PENSOFT

CAUCASIANA
Journal on the biodiversity of the Caucasus and the adjacent regions

Parasite ecology of *Carassius gibelio* (Bloch, 1782) in Jandari Lake (Georgia)

Lali Murvanidze[1], Ketevan Nikolaishvili[1], Tsitsino Lomidze[1], Bella Japoshvili[1], Lela Arabuli[1], Ketevan Asatiani[1]

1 *Institute of Zoology, Ilia State University, Cholokashvilli Ave 3/5, Tbilisi 0162, Georgia*

http://zoobank.org/FFD924AF-A596-47A9-BDA2-FE2DDB7F6CA1

Corresponding author: Lali Murvanidze (lali.murvanidze@iliauni.edu.ge)

Academic editor: Anna Faltynkova ♦ **Received:** 28 September 2022 ♦ **Accepted:** 24 February 2023 ♦ **Published:** 21 March 2023

Abstract

The aim of the investigation was to study the current structure of the parasitic fauna of the gibel carp (*Carassius gibelio*) population in the Georgian part of Jandari Lake. In total, 423 young gibel carp collected during 2014-2018 years from Jandari Lake have been subject to parasitological examination. The 20.3% (n=86) of examined fish were invaded by 11 species of parasites belonging to 5 taxonomic groups. The dominant taxonomic groups were discovered to be Protozoa and Monogenea. The eight species were registered for the first time in the gibel carp of freshwater reservoirs in Georgia. In general, young fish were more invaded by the monoxenic species of the direct life cycle. None of the revealed parasites were specific to gibel carp. The parasitic fauna of Jandari Lake is relatively poor, though it is comparatively rich and diverse in spring. *Trichodina* sp. from Protozoa, *Ancyrocephalus* sp., *Dactylogyrus vastator*, *Gyrodactylus elegans* from Monogenea, and *Contracaecum* sp. from Nematoda were revealed as the species most sensitive to annual changes. The main factor determining the parasite fauna of gibel carp in Lake Jandari is anthropogenic eutrophication, which changes the qualitative and quantitative composition of zooplankton, the main food source of juvenile fish and intermediate hosts of helminths. The difference in invasion indices between female and male gibel carp was insignificant. The synergetic relationship between some parasitic protozoans and monogeneans was marked.

Key words

Protozoa, Monogenea, Nematoda, Trematoda, Copepoda, eutrophic lake, fish, Caucasus

Introduction

Gibel carp (*Carassius gibelio* (Bloch, 1782)) is one of the most successful invasive fish species in Eurasia. Its strong adaptive and high reproduction abilities ensure the gibel carp's survival and frequently its dominance in nearly all kinds of freshwater systems globally (Lusková et al. 2010; Arslan and Emiroğlu 2011; Docherty et al. 2017; Japoshvili et al. 2017). The species belonged to *Carassius* was first reported in Georgia in 1985 as a *C. carassius* (Daraselia 1985). However, later on, morphological and genetic studies revealed that the species actually belonged to *C. gibelio* (Japoshvili et al. 2004; Japoshvili et al. 2013). Gibel carp is an omnivorous fish, though young fish mainly feed on plankton. It belongs to the phytophilic ecological group of fishes (Kunz 2004). It is extremely tolerant of the variable environmental conditions that resulted in its rapid and simultaneous invasion of almost all water bodies in Georgia (Japoshvili et al. 2004; Japoshvili and Kücük 2013). Currently, there is insufficient information on the impact of the invasive gibel carp on Georgia's water ecosystems (Japoshvili et al. 2017; Kuljanishvili et al. 2021). The lack of knowledge is evident when it comes to the parasite diversity and distribution of gibel carp. For instance, in the 1990s of the last century, *Carassius* has been identified as the host of monogeneans (*Dactylogyrus vastator*, *D. achmerowi*, *D. extensus*, *D. anchoratus*, *D. linstowi*, *D. goktschaicus*, *D. affinis*, *D. crassus*, *D. polylepidis, Gyrodactylus kathariner*i, *G. shulmani, G. sprostonae*, *G. longoacuminatus*) in various freshwater bodies of Georgia (Matsaberidze 1993). After nearly two decades of

lag, parasitological studies of *C. gibelio* populations in Madatapa and Khanchali lakes (Javakheti region, Georgia) revealed that heteroxenous helminth species, including *Ligula intestinalis*, *Diplostomum spathaceum*, and *Tylodelphys clavata*, were also the major parasites in the gibel carp population (Japoshvili et al. 2017; Murvanidze et al. 2019).

Parasitological examination of invasive gibel carp has been carried out in neighboring countries of Georgia, with considerable intensity in Turkey (Tekin-Özan and Kir 2005; Koyun and Altunel 2007; Arslan and Emiroğlu 2011; Kir and Samanci 2012; Çolak 2013; Demir and Karakişi 2016) and relatively infrequently in Iran (e.g., Khara et al. 2011; Daghigh Roohi et al. 2014) and Azerbaijan (Shakaralieva 2016). The later study refers to the transboundary Jandari Lake, located at the border between Georgia and Azerbaijan. Shakaralieva (2016) has studied 246 specimens of 18 species of fish in 2007-2015 from the Azerbaijan part of Jandari Lake, in which gibel carp were represented with 17 specimens and the parasite fauna infesting the species was represented only by trematodes. Research on the parasite fauna of gibel carp in the Georgian part of Jandari Lake has not been conducted before. The aim of our work was thus to investigate the structure of the parasite fauna of gibel carp in the Georgian part of this lake and evaluate the effect of several ecological factors on the formation of the parasite community.

Materials and Methods

Study area

Jandari Lake (N41.429045, E45.217235; 290 m a.s.l.) is located on the Kvemo Kartli lowland, in a temperate dry climate zone (*Csa* according to Köppen-Geiger climate classification (Beck et al. 2018)). The lake is known in literature also as Karaia and Gardabani Lake (Fig. 1A,B). It is one of the most important eutrophic lakes in the Mtkvari River Basin in eastern Georgia. The river Mtkvari is the primary source of water supply for the lake. The surface area of the lake is 10.6 km², and its maximum depth approaches to 7.2 m. The Jandari Lake is a transboundary lake, half of which is located on the territory of Azerbaijan in the south-eastern direction. Lake sides are mostly swamped with reed and bulrush. The process of eutrophication continues, and the content of dissolved oxygen in the water is limited by the metabolism of phytoplankton (Tsiskarishvili et al. 2004). Jandari Lake is characterized by high productivity (296.8 kg/g), as suggested by a study of zoobenthos biomass (Pataridze 2004).

Examination of fish for parasites

The young individuals (up to 4 years old) of 423 specimens of gibel carp were collected by fishing net from Jandari Lake between July 2014 and May 2018. Materials were collected in all seasons during the period examined: in 2014 (July and October), 2015 (April, May, November, and December), 2016 (January and October), 2017 (June, July, and November), and 2018 (May). In each month, at least 30 specimens were investigated. Fish were immobilized, and individuals were measured and weighed before the examination. Scales were used for age determination. Three age groups (1+, 2+, and 3+) with lengths of 8–15 cm have been studied. The parasites in the specimens were investigated by parasitological dissection of the fish. For further processing, standard parasitological methods were used (Bykhovskaya-Pavlovskaya 1969; Gussev 1983; Gerasev et al. 2010; Kvach et al. 2016). The skin, fins, and gills of each specimen were examined for ectoparasites. These organs were carefully scraped with a scalpel, and a mucus smear was made, which was evenly distributed on a glass slide in a drop of water, covered with a coverslip, gently pressed, and examined with a microscope. Eyes and internal organs were also investigated for endoparasites. Parasites were fixed, and temporary or permanent plates were prepared according to the taxonomy groups. Identification of parasite specimens was performed based on Bykhovskaya-Pavlovskaya et al. (1962) and Gussev (1978). Not all parasites were identified at the species level, though. The infection level has been expressed by prevalence and intensity and was calculated according to Bush et al. (1997).

Results

Among the 423 individuals of gibel carps studied, 20.3% (n=86) were infested with eleven species from five taxonomic groups of parasites (Protozoa, Monogenea, Trematoda, Nematoda, Copepoda) (Table 1). Among them, Protozoa were 3 species (*Trichodina* sp., *Ichthyophthirius multifillis*, *Dermocystidium* sp.), Monogenea – 4 (*Dactylogyrus vastator*, *Gyrodactylus elegans*, *Ancyrocephalus* sp., *Diplozoon paradoxum*), Trematoda – 1 (*Diplostomum spathaceum*), Nematoda – 2 (*Philometra* sp., *Contracaecum* sp.) and Copepoda (*Ergasilus* sp.) – 1.

Simultaneous invasion with three species of parasites was revealed in 9.3% (n=8) of infested gibel carps, with two species – in 16.2% (n=14), and the majority (73.2%, n=63) were infested with a single species. Eight species (*Ichthyophthirius multifiliis*, *Trichodina* sp., *Dermocystidium* sp., *Gyrodactylus elegans*, *Ancyrocephalus* sp., *Diplozoon paradoxum*, *Philometra* sp., *Contracaecum* sp.) were registered for the first time in gibel carp in Georgia. The dominant species were – *Trichodina* sp. from Protozoa and *Ancyrocephalus* sp., *Dactylogyrus vastator*, and *Gyrodactylus elegans* – from Monogenea. In general, the invasion of gibel carp with parasites was low and slightly fluctuated during the study period (Table 2).

Discussion

Overview of parasites of *Carassius gibelio* in Georgia

Protozoa
Ciliata

Ichthyophthirius multifiliis (Ichthyophthiriidae) is a non-specific, single-celled fish parasite that is widely distributed around the world. In Georgia, *I. multifiliis* was found in many species of fish in the water bodies of the river Mtk-

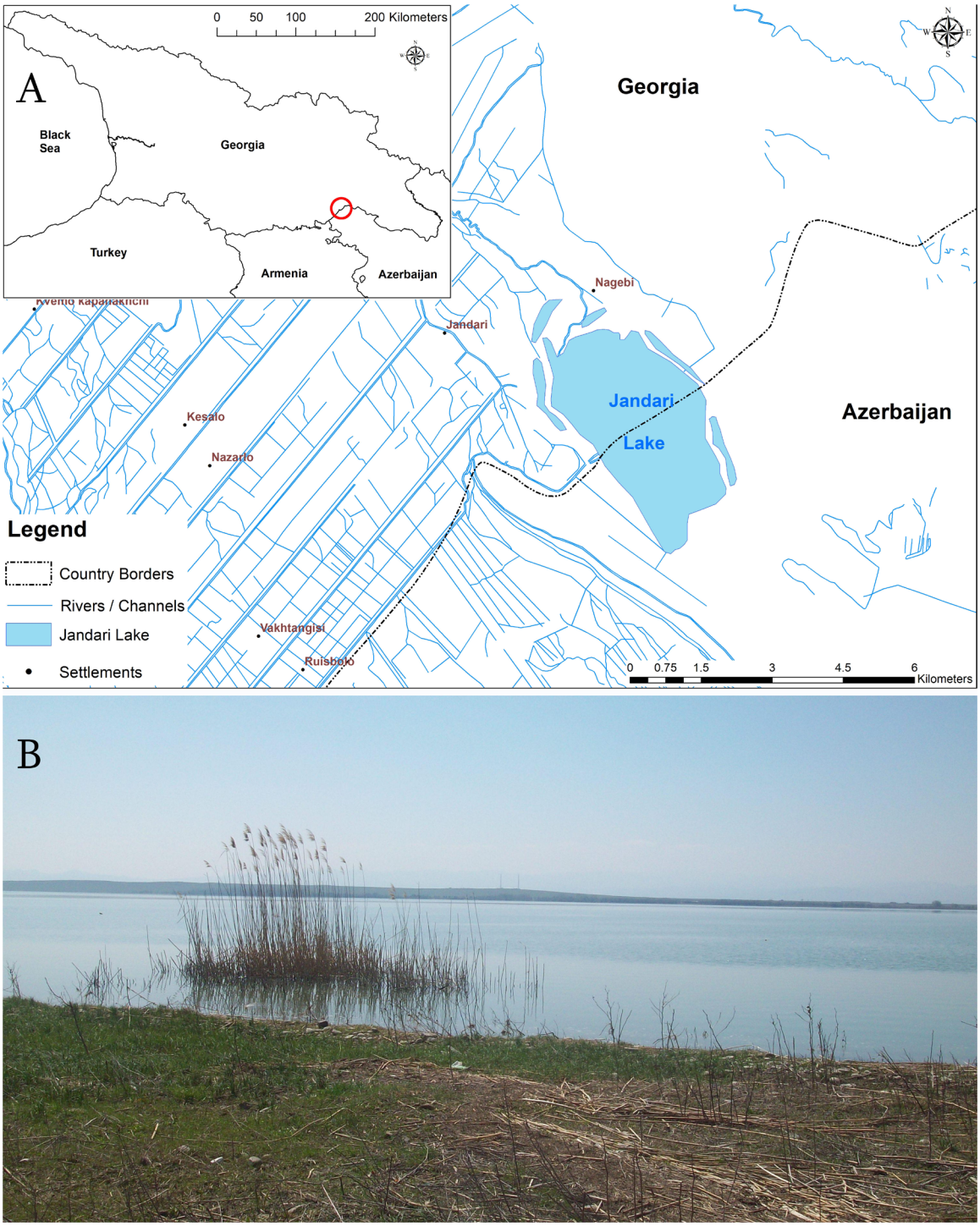

Figure 1. A map (A) and the view (B) of Jandari Lake.

vari basin (Gogebashvili 2000), as well as in Paliastomi and Japana Lakes (Chernova 1973). In Jandari Lake, *Ichthyophthirius* was found in one (0.2%) individual of gibel carp in the autumn, with a very low intensity (3 parasites in a single individual).

Trichodina sp. (Trichodinidae) – this single-celled parasite is also nonspecific towards the host and is very common in fish. Sixteen species of Trichodina have been registered in freshwater fishes of Georgia, mostly in Cyprinidae (Chernova 1973; Gogebashvili 2000). In Jandari Lake, this protozoans was detected in 25 (5.9%) individuals of gibel carp. Most of them, 22 (5.2%), were registered in the spring, and in all cases, *Trichodina* occurred together with monogeneans.

Mesomycetozoea

Dermocystidium sp. (Dermocystidae) – has been found in Cyprinidae on the skin, subcutaneous tissue, and gills (Cervinka et al. 1974; Kurashvili et al. 1980; Kovacs-Gayer et al. 1986; Beretar and Shevkoplyas 2011). In *Carassius* fish, it has been registered in the kidneys and spleen (Landsberg and Paperna 1992), as well as in the eyes (Molnar et al. 2008).

In Jandari Lake, cysts of *Dermocystidium* (Fig. 2A,B) were found on the gills of 5 (1.1%) individuals of gibel carp (age 3+). In three cases, cysts were spherical, 1.5–1.8 mm in diameter, fringed with a double-layer membrane, and zoospores spherical, refracting, with the white vacuole. In two

Table 1. The prevalence and mean intensity of parasites of *Carassius gibelio* in Jandari Lake.

Parasite	*Prevalence (%)	Intensity (min–max)
Protozoa		
Ichthyophthirius multifiliis	0.2	3**
Trichodina sp.	5.9	10–100››
Dermocystidium sp.	1.1	1–3
Monogenea		
Dactylogyrus vastator	3	1–5
Gyrodactylus elegans	1.8	207
Ancyrocephalus sp.	4.9	109
Diplozoon paradoxum	0.2	7**
Trematoda		
Diplostomum spathaceum	1.4	1–10
Nematoda		
Philometra sp.	2.8	1–3
Contracaecum sp.	1.4	1–3
Copepoda		
Ergasilus sp.	0.5	1

* Percentage prevalence of parasite species in investigated *C. gibelio*
** Intensity of parasite in one specimen of fish

fish, the membrane of some cysts was disrupted, and spores occurred as heaps that connected with each other. In both cases, the shape and size of the zoospores were identical.

Helminths

Monogenea

Monogenea is a widespread group of parasites among fish, including crucian carps. It was found by Pakosta et al. (2018) that both in the sexual and gynogenetic forms of gibel carp, monogeneans were the most frequently observed group of parasites. The majority of Monogenea species are specific to the host fish (Dogiel 1958; Bykhovskaya-Pavlovskaya et al. 1962), though nonspecific species are detected as well. For example, 29 species of fish inhabiting freshwater bodies in Georgia turned out to be invaded by monogeneans that were nonspecific for them (Matsaberidze 1993, 1996); furthermore, parasite species that were systematically close to each other were often detected in taxonomically remote but ecologically close hosts, which was explained by the author due to the ecological specificity. Fifty-five Monogenea species have been identified in fishes of Georgian freshwaters (except Jandari Lake), and 7 species (*D. vastator*, *D. anchoratus*, *D. crassus*, *G. kattharineri*, *G. sprostonae*, *G. longoacuminatus*, and *G. shulmani*) were registered in *Carassius* fish (Matsaberidze 1993). Only four species of Monogenea were found in 10.1% (n = 43) of the gibel carp examined in Jandari Lake during our investigation.

Dactylogyrus vastator (Dactylogyridae) is a typical species parasitizing *Carassius* spp. and *Cyprinus carpio* (Benovics et al. 2017). This monogenea is one of the most common parasites of freshwater fish in Georgia (Kurashvili and Petriashvili 1978). In *Carassius* fishes, *D. vastator* was registered in West Georgia (Matsaberidze 1993). In the present study, this species was recorded on the gills of 3% (n = 13) of young (1+ and 2+) gibel carp. It was also registered in the gills of *Cyprinus carpio* (3+) and the oral cavity of *Hypophthalmichthys molitrix* (3+) (Murvanidze et al. 2015).

Gyrodactylus elegans (Gyrodactylidae) has been reported in Cyprinidae fish inhabiting rivers and water reservoirs in Georgia (Chiaberashvili 1962, 1967; Petriashvili 1971; Kurashvili and Petriashvili 1978). The 4 species of *Gyrodactylus* (*G. kattharineri*, *G. shulmani*, *G. sprostonae*, and *G. longoacuminatus*) have been detected in *Carassius* fish; however, the intensity of invasion was exhibited by single individuals (Matsaberidze 1993). The present specimen in Jandari Lake has been found on the gills of *Cyprinus carpio* (Chiaberashvili 1959). *G. elegans* was reported by us for the first time in 2015 from the gibel carp of Jandari Lake (Murvanidze et al. 2015). In the following years (2015–18), this species was fixed with low intensity (2–7 individuals per fish) in 1.8% (n = 8) of young gibel carp (1+).

Ancyrocephalus sp. (Ancyrocephalidae) – In Georgia, five species of ***Ancyrocephalus*** have been identified in freshwater fishes (Chernova 1973; Matsaberidze 1993; Kurashvili and Petriashvili 1978), from which only *A. vistulensis* (= *Thaparocleidus vistulensis*) has been recorded in Jandari Lake parasitizing *Silurus glanis* (Chiaberashvili 1959). At present, *Ancyrocephalus* sp. is a dominant monogenean parasite of the gibel carp of Jandari Lake; it occurs in 4.9% (n = 21) of fishes.

Diplozoon paradoxum (Diplozoidae) has been recorded in Georgian Cyprinidae fishes, including *Barbus lacerta*, *Capoeta capoeta*, and *Rutilus rutilus* (Matsaberidze 1993). Only a single case of low-intensity invasion with *D. paradoxum* has been revealed in gibel carp in Jandari Lake. On the other hand, other cyprinid fishes such as *Ballerus sapa*, *Leuciscus leuciscus*, *Chondrostoma cyri*, *Alburnus filippi*, and *Aspius aspius* were intensely infested by this species (own unpublished data).

Trematoda

Thirty-five species of digenetic trematodes are so far registered for the Georgian ichthyofauna (Murvanidze et al. 2018). Twelve of them are present in the larval stage, and twenty-three are adults. Diplostomum species are one of the most common helminths in freshwater fish in Georgia. They have been recorded in 16 species of fish (Murvanidze et al. 2018). *Diplostomum clavatum* (= *Tylodelphys clavata*) was recorded in *Rhodeus sericeus* in Jandari Lake in the 1950s (Chiaberashvili 1959). Between 2007 and 2015, five types of trematodes were identified in 17 specimens of gibel carp examined from the Azerbaijan part of Jandari Lake (Shakaralieva 2016). Two of them belong to the family Diplostomidae (*Diplostomum mergi* and *D. nordmanni*). Iranian researchers (Daghigh Roohi et al. 2014) reported *D. spathaceum* in the eyes of gibel carp with a fairly high percentage of invasion (58.8%).

Diplostomum spathaceum (Diplostomidae) is a widespread trematode among fishes (Heckmann 1983). In recent years, the parasite was found with great intensity (22 metacercariae) in 38% of the studied gibel carps of Madatapa Lake (Japoshvili et al. 2017; Murvanidze et al. 2019). Only several metacercariae were found in the eye lenses of the gibel carp of Jandari Lake. This species was registered in 1.4% of the investigated and 6.9% (n = 6) of infested fish (intensity: min. 1-2, max. 9–10 per fish).

Table 2. The prevalence of parasites of *Carassius gibelio* from Jandari Lake in different seasons

Parasite taxa	Spring	Summer	Autumn	Winter
	n = 133/49 (36.8%)	**n = 48/4 (8.3%)**	**n = 73/11 (15.0%)**	**n = 169/22 (13.0%)**
Trichodina sp.	22 (16.5)	2 (2.7)	–	1 (0.5)
Ichthyophthirius multifiliis	–	–	2 (0.5)	–
Dermocystidium	–	–	–	5 (2.9)
Dactylogyrus vastator	7(5.2)	–	–	5 (2.7)
Gyrodactylus elegans	8 (6.0)	–	–	–
Ancyrocephalus sp.	19 (14.2)	–	–	2 (1.0)
Diplozoon paradoxum	–	–	–	1 (0.5)
Diplostomum spathaceum	1 (0.75)		3 (3.2)	3 (1.6)
Philometra sp.	6 (4.5)	2 (4.3)	4 (6.5)	–
Contracaecum sp.	–	–	–	6 (3.2)
Ergasilus sp.	–	–	2 (0.5)	–

Nematoda

Larvae of two taxonomic groups of nematodes (Philometridae and Anisakidae) were detected in the gibel carp population of Jandari Lake. *Philometra* and *Contracaecum* are widely distributed nematodes in freshwater fish in Georgia. Decades ago, 3 species of *Philometra* (*Ph. abdominalis=Ph. ovata*, *Ph. rischta*, and *Ph. intestinalis=Kalmanmolnaria intestinalis*) and 3 species of *Contracaecum* (*C. siluriglandis*, *C. squalii*, and *C. aduncum =Hysterothylacium aduncum*) were registered in freshwater fishes in Georgia (Chiaberashvili 1959; Chernova 1973; Kurashvili and Petriashvili 1978) There have been cases of intensive infestations with the *Contracaecum* in gibel carp – 27 parasites per fish (Innal et al. 2020), from 7 to 1078 parasites per fish (Turković et al. 2020).

***Philometra* sp.** in Jandari Lake was found in 2.8% (n = 12) of the examined gibel carp. Larvae were localized in the swimming bladder (9 cases) and intestine (3 cases). The intensity of the invasion was low in all cases and affected 1-2 or 3 individuals per fish.

Contracaecum sp. – Larvae of this anisakid nematode were found in 6 cases (1.4% of the total) in Jandari Lake. They have been found in 3+ gibel carp and were localized in the swimming bladder (2 cases) and the body cavity (4 cases). The intensity was 1-3 individuals per fish.

Copepoda

***Ergasilus* sp.** (Ergasilidae) are typical representatives of parasitic arthropods. The parasite is less specific to the hosts and is widely distributed among the fish. They are found in greater quantities in adult fish, where they accumulate as the fish's age increases (Poliansky and Shulman, 1956). In the young gibel carp of Jandari Lake, *Ergasilus* sp. was detected in the gills of 0.5% (n = 2) of the fish investigated. The infestation of gibel carp by this parasite was limited to one individual per fish.

Ecological analysis

There is no convincing evidence that fish parasite populations are stable over time (Kennedy 2009). Parasite communities in fish hosts are also not uniform. Their diversity, composition, and abundance vary across the geographical range of a host species (Poulin 2007). Each parasite's host and parasites at different life history stages usually have their own unique direct and indirect responses to a stressor (Lafferty and Kuris 1999). The formation of parasitic fauna in freshwater fishes is determined by a complex of biotic and abiotic factors. The feeding behavior and habitat selection of the host fish, environmental changes, including those of an anthropogenic nature, and seasonal changes in radiation level are the key factors in causing differences in the parasitic fauna of fishes (Dogiel 1958; Poliansky 1958; Chubb 1977, 1979; Thomas 2002; Kennedy 2009; Garrido-Olvera 2012).

The fish parasite community shows a tendency for change during the eutrophication of lake ecosystems. The diversity of parasitic fauna of fish in eutrophic water reservoirs is much lower with the dominance of monoxenous parasites with a direct life cycle (Ieshko and Novokhatskaya 2008; Zargar et al. 2012). This tendency is well illustrated by the chronology of the fish parasite fauna study in the eutrophic Jandari Lake. It is clear that, over the decades, the composition of the parasitic fauna of fish changed in tandem with changes in the ecosystem of the water reservoir and ichthyofauna. In the 1950s (Chiaberashvili 1959), 20 parasitic species were discovered in the fish of Jandari Lake. Among them, the polyxenic *Ligula intestinali*s was the most common in Cyprinidae fishes. In the 1970s, the lake's dominant fishes (*Silurus glanis*, *Abramis brama*, and *Aspius aspius*) were infested by the helminths of the complex life cycle (*Proteocephalus osculatus*, *Ligula intestinalis*, and *Neoechinorhynchus rutilli*) (Kurashvili et al. 1975). Presently, in conditions of strong eutrophication of the water body, the parasitological situation is completely modified. According to our data, the peculiarity of the parasitic fauna of young gibel carp and several adult Cyprinid fishes (*Cyprinus carpio*, *Hypophthalmichthys molitrix*, and *A. brama*) is characterized by the dominance of a taxonomic group of parasites with a simple life cycle (Murvanidze et al. 2015). The parasite fauna of the gibel carp is predominated by ectoparasites localized on the gills and skin, namely representatives of Protozoa (*Trichodina*) and helminths (Monogenea), which spread without an intermediate host. Even though during the migration and wintering the Jandari Lake is used by up to 20 000 swimming birds (Paposhvili et al., 2016), in gibel carp and other fish of this lake, the ligulosis, which was ex-

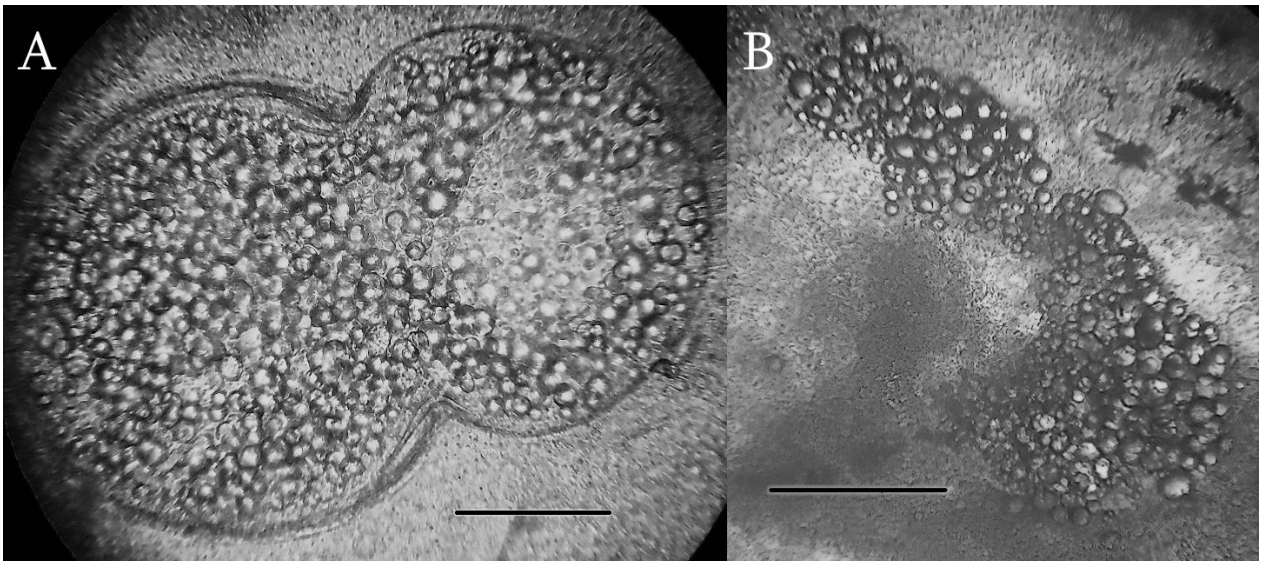

Figure 2. A–B: Cysts of *Dermocystidium* sp. on the gills of *Carassius gibelio*. Scale: 0,5 mm.

tremely prevalent in the 50th–70th years of the last century, was not revealed at all. No cases of invasion with Acanthocephala were fixed. The impact of overgrown aquatic vegetation on intermediate hosts of heteroxenous fish parasites was recorded for Japana Lake (Chernova 1973). Our results showed that the current ecological processes in the eutrophic Jandari Lake have a negative impact on the intermediate hosts of helminth parasites, inhibiting the development of the first intermediate hosts of heteroxenous cestodes and acanthocephals (Copepoda: Cyclopidae; Amphipoda: Gammaridae), as well as the development of parasitic crustaceans. This opinion is supported by the hydrobiological studies conducted in the reservoir in the 2000s (Macharashvili and Tsiskarishvili 2004; Pataridze 2004), when the tendency of decreasing quality and quantity of zooplankton and zoobenthos was detected due to a burden of organic pollutants. At this stage, the absence of polyxenic helminths in the fish of Jandari Lake indicates that the number of intermediate hosts in the reservoir has further decreased. To this end, the view of Strelkov and Schulman (1971) that the sharp abundance of parasites in the fish parasite fauna with a direct development cycle can be explained by their resilience and easy adaptability to reservoir regression and adverse climate change could also be considered.

Fish parasite fauna is strongly affected by the seasonal changes in water temperature regime and feeding intensity (Chubb 1977, 1979). The parasitic fauna of freshwater fishes is much more rich and diverse during the spring and summer seasons—during the period of active feeding of fish (Dogiel 1958). Though in each particular case the local conditions restrict or favor the development of the parasite (Chubb 1977; Kennedy 1978, 2009). Analysis of the obtained results has shown that under local climate conditions the degree of invasion of gibel carp in Jandari Lake, in general, is low (P = 20%), though it is comparatively high in the spring (P = 36.8%).

Different groups and species of parasites respond in different ways to the changes in the seasonal temperature regime of the water. For instance, the *Trichodina* invasion was highest in the spring (16.5%), two cases were discovered in the summer, and no cases were discovered in the autumn. The highest level of monogenean invasion was observed in spring (*Dactylogyrus*, *Gyrodactylus*, and *Ancyrocephalus*: 5.2%, 6.0%, and 19%, respectively).

Other species such as *Ichthyophthirius* (0.5%) were recorded in autumn; *Dermocystidium* – in winter (2.9%); *D. spathaceum* – with very low extensity and intensity in spring (0.75%), autumn (3.25%), and winter (1.6%); *Contracaecum* sp. has been revealed only during the winter period (3.2%); and *Philometra* sp. – in spring, summer, and autumn. Based on these data, the parasites of gibel carp in Jandari Lake can be conventionally divided into two groups according to their seasonal distribution. More sensitive to seasonal temperature changes are *Trichodina*, *Dactylogyrus*, *Gyrodactylus*, *Ancyrocephalus*, and *Contracaecum*, while *Dermocystidium*, *Diplozoon*, *Philometra*, and Copepoda are more uniform throughout the year.

The distribution of parasites among age groups (1+, 2+, and 3+) of gibel carp (Table 3) has shown that the species *Trichodina* sp., *Gyrodactylus elegans*, *Ancyrocephalus* sp., and *Phylometra* sp. were detected in all three age categories of gibel carp, with maximum invasion in the 1+ age group. *Dactylogyrus vastator* was registered only in 1+ and 2+-aged gibel carps. *Diplostomum spathaceum* was found in a minimum quantity in 1+ age fishes in the spring. Though in two- and three-year-old individuals, the metacercariae of *Diplostomum* were detected in autumn and winter (Table 2).

Our investigations have shown that 1+ and 2+ age individuals of gibel carp were mostly invaded by species of the direct life cycle (*Trichodina* sp., *Dactylogyrus vastator*, *Gyrodactylus elegans*, and *Ancyrocephalus* sp.). These findings are in agreement with Dogiel's (1958) postulates on the age dynamics of fish parasitic fauna, which state that young fish individuals are primarily infested with parasites, which develop without an intermediate host. The difference in invasion between female and male individuals of gibel carp in Jandari Lake was negligible (females, 37.5%, and males, 35.8%). Similar results were shown for the population of prussian carp in Lake Sakadaš, Croatia (Vuić et al. 2022).

Table 3. The prevalence of parasites in different age groups of *Carassius gibelio* in spring.

Parasites	Carassius gibelio	Age of fish		
	No. Investig.	1+	2+	3+
Trichodina sp.	133	13	4	5
Dactylogyrus vastator	133	5	2	0
Gyrodactylus elegans	133	6	1	1
Ancyrocephalus sp.	133	8	6	5
Diplostomum spathaceum	133	1	0	0
Philometra sp.	133	3	2	1

In the parasitic fauna of fish, the coexistence of different species is often noted among the various forms of parasitic relationships (Kennedy 2009; Dallas et al. 2019; Giari et al. 2020). A parasitological examination of gibel carp in Jandari Lake revealed the simultaneous invasion of two different taxonomic groups into the fish gills—protozoans and monogeneans. In particular, during the spring and summer seasons, *Trichodina* was registered in all cases together with Monogenea: *Trichodina+Ancyrocephalus* – 14 cases (16.2% from infected fish); *Trichodina+Dactylogyrus+Gyrodactylus* – 8 cases (9.3% from infected fish). A similar synergistic relationship between these taxa in Georgia was registered in cyprinid fishes of the Aragvi river basin (Kurashvili 1975). *Trichodina* and Monogenea are major members of the parasitocenosis of fish gills. They are particularly well adapted to freshwater regressive conditions, and their aggregation is common in gill habitat.

Conclusions

The results of the present study showed that the parasitic fauna of gibel carp in Jandari Lake, in general, is poor. Eleven protozoan and metazoan parasites were discovered in young *Carassius gibelio*. Protozoa and Monogenea are emerging as the dominant taxonomic groups. Ten species were the first recorded in the fishes of Jandari Lake. Among them, the eight species (*Ichthyophthirius multifiliis*, *Trichodina* sp., *Dermocystidium* sp., *Gyrodactylus elegans*, *Ancyrocephalus* sp., *Diplozoon paradoxum*, *Philometra* sp., *Contracaecum* sp.) were registered for the first time in gibel carp of freshwater bodies in Georgia.

The process of eutrophication negatively affects the intermediate hosts of some helminthic parasites and can be singled out as the main ecological factor determining the parasitic fauna of gibel carp in Jandari Lake. The absence of polyxene helminths in the fish of Lake Jandari at the present stage indicates a sharp decrease in the number of planktonic intermediate hosts in the reservoir. On the other hand, the same factor contributed to the development of monoxenic *Trichodina* and Monogenea, which were found to be more resistant to regressive changes in the reservoir.

A synergetic relationship between *Trichodina* from protozoans and monogeneans of gibel carps was evident. In all cases, *Trichodina* appeared alongside monogeneans, resulting in the formation of a long-term association. We think that the invasive gibel carp is well adapted to the Jandari Lake ecosystem and contributes to the spread of parasitic protozoa and helminths in commercial fish. None of the revealed parasites represented a threat to human health.

Acknowledgements

We would like to express our gratitude to two anonymous reviewers for their valuable recommendations in the manuscript, Dr. Levan Mumladze for giving further advice and improving the language, Giorgi Epitashvili for helping in fish age determination, and Diana Egiazarova for map design.

References

Arslan N, Emiroğlu Ö (2011) First Record of Parasitic Annelida-Hirudinea (*Piscicola geometra* Linnaeus, 1761) on *Carassius gibelio* (Bloch, 1782) in Lake Uluabat (Turkey). Kafkas Üniversitesi Veteriner Fakültesi Dergisi 17(1): 131-133.

Benovics M, Kičinjaová, ML, Šimková A (2017) The phylogenetic position of the enigmatic Balkan *Aulopyge huegelii* (Teleostei: Cyprinidae) from the perspective of host-specific Dactylogyrus parasites (Monogenea), with a description of *Dactylogyrus omenti* n. sp. Parasites & Vectors 10(1): 547. https://doi.org/10.1186/s13071-017-2491-z.

Beck HE, Zimmermann NE, McVicar TR, Vergopolan N, Berg A, Wood EF (2018) Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific Data 5: 180214. https://doi.org/10.1038/sdata.2018.214.

Beretar IM, Shevkoplyas VN (2011) Epizootological peculiarities of dermocystidiose of carps in pond fisheries of Krasnodar region. Veterinaria Kubani 4(11): 1-3.

Bush AO, Lafferty KD, Lotz JM, Shostak AW (1997) Parasitology meets ecology on its own terms: Margolis et al. revisited. Journal of Parasitology 83(4): 575-583. https://doi.org/10.2307/3284227.

Bykhovskaya-Pavlovskaya IE (1969) Parasitological study of fishes. Methods of Parasitological Research. Nauka, Leningrad, 108 pp. [In Russian].

Bykhovskaya-Pavlovskaya IE, Gussev AV, Dubinina MN, Izyumova NA, Smirnova TS, Sokolovskaya AL, Schtein GA, Shulman SS, Epshtein VM (1962) Key to parasites of freshwater fish of the USSR. Academia Nauk SSSR, Moscow, 776 pp. [In Russian].

Cervinka S, Vitovec J, Hoska J, Kubu F (1974) Dermocystidiosis – a gill disease of the carp due to Dermocystidium cyprini n.sp. Journal of Fish Biology 6: 689-699.

Chernova TN (1973) Parasitic fauna of the fish of some basins of Colchic-Anatolian section. Ph.D. Thesis, State Research Institute of Lake and River Fisheries, Leningrad, Russia. [In Russian].

Chiaberashvili EA (1959) Results of the study of parasitic fauna of the river Chernoy and Gardabani Lake. Works of the Georgian Institute of Zootechnics and Veterinary 31: 124-129. [In Russian].

Chiaberashvili E (1962) The parasitic fauna of river Rioni and some of its inflows. Works of the Georgian Institute of Zootechnics and Veterinary 33: 259-287. [In Georgian].

Chiaberashvili EA (1967) Parasitic fauna of the rivers Mtkvari, Alazani, and Iori. Works of The Georgian institute of Zootechnics and Veterinary 36: 447-462. [In Russian].

Chubb JC (1977) Seasonal occurrence of helminths in freshwater fishes. Part I. Monogenea. Advances in Parasitology 15: 133-199.

Chubb JC (1979) Seasonal occurrence of helminths in freshwater fishes. Part II. Trematoda. Advances in Parasitology 17(2): 141-313.

Çolak HS (2013) Metazoan parasites of fish species from Lake Sığirci (Edirne, Turkey). Turkish Journal of Veterinary and Animal Sciences 37: 200-205. https://doi.org/10.3906/vet-1202-28.

Dallas TA, Laine AL, Ovaskainen O (2019) Detecting parasite associations within multi-species host and parasite communities. Proceedings of the Royal Society B: Biological Sciences 286(1912): 20191109. https://doi.org/10.1098/rspb.2019.1109.

Daghigh Roohi J, Sattari M, Nezamabadi H, Ghorbanpour N (2014) Occurrence and intensity of parasites in Prussian carp, Carassius gibelio from Anzali wetland, Southwest Caspian Sea. Iranian Journal of Fisheries Sciences 13(2): 276-288.

Daraselia TG (1985) Existence of crucian carp – *Carassius carassius* (L) in inland waters of Georgia. In: Kurashvili B (Eds) Proceedings of the seventh scientific conference of Young Scientists. Institute of Zoology, Tbilisi, 12-14. [In Russian].

Demir S and Karakişi H (2016) Metazoan parasite fauna of the prussian carp, *Carassius gibelio* (Bloch, 1782) (Cyprinidae), from Marmara Lake, Turkey. Acta Zoologica Bulgarica 68(2): 265-268.

Docherty C, Ruppert J, Rudolfsen T, Hamann A, Poesch M (2017) Assessing the spread and potential impact of Prussian Carp *Carassius gibelio* (Bloch, 1782) to freshwater fishes in western North America. BioInvasions Records 6(3): 291-296. https://doi.org/10.3391/bir.2017.6.3.15.

Dogiel VA (1958) Parasite fauna and environment. Some questions of ecology of freshwater fish parasites. In: Dogel VA, Petrushevsky YI, Polyansky YI (Eds) The main problems of parasitology of the fish. Leningrad State University, Leningrad, 9-54. [In Russian].

Garrido-Olvera L, Arit HT and Perez-Ponce De Leon G (2012) The influence of host ecology and biogeography on the helminth species richness of freshwater fishes in Mexico. Parasitology 139(12): 1652-65. https://doi.org/10.1017/s003118201200100x.

Gerasev PI, Dmitrieva EV, Pugachov ON (2010) Methods for Studyng Monogenea (Plathelminthes) by the example of mullets (Mugilidae) Parasites. Zoological Journal 89(8): 1-15. [In Russian].

Giari L, Fano EA, Castaldelli G, Grabner D, Sures B (2020) The Ecological Importance of Amphipod–Parasite Associations for Aquatic Ecosystems. Water 12: 2429. https://doi.org/10.3390/w12092429.

Gogebashvili IV (2000) Parasitic Protozoa of the Georgian Fresh Water Fishes. Proceedings of the Institute of Zoology 10: 13-23.

Gussev AV (1978) Monogenoidea of freshwater fishes. Principles of systematics, analysis of the world fauna and its evolution. Parasitological Collections 28: 96-198. [In Russian].

Gussev AV (1983) The Methods of Collection and Processing materials on Monogeneans, parasitic in fish. Science, Leningrad, 48 pp. [In Russian].

Heckmann R (1983) Eye fluke (*Diplostomum spataceum*) of fishes from the upper salmon river near Obsisian, Idaho. The Great Basin Naturalist 43(4): 675–683. http://www.jstor.org/stable/41712025.

Ieshko EP, Novokhatskaya OV (2008) Trends of a succession of Parasitofauna of Fish of Eutrophied water bodies. Journal of Ichthyology 48(8): 665-670. https://doi.org/10.1134/S0032945208080134.

Innal D, Stavrescu-Bedivan M, Özturk O, Özmen Ö (2020) First Record of *Contracaecum rudolphii* Hartwich, 1964 in *Carassius gibelio* (Bloch, 1782) from Turkey. Aquatic Sciences and Engineering 35(1): 1-5. http://dx.doi.org/10.26650/ASE2019566509.

Japoshvili B, Ertan O, Diler O (2004) A study of morpho-ecological characters of *Carassius auratus* L. and *Carassius carassius* L. Proceedings of the Institute of Zoology 12: 280-283.

Japoshvili B, Mumladze L, Küçük F (2013) Invasive *Carassius* carp in Georgia: Current state of knowledge and future perspectives. Current Zoology 59(6): 732-739. https://doi.org/10.1093/czoolo/59.6.732.

Japoshvili B, Mumladze L, Murvanidze L (2017) The population of Carassius gibelio (Bloch, 1782) and its parasites in Madatapa Lake (South Georgia). Iranian Journal of Fisheries Sciences 16(2): 793-799. http://dorl.net/dor/20.1001.1.15622916.2017.16.2.24.7.

Kennedy CR (1978) Ecological Animal Parasitology. Mir, Moscow, 229 pp. [In Russian]

Kennedy CR (2009) The Ecology of Parasites of Freshwater Fishes: the search for patterns. Parasitology 136: 1653-1662. https://doi.org/10.1017/S0031182009005794.

Khara, H., Sattari, M., Nezami, S., Mirhasheminasab, S. F., Mousavi, S. A., & Ahmadnezhad, M. (2011). Parasites of some bonyfish species from the Boojagh wetland in the southwest shores of the Caspian Sea. Caspian Journal of Environmental Sciences 9(1): 47-53.

Kir I, Samanci I (2012) Parasite Fauna of Pond Fish (*Carassius gibelio* Bloch., 1782) Living in Karacaören II Dam Lake (Burdur, Isparta). Süleyman Demirel University Egirdir Faculty of Fisheries Journal 8(2): 38-42.

Koyon M and Altunel FN (2007) Metazoan Parasites of Bleak (*Alburnus alburnus*), Crucian Carp (*Carassius carassius*) and Golden Carp (*Carassius auratus*) in Enne Dam Lake, Turkey. International Journal of Zoological Research 3(2): 94-100.

Kovacs-Gayer E, Csaba G, Ratz F, Bekesi L, Szakolczai J (1986) Granulomatosis of common carp (*Cyprinus carpio* L.,). Bulletin of the European Association of Fish Pathologists 6: 72-75.

Kuljanishvili T, Mumladze L, Japoshvili B, Mustafayev N, Ibrahimov S, Patoka J, Pipoyan S, Kalous L (2021) The first unified inventory of non-native fishes of the South Caucasian countries, Armenia, Azerbaijan, and Georgia. Knowledge & Management of Aquatic Ecosystems 422: 1–16. https://doi.org/10.1051/kmae/2021028.

Kunz YW (2004) Developmental Biology of Teleost Fishes. Springer Science & Business Media, Netherlands, 511 pp.

Kurashvili B (1975) The Interrelation between the Animal Intestinal Parasites in Parasitocenosis. Proceedings of the Georgian Academy of Sciences, Biological Series 1(4): 317-320. [In Georgian].

Kurashvili B, Andguladze V, Giorgadze J, Jordanja L (1975) Ecological and helminthological investigation of Jandari Lake animals. Materials for Georgian fauna 5: 156-179. [In Georgian].

Kurashvili BE, Petriashvili LI (1978) Helminths of the fresh-water basins of Georgia. In: Kurashvili B (Eds) Materials of the first trans-Caucasian conference. Metsniereba, Tbilisi, 178-183. [In Russian].

Kurashvili BE, Mikailov TK, Gogebashvili IV (1980) Parasitic fauna of the fish of river Mtkvari basin within USSR. Metsniereba, Tbilisi, 258 pp. [In Russian].

Kvach Y, Ondračková M, Janáč M, Jurajda P (2016) Methodological issues affecting the study of fish parasites. I. Duration of live fish storage prior to dissection. Diseases of Aquatic Organisms 119: 107-115. https://doi.org/10.3354/dao02990.

Lafferty KD, Kuris AM (1999) How environmental stress affects the impacts of parasites. Limnology and Oceanography 44 (3): 925-931.

Landsberg JH, Paperna I (1992) Systematic granuloma in goldfish caused by a Dermocystidium-like aetiological agent. Diseases of Aquatic Organisms 13: 75-78.

Lusková V, Lusk S, Halačka K, Vetešník L (2010) *Carassius auratus gibelio* – The Most Successful Invasive Fish in Waters of the Czech Republic. Russian Journal of Biological Invasions 1(3): 176-180.

Macharashvili V, Tsiskarishvili T (2004) Zooplankton of the Lake Jandari. Proceedings of the Institute of Zoology 12: 374-377. [In Russian].

Matsaberidze KG (1993) The fauna of Monogenea of the freshwater fish of Georgia. PhD Thesis, State University of Saint Petersburg, Saint Petersburg, Russia. [In Russian].

Matsaberidze K (1996) Some peculiarities of the distribution and localisation of Monogenea of the freshwater fish of Georgia. In: Kurashvili B (Eds) Materials of the scientific conference of Parasitologists, Tbilisi (Georgia), June 1992. Metsniereba, Tbilisi, 64-66. [In Russian].

Molnar K, Müller T, Lefler KK, Csorbai B (2008) Dermocystidium infection in the eye of crucian carp. Magyar Allatorvosok Lapja 130(1): 53-56.

Murvanidze L, Lomidze T, Nikolaishvili K, Arabuli L, Davitaia K, Asatiani K (2019) Ecological Peculiarities of the Helminth Fauna of Invasive *Carassius gibelio* (Bloch 1782) from Madatapa and Khanchali Lakes (Javakheti Wetlands, South Georgia). In: Trajanovski S (Ed.) Joint ESENIAS and DIAS conference and 9th Esenias workshop, Ohrid (North Macedonia), September 2019. PSI Hydrobiological Institute Ohrid, North Macedonia, 3-6.

Murvanidze LP, Nikolaishvili KG, Lomidze TV, Arabuli S, Asatiani, KD (2015) Biodiversity and recent condition of fish parasitic fauna of Jandari Lake. In: Titok VV (Ed.) Materials of the III scientific-practical conference, dedicated to the 110-year jubilee of the academician N.V. Smolsky, Minsk (Belorus), October 2015. Minsk, Belorus, 200-203.

Pakosta T, Vetešník L, Šimková A (2018) A Long Temporal Study of Parasitism in Asexual-Sexual Populations of *Carassius gibelio*: Does the Parasite Infection Support Coevolutionary Red Queen Dynamics? BioMed Research International 2018: 6983740. https://doi.org/10.1155/2018/6983740.

Paposhvili N, Ninua L, Dekanoidze D, Shvelidze T, Janiashvili Z, Javakhishvili Z (2016) Special Protection Areas (SPA) for birds in Georgia. available at: https://aves.biodiversity-georgia.iliauni.edu.ge/.

Pataridze A (2004) Zoobenthos of the Lake of Jandari. Proceedings of the Institute of Zoology 12: 377-382. [In Georgian].

Petriashvili L (1971) Helminthes of Fishes of Basalety Lake. Parasitological collection 2: 96-101. [In Georgian].

Poliansky YI (1958) Parasitic fauna and environment. Some questions about the ecology of parasites of marine fish. In: Dogiel VA, Petrushevsky GK, Polyansky YI (Eds) The main problems of fish parasitology. Leningrad State University, Leningrad, 55-89. [In Russian].

Poliansky YI, Shulman SS (1956) Age alteration in the parasite fauna of fish. Proceedings of the Karelian-Finnish Branch of the Academy of Sciences of the USSR 4: 3-26. [In Russian].

Poulin R (2007) The structure of parasite communities in fish hosts: ecology meets geography and climate. Parassitologia 49(3): 169-172.

Shakaralieva YV (2016) Biodiversity of trematodes of the transboundary Jandar Lake fishes, Azerbaijan. The Journal of V.N.Karazin Kharkiv National University 26: 141-147. [In Russian].

Strelkov YA, Shulman SS (1971) Ekologo-faunisticheskiy analiz parazitov ryb Amuri. Parazitologicheskiy sbornik 15: 196-292. [In Russian].

Tekin-Özan S, Kir I (2005) An investigation on parasites of goldfish (*Carassius carassius* L., 1758) in Kovada Lake. Acta Parasitologica Turcica 29(3): 200-203. [In Türkish].

Thomas JD (2002) The ecology of fish parasites with particular reference to helminth parasites and their salmonid fish hosts in Welsh rivers: a review of some of the central questions. Advances in Parasitology 52: 1-154.

Tsiskarishvili L, Ekshi A, Tsiskarishvili M (2004) The Hydrochemical regime of Jandary Lake. Proceedings of the Institute of Zoology 12: 359-364.

Turković ČI, Nera V, Dubravka Č (2020) First finding of roundworms (*Contracaecum* sp.) in Prussian carps (*Carassius gibelio* Bloch, 178) in Lake Sakadaš. Hrvatske vode 28(111): 21-28. [In Croatian].

Vuić N, Ćakalić IT, Vlaičević B, Piperac MS, Ćerba D (2022) The Influence of *Contracaecum* larvae (Nematoda, Anisakidae) Parasitism on the Population of Prussian carp (*Carassius gibelio*) in Lake Sakadaš, Croatia. Pathogens 11(5): 600. https://doi.org/10.3390/pathogens11050600.

Zargar UR, Yousuf AR, Chishti MZ, Ahmed F, Bashir H, Ahmed F (2012) Effects of water quality and trophic status on helminth infections in the cyprinid fish, *Schizothorax niger* Heckel, 1838 from three lakes in the Kashmir Himalayas. Journal of Helminthology 86(1): 70-76. https://doi.org/10.1017/s0022149x11000071.