Helminths of amphibians (Amphibia) in beaver ponds in the Central Russia

[1]Igor V. Chikhlyaev, [2]Alexander B. Ruchin

[1] Samara Federal Research Scientific Center of RAS, Institute of Ecology of Volga River Basin of RAS, Togliatti, Komzina str., 10, 445003, Samara region, Russia; [2] Joint Directorate of the Mordovia State Nature Reserve and National Park «Smolny», Saransk, Krasnaya str., 30, 430005, Republic of Mordovia, Russia. Corresponding author: A. B. Ruchin, ruchin.alexander@gmail.com

Abstract. The European beaver *Castor fiber* Linnaeus, 1758 is a mammal that determines the composition of the small river ecosystems in Europe and Asia. It influences the environment forcing many other animals to adapt to completely different living conditions. The results of the study are presented on the helminthic fauna of amphibians inhabiting beaver ponds in the National Park "Smolny" (Republic of Mordovia, Russia). Six amphibian species (*Pelophylax lessonae* (Camerano, 1882), *Rana arvalis* Nilsson, 1842, *Rana temporaria* Linnaeus, 1758, *Bufo bufo* (Linnaeus, 1758), *Lissotriton vulgaris* (Linnaeus, 1758), *Triturus cristatus* (Laurenti, 1768)) were examined by complete helminthological autopsy. Amphibians were caught in three ponds with different conditions: 1) lowland and water-abundant pond; 2) percolating and went low pond, restored by beavers after breaking the dam; 3) channel pond, abandoned by beavers because of drought. Nineteen helminth species, belonging to Trematoda (13), Chromadorea (5), and Dorylaimea (1), have been found. The water-abundant pond had the greatest number of helminth species. The pond abandoned by beavers had the smallest number of helminths. The presence of green frogs was an indicator of the pond flourishing and showed the presence of trematodes in this pond. There was a low level of trematodas infestation everywhere.

Key Words: amphibians, beaver ponds, trematodes, nematodes.

Introduction. Today, the European beaver *Castor fiber* Linnaeus, 1758 in Eurasia is considered an invasive species, and its main activity is to transform the environment. Due to hunting, it was exterminated in most of its range and was absent from its natural habitats for more than 50 years. In the 50-60s of the XX century as a result of extensive reintroduction and self-settlement, re-emerged the European beaver has spread widely in the old territories, developed new habitats and has restored its range and population (Dgebuadze 2000; Zavyalov et al 2005; Bashinsky 2009; Bashinskiy & Osipov 2018; Gorczyca et al 2018).

European beaver's construction and feed production activities lead to environmental transformation and intensive succession processes in ecosystems. New landscape units (beaver ponds) are being formed, the hydrological regime and illumination, the composition of plant communities and hydrobionts are changing, and the heterogeneity of the environment is increasing (Hägglund & Sjöberg 1999; Law et al 2019; Bashinsky 2013, 2014; Logofet et al 2015). The introduction of beavers has a generally positive effect on amphibians in small rivers (Russel et al 1999; Balciauskas et al 2001; Stevens et al 2006; Cunningham et al 2007; Grudzinski et al 2020). Also, stagnant and low-flow reservoirs suitable for spawning are formed, species richness increases, and amphibian population and densities increase (Dalbeck et al 2007; Dalbeck & Weinberg 2009; Karraker & Gibbs 2009; Bashinsky 2014; Anderson et al 2015; Bashinsky & Osipov 2016; Osipov et al 2017). There is no information about the impact of the European beaver on the helminth fauna of amphibians.

This study is aimed to characterize the composition and structure of the amphibian helminth community, as well as the infestation of amphibians inhabiting beaver ponds.

Material and Method

***Location**.* The material for this study was our collection of helminths from 113 specimens of amphibians of six species: *Pelophylax lessonae* (Camerano, 1882), *Rana arvalis* Nilsson, 1842, *Rana temporaria* Linnaeus, 1758, *Bufo bufo* (Linnaeus, 1758), *Lissotriton vulgaris* (Linnaeus, 1758), *Triturus cristatus* (Laurenti, 1768). The amphibians were caught in 2018-2020 in three localities within National Park "Smolny" (Republic of Mordovia, Russia).

Locality I (N 54.760174, E 45.406634): beaver pond on the Kuznal stream. Previously, it was a lowland peatbog, its development was carried out in 1948-1958. In 2016, beavers flooded it. The pond is surrounded by rare dry birch, and in some places, by black alder. Along the banks there are a broad-leaved cattail, sedge, marsh whitefly, willow-leaved turf, dioecious nettle. The surface of the pond has several fallen birches and is covered with duckweed. It is a habitat of *P. lessonae;* spawning sites for *R. arvalis, R. temporaria, B. bufo, L. vulgaris* and *T. cristatus*. A dirt road runs along the Southern bank; a power line runs along the Northern bank. On the Eastern side of the pond there is a spring and a recreation area "Silver spring". The territory is experiencing transport and recreational anthropogenic impact – spring water is actively taken by the local population all year round. The pond belongs to the category of perennial (more than 3 years) and it is water-abundant.

Locality II (N 54.879431, E 45.493171): percolating pond in the vicinity of the Lesnoy village. It is surrounded by a deciduous forest of oak, linden, birch, aspen, elm; the banks are overgrown with alder and willow. Water vegetation is represented by duckweed and marigold. The pond is divided by sedge dams into several parts with different water levels. It is a habitat of *P. lessonae*; spawning place for *R. arvalis, R. temporaria, B. bufo, L. vulgaris* and *T. cristatus*. It is one of the oldest beaver ponds in the National Park "Smolny". In 2007, as a result of a dam break, the pond was lowered, but soon restored by beavers. After the 2020 drought, it was partially shallowed.

Locality III (N 54.770564, E 45.373286): young channel beaver pond on the Kuzoleika river. In the western part, it is surrounded by thickets of willow and alder; in the East, there are floodplain meadows. The water is covered with duckweed in several places; inside the pond, there are pieces of dried birch. Broad-leaved cattail, sedge, willow-leaved turf, marsh whitefly and dioecious nettle grow along the banks. The green frogs do not inhabit this place; it is the spawning site for *R. arvalis* and *B. bufo*. The surrounding meadows are mowed down. In 2020, the pond was abandoned by beavers. The reason for that is the drought, that led to a drop in the water level on the Kuzoleika river and transformed it into a chain of smaller standing waters.

***Research method**.* Amphibians were examined by complete helminthological autopsy (Skrjabin 1928). The material was collected, recorded, and processed in the laboratory using standard methods (Byhovskaya-Pavlovskaya 1985). The species of helminths was determined from the reports of Ryzhikov et al (1980) and Sudarikov et al (2002). In the analysis of amphibian infestation, the values of the prevalense (P, %) and intensity (R, specimens) of infestation, and the abundance index (A, specimens) are given. Statistical data processing was performed using the programs Statistica 7 and Microsoft Office Excel 2007.

Results

***Identification of parasite types**.* Nineteen species of helminthes from 16 genera, 12 families, 6 orders, and 3 classes were found in amphibians in beaver ponds: Trematoda (13), Chromadorea (5), and Dorylaimea (1) (Tables 1 and 2).

Table 1

Life cycles of amphibian helminths from beaver ponds

Helminthes	*Life cycle*	*Authors*
Gorgodera asiatica Pigulevsky, 1945	Bivalvia^1 – Odonata^3 – Ranidae^5	Pigulevsky (1952)
Gorgodera microovata Fuhrmann, 1924	Bivalvia^1 – Odonata^3 – Ranidae^5	Pigulevsky (1952)
Pneumonoeces variegatus (Rudolphi, 1819)	Planorbidae^1 – Culicidae, Libellulidae, Calopterygidae^3 – Anura^5	Skrjabin & Antipin (1962)
Opisthioglyphe ranae (Frölich, 1791)	Lymnaeidae^1 – Lymnaeidae, tadpoles of Anura^3 – Anura^5	Dobrowolsky (1965); Grabda-Kazubska (1969)
Prosotocus confusus (Looss, 1894)	Bithyniidae^1 – Odonata, Coleoptera, Trichoptera, Megaloptera, Gammaridae^3 – anurans (Anura)^5	Shevchenko & Vergun (1961); Khotenovsky (1970)
Pleurogenes claviger (Rudolphi, 1819)	Bithyniidae^1 – Odonata, Coleoptera, Trichoptera, Ephemeroptera, Megaloptera, Gammaridae, Asellidae^3 – anurans (Anura)^5	Khotenovsky (1970); Grabda-Kazubska (1971)
Pleurogenoides medians (Olsson, 1876)	Bithyniidae^1 – Odonata, Coleoptera, Ephemeroptera, Trichoptera, Megaloptera, Culicidae, Gammaridae, Asellidae^3 – anurans (Anura)^5	Khotenovsky (1970)
Diplodiscus subclavatus (Pallas, 1760)	Planorbidae^1 – Amphibia^5	Skrjabin (1949)
Paralepoderma cloacicola (Lühe, 1909), mtc.	Planorbidae^1 – Anura^3 – Colubridae^5	Dobrowolsky (1969); Grabda-Kazubska (1975)
Strigea strigis (Schranck, 1788), mtc.	Planorbidae^1 – tadpoles of Anura^2 – Anura^{3,4} – Colubridae, Eulipotyphla, Mustelidae, Canidae^4 – Strigiformes^5	Sudarikov (1959a, 1960)
Strigea sphaerula (Rudolphi, 1803), mtc.	Planorbidae^1 – tadpoles of Anura^2 – Anura^{3,4} – Colubridae^4 – Corvidae^5	Sudarikov (1959a, 1960)
Strigea falconis Szidat, 1928, mtc.	Planorbidae^1 – tadpoles of Anura^2 – Anura^{3,4} – Colubridae, Eulipotyphla, Mustelidae, Canidae^4 – Accipitriformes, Falconiformes^5	Sudarikov (1959a)
Alaria alata (Goeze, 1782), msc.	Planorbidae^1 – Anura^2 – frogs, snakes, crows, seagulls, ducks, owls, birds of prey, rodents, insectivorous and predatory mammals^4 – Canidae^5	Potekhina (1950); Sudarikov (1959b)
Rhabdias bufonis (Schranck, 1788)	soil – oligochaetes, gastropods^4 – Anura^5	Savinov (1963); Hartwich (1975)
Oswaldocruzia filiformis (Goeze, 1782)	soil – Amphibia^5	Hendrix (1983); Moravec & Vojtkova (1975)
Oxysomatium brevicaudatum (Zeder, 1800)	soil – Anura^5	Skrjabin et al (1961); Moravec & Vojtkova (1975)
Cosmocerca ornata (Duiardin, 1845)	water – Anura^5	Kirillov & Kirillova (2016); Kirillova & Kirillov (2017)
Icosiella neglecta (Diesing, 1851)	Ceratopogonidae^1 – Ranidae^5	Desportes (1942); Sonin (1968)
Thominx filiformis (Linstow, 1885)	oligochaetes^1 – *Triturus cristatus*^{5}	Skrjabin et al (1957)

Note: 1 – intermediate host; 2 – intercalary host; 3 – additional host; 4 – paratenic host; 5 – definitive host.

Table 2

Helminths of amphibians from beaver ponds of the «Smolny» National Park

Helminthes	Pond an Kuznal stream (I)			Pond in vicinity of the village Lesnoy (II)				Pond an Kuzoleika River (III)	
	Pelophylax lessonae	*Rana arvalis*	*Rana temporaria*	*Pelophylax lessonae*	*Rana arvalis*	*Rana temporaria*	*Triturus cristatus*	*Bufo bufo*	*Rana arvalis*
G. asiatica	2.70(1)0.03								
G. microovata	2.70(2)0.05			7.69(1-3)0.15					
P. variegatus	16.22(1-4)0.24			11.54(1-2)0.19					
P. confusus	13.51(1-4)0.24								
P. claviger	2.70(1)0.03								
O. ranae	5.41(1-2)0.08			3.85(1)0.04					
P. medians	8.11(1-27)0.78								
D. subclavatus	2.70(1)0.03	6.25(1)0.06							
P. cloacicola, mtc.		6.25(2)0.13	1(1)						
S. strigis, mtc.	2.70(5)0.14		1(1)	7.69(1-3)0.15					
S. sphaerula, mtc.	2.70(1)0.03								
S. falconis, mtc.	2.70(1)0.03								
A. alata, msc.	8.11(1-35)1.05	12.50(1-22)1.44	3(15-28)						1(1)
Rh. bufonis		18.75(1-1)0.19	1(1)			1(3)		87.50(1-17)5.50	1(1)
O. filiformis	5.41(1-1)0.05	50.00(1-9)2.13	1(1)	3.85(3)0.12				100(1-44)11.69	2(1-5)
O. brevicaudatum	8.11(1-7)0.24	12.50(1-2)0.19	4(1-4)					62.50(1-13)2.19	1(1)
C. ornata		12.50(1-1)0.13		7.69(1-1)0.08	1(1)	1(1)			
I. neglecta	37.84(1-18)1.89	12.50(2-7)0.56		30.77(1-7)0.62					
Th. filiformis							1(1)		
Number of species	15[4]	8[2]	6[3]	7[1]	1	2	1	3	4[1]
Trematoda	12[4]	3[2]	3[3]	4[1]					1[1]
Chromadorea	3	5	3	3	1	2		3	3
Dorylaimea							1		
Number of amphibians studied	37	16	11	27	1	2	1	16	2

Note: prevalence (P, %) is in front of round brackets; intensity range (R, specimens) is in round brackets; abundance (A, specimens) is behind the round brackets; square brackets show the number of helminth species at the larval stage. Infestation indicators were calculated for a sample of at least 15 amphibian specimens. In another case, the number of infected hosts and the intensity of the infestation are indicated.

Helminth species are distributed according to the degree of host specificity as follows: 15 species are widespread polyhostal parasites of amphibians, 3 species (trematodes *Gorgodera asiatica* Pigulevsky, 1945, *G. microovata* Fuhrmann, 1924 and nematode *Icosiella neglecta* (Diesing, 1851)) are specific, oligohostal parasites for frogs of the family Ranidae. The nematode *Thominx filiformis* (Linstow, 1885) is the only narrowly specific monohostal parasite of the crested newt.

Amphibians serve as the definitive hosts for 13 species of helminths that parasitize at the adult stage of development. For another 5 species of trematodes at the larval stage (*Paralepoderma cloacicola* (Lühe, 1909), mtc., *Strigea strigis* (Schrank, 1788), mtc., *S. sphaerula* (Rudolphi, 1803), mtc., *S. falconis* Szidat, 1928, mtc. and *Alaria alata* (Goeze, 1782), msc.), amphibians are intercalary (mesocercar), additional (metacercar), and/or paratenic (metacercar) hosts. *Opisthioglyphe ranae* (Frölich, 1791) combines different stage of development in the organism of amphibians, what characterizes them as amphixenic hosts.

There are three ecological groups of helminth species depending on the way of invasion, stage of development and specifics of the life cycle (Table 1).

Group I includes adult stages (maritae) of trematodes (8 species). They settle in the internal organs: the bladder (*G. asiatica*, *G. microovata*), lungs (*P. variegatus*), intestines (*O. ranae, P. confusus, P. claviger, P. medians* and *D. subclavatus*). Amphibians are infected with trematode maritae in a trophic way, consuming their additional (metacercar) hosts – aquatic invertebrates (insects, crustaceans, gastropods) and vertebrates (amphibian tadpoles).

The nematode *Th. filiformis* is very close to the group I. The life cycle of the parasite is not known. But the species of this genus are biohelminth, their development includes the obligatory participation of intermediate hosts – earthworms.

Group II includes larval stages (mesocercariae and metacercariae) of trematodes (5 species). They settle in the body cavity, on the walls of internal organs, mesentery and amphibian musculature. Infection with them occurs in two ways: for some species (*Strigea*), it is associated with the use of additional and/or paratenic hosts of the underlying trophic level; for others, it is a consequence of oral or percutaneous penetration of cercariae. Findings of trematodes larvae indicate the participation of different amphibian species as an additional and/or paratenic host in the circulation of predator parasites of higher trophic levels.

The nematode *I. neglecta* is very close to the group II. It belongs to biohelminths, its development goes on with the change of hosts. Invasive larvae after the death of intermediate hosts – woodlice – fall into the water, from where they percutaneously enter the amphibian body, followed by migration and settlement in the tissues of the throat, tongue and fascia of the femoral muscles.

Group III includes adult stages of nematodes of the geohelminth group (4 species). They settle in the internal organs: lungs (*Rh. bufonis*), intestines (*O. brevicaudatum, O. filiformis* and *C. ornata*). Infection with them is random and occurs when the host has oral and/or percutaneous contact with invasive larvae on land or in water.

Pelophylax lessonae had the largest number of helminth species (16 species); *R. arvalis* and *R. temporaria* had less helminth species: 8 and 7 respectively; *B. bufo* and *T. cristatus* had the smallest number of helminth species: 3 and 1 respectively. No helminths were found in *L. vulgaris*.

Pelophylax lessonae. Sixty-four specimens were examined from two beaver ponds: on the Kuznal stream (37) and near the Lesnoy village (27). Sixteen species of helminths were found: Trematoda (12) and Chromadorea (4) (Table 2). Fifteen species were found in green frogs on the Kuznal stream and 7 species – in the vicinity of the Lesnoy village. Trematodes both adults and larvae predominate in the composition of helminths. The long relation between of the *P. lessonae* with habitats creates optimal conditions for infection with trematodes that penetrate through food. Nematodes are mainly represented by adult stages from the group of geohelminths. Infestation of green frogs with helminths is generally low; the extent of infestation does not exceed 40%. The nematode *I. neglecta* infected fogs the most (30.77-37.84%; 0.62-1.89 specimens). Among trematodes, *P. variegatus* is more common (11.54-16.22%; 0.19-0.24 specimen). Frogs from the population on the Kuznal stream are more infected with most helminth species than those from the population in the vicinity of the Lesnoy village (Table 2).

Rana arvalis. Nineteen specimens were examined from three beaver ponds: on the Kuznal stream (16), on the Kuzoleika river (2) and near the village Lesnoy (1). Eight helminth species were found: Trematoda (3) and Chromadorea (5) (Table 2). Nematodes from the group of geohelminths mainly dominate in *R. arvalis*. It is due to the terrestrial way of life of *R. arvalis*. Trematodas are mainly represented by larval stages and are rare parasites of this host. The infestation with marita trematodes is possible only in the spring during the breeding season but is limited to the "mating post". The rate of infestation with most species of helminths is low. The most common nematode is *O. filiformis* (50.00%; 2.13 specimens); infection with other species does not exceed 20%. Concerning trematodas, mesocercariae *A. alata*, msc. is the most common (12.50%; 1.44 specimens) (Table 2).

Rana temporaria. Thirteen specimens were examined from two beaver ponds: on the Kuznal stream (11) and near the Lesnoy village (2). Seven helminth species were found: Trematoda (3) and Chromadorea (4) (Table 2). Composition and community structure of helminth species in *R. temporaria* are similar to those in *R. arvalis*. Nematodes from the group of geohelminths dominate. Trematodes are represented exclusively by larval stages. The "mating post" of the host prevents infection with maritae trematodes during the breeding season. The rate of infestation with most species of helminths is low. The nematode *O. brevicaudatum* and mesocercariae trematodes *A. alata*, msc. Are more common than other species (Table 2).

Bufo bufo. Sixteen specimens were examined from the beaver pond on the Kuzoleika river. Three nematode species were found: Chromadorea (3) (Table 2). All of them are geohelminths. The presence or absence of nematodes are associated with the land – based way of life of the host. "Mating post" prevents infection with marite trematodes during the breeding season. The density of the frog's skin and the poisonous secret of the skin glands prevent percutaneous penetration of cercariae. Infection of common toads with nematodes is high. *O. filiformis* occurs the most (100%; 11.69 specimens). *Rh. bufonis* (87.50%; 5.50 specimens) and *O. brevicaudatum* (62.50%; 2.19 specimens) occur less often (Table 2).

Triturus cristatus. One specimen was examined from the beaver pond near the Lesnoy village. Only one specimen of *Th. filiformis* from the class Dorylaimea was found (Table 2). This is a biohelminth transmitted through earthworms. Newts are unable to hunt large or fast prey due to their body structure and small mouth size. As a result, their main food in the terrestrial life phase is sedentary earthworms, slugs, and insect larvae.

Only two species of nematodes, *O. filiformis* and *O. brevicaudatum*, are most common for the amphibians of beaver ponds. They have been found in 4 species of tailless amphibians: *P. lessonae*, *R. arvalis*, *R. temporaria*, and *B. bufo*. Two more species of trematodes (*A. alata*, msc.) and nematodes (*C. ornata*) were found in all 3 frog species. Two species (*D. subclavatus*, *I. neglecta*) of helminths infect the *P. lessonae* and *R. arvalis*. Other two species (*P. cloacicola*, mtc., *Rh. bufonis*) infect the *R. arvalis* and *R. temporaria*. The remaining 11 species of parasitic worms had only one host.

The greatest variety of helminths was found in amphibians in the old and permanent beaver pond on the Kuznal stream (18 species). In the vicinity of the Lesnoy village, there were half as many helminth species in the pond restored by beavers (9 species). The abandoned pond on the Kuzoleika river had the poorest composition of helminths (4 species) (Table 2).

Out of the total number of helminths, only 2 nematode species were found in all localities: *Rh. bufonis* and *O. filiformis*. Another 8 species of trematodes (*G. microovata, P. variegatus, O. ranae, S. strigi*s, mtc. and *A. alata*, msc.) and nematodes (*O.*

brevicaudatum, C. ornata and *I. neglecta*) were found in two of the three studied ponds. The findings of the other 9 helminth species were very local.

Discussion. The helminth fauna of amphibians is formed during the implementation of their biological characteristics (way of life, food spectrum, stage of development, age, and gender) in their habitat (biotope) for a certain period. Each biotope also has its own unique set of biotic (composition of flora and fauna) and abiotic (terrain, microclimate, presence and nature of reservoirs, illumination, type of soil) factors (Rohde 1979; Aho 1990; Ruchin et al 2009; Hamann et al 2013; Chikhlyaev et al 2018a). Some of them change during different seasons (Vanderburgh & Anderson 1987; King et al 2008). These factors influence the formation of the amphibian population of beaver ponds and their helminth fauna.

When beavers start settling the pond, massive land amphibian species – *R. arvalis* and *B. bufo* – only appear there during the breeding season. The appearance of aquatic amphibian species at this stage is impossible due to the frequent erosion of dams and the lack of food supply. When beaver ponds become perennial with stable water levels and rich hydrobionts, green frogs and newts settle there (Dalbeck et al 2007; Dalbeck & Weinberg 2009; Bashinsky 2014). These processes are similar for ponds on the Kuznal stream and around the Lesnoy village. When the beavers leave, the dams gradually erode, the pond becomes shallow and may drain, forcing the aquatic amphibians to leave the habitat. Probably something similar happened at the beaver pond on the Kuzoleika river.

The helminth fauna of aquatic amphibian species, in particular green frogs (genera *Pelophylax*), is known to be the richest (Okulewicz et al 2014; Herczeg et al 2016; Chikhlyaev et al 2018b, 2019a, b; León-Règagnon 2019; Kuzmin et al 2020). Their dominant group of helminths is trematodes, whose life cycle includes a wide variety of species of hydrobionts (bivalves and gastropods, insect larvae and imagos, crustaceans, amphibian tadpoles). Therefore, the existence of trematodes directly depends on the presence and nature of the reservoir. Most nematodes species of amphibians are geohelminths. For them, the presence of land-dwelling hosts, such as brown frogs and toads, is the most important factor (Chikhlyaev & Ruchin 2014; Okulewicz et al 2014; Zhigileva & Kirina 2015; Chikhlyaev et al 2016, 2020; Korzikov & Aleksanov 2018; Kirillova et al 2020). Brown frogs and toads have a short-term connection with ponds only during the breeding season, and therefore they only temporarily depend on their condition. The dependence of nematodes on the state of reservoirs is even less, which explains their wide distribution.

Beavers have a positive effect on amphibians, but, on the contrary, their effect on helminths is negative. This is especially true for biohelminth (trematodes). On the one hand, mainly in green frogs, there is a generally low level of infestation with most helminth species. On the other hand, with the deterioration of beaver ponds, the species composition of helminths is impoverished due to the loss of certain species of trematodes, often at the marita stage. In a lowland and water-abundant pond on the Kuznal stream, 12 species of trematodes were found in the green frogs. In a percolating and went low pond, restored by beavers, only 4 species of trematodes were found near the village Lesnoy. Only 1 species was found in a channel pond, abandoned by beavers on the Kuzoleika river (Table 2), where green frogs were not found at all.

There are several probable reasons for the low infestation of amphibians with helminth in beaver ponds. First, the artificial nature of reservoirs affects since parasitic connections and systems there have not yet formed completely due to the absence of any invertebrates and/or vertebrate hosts of different ranks. Secondly, the special dynamics of the hydrological regime (fluctuation of the water level due to the break/repair of dams) has a negative impact both directly on the free-living invasive stages of helminths, and indirectly through the suppression of the vital activity of hydrobionts (intermediate hosts). Third, climate factors play an important role. For example, insufficient snow cover in winter and low precipitation in the summer 2020 led to shallowing of small rivers in the National Park "Smolny".

Conclusions. The data obtained show that the composition and structure of the community of amphibian helminths inhabiting beaver ponds is according to the general parasitological rules on the influence of the host's habitat on its parasites. The state of the beaver pond, which determines the species composition of the amphibian population, plays a key role. The helminth fauna varies from the richest in long-term flooded ponds, where beavers regularly repair dams, to the poorest in shallowed and restored ponds. The disappearance of some of the hosts (green frogs) in ponds abandoned by beavers leads to a sharp decrease in the number of trematode species. Thus, the criteria “presence/absence of green frogs” makes it possible to determine the state of the beaver pond and the presence/absence of trematodes. Green frogs can be considered as a biological indicator of the helminth fauna structure in the amphibian population of beaver ponds.

Acknowledgements. The research was carried out on the subject of research of the Institute of Ecology of the Volga River Basin of the Russian Academy of Sciences – Branch of the Samara Federal Research Center of the Russian Academy of Sciences AAAA-A17-117112040040-3 “Assessment of modern biodiversity and forecast of its change for the ecosystems of the Volga basin in the conditions of their natural and anthropogenic transformation” (theme 52 “Biological diversity”). The study was partially supported by grants of Russian Foundation for Basic Research (project 18-04-00640).

References

Aho J. M., 1990 Helminth communities of amphibians and reptiles: comparative approaches to understanding patterns and processes. In: Parasite communities: patterns and processes. Esch G. W., Bush A. O., Aho J. M. (eds), Springer, Dordrecht, pp. 157-195.

Anderson N. L., Paszkowski C. A., Hood G. A., 2015 Linking aquatic and terrestrial environments: can beaver canals serve as movement corridors for pond-breeding amphibians? Animal Conservation 18(3):287-294.

Balciauskas L., Balciauskiene L., Trakimus G., 2001 Beaver influence on amphibian breeding in the agrolandscape. The European beaver in a new millennium. Proceedings of 2nd European Beaver Symposium, pp. 105-112.

Bashinsky I. V., 2009 [Influence of environmental activity of the European beaver (*Castor fiber* Linnaeus, 1758) on the amphibian population of small rivers]. Works of the “Rdeisky” State Nature Reserve 1:135-156. [in Russian]

Bashinsky I. V., 2013 [Amphibians of beaver ponds. Modern herpetology: problems and ways to solve them]. Articles on the reports of the First International Youth Conference of Herpetologists of Russia and Neighboring Countries, St. Petersburg: Zoological Institute of the Russian Academy of Sciences, pp. 57-60. [in Russian]

Bashinsky I. V., 2014 [Impact assessment of European beaver reintroduction on amphibians of small rivers]. Russian Journal of Biological Invasion 2:15-32. [in Russian]

Bashinsky I. V., Osipov V. V., 2016 Beavers in Russian forest-steppe – characteristics of ponds and their impact on fishes and amphibians. Russian Journal of Theriology 15(1):34-42.

Bashinskiy I. V., Osipov V. V., 2018 Distribution and dynamic of *Castor fiber* (Castoridae, Mammalia) population in forest-steppe rivers: a case of the State Nature Reserve Privolzhskaya Lesostep', Penza region, European Russia. Nature Conservation Research 3(2):110-115.

Byhovskaya-Pavlovskaya I. E., 1985 [Parasites of fishes, a study guide]. Leningrad: Nauka, 123 pp. [in Russian]

Chikhlyaev I. V., Ruchin A. B., 2014 The helminth fauna study of European common brown frog (*Rana temporaria* Linnaeus, 1758) in the Volga basin. Acta Parasitologica 59(3):459-471.

Chikhlyaev I. V., Ruchin A. B., Fayzulin A. I., 2016 The helminth fauna study of European common toad in the Volga Basin. Nature Environment and Pollution Technology 15(3):1103-1109.

Chikhlyaev I. V., Kirillova N. Yu., Kirillov A. A., 2018a Ecological analysis of trematodes (Trematoda) of marsh frog *Pelophylax ridibundus* (Ranidae, Anura) from various habitats of the National Park «Samarskaya Luka» (Russia). Nature Conservation Research 3(1):36-50.

Chikhlyaev I. V., Ruchin A. B., Fayzulin A. I., 2018b An overview of the trematodes fauna of pool frog *Pelophylax lessonae* (Camerano, 1882) in the Volga Basin, Russia: 1. Adult stages. Nusantara Bioscience 10(4):256-262.

Chikhlyaev I. V., Ruchin A. B., Fayzulin A. I., 2019a An overview of the trematodes fauna of Pool frog *Pelophylax lessonae* (Camerano, 1882) in the Volga Basin, Russia: 2. Larval stages. Nusantara Bioscience 11(1):106-111.

Chikhlyaev I. V., Ruchin A. B., Fayzulin A. I. 2019b Parasitic nematodes of Pool frog (*Pelophylax lessonae*) in the Volga Basin. Revista MVZ Cordoba 24(3): 7314–7321.

Chikhlyaev I. V., Ruchin A. B., Kirillov A. A., 2020 Ecological analysis of the helminth fauna in *Bufo bufo* (Amphibia: Anura) from various habitats. Nature Conservation Research 5(2):1-10.

Cunningham J. M., Calhoun A. J. K., Glanz W. E., 2007 Pond-breeding amphibian species richness and habitat selection in a beavermodified landscape. Journal of Wildlife Management 71:2517-2526.

Dalbeck L., Weinberg K., 2009 Artificial ponds: a substitute for natural beaver ponds in a Central European Highland (Eifel, Germany)? Hydrobiologia 630:49-62.

Dalbeck L., Luscher B., Ohlhof D. 2007 Beaver ponds as habitat of amphibian communities in a central European highland. Amphibia–Reptilia 28:493-501.

Desportes C., 1942 *Forcipomyia velox* Winn et *Sycorax silacea* Curtis, vecteurs d'*Icosiella neglecta* (Diesing, 1850) filaire commune de la grenouille verte. Annales de Parasitologie Humaine et Comparee 19:53-68.

Dgebuadze Y. Y., 2000 Ecology of animal invasions and population contacts: common approaches. In: Universe species in the European seas of Russia. Apatity: Murmansk Marine Biological Institute of the Kola Scientific Center of the Russian Academy of Sciences, pp. 35-50.

Dobrowolsky A. A., 1965 Some information about the life cycle of the trematode *Opisthioglyphe ranae* (Froelich, 1791) (Plagiorchiidae). Helminthologia 3:205-221.

Dobrowolsky A. A., 1969 [The life cycle of *Paralepoderma cloacicola* (Luhe, 1909) Dollfus, 1950 (Trematoda, Plagiorchiidae)]. Bulletin Leningrad University 9:28-38. [in Russian]

Gorczyca E., Krzemień K., Sobucki M., Jarzyna K., 2018 Can beaver impact promote river renaturalization? The example of the Raba River, southern Poland. Science of the Total Environment 615:1048-1060.

Grabda-Kazubska B., 1969 Studies on abbreviation of the life-cycle in *Opisthioglyphe ranae* (Froelich, 1791) and *O. rastellus* (Olsson, 1876) (Trematoda, Plagiorchiidae). Acta Parasitologica Polonica 16:20-27.

Grabda-Kazubska B., 1971 Life cycle of *Pleurogenes claviger* (Rudolphi, 1819) (Trematoda: Pleurogenidae). Acta Parasitologica Polonica 19:337-348.

Grabda-Kazubska B., 1975 A study of the trematode genus *Paralepoderma* Dollfus, 1950 (Trematoda: Plagiorchiidae). Acta Parasitologica Polonica 23:463-484.

Grudzinski B. P., Cummins H., Vang T. K., 2020 Beaver canals and their environmental effect. Progress in Physical Geography 44(2):189-211.

Hägglund Å., Sjöberg G., 1999 Effects of beaver dams on the fish fauna of forest streams. Forest Ecology and Management 115(2-3):259-266.

Hamann M. I., Kehr A. I., González C. E., 2013 Biodiversity of trematodes associated with amphibians from a variety of habitats in Corrientes Province, Argentina. Journal of Helminthology 87(3):286-300.

Hartwich G. 1975 Die Tierwelt Deutschlands. I.: Rhabditida und Ascaridida. Mitteilungen aus dem Zoologischen Museum in Berlin 62:1-256.

Hendrix W. M. L., 1983 Observations of the routes of infection of *Oswaldocruzia filiformis* (Nematoda, Trichostrongylidae) in amphibian. Zeitschrift für Parasitekunde 69(1): 119-126.

Herczeg D., Vörös J., Végvári Z., Kuzmin Yu., Brooks D. R., 2016 Helminth parasites of the *Pelophylax esculentus* complex (Anura: Ranidae) in Hortobágy National Park (Hungary). Comparative Parasitology 83(1):36-48.

Karraker N. E., Gibbs J. P., 2009 Amphibian production in forested landscapes in relation to wetland hydroperiod: a case study of vernal pools and beaver ponds. Biological Conservation 142(12):2293-2302.

Khotenovsky I. A., 1970 [Family Pleurogenidae Looss, 1899]. In: [Trematodes of animals and man. Basics of trematodology. Vol. 23]. Skrjabin K. I. (ed), Moscow: Nauka, pp. 139-306. [in Russian]

King K. C., Gendron A. D., McLaughlin J. D., Giroux I., Brousseau P., Cyr D., Ruby S. M., Fournier M., Marcogliese D. J., 2008 Short-term seasonal changes in parasite community structure in Northern leopard froglets (*Rana pipiens*) inhabiting agricultural wetlands. Journal of Parasitology 94(1):13-22.

Kirillov A. A., Kirillova N. Y., 2016 [Analysis of the reproductive structure of the hemipopulation of the *Cosmocerca ornata* (Dujardin, 1845) (Nematoda: Cosmocercidae) in marsh frogs of different ages]. Inland Water Biology 9(3):310-318. [in Russian]

Kirillova N. Y., Kirillov A. A., 2017 [To study of life circle of amphibian parasite, *Cosmocerca ornata* (Nematoda: Cosmocercidae)]. In: [Ecological proceedings of young scientists of the Volga region – 6]. Senator S. A. et al (eds), Togliatti: Institute of Ecology of Volga River Basin RAS, Cassandra, pp. 192-194. [in Russian]

Kirillova N. Y., Kirillov A. A., Shchenkov S. V., Chikhlyaev I. V., 2020 *Oswaldocruzia filiformis* sensu lato (Nematoda: Molineidae) from amphibians and reptiles in European Russia: morphological and molecular data. Nature Conservation Research 5(2):41-56.

Korzikov V. A., Aleksanov V. V., 2018 On some factors driving the presence of amphibians in water bodies of the Upper Oka Basin (Central Russia). Nature Conservation Research 3(1):110-119.

Kuzmin Y., Dmytrieva I., Marushchak O. S., Morozov-Leonov O., Oskyrko O. Nekrasova O., 2020 Helminth species and infracommunities in frogs *Pelophylax ridibundus* and *P. esculentus* (Amphibia: Ranidae) in Northern Ukraine. Acta Parasitologica 65:341-353.

Law A., Levanoni O., Foster G., Ecke F., Willby N. J., 2019 Are beavers a solution to the freshwater biodiversity crisis? Diversity and Distributions 25(11):1763-1772.

León-Règagnon V., 2019 Helminths of the Eurasian marsh frog, *Pelophylax ridibundus* (Pallas, 1771) (Anura: Ranidae), from the Shiraz Region, Southwestern Iran. Helminthologia 56(3):261-268.

Logofet D. O., Evstigneev O. I., Aleinikov A. A., Morozova A. O., 2015 Succession caused by beaver (*Castor fiber* L.) activity: I. What is learnt from the calibration of a simple Markov model. Biology Bulletin Reviews 5:28-35.

Moravec F., Vojtkova L., 1975 Variabilität von zwei Nematodenarten *Oswaldocruzia filiformis* (Goeze, 1782) und *Oxysomatium brevicaudatum* (Zeder, 1800). Der gemeinsamen Parasiten der Europäischen Amphibien und Reptilien. Scripta Facultatis Scientiarum Naturalium Universitatis Purkynianae Brunensis. Biologia 2(5):61-76.

Okulewicz A., Hildebrand J., Łysowski R., Buńkowska K., Perec-Matysiak A., 2014 Helminth communities of green and brown frogs from Poland (Lower Silesia region). Journal of Herpetology 48(1):34-37.

Osipov V. V., Bashinsky I. V., Podshivalina V. N., 2017 [On the *Castor fiber* (Castoridae, Mammalia) activity influence on the ecosystem biodiversity of small rivers in the forest-steppe zone]. Povolzhskiy Journal of Ecology 1:69-83. [in Russian]

Pigulevsky S. V., 1952 [Family Gorgoderidae Looss, 1901. Part 1]. In: [Trematodes of animals and man. Basics of trematodology. Vol. 7]. Skrjabin K. I. (ed), Moscow: Publisher of the Academy of Sciences of the USSR, pp. 605-760. [in Russian]

Potekhina L. F., 1950 [The development cycle of alariosis pathogen in foxes and dogs]. Proceedings of Skryabin All-Union Helminthology Institute 4:7-17. [in Russian]
Rohde K., 1979 A critical evaluation of intrinsic and extrinsic factors responsible for niche restriction in parasites. American Naturalist 114:648-671.
Ruchin A. B., Chikhljaev I. V., Lukijanov S. V., 2009 [Analysis of helminthofauna of common spaedfoot *Pelobates fuscus* (Laurenti, 1768) and moor frog *Rana arvalis* Nilsson, 1842 (Amphibia: Anura) at their joint habitation]. Parazitologiya 43(3): 240-247. [in Russian]
Russel K. R., Moorman C. E., Edwards J. K., Metts B. S., Guynn Jr. D. C., 1999 Amphibian and reptile communities associated with beaver (*Castor canadensis*) ponds and unimpounded streams in the Piedmont of South Carolina. Journal of Freshwater Ecology 14(2):149-158.
Ryzhikov K. M., Sharpilo V. P., Shevchenko N. N., 1980 Helminths of amphibians of the USSR fauna. Moscow: Nauka, 279 pp. [in Russian]
Savinov V. A., 1963 [Some new experimenrtal data about nematode paratenic parasitism]. In: [Materials of scientific conference of All-Union community of Helmintologists. Part 2]. Moscow: Academy of Sciences of the USSR, pp. 73-75. [in Russian]
Shevchenko N. N., Vergun G. I., 1961 On the life cycle of the amphibian trematode *Prosotocus confusus* (Looss, 1894) Looss, 1899. Helminthologia 3(1-4):294-298.
Skrjabin K. I., 1928 Method of complete helminthological dissection of vertebrates, including man. Moscow: Moscow State University, 45 pp. [in Russian]
Skrjabin K. I. (ed), 1949 [Trematodes of animals and man. Basics of trematodology. Vol. 3. Suborder Paramphistomatata (Szidat, 1936) Skrjabin et Schulz, 1937]. Moscow-Leningrad: Nauka, 623 pp. [in Russian]
Skrjabin K. I., Antipin D. N., 1962 [Superfamily Plagiorchioidea Dollfus, 1930]. In: [Trematodes of animals and man. Basics of trematodology. Vol. 20]. Skrjabin K. I. (ed), Moscow: Nauka, pp. 49-166. [in Russian]
Skryabin K. I., Shikhobalova N. P., Orlov I. V., 1957 [Trichocephalids and capillariids of animals and humans and the diseases caused by them]. In: [Basics of nematodology. Vol. 6]. Skryabin K. I. (ed), Moscow: Publishing House of the USSR Academy of Sciences, 588 pp. [in Russian]
Skrjabin K. I., Shikhobalova N. P., Lagodovskaya E. A., 1961 [Oxyurats of animals and humans. Part 2]. In: [Basics of nematodology. Vol. 10]. Skryabin K. I. (ed), Moscow: Publishing House of the USSR Academy of Sciences, 500 pp. [in Russian]
Sonin M. D., 1968 [Filarias of animals and humans and the diseases caused by them. Part 2. Diplotrienoids]. In: [Basics of nematodology. Vol. 21]. Skrjabin K. I. (ed), Moscow: Nauka, 392 pp. [in Russian]
Stevens C. E., Paszkowski C. A., Scrimgeour G. J., 2006 Older is better: beaver ponds on boreal streams as breeding habitat for the wood frog. Journal of Wildlife Management 70(5):1360-1371.
Sudarikov V. E., 1959a [Order Strigeidida (La Rue, 1926) Sudarikov, 1959. Part 1]. In: [Trematodes of animals and humans. Basics of trematodology. Vol. 16]. Skryabin K. I. (ed), Moscow: Publishing house of USSR Academy of Sciences, pp. 219-631. [in Russian]
Sudarikov V. E., 1959b [Biological features of trematodes of the genus *Alaria*]. Papers of the Helminthological Laboratory of USSR Academy of Sciences (GELAN) 11:326-332. [in Russian]
Sudarikov V. E., 1960 [The biology of trematodes *Strigea strigis* (Schr., 1788) and *S. sphaerula* (Rud., 1803)]. Papers of the Helminthological Laboratory of USSR Academy of Sciences (GELAN) 10:217-226. [in Russian]
Sudarikov V. E., Shigin A. A., Kurochkin Y. V., Lomakin V. V., Stenko R. P., Yurlova N. I., 2002 [Metacercariae of trematodes — parasites of freshwater aquatic organisms in Central Russia. Metacercariae trematodes — parasites of aquatic organisms in Russia. Vol. 1]. Moscow: Nauka, 298 pp. [in Russian]

Vanderburgh D. J., Anderson R. C., 1987 Seasonal changes in prevalence and intensity of *Cosmocercoides dukae* (Nematoda: Cosmocercoidea) in *Deroceras laeve* (Mollusca). Canadian Journal of Zoology 65:1662-1666.
Zavyalov N. A., Krylov A. V., Bobrov A. A., Ivanov V. K., Dgebuadze Y. Y., 2005 [Impact of the European beaver on small river ecosystems]. Moscow: Nauka, 186 pp. [in Russian, with English summary]
Zhigileva O. N., Kirina I. Y., 2015 Helminth infestation of the moor frog (*Rana arvalis* Nilsson, 1842) and the Siberian tree frog (*Rana amurensis* Boulenger, 1886) in Western Siberia. Contemporary Problems of Ecology 8:232-236.

Received: 02 October 2020. Accepted: 17 November 2020. Published online: 26 December 2020.
Authors:
Igor V. Chikhlyaev, Samara Federal Research Scientific Center of RAS, Institute of Ecology of Volga River Basin of RAS, Togliatti, Komzina str., 10, 445003, Samara region, Russia, e-mail: diplodiscus@mail.ru
Alexander B. Ruchin, Joint Directorate of the Mordovia State Nature Reserve and National Park «Smolny», Saransk, Krasnaya str., 30, 430005, Republic of Mordovia, Russia, e-mail: ruchin.alexander@gmail.com

How to cite this article:
Chikhlyaev I. V., Ruchin A. B., 2020 Helminths of amphibians (Amphibia) in beaver ponds in the Central Russia. AACL Bioflux 13(6):3810-3821.