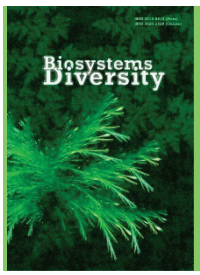

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Ecological and faunal characteristics of helminths of wetland birds in North-Western Uzbekistan

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The article studies some faunistic features of helminths of wetland birds in the ecological crisis zone in North-Western Uzbekistan. Parasites of wetland birds collected in the basin of the lower reaches of the Amu Darya during the hunting seasons of 2018–2022 were used as material for this work. 500 individuals of birds representing 39 species from 24 genera, 13 families and 9 orders were examined using the parasitological dissection method. The article discusses the distribution and ecology of the helminths in the studied groups of birds. A total of 112 helminth species were identified in the region – 28 species belong to the class Cestoda, the class Trematoda is represented by 57 species, Nematoda – 23 and Acanthocephala – 4 species. 92 species of heminths were identified in the study area for the first time. The work provides original data on the structure of the helminth fauna from 9 orders of wetland birds. Various paths of helminth transmission in the circulation of infection were specified. The researchers identified four ways parasites use to enter their definitive host: helminths penetrate the host's body when the latter eats other organisms, intermediate or reservoir hosts of helminths, which are part of the definitive's host's diet; helminths enter the host as mechanical impurity to food or water; they make active efforts to penetrate their host; helminths are transmitted by the intermediate host when the latter forages on the definitive host. Most of intermediate hosts for representatives of the class Cestoda were crustaceans – inhabitants of different types of water bodies; Oligochaeta are also included here as second or reservoir hosts. The development of trematodes occurs with the participation of aquatic molluscs acting as the first intermediate host. Various species of insects, fish, amphibians, reptiles and small mammals were identified as the second hosts. Nematoda use a wider range of intermediate hosts (Oligochaeta, crustaceans, insects – aquatic and terrestrial). Fish and amphibians were registered as the second and reservoir hosts of nematodes. The food chains of individual orders of wetland birds largely determine the composition of helminths parasitising them and are the main factor in the formation of their helminth fauna. These processes undoubtedly occur in time and space under the strict control of environmental factors.

Keywords: fauna; ecology; distribution; wetland birds; molluscs; intermediate hosts; definitive hosts.

Introduction

North-Western Uzbekistan is a vast territory in the lower reaches of the Amu Darya. Occupying about 42% of the area of Uzbekistan, this is the largest region of the country. Administratively, this area encompasses Khorezm region and the Republic of Karakalpakstan. The wildlife of the region generally differs from those in other parts of Uzbekistan (Jumanov, 2017). The territory of North-Western Uzbekistan, located on bird migration routes and featuring extensive wetlands inhabited by various species of wetland birds, remains poorly studied from the parasitological aspect. The available information on the helminth fauna of fish-eating birds in the Aral Sea basin (Turemuratov, 1964) is of historical importance. By now, those research data have become noticeably outdated, which is confirmed by recently resumed studies of the helminth fauna of wetland birds in the region (Akramova, 2011; Saparov, 2016; Arepbaev, 2020; Shakarbaev et al., 2020). What makes the available helminthological studies significant is that wetland birds living here are important objects of amateur hunting; in addition, many of the species are protected and listed as endangered representatives of the fauna of Uzbekistan. It should also be borne in mind that birds transmit various helminthiases. The Cestoda, Trematoda and Nematoda faunas play an important part, many of their representatives causing real threat to fish, birds and mammals, including humans. This paper is in fact the first attempt to study in detail the helminths of wetland birds in the northwestern part of Uzbekistan, to assess the role of various species or groups of hosts, and identify the peculiarities of biocoenotic relationships between helminths and their hosts in the formation of the helminth fauna against the modern ecological background within the region in question.

Materials and methods

Parasites of wetland birds collected in the lower Amu Darya basin (lakes Takirkul, Dautkul, Karateren, Sudochye, Zhyltirbas, Khojakul, Shegekul and Mashankul, as well as Karajar and Kyzylzhar wetland systems, Fig. 1) in the hunting seasons of 2018–2022 were used as material for this work. The material also included birds killed by hunters and those collected by fishermen in fishing nets (cages, shutter nets). 500 individuals of birds representing 38 species from 24 genera, 13 families and 9 orders were examined using the parasitological dissection method (Table 1).

Birds were dissected, helminths were found, extracted and treated, and temporary and permanent preparations were produced according to

standard parasitological methods (Dubinina, 1971). Cestoda, Trematoda, Acanthocephala and Nematoda were examined, measured, photographed and drawn using modern microscopic equipment (inverted microscope Olympus CK2-TR, research microscope Lomo, binocular microscope ML-2200, and trinocular microscope N-300 from Ningo Yongkin Optics). Cestoda, Trematoda, Acanthocephala and Nematoda species were identified by well-known monographs by national and foreign authors. Other guides were also used for certain groups of higher taxa (Ryzhikov et al., 1973, 1974; Baruš et al., 1978; Sudarikov et al., 1983; Sudarikov, 1984; Shigin, 1993; Anderson, 2000; Gibson et al., 2002, 2005, 2008; Movsesian, 2003). The taxonomy of birds is given according to Stepanyan (2003).

Fig. 1. Map of northwestern Uzbekistan: *1* – Lake Takirkul, *2* – Lake Dautkul, *3* – Kyzylzhar wetland system, *4* – Lake Mashankul, *5* – Lake Khojakul, *6* – Lake Sudochye, *7* – Karajar wetland system, *8* – Lake Shegekul, *9* – Lake Jyltirbas, *10* – Lake Karateren

Table 1
Species composition of birds examined for infection with helminths in North-Western Uzbekistan

No.	Birds	Examined, individuals
	Gaviiformes	
1.	Red-throated loon – *Gavia stellata* (Pontoppidan, 1763)	2
2.	Black-throated loon – *Gavia arctica* (L., 1758)	2
	Podicipediformes	
3.	Little grebe – *Tachybaptus ruficollis* (Pallas, 1764)	11
4.	Red-necked grebe – *Podiceps grisegena* (Boddaert, 1783)	10
5.	Great crested grebe – *Podiceps cristatus* (L., 1758)	13
	Pelecaniformes	
6.	Great white pelican – *Pelecanus onocrotalus* (L., 1758)	2
7.	Great cormorant – *Phalacrocorax carbo* (L., 1758)	9
8.	Pygmy cormorant – *Phalacrocorax pygmaeus* (Pallas, 1773)	3
	Ciconiiformes	
9.	Great bittern – *Botaurus stellaris* (L., 1758)	3
10.	Black-crowned night heron – *Nycticorax nycticorax* (L., 1766)	5
11.	Great white egret– *Egretta alba* (L., 1758)	3
12.	Grey heron – *Ardea cinerea* (L., 1758)	5
13.	Glossy ibis – *Plegadis falcinellus* (L., 1766)	3
	Phoenicopteriformes	
14.	Greater flamingo – *Phoenicopterus roseus* (Pallas, 1811)	3
	Anseriformes	
15.	Greylag goose – *Anser anser* (L., 1758)	8
16.	Mute swan - *Cygnus olor* (Gmelin, JF, 1789)	3
17.	Domestic goose – *Anser anser dom.*	35
18.	Mallard – *Anas platyrhynchos* (L., 1758)	35
19.	Common teal – *Anas crecca* (L., 1758)	11
20.	Gadwall – *Anas strepera* (L., 1758)	30
21.	Northern pintail – *Anas acuta* (L., 1758)	36
22.	Eurasian wigeon – *Anas penelope* (L., 1758)	27
23.	Garganey – *Anas querquedula* (L., 1758)	25
24.	Northern shoveler – *Anas clypeata* (L., 1758)	5
25.	Common pochard – *Aythya ferina* (L., 1758)	15
26.	Tufted duck – *Aythya fuligula* (L., 1758)	11
27.	Common goldeneye – *Bucephala clangula* (L., 1758)	7
28.	Smew – *Mergellus albellus* (L., 1758)	9
29.	Domestic duck – *Anas platyrhynchos dom.*	75
30.	Red-crested pochard – *Netta rufina* (Pallas, 1773)	11
	Gruiformes	
31.	Common moorhen – *Gallinula chloropus* (L., 1758)	9
32.	Common coot – *Fulica atra* (L., 1758)	25
	Charadriiformes	
33.	Black-winged stilt – *Himantopus himantopus* (L., 1758)	7
34.	Wood sandpiper – *Tringa glareola* (L., 1758)	6
35.	Black-headed gull – *Larus ridibundus* (L., 1758)	13
36.	Caspian gull – *Larus cachinnans* (Pallas, 1811)	9
37.	Little tern – *Sterna albifrons* (Pallas, 1764)	11
	Falconiformes	
38.	White-tailed eagle – *Haliaeetus albicilla* (L., 1758)	1
39.	Western marsh harrier – *Circus aeruginosus* (L., 1758)	2
	Total	500

Results

We have established that parasitic worms of wetland birds in North-Western Uzbekistan are now represented by 112 species of helminths, of

which 28 species belong to the class Cestoda, 57 species to Trematoda, 4 to Acanthocephala and 23 to Nematoda. The data we have obtained show that among the helminths discovered in wetland birds in North-Western Uzbekistan the highest species diversity is demonstrated by flatworms (85 species), which is followed by roundworms – 23 species, with the lowest species diversity shown by ribbon worms – 4 species (Table 2).

Table 2
Species composition of helminths
of wetland birds in North-Western Uzbekistan

Class	Family	Species
Cestoda	Diphyllobothriidae	*Diphyllobothrium ditremum* (Creplin, 1825)
		Digramma interrupta (Rudolphi, 1810)
		Schistocephalus solidus (Muller, 1776)
	Ligulidae	*Ligula colymbi* Zeder, 1803
		L. intestinalis (Linnaeus, 1758)
	Tetrabothriidae	*Tetrabothrius macrocephalus* (Rudolphi, 1810)
	Davaineidae	*Davainea proglottina* (Davaine, 1860)
	Hymenolepididae	*Aploparaksis clavata* Spasskaya, 1970
		A. furcigera (Rudolphi., 1819)
		Dicranotaenia coronula (Dujardin, 1845)
		Diorchis elisae (Skrjabin, 1914)
		D. nyrocoides (Spasskaja, 1961)
		Drepanidotaenia lanceolata (Bloch, 1782)
		Fimbraria fasciolaris (Pallas, 1781)
		Microsomacanthus arcuata (Kowalewski., 1904)
		M. microsoma (Creplin, 1829)
		M. compressa (Linton, 1892)
		Myxolepis collaris (Batsch, 1786)
		Flamingolepis flamingo (Skrjabin, 1914)
		F. megalorchis (Luhe, 1898)
		F. tengizi Gvozdev et Maksimova, 1968
		Sobolevicanthus gracilis (Zeder, 1803)
		S. dafilae (Polk, 1942)
		Tschertkovilepis setigera (Fröhlich, 1789)
		Wardium fusa (Krabbe, 1869)
		W. spasskii Schigin, 1961
	Amabilliidae	*Tatria bremis* Kowalewski, 1904
	Dilepididae	*Paradilepis scolecina* (Rudolphi, 1819)
Trematoda	Echinostomatidae	*Echinostoma revolutum* (Frohlich, 1802)
		E. dietzi Skrjabin, 1923
		E. paraulum Dietz, 1909
		E. miyagawai Ischii, 1932
		E. robustum Yamaguti, 1935
		E transfretanum Dietz, 1909
		Echinoparyphium recurvatum (Linstow, 1873)
		E. cinctum (Rudolphi, 1802)
		E. aconiatum Dietz, 1909
		Paryphostomum radiatum (Dujardin, 1845)
		Echinochasmus coaxatus Dietz, 1909
		E. euryporus (Looss, 1896)
		Mesorchis denticulatus (Rud., 1802)
		Aporchis rugosus Linton, 1928
		Hypoderaeum conoideum (Bloch, 1782)
		Petasiger aerates Oschmarin, 1947
		P. skrjabini Bashkirova, 1941
	Cyclocoelidae	*Cyclocoelum mutabile* (Zeder, 1800)
		C. obscurum (Leidy, 1887)
	Typhlocoelidae	*Typhlocoelum cucumerinum* (Rud., 1809)
		T. sisowi (Skrjabin, 1913)
	Notocotylidae	*Notocotylus attenuates* (Rud., 1809)
		N. chionis Baylis, 1928
		Catatropis verrucosa (Frölich, 1789)
		Paramonostomum bucephalae Yamaguti, 1935
		P. elongatum Yamaguti, 1934
	Gymnophallidae	*Cryptocotyle concavum* (Creplin, 1825)
	Microphallidae	*Microphallus claviformis* (Brandes, 1888)
		M. pygmaeus (Levinsen, 1881)
	Opistorchidae	*Opistorchis geminus* Looss, 1896
		Metorchis xanthosomus (Creplin, 1846)
	Renicolidae	*Renicola lari* Timon-David, 1933
	Clinostomatidae	*Clinostomum complanatum* (Rudolphi, 1819)
	Eucotylidae	*Eucotyle cohni* Skrjabin, 1924
		Tanaisia atra (Neslobinsky, 1926)
	Plagiorchiidae	*Plagiorchis elegans* (Rudolphi., 1802)
		P. laricola Skrjabin, 1924
	Prosthogonimidae	*Prosthogonimus ovatus* (Rudolphi., 1803)
		P. cuneatus (Rudolphi., 1809)
	Psilostomidae	*Psilostomum brevicolle* (Creplin, 1829)
		Psilotrema spiculigerum (Muhling, 1898)
		Psilochasmus oxyurus (Creplin, 1828)
	Strigeidae	*Strigea falconis* Szidat, 1928
		Cotylurus cornutus (Rudolphi., 1808)
		Apatemon gracilis (Rudolphi., 1819)
	Diplostomidae	*Diplostomum spathaceum* (Rudolphi, 1819)
		D. commutatum (Diesing, 1850)
		Postdiplostomum brevicaudatum (Nord., 1832)
		Tylodelphus clavata (Nord., 1832)
		Neodiplostomum spathulaeforme (Brandes, 1888)
	Schistosomatidae	*Bilharziella polonica* (Kowalewski, 1895)
		Trichobilharzia tatianae (Spasskaja, 1952)
		Ornithobilharzia canaliculata (Rudolphi., 1819)
		Austrobilharzia chapini (Price, 1929)
		Dendritobilharzia loossi Skrjabin, 1924
		D. pulverulenta (Braun, 1901)
		Gigantobilharzia acotylea Odhner, 1910
Acantho-cephala	Polymorphidae	*Polymorphus minutus* (Zeder, 1800)
		P. magnus Skrjabin, 1913
		P. striatus (Goeze, 1782)
	Giganthorhynchidae	*Mediorhynchus papillosus* Van Cleave, 1916
Nematoda	Trichuridae	*Capillaria anseris* Madsen, 1945
		Thominx anatis Schrank, 1790
		Th. skrjabini (Lubimov, 1947)
		Th. spinulosa (Linstow, 1890)
	Dioctophymidae	*Eustrongylides tufifex* (Nitzsch, 1819)
		Eu. mergorum (Rud., 1809)
	Strongyloididae	*Strongyloides turkmenica* Kurtieva, 1953
	Amidostomidae	*Amidostomum anseris* (Zeder, 1800)
		A. skrjabini Boulenger, 1926
		Amidostomoides monodon Linstow, 1882
		Epomidiostomum uncinatum (Lindahl, 1848)
	Trichostrongylidae	*Trichostrongylus tenuis* (Mehlis, 1846)
	Ascarididae	*Ascaridia galli* (Schrank, 1788)
		Porrocaecum crassum (Deslongchmaps., 1824)
		P. semiteres (Zeder, 1800)
	Anisakidae	*Contracaecum spiculigerum* (Rudolphi., 1809)
		C. microcephalum (Rudolphi., 1819)
	Heterakidae	*Ganguleterakis dispar* (Schrank, 1790)
	Tetrameridae	*Tetrameres fissispina* (Diesing, 1861)
		T. nouveli (Seurat, 1914)
	Acuaridae	*Streptocara crassicauda* (Creplin, 1829)
	Desmidocercidae	*Desmidocercella numidica* (Seurat, 1920)
	Onchocercidae	*Paronchocerca tonkinensis* (Chow, 1939)

As the results of the study shows, the total recorded prevalence was 85.8%. The intensity of infection is low and varies widely from single to several dozen individuals.

The helminth fauna is unequally distributed across the 9 orders of the studied birds (Falconiformes, Charadriiformes, Gruiformes, Anseriformes, Phoenicopteriformes, Ciconiiformes, Pelecaniformes, Podicipediformes, Gaviiformes). Anseriformes show the highest helminth species diversity (75 species). The smallest number of species of birds' helminths was observed in the orders Gaviiformes and Falconiformes, which were infected with 9 and 6 species of parasites, respectively. This is associated with the ecological characteristics of these groups of host birds.

About 145 species of wetland birds have been registered on the territory of Uzbekistan. This category includes several species of raptors, which also live mainly at or near bodies of water. A significant proportion of the species have adapted to inhabiting bodies of water in northwestern Uzbekistan, where wetland birds concentrate in large numbers during seasonal migrations from Siberia and Kazakhstan to their wintering grounds in the Caspian Sea, India, Pakistan and Africa (Kreuzberg-Mukhina et al., 2005).

Given below is a faunistic analysis of helminths recorded in certain orders of birds.

Helminths of Gaviformes. These are relatively large birds, whose lifestyle is closely related to the aquatic environment. They inhabit extensive and deep bodies of water. They winter mainly on sea coasts. During migration, they stop on lakes and large rivers. The breeding range covers the northern outskirts of Eurasia and America. In the Central Asian region, they are recorded on the Caspian Sea shore in Iran and Turkmenistan. In Uzbekistan, they are limited to the mouth of the Amu Darya (Kreuzberg-Mukhina et al., 2005). Two species from the order Gaviformes have been recorded in Uzbekistan – *Gavia stellata* (Pontoppidan, 1763) and *Gavia arctica* (L., 1758) on the water bodies of the Syr Darya and Amu Darya.

4 individuals of birds (two from each species) were examined, of which 3 turned out to be infected with helminths. In total, 9 species of parasites were found in Gaviformes (Cestoda – 5 species, Trematoda – 2 species, Nematoda – 2 species): *Diphyllobothrium ditremum*, *Ligula intestinalis*, *Ligula colymbi*, *Digramma interrupta*, *Tetrabothrius microcephalus*, *Eucotyle cohni*, *Diplostomum commutatum*, *Eustrongylides tubifex*, *Contracaecum spiculigerum*.

Some helminths recorded in Gaviformes were also found in birds from other orders. They included *L. intestinalis*, *D. interrupta*, *D. commutatum* and *C. spiculigerum*, which are recorded in many species from the orders Podicipediformes, Ciconiiformes and Anseriformes. For some helminth species – *D. ditremum*, *L. colymbi*, *T. microcephalus*, *E. cohni*, *E. tubifex* – Gaviformes are the main (obligate) hosts. The studied Gaviformes were infected with heteroxenic helminth species, for which fish serve as the second intermediate and reservoir (= paratenic) hosts. According to our research, there are few species common for domestic waterfowl and Gaviformes. Only one Nematoda species can be referred to this category – *C. spiculigerum*. Gaviformes play a secondary role in the spread of helminthiases of domestic birds in northwestern Uzbekistan.

Helminths of Podicipediformes. These are birds of medium and small size associated with the aquatic environment. There are 22 known species in the world fauna. 5 species are recorded in Central Asia, all of them also registered in Uzbekistan (Kreuzberg-Mukhina et al., 2005. Shernazarov et al., 2006).

Habitats: lowland lakes, reservoirs, shallow bodies of water, river floodplains covered with emergent aquatic vegetation. They are also widespread in Uzbekistan, inhabiting the lower reaches of the Amu Darya and other rivers. These are migratory and nesting birds. They also forage diving under water. They feed on invertebrates and small fish. The numbers are quite stable.

Our team studied 34 individuals of 3 species (Table 1), of which 31 were infected with helminths (90.9%). The helminth fauna recorded in Podicipediformes in North-Western Uzbekistan consists of 44 species (Cestoda – 13, Trematoda – 24, Nematoda – 7). Trematoda and Cestoda noticeably predominate in terms of specis composition. The Cestoda fauna is based on the families Ligulidae, Hymenolepididae and Tetrabothriidae. Trematoda are represented by 24 species, which is more than half (54.3%) of the helminthofauna recorded in Podicipediformes. The families Echinostomatidae, Notocotylidae, Strigeidae, Diplostomatidae and Schistosomatidae are widely represented (Table 2). The Nematoda fauna is noticeably poorer in Podicipediformes (7 species).

Podicipediformes in North-Western Uzbekistan are infected mainly with heteroxenic helminth species. Aquatic invertebrates, inhabitants of bodies of water in the studied region, mainly participate in the development of helminths of Podicipediformes. About 15 species from the classes Cestoda, Trematoda and Nematoda are common to domestic birds and Podicipediformes.

Helminths of Pelecaniformes. Large and medium-sized birds of various body shapes. There are 4 species from this order registered in Uzbekistan. They inhabit large lowland bodies of water: lakes, rivers and their deltas. They feed on fish. Status: 4 species (*Pelecanus crispus*, *P. onocrotalus*, *Phalacrocorax carbo* and *Ph. pygmaeus*).

We studied 2 individuals of *Pelecanus onocrotalus* and 3 individuals of *Phalacrocorax pygmaeus*, which had died naturally or been killed by poachers. 9 individuals of *Ph. carbo* were obtained in the hunting seasons on large bodies of water in Karakalpakstan.

Of the 14 studied individuals representing 3 species of Pelecaniformes (*Pelecanus onocrotalus*, *Phalacrocorax pygmaeus* and *Ph. carbo*) found in North-Western Uzbekistan, 12 individuals (85.7%) were infected with helminths.

According to our research (Akramova, 2011; Saparov, 2016), all the Pelecaniformes species (4) in the fauna of Uzbekistan are known as hosts of helminths.

The helminth fauna of Pelecaniformes consists of 17 species: Cestoda – 2, Trematoda – 12, Nematoda – 3 species. Nematoda are represented by an extremely poor species composition.

The most interesting helminth representatives found in Pelecaniformes are *Ligula intestinalis*, *Prosthogonimus cuneatus*, *Strigea falconis*, *Diplostomum commutatum*, *Postdiplostomum brevicaudatum*, *Dendritobilharzia loossi*, *Dendritobilharzia pulverulenta*, *Contracaecum microcephalum*, *Porrocaecum crissum* and *Desmidocercella numidica*, which are of considerable epizootological and epidemiological significance.

Helminths of Ciconiiformes. These birds are mainly large and medium-sized. Representatives of 13 species from 3 families have been recorded in Uzbekistan: Ardeidae (9 species), Ibididae (2 species) and Ciconiidae (2 species).

They nest on lakes with thickets of reeds and cattails. During migration and wintering, they are found widely along the shores of lowland bodies of water in the north of Uzbekistan, in the Aral Sea region.

Ciconiiformes are mainly ichthyophages, they forage in shallow water for aquatic and terrestrial animals. Of 13 species from this bird class inhabiting the country, we studied 5 species (Table 1), which turned out to be hosts for helminths. 45 helminth species representing Cestoda, Trematoda and Nematoda were identified.

The class Cestoda is represented by 10 species, Trematoda – 26 species and Nematoda – 9 species.

The helminth fauna of Ciconiiformes characterises these birds as typical fish-eaters. This is particularly noticeable in the case of representatives of Trematoda. Most of the trematode species are meracercariae, which develop in fish (Strigeidae, Diplostomidae).

Helminths of Phoenicopteriformes. Large birds with very long legs. The general colour of the plumage is white with a pink tinge of varying intensity or red. The order includes 5 species from 1 family – Phoenicopteridae, of which 1 species, *Phoenicopterus roseus*, inhabits Uzbekistan. It lives on the open sides of large bodies of water. Currently, it is recorded in the country only during migration and wintering. This is a migratory and breeding species in the wider region. The birds nest in large colonies (Jumanov, 2017; Ametov, 2019). The authors report the nesting of a large colony of *Ph. roseus* on the eastern edge of Lake Sudochye (25 May 2014), where about 7,000 individuals were counted and 2,985 nests found. They feed on aquatic invertebrates, mainly small crustaceans and molluscs, dipteran larvae and seeds of aquatic plants. Vulnerable, naturally rare species.

3 individuals of birds, which had died and been killed by poachers near Lake Sudochye, were examined. All the 3 individuals were infected with helminths. The helminth fauna of *Ph. roseus* consists of 18 species (Cestoda – 6, Trematoda – 7, Acanthocephala – 1 and Nematoda – 4). The discovered Cestoda are predominantly representated by the family Hymenolepididae (6 species), with 3 species – *Flamingolegis tengizi*, *F. megalorchis* and *F. flamingo* – specific to this bird. Trematoda are represented by common species that occur in other orders of wetland birds.

It should be noted that data on the fauna of flamingo helminths is preliminary in the studied region.

Helminths of Anseriformes. Aquatic birds of different sizes. They are also widely distributed in the territory of North-Western Uzbekistan. They nest on the waterside or in waterside thickets, feed on various plant and animal food. More than 36 species from the family Anatidae inhabit Uzbekistan (Kreuzberg-Mukhina et al., 2005; Shernazarov et al., 2006).

343 individuals of birds belonging to 16 species were studied (Table 1).

The most fully studied are some species from the genera *Anser*, *Anas*, *Aythya*, *Mergus*, *Netta* and *Bucephala*. We have material on 16 species of Anatidae. The total prevalence of infection in this bird class is quite high. Of the 343 individuals of birds we dissected, 322 were infected with parasites (prevalence 93.8%).

The helminth fauna in Anseriformes consists of 75 species (Cestoda – 17, Trematoda – 36, Acanthocephala – 4 and Nematoda – 18). The intensity of infection, with rare exceptions, ranges from single to dozens of individuals. In most cases, helminths occur in a mixed form. Helminthocoenoses of the digestive system were detected in 275 individuals (77.2%) of birds.

The parasites inhabiting the digestive system include 47 species representing Trematoda, Cestoda, Acanthocephala and Nematoda.

The components of parasitocoenosis form various combinations: associations of from three to seven species. Most often, three to five species were recorded in the parasitocenoses of Anseriformes.

For the majority of helminth species, Anseriformes are obligate hosts which play an important role in the distribution of parasitic worms in North-Western Uzbekistan.

About 40 species from the classes Cestoda, Trematoda, Acanthocephala and Nematoda are common to wild Anseriformes and domestic waterfowl (ducks and geese).

Helminths of Gruiformes. The Gruiformes fauna of Uzbekistan is represented by Gruidae, Rallidae and Otididae. Most of them are semi-aquatic birds living in damp places with dense vegetation, on lakes with thickets and wet meadows. They feed mainly on plants, but can also eat animal food. In Uzbekistan, this order is represented by 3 families: Gruidae (3 species), Rallidae (7 species) and Otididae (3 species). There are 13 species in total. We examined 34 individuals belonging to two species – *Gallinula chloropus* and *Fulica atra*, of which 22 individuals were infected with helminths (64.6%).

The helminth fauna of Gruiformes consists of 39 species, representing Cestoda (8 species), Trematoda (22 species), Acanthocephala (2 species) and Nematoda (7 species). The highest helminth species diversity of all classes was found in *Fulica atra*, which is directly associated with its aquatic lifestyle.

Gruiformes are parasitised with helminths common to birds from other orders. The studied birds in North-Western Uzbekistan are infected mainly with heteroxenic forms of helminths.

Helminths of Charadriiformes. The order Charadriiformes unites birds of varying biology and ecology. The vast majority of its species are aquatic or semi-aquatic. Representatives of 8 families are recorded in Uzbekistan. They eat mainly animal food (insects, worms, aquatic and terrestrial molluscs, crustaceans, fish). The diet also includes plants – algae, aquatic plants, their seeds and berries. The total number of Charadriiformes species belonging to the fauna of Uzbekistan is 72. Several studied bird species (Sultanov, 1963; Turemuratov, 1964) turned out to be hosts for a complex of helminth species from the classes Cestoda, Trematoda, Acanthocephala and Nematoda. 46 individuals belonging to five bird species from the order Charadriiformes were studied. The total prevalence was 80.4%; the intensity of infection ranged from single to dozens of parasite individuals.

The fauna of helminths of Charadriiformes consists of 57 species. The class Cestoda is represented by 13 species, Trematoda by 33 species, Nematoda by 10 species and Acanthocephala by only one species.

The highest helminth species diversity in Charadriiformes was shown by Trematoda, which accounted for 56.1% of the total helminth fauna. Of the recorded Trematoda species (33), representatives of the families Echinostomatidae, Notocotylidae, Microphillidae, Plagiorchidae, Prosthogonimidae, Strigeidae and Schistosomatidae are the commonest in the studied region.

Helminths of Falconiformes. Falconiformes are birds of prey; mostly carnivorous, foraging for live prey or carrion. There are about 40 species in the fauna of Uzbekistan, some of which are closely associated with water bodies by their lifestyle and depend on fish or wetland birds (Mukhina-Kreuzberg et al., 2005). Two individuals of two bird species were studied (Table. 1); both were infected with parasites. We identified 6 species of Trematoda: *Opistorchis geminus*, *Plagiorchis elegans*, *Strigea falconis*, *Diplostomum spathaceum*, *D. commutatum* and *Neodiplostomum spathula*. Data on the helminth fauna of the Falconiformes obtained by us is of a purely representative nature. Further research based on sufficiently complete helminthological material is needed.

Thus, in North-Western Uzbekistan, helminths were recorded in 39 species of wetland birds. Of the total number of 500 individual birds we studied, 429 (85.8%) were infected with helminths. The intensity of infection is low and varies widely from single to several dozen individuals.

The helminth fauna is unequally distributed across the orders of wetland birds (Table 3). The highest helminth species diversity is recorded in Anseriformes (75 species), Charadriiformes (57 species) and Ciconiiformes (45 species). Significantly fewer species were observed in Falconiformes (6 species), Gaviiformes (9 species) and Phoenicopteriformes (18 species).

Table 3
Distribution of helminths across hosts

Bird orders	Number of helminth species			
	Cestoda	Trematoda	Acanthocephala	Nematoda
Gaviiformes	5	2	–	2
Podicipediformes	13	24	–	7
Pelecaniformes	2	12	–	3
Ciconiiformes	10	26	–	9
Phoenicopteriformes	6	7	1	4
Anseriformes	17	36	4	18
Gruiformes	8	22	2	7
Charadriiformes	13	33	1	10
Falconiformes	–	6	–	–

The noticeable similarity of helminth faunas in different orders of birds (with the exception of Falconiformes, Phoenicopteriformes and Gaviiformes, which have not been sufficiently studied) is obvious due to the high trophic plasticity of wetland birds and the natural and climatic conditions of North-Western Uzbekistan. As is known, the diet of wetland birds is highly diverse, and intermediate and reservoir (=paratenic) hosts of helminths – various groups of invertebrates and vertebrates (fish) – make up a significant portion of it. Analysis of the sources of helminth infection for individual groups of wetland birds showed that the vast majority of the identified helminth species are heteroxenic forms, developing through intermediate and reservoir hosts. They include all species of Cestoda, Trematoda and Acanthocephala.

Monoxenic forms of helminths were found only among nematodes (4 species: *Strongyloides turkmenica*, *Trichostrongylus tenuis*, *Epomidiostomum uncinatum* and *Ascaridia galli*), which accounts for 3.4%. Thus, of 112 identified helminth species, the life cycles of 111 (99.1%) take place in freshwater ecosystems, and 1 (*Davainea proglottina*) in terrestrial ones. In the studied region, we found this species in two individuals out of 75 studied domestic ducks in a private sector of Nukus District of the Republic of Karakalpakstan. The intensity of infection was two and three individuals of mature Cestoda. The issue of parasitisation of *D. proglottina* in ducks is not entirely clear. According to known data (Movsesian, 2003), this species is a parasite of terrestrial birds, mainly domestic and wild Galliformes. Our discoveries probably indicate the participation of the duck population in the life cycle of this species as an accidental host.

We think we can specify some patterns of spatial distribution of helminths whose final developmental stage takes place in the wetland birds of North-Western Uzbekistan.

When we attempted to specify the sources of infection for wetland birds, it turned out that the development of many helminth species had not yet been studied. Therefore, we were guided by the known data on the life cycles of helminths from specific groups by analogy with similar species of parasites, taking into account the diet of host birds (Table 4).

It was found that most of the detected helminth species enter the body of birds in various ways, where intermediate, additional and reservoir hosts serve as sources of infection. We used the data provided in Table 4 to find out the importance of various paths by which helminths are transmitted in the circulation of infections.

Classifying ways of the penetration of helminths into the definitive host, Kontrimavicius (1969) identifies the following four :

1) a helminth penetrates the host when the latter eats other organisms, which as intermediate or reservoir hosts are included in its diet;

2) a helminth enters the host as mechanical impurity in food or water;

3) a parasite actively penetrates the host's body;

4) a helminth is transmitted by an intermediate host eaten by a definitive one.

Our material demonstrates these ways of transmitting helminths to host birds. Most of the intermediate hosts for representatives of the class

Cestoda were crustaceans – inhabitants of different types of water bodies; Oligochaeta are also included here as second or reservoir hosts. Terrestrial molluscs were recorded as intermediate hosts only for Cestoda from the genus *Davainea*.

Table 4

Information about the main sources of infection with helminths in various trophic-ecological groups of wetland birds in North-Western Uzbekistan

Sources of infection	Classes of helminths			
	Cestoda	Trematoda	Acanthocephala	Nematoda
Oligochaeta	+			+
Aquatic molluscs		+		
Terrestrial molluscs	+			
Crustaceans	+		+	+
Insects		+		+
Fish, amphibians, reptiles	+	+		+
Adolescaria on plants and water objects		+		
Trematode cercariae (nematode larvae), which actively penetrate into organisms		+		+
Invasive eggs, helminth larvae ingested with food or water				+

The development of trematodes occurs with the participation of aquatic molluscs acting as the first intermediate host. Various species of insects, fish, amphibians, reptiles and small mammals were identified as the second hosts. Nematoda use a wider range of intermediate hosts (Oligochaeta, crustaceans, insects – aquatic and terrestrial). Fish and amphibians were registered as the second and reservoir hosts of nematodes.

If we distribute the known helminths of wetland birds in the studied region of Uzbekistan across the mentioned groups, we can obtain a very clear picture reflected in Table 5. Helminths referred to accidental parasites of wetland birds (*Davainea proglottina*), which we found in domestic ducks, are not included in it. The helminthofauna of aquatic and semi-aquatic birds in North-Western Uzbekistan is strongly dominated by parasites associated with hosts by trophic relations (87.3% of the total number of species). This group includes Cestoda – 100% (with the exception of one species – *Davainea proglottina*), Trematoda – 92.1%, Acanthocephala – 100% and Nematoda – 77.2%.

Infection of 14.4% of helminth species occurs topically. This should include 2–4 groups of parasites (Table 4). Cercariae of 6 species of trematodes (Schistosomatidae: representatives of the genera *Bilharziella*, *Trihobilharzia*, *Ornithobilharzia*, *Dendritobilharzia* and *Gigantobilharzia*) and larvae of one species of nematode (Strongyloididae: *Strongyloides turkmenica*) penetrate the body only parenterally. Three species of monoxenic nematodes (13.6%) can parasitise only orally, when infectious eggs or larvae are ingested accidentally. Only one species of nematodes (*Paronchocerca tonkinensis*) is transmitted through the bites of blood-sucking Diptera, which makes up 0.9%.

Table 5

Distribution of helminths of wetland birds across groups depending on the way of infecting a definitive host

Groups	Nature of coenotic relationship	Way of infecting a host	Number of species				
			total	Cestoda	Trematoda	Acanthocephala	Nematoda
1	Trophic	Eating animals as food objects	96 (87.3%)	27 (100%)	51 (92.1%)	4 (100%)	17 (77.2%)
2	Topical	Accidental ingestion of eggs or larvae	8 (72.0%)	–	5 (90.0%)	–	3 (13.6%)
3	Topical	Active penetration of larvae through the skin	7 (6.3%)	–	6 (11.5%)	–	1 (4.5%)
4	Topical	Transmission by biting insects	1 (0.9%)	–	–	–	1 (4.5%)
		Total	112	27	62	4	22

The ecological connections of birds with helminths infecting hosts topically are quite clear and do not require much discussion.

Let us take a closer look at the trophic relationships of wetland birds that affect the composition of their helminth fauna.

Table 3 provides information about the intermediate hosts of helminths of aquatic and semi-aquatic birds. Animals from many classes participate in the transmission of infectious helminth larvae. The pattern quite often includes reservoir hosts consisting of both invertebrates and vertebrates.

Oligochaeta serve as intermediate hosts for five species of nematodes; three of them (Capillaridae) are transmitted through eating earthworms (Oligochaeta). Intermediate hosts for two species (Dioctophymidae) are aquatic Oligochaeta from the family Tubificidae and fish. The cycle may involve reservoir hosts: predatory fish, amphibians and aquatic reptiles. Birds become infected through eating both intermediate and reservoir hosts.

Pulmonate molluscs (terrestrial) in our material turned out to be intermediate hosts only for *Davainea proglottina*. Birds become infected also by eating infected molluscs.

Examining 4,310 individuals of molluscs from bodies of water in North-Western and Central Uzbekistan, in places of concentration of wetland birds, we recorded Trematoda cercariae in representatives of the Lymnaeidae, Planorbidae, Physidae and Thiaridae.

The discovered cercariae were representatives of the following trematode families: Notocotylidae, Echinostomatidae, Phylophtalmidae, Schistosomatidae, Strigeidae and Diplostomatidae. Birds become infected through eating molluscs infected with larvae, with the exception of Schistosomatidae, whose cercariae penetrate through the skin of birds.

Crustaceans, an extensive group of inhabitants of different types of water bodies, are intermediate hosts for Cestoda, Acanthocephala and Nematoda. In our material, most representatives of Cestoda, all of Acanthocephala and some nematode species developed with the participation of crustaceans. It should be noted that reservoir hosts – fish, amphibians and aquatic reptiles – are involved in the life cycles of a number of species. Birds are infected when eating parasitised intermediate hosts, crustaceans, on the one hand, and reservoir ones (fish and other) on the other hand. Fish are readily eaten by fish-eating birds, which determines their role in the transmission of infectious elements of the mentioned helminths – Cestoda, Acanthocephala and Nematoda of wetland birds.

Insects are intermediate hosts for several species of flukes and nematodes of aquatic and semi-aquatic birds in northwestern Uzbekistan. For two species of trematodes from the family Plagiorchidae and two species from Prosthogonimidae, insects (dragonflies) serve as second intermediate hosts. In the life cycles of nematodes, insects (orthopterans) participate as intermediate hosts. Our material presents nematodes from the families Tetrameridae, Streptocaridae and Oswaldofilariidae, in whose development some species of terrestrial insects participate, acting as intermediate hosts (Ryzhikov et al., 1973; Anderson, 2000). Birds become infected by eating infected insects.

Fish are involved as a second intermediate host in the life cycles of a number of species of cestodes, trematodes and nematodes. The development of five species of cestodes (Diphyllobothridae, Ligulidae, Tetrabothridae), eight species of trematodes (Strigeidae, Diplostomatidae) and three species of nematodes (Desmidocercidae, Dioctophymidae) occurs with the participation of fish, which acts as an intermediate host.

Thus, from among obligate and accidental parasites of wetland birds in North-Western Uzbekistan, about 88% of parasite species infecting with the help of trophic relations penetrate into birds' organisms when the latter eat intermediate and reservoir hosts.

Cercariae of six species of trematodes (Schistosomatidae) and larvae of one nematode species (Strongyloidae) penetrate the body of birds actively. Adolescariae of five species (Notocotylidae) are swallowed by birds with plants and other objects submerged in water.

The food chains of individual orders of wetland birds largely determine the composition of the helminths parasitising them and are the main factor in the formation of their helminth fauna. These processes undoubtedly occur in time and space under the strict control of environmental factors.

The combination of these factors has determined the appearance of the modern helminth fauna in wetland birds in North-Western Uzbekistan.

Our research shows that a wide range of animals acting as intermediate, additional and reservoir hosts participate in the formation of the helminth fauna of wetland birds and the circulation of infections (Fig. 2).

As already mentioned, the helminthofauna of aquatic and semi-aquatic birds in North-Western Uzbekistan consists of 112 species, 36 of which (32.1%) are associated with representatives of other classes of vertebrates inhabiting the studied territory. The circulation of 25 species (22.30%) involves fish, 5 species (4.46%) – amphibians, 4 species (3.57%) – aquatic reptiles and 2 species (1.78%) – mammals.

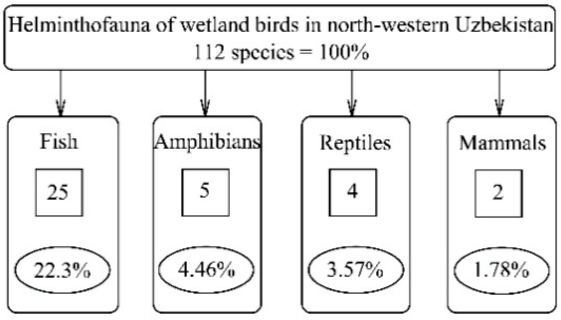

Fig. 2. Relation of helminthofauna of wetland birds with other classes of vertebrates in North-Western Uzbekistan: □ – number of helminth species, ⬭ – %

It should be emphasised that cercariae of six species of trematodes from the family Schistosomatidae – parasites of wetland birds – can actively penetrate through the skin of humans in bodies of water (Akramova et al., 2019). For these flukes, the human body is a biological dead end.

These data indicate that fish (25 species of parasites) have a fairly close relationship with the helminths of wetland birds, due to the common habitats of the animal groups in question.

Among the discovered helminths of wetland birds, a number of species are pathogenic (Ligulidae, Hymenolepididae, Echinostomatidae, Notocotylidae, Prostogonimidae, Strigeidae, Diplostomatidae, Schistosomatidae, Polymorphidae, Amidostomatidae, Ascarididae, Anisakidae, Acuaridae, Tetrameridae, Desmidocercidae), causing dangerous helminthiases of wild and domestic birds, fish and humans.

Discussion

The Aral Sea, a large endorheic lake located in the deserts of Central Asia, has shrunk and become salinised to an unprecedented degree over the past 60 years. This has had a negative environmental impact on the lake and the deltas of two rivers flowing into it – the Amu Darya and the Syr Darya. The population of the territories adjacent to the lake has also felt the negative consequences of the degradation of the sea, which has led to the deterioration of the environment and the biological diversity of wildlife (Geographical Atlas of Uzbekistan, 2012).

The modern regression of the Aral Sea also had an impact on the parasitofauna of wetland birds of this specific region, which made it necessary to study it against the modern environmental background.

The first information about the helminthofauna of the fish-eating birds of the Aral Sea was provided by Skrjabin (1924), which provides data on the discovery of 12 species of helminths in the greater pelican, gulls, terns and grebes (trematodes – 9 species, cestodes – 2 and nematodes – 1). Similar studies on the helminths of fish-eating birds on the Aral Sea were conducted by A. Turemuratov during 1958–1960. Based on the results of this work and available data of previous studies, the number of helminth species parasitising the fish-eating birds of the Aral Sea rose to 133 species from the classes Cestoda (24 species), Trematoda (67 species), Acanthocephala (4 species) and Nematoda (38 species). In the Aral Sea basin, comprehensive studies of the helminth fauna of wetland birds, with the exception of fish-eaters, have not been conducted. The available information about the helminthofauna of the birds of Uzbekistan (Sultanov, 1963) refers to general faunal works, the author of which presents fragmentary material collected from a limited number of species of wetland birds only on the territory of two districts (Chimbay and Kegeili) of Karakalpakstan.

In the early 2020, the research into the fauna of parasites of birds in Uzbekistan were resumed (Akramova, 2011; Saparov, 2016), which resulted in the publication of a series of papers on trematodes (Schistosomatidae) and nematodes (Filariata) parasitizing the wetland birds of Uzbekistan. The Schistosomatidae fauna in wetland birds consists of 13 species, representatives of the following genera: *Bilharziella* (1 species), *Trichobilharzia* (4 species), *Macrobilharzia* (1 species), *Ornitobilharzia* (1 species), *Dendritobilharzia* (3 species), *Gigantobilharzia* (1 species) and *Gigantobilharziella* (1 species) (Akramova, 2011).

Nematodes from the suborder Filariata parasitising the birds of Uzbekistan, including wetland ones, are represented by 53 species belonging to the families Filariidae, Aproctidae and Diplotrinenidae (Saparov, 2016). The author notes that the total prevalence among birds infected with nematodes from the suborder Filariata was 13.8%. In individual groups of birds the prevalence ranged from 2.0% to 31.6%.

Data on the species diversity of helminths of fish-eating birds in Karakalpakstan (the Aral Sea) presented by Sultanov (1963) and Turemuratov are quite outdated and do not reflect the modern helminth fauna of wetland birds. This is confirmed by the results of our research. We identified 112 species of helminths parasitising wetland birds of North-Western Uzbekistan.

More than 20 species were absent from our material: from the class Cestoda – the genera *Tatria*, *Dendrouterina*, *Dubininolepus*, *Wardium*; from the class Trematoda – *Euclinostomum*, *Diplostomum*, *Bolboforus*, *Hystymorpho*, *Neodiplostomum*, *Postdiplostomum*, *Pegosomum*, *Tanaisia*, *Pylophtalmus*, *Renicola*; from the class Nematoda – *Antennocara*, *Cosmocephalus*, *Strepocara*, *Skrjabinocara*, *Eucoleus*, *Aviocerpens*, *Chinerocerca*, *Cyastosoma*, *Agamospirura*. This was probably caused by changes in the environmental situation in the Aral Sea region and adjacent territories. Birds that had lived there previously moved to other bodies of water, where the parasite-host relationships with the above-mentioned groups of helminths probably did not stabilise and, as a result, they were removed from the common helminth fauna of wetland birds.

Wetland birds are known to show high ecological and trophic flexibility. Birds are mainly infected through food connections with food objects – intermediate and reservoir hosts, which is typical for heteroxenic forms of helminths. This is confirmed by numerous publications by both national and foreign authors (Schultz & Gvozdev, 1972; Ryzhikov et al., 1973, 1974; Anderson, 2000). The larvae of some species (Schistosomatidae and Strongyloididae) penetrate actively through birds' skin, even though they are not part of the birds' diet (Akramova, 2011).

The studies show that animals from a number of classes (Oligochaeta, aquatic and terrestrial molluscs, crustaceans, insects, fish, amphibians, reptiles) participate in the transmission of invasive elements of helminths of birds. They can act as intermediate or reservoir hosts (Panin, 1957; Karmanova, 1968; Smogorzhevskaya, 1976; Krasnolobova, 1987; Anderson, 2000).

Thus, the data we have obtained are generally consistent with the information available in literature on the fauna of helminths of wetland birds in Uzbekistan (Sultanov, 1963; Turemuratov, 1964) and adjacent territories – Tajikistan (Borgarenko, 1981, 1984, 1990). The comparison of data on the modern fauna of helminths of aquatic and semi-aquatic birds in the north-west of Uzbekistan with the material of earlier studies (Sultanov, 1963; Turemuratov, 1964) indicates some changes in the species diversity of parasites, probably due to the current environmental characteristics of North-Western Uzbekistan.

Conclusion

The helminth fauna of wetland birds in North-Western Uzbekistan is characterised by high species diversity. Faunistic complexes consisting of representatives of four classes of helminths (Cestoda, Trematoda, Acanthocephala and Nematoda) show the originality of the helminth fauna of birds – inhabitants of aquatic ecosystems. The diversity of parasite species and their ratios in this region are determined by the history of the formation of water bodies and the distribution of helminths across main hosts.

The most diverse and ample helminth fauna is characteristic of representatives of Anseriformes (75 species).

Representatives of the class Trematoda are dominant in terms of species composition (57 species) and occurrence in the studied region.

The specific ecological characteristics and location of large bodies of water in the region account for the diversity of flukes of aquatic and semi-aquatic birds. Bodies of water provide a high variety of faunistic complexes with their trophic relations and, as a result, ensure optimal conditions for the circulation of trematodes with different life cycles.

In general, the data obtained on the helminthofauna of wetland birds in North-Western Uzbekistan made it possible to expand the fauna and specify the general trend in changes in the species diversity of parasites, which probably depends on the ecological characteristics of the region.

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