. (Myxosporidia: Sphaerosporidae), *Proteocephalus percae* (Müller, 1780) (Cestoda: Proteocephalidae), *Apophallus donicus* (Skrjabin et Lindtrop, 1919) (Trematoda: Heterophyidae), *Clinostomum complanatum* (Rudolphi, 1814) (Trematoda: Clinostomatidae), *Anisakis schupakovi* Mosgovoy, 1951, larva (Nematoda: Anisakidae), *Eustrongylides excisus* Jagerskiold, 1909, larva (Nematoda: Dioctophymidae), *Camallanus truncatus* (Rudolphi, 1814),

Table 1. The volume of the analyzed material, specimens.

Fish species	Season	Year				
		2016	2017	2018	2019	2020
Perch	spring	100	100	100	100	81
	summer	44	50	50	10	23
	autumn	100	100	100	100	130
Zander	spring	6	15	120	62	46
	summer	50	50	20	4	6
	autumn	101	68	100	108	110

C. lacustris (Zoega, 1776) (Nematoda: Camallaninae), *Raphidascaris acus* (Bloch, 1779) (Nematoda: Anisakidae), *Corynosoma strumosum* (Rudolphi, 1802) (Acanthocephala: Polymorphidae), *Pseudoechinorhynchus borealis* (Linstow, 1901) (Acanthocephala: Echinorhynchidae), *Achteres percarum* Nordmann, 1832 (Crustacea: Lernaeopodidae), *Argulus* sp. (Crustacea: Argulidae), *Piscicola geometra* (Linnaeus, 1761) (Hirudinea: Piscicolidae). At the same time, common types of parasitic organisms were observed in zander and perch (Table 2).

The parasite fauna included species of marine, euryhaline, and freshwater associations. The fauna was based on parasites with a complex and direct life cycle. The most common were representatives of the class Nematoda. In both fish species, the “core” of the parasitic community was represented by species of sanitary and epizootic significance. The nematode larvae of *A. schupakovi* and *E. excisus* dominated, while the maximum degree of infection with *Anisakis* was characteristic of zander, and *Eustrongylides* – for perch. Parasitic copepods *A. percarum,* specific to perch fishes, were frequent in zander and metacercariae of the trematode *A. donicus* were common in perch (Terpugova et al., 2018; Voronina et al., 2021). *Acantella acantella, Corynosoma strumosum* and the nematode *Camallanus truncatus*, respectively, were common in zander and perch (Table 1).

The dynamics of infestation with *Anisakis* larvae showed that during the study period (2016–2020), the peak of invasion occurred in 2018, amounting to 81.25% in zander with an invasion intensity of 1–71 ind., in perch this indicator was significantly lower – 28.0% with 1–17 specimens (Fig. 1). A different situation was observed regarding infection with *Eustrongylides*. The numerical indicators of *E. excisus* larvae reached a maximum in perch in 2019 – 72.4% at an invasion intensity of 1–51 specimens, while in zander the highest value was observed in 2017 and amounted to 39.9% at an infection intensity of 1–12 specimens (Fig. 1). This distribution is caused by different means of transmission of invasion by this nematode. Thus, the perch prefers a shallow desalinated zone with weak or no current, while zander chooses places with depths and currents, and feels comfortable in the sea, where it actively feeds. Different biotopes also suggest corresponding parasitic associations: *A. schupakovi* belongs to the marine environment, while *E. excisus* is associated with estuary-freshwater with a pronounced degree of euryhaline, which predetermines the distribution of these nematode species in the population of zander and perch. A high level of infection and intensity of invasion, and different localization of *Eustrongylides* provokes the development of the disease – eustrongylidosis. During the observation period, this disease was observed annually in perch at the subclinical level. Eustrongylidosis was not recorded in zander.

Helminth larvae parasitized the internal organs (liver, stomach, fatty tissue), in the body cavity and muscle tissue of the perch, causing a violation of the structure, multiple perforation of the affected organs. The invasion of parenchymal organs was accompanied by purulent inflammation, small-focal hyperemia of the affected organs (liver, stomach, muscles), which agrees with the symptoms of eustrongylidosis.

During the study period, the incidence of perch with eustrongylidosis increased (from 5.73% in 2016 to 6.41% in 2020). It was found that the incidence of eustrongylidosis in perch depends on the intensity of nematode invasion, and the correlation coefficient is determined by a polynomial function ($r = 0.691$). The period of growth and parasitism of this species in representatives of the ichthyofauna is about three years. The nematodes are capable of accumulating in the host organism, while in the studied region no complete biological purification of fish from this helminth has been observed. Until 2018, there was a decrease in the total abundance of *E. excisus* in the parasite fauna of perch from spring to autumn (from AI 8.76 ± 0.96 ind. to AI 4.90 ± 1.65 ind.). Subsequently (2018–2020), there was an increase in autumn indicators (from AI 5.11 ± 0.51 ind. in spring to AI 7.36 ± 0.32 ind. in autumn), which was caused by an increase in the arrival and distribution of the invasive onset and the number of hosts. A character-

Table 2. The occurrence of parasites in perch fish during the study period 2016–2020.

Parasite	Localization	Host fishes	EI, %
Sphaerospora sp.	gills	zander	0.91 ± 0.59
Proteocephalus percae	gut	perch	few
Apophallus donicus	fins, integument, musculature	zander	0.69 ± 0.59
		perch	31.02 ± 6.58
Clinostomum complanatum	subcutaneous muscle layer	perch	1.19 ± 0.80
Anisakis schupakovi	intestinal wall, abdominal fat	zander	71.02 ± 4.29
		perch	19.77 ± 2.94
Eustrongylides excisus	body cavity, muscles and internal organs	zander	27.49 ± 4.00
		perch	70.76 ± 1.49
Camallanus truncatus	pyloric appendages	perch	11.47 ± 3.32
C. lacustris	pyloric appendages	zander	2.64 ± 1.61
Raphidascaris acus	gastrointestinal tract	zander	few
Corynosoma strumosum	intestinal wall, fat	zander	10.46 ± 1.21
		perch	few
Pseudoechinorhynchus borealis	gastrointestinal tract	perch	0.16 ± 0.10
Achteres percarum	gills, oral cavity, pharynx	zander	47.49 ± 3.25
		perch	4.33 ± 1.34
Argulus sp.	fins, body coverings	zander	0.62 ± 0.44
		perch	1.44 ± 1.02
Piscicola geometra	skin	zander	1.02 ± 0.64
		perch	1.69 ± 0.60

istic feature of the environment of the first order is that, due to the existing antagonistic relations, it itself actively reacts to the presence of the parasite. As a result, one of the main tasks of the latter is to overcome the action of the host's defenses (Tsyganova and Drozhdina, 2011).

In the nematode fauna of perch fish, there were not only perennial species, but also forms with a one-year cycle, *Camallanus truncatus* and *Camallanus lacustris*. The highest percentage of infection with *C. lacustris* nematodes was noted in 2016 in zander (EI 8.3%; AI 0.02), *C. truncatus* in 2017 in perch (EI 22.8%; AI 0.80), which indicates more favorable conditions for development of nematodes during these study periods. Different-sized groups of perch fish play different roles in the parasitism of these species. Large individuals of perch are the main carriers of the reproductive and functional groups of *C. truncatus* and provide a high number of future generations of nematodes. There are data on the dependence of the prevalence of invasion by nematodes *C. truncatus* and *C. lacustris* on the proportion of the abundance of zooplankton species associated with them (*Mesocyclops leuckarti* (Claus, 1854) and *Megacyclops viridis* (Jurine, 1820)), as well as on water temperature. This information indirectly indicates a significant influence of the temperature factor on the number of intermediate hosts, and hence on the probability of

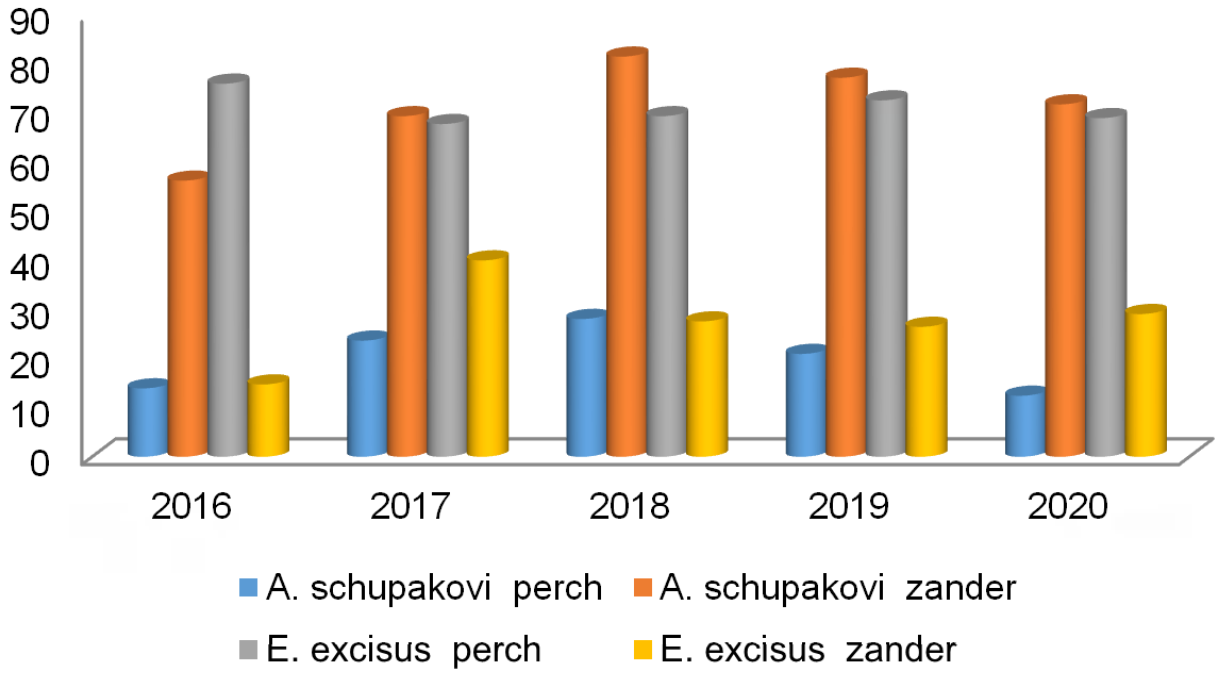

Fig. 1. Dynamics of perch and zander infestation with nematodes *A. schupakovi* and *E. excisus* in the period 2016–2020.

passing through the life cycle of parasites (Rubanova et al., 2020). Usually, in the winter-spring period, the reproductive activity of the *C. truncatus* hemipopulation goes down, since not only the total number of helminths decreases, but also the number of mature females of the parasite (Evlanov, 1995). Along with euryxenic nematodes, the helminth fauna included sporadically infecting species: for example, the pike-specific nematode *Raphidascaris acus* was detected on one occasion in zander.

The trematode fauna was represented by flatworms with a high epidemiological potential. Metacercariae of the trematode *Apophallus donicus* were found in both percid species with a maximum in perch in 2016, which was 50.0% at an invasion intensity of 1–4473 ind. In zander, digenetic flukes did not exceed an infection level of 3.0%, and in the last two years they were not found at all. In the Volga basin, marites of the trematode *A. donicus* were recorded in gulls, as well as other birds and mammals. These trematodes are potential human parasites. The first intermediate hosts are molluscs of the genus *Lithoglyphus* (Gastropoda: Prosobranchia); additional hosts are perch fish (Biserova, 2005). The high level of infection of perch with trematodes is determined by their shared range.

Another representative of the class Trematoda, *Clinostomum complanatum*, was recorded from the muscles of perch with a maximum frequency of occurrence in 2020 (EI 4.2%; AI 0.07). As a rule, fish are subjected to intense infection in the coastal zone overgrown with higher aquatic vegetation, inhabited by pond snails (*Lymnaea* sp.), carriers of the invasive organisms (Zhatkanbaeva et al., 2008). Despite the fact that an increased infestation with the parasite is typical for inhabitants of reed thickets, the probability of coincidence of the biotopes of the host and *C. complanatum* cercariae in the study areas is quite low, which does not allow passing the next stage in the development cycle of the parasite and contributes to a low level of infection.

The parasitic fauna of perch and zander each contained one species of acanthocephalan. The highest degree of invasion by *Corynosoma strumosum* was found in zander in 2016 (EI 12.7%; AI 0.40); in perch, infection was random. Acantellae are permanent members of the zander parasite fauna, the presence of which, as in the case of *Anisakis* invasion, is explained by the habitat and feeding conditions of the predator. *C. strumosum* belongs to the marine assemblage and is transmitted through infested intermediate hosts (Amphipoda) to fish, mainly Clupeidae, which is the main link in the infection of zander in the sea. The Caspian seal (*Pusa caspica* (Gmelin, 1788)) contribute to the persistence of corynosomiasis. This helminth (Corynosoma) is pathogenic, including to humans, which indicates the epidemiological danger of the acanthocephalan. Another representative of this class, *Pseudoechinorhynchus borealis*, was periodically detected in perch during a single infection. As a rule, these acanthocephalans are acquired by perch when feeding on benthic amphipods (Mitenev and Shulman, 2006).

Crustaceans *Achteres percarum* and *Argulus* sp. observed in both species of predatory fish. The dominant position among them was occupied by *A. percarum*, specific to percids (EI 55.2%, AI 2.1 in zander; EI 7.6%, AI 0.1 in perch) with a maximum in 2019, which was characterized by a dry period of the Volga River. In the spring of 2019, a disease caused by this parasitic crustacean was detected in 1.6% of zander. The disease proceeded in a subclinical form, accompanied by inflammatory reactions of the respiratory apparatus and mechanical damage to the gill filaments. The life cycle of this ectoparasite is associated with environments, i.e., temperature is the main factor limiting or accelerating the maturation of crustaceans. With an increase in water temperature, parasites begin to actively develop. In addition, the parasitic copepod *A. percarum* has a certain resistance to water pollutants. It is noteworthy that during infection with a pathogenic crustacean, zander is periodically infected by myxosporidia. This further enhances the pathological changes in the gill filaments and, consequently, worsens the general condition of the host organism (Bogdanova, 1995). Unlike *A. percarum,* the genus *Argulus* occurred sporadically with the highest invasion prevalence in perch in 2017 (EI 5.2%; AI 0.1). Representatives of this genus prefer stagnant or slow-flowing water bodies and elevated water temperatures therefore, they acquire the greatest significance under conditions of artificial rearing of fish (Zhiliukas and Rautskis, 1982). Under such conditions, during the summer, the population of crustaceans increases sharply, in some cases contributing to the development of crustaceosis. No mass infection with *Argulus* is possible under natural conditions.

Rare parasites include plerocercoids *Proteocephalus percae*, found only in perch during a single invasion. Sporadic infection indicates the presence of the copepod group of zooplankton (intermediate hosts of flatworms) in the perch's diet. A wide range of intermediate hosts tend to help parasites adapt to environmental changes. Of the total number of recorded parasites, only the cestode *P. percae* and the acanthocephalan *P. borealis* complete the development cycle in the perch. For other parasite species, perch fish serve as intermediate or reservoir hosts.

The leech *Piscicola geometra*, an endemic parasite of the Volga-Caspian region, parasitized both species of perch fish with a predominance in perch in 2018 (EI 3.60%; II 1–8 specimens). *P. geometra* was recorded mainly in spring, since the reproductive period of this species begins at a water temperature of 6 °C and lasts more than a month, after which the parental generation dies off, leaving new young generations. In winter, these ectoparasites are more common on fish leading a mobile lifestyle, which creates better oxygen conditions, which are an important factor in the development of leeches (Lapkina et al., 2002). It is the leech that is the carrier of many blood parasites. In addition, feeding on blood, it can cause the development of anemia, and damage to the skin contributes to the occurrence of infectious processes.

Conclusions

It should be noted that the parasite fauna of perch fish was relatively low diverse taxonomically with a high percentage of invasion of parasitic organisms common to perch and zander suggesting their joint biotic relationships. The most common were representatives of roundworms (class Nematoda). The parasite fauna was dominated by the most common specific (*A. donicus, A. percarum*) and euryxenic (*E. excisus, A. schupakovi, C. truncatus, C. strumosum*) species of marine and freshwater associations. The distribution of the identified parasites within the perch and zander population is determined by the ecological characteristics of the parasites themselves and their hosts, as well as by the hydrological and trophic conditions of the basin. The larval forms of nematodes *E. excisus* in perch and crustaceans *A. percarum* in zander showed the highest pathogenicity; the disease proceeded at the subclinical level. Invasion by other parasitic forms was asymptomatic. It has been established that the disease with eustrongylidosis is associated with an increase in the numbers of the pathogens, as well as with the adaptive abilities of the host. Changes in the infestation of perch fish with the species that dominates the parasitic fauna is a mechanism for regulating the abundance of parasites and ensures the stability of these parasitic systems. The annual detection of epizootically and sanitarily important parasites in the population of perch and zander with a systematic manifestation of pathogenic properties indicates the persistence of natural foci of invasions, which makes it possible to assess the parasitological state of perch fish in the Volga-Caspian fishery subarea as satisfactory.

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