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A REVIEW OF CURRENT KNOWLEDGE ON PARASITES OF NON-INDIGENOUS FISH SPECIES IN THE INLAND WATERS OF TURKEY

Deniz INNAL * and *Mala-Maria STAVRESCU-BEDIVAN* **

* Mehmet Akif Ersoy University, Department of Biology, Burdur, Turkey, TR-15030, innald@gmail.com, ORCID: 0000-0002-1686-0959.

** University of Agronomic Sciences and Veterinary Medicine of Bucharest, Faculty of Agriculture, Department of Plant Protection, Mărăşti Boulevard 59, Bucharest, Romania, RO-011464, mala_stavrescu@yahoo.com, ORCID: 0000-0001-9825-417X.

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ABSTRACT

The parasite fauna of alien fish species living in the new habitats has rarely been investigated and there is still poor information about this topic.

This research not only provides a thorough list of parasite taxa found in non-indigenous fish species in Turkey, but it highlights the risk of infection for both native and alien ichthyofauna.

With respect of native range, exotic fishes imported into Turkey have been found to be hosts for parasities from Eurasian, Asian, and North American origins, respectively.

RÉSUMÉ: Une revision des connaissances actuelles sur les parasites des espèces de poissons non indigènes dans les eaux intérieures de la Turquie.

La faune parasitaire des espèces de poissons exotiques vivant dans les nouveaux habitats a été rarement étudiée et il y a encore peu d'informations sur ce sujet.

Cet article fournit non seulement une liste de contrôle complète sur les différents taxons de parasites des espèces de poissons non indigènes de Turquie, mais en même temps, met en évidence le risque d'infection pour l'ichtyofaune indigène et aussi pour l'ichtyofaune invasive.

En ce qui concerne la zone de répartition natale, on a été montré que les poissons exotiques introduits en Turquie sont des hôtes à la fois pour les parasites d'origine eurasienne ou d'origine asiatique et nord-américaine, respectivement.

REZUMAT: O revizuire a cunoștințelor actuale despre paraziții speciilor de pești neindigeni din apele interioare ale Turciei.

Fauna parazită a speciilor de pești străini introduși în habitate noi a fost rareori investigată și există încă informații sporadice despre acest subiect.

Această lucrare oferă nu numai o listă de verificare cuprinzătoare a diferiților taxoni de paraziți ai speciilor de pești neindigeni din Turcia ci, în același timp, evidențiază riscul de infecție pentru ihtiofauna nativă și, de asemenea, pentru ihtiofauna invazivă.

În legătură cu arealul nativ, s-a arătat că peștii exotici introduși în Turcia sunt gazde atât pentru paraziți de origine eurasiatică, cât și pentru cei cu origine asiatică și nord-americană.

INTRODUCTION

Freshwater fish are threatened by many factors, such as habitat degradation and fragmentation, species introductions and translocations, impoundment of rivers, water quality deterioration as well as overexploitation (Cowx and Collares-Pereira, 2002).

Non-native fish species have been intentionally introduced in numerous regions of the world for various reasons and by several vectors, such as sport, food, biocontrol, ornamental, contaminated stock, escapes from cage aquaculture, or man-made water connections (Welcomme, 1988; Copp et al., 2005a; Canning-Clode, 2015; Tarkan et al., 2015). Non-indigenous fish introductions in freshwater resources can result in extremely severe issues, including: wide borders of tolerance, competition with indigenous species, parasitism, emergence of new diseases, predation, hybridization, alteration of habitat quality, and ecosystem health (Kumar, 2000; Copp et al., 2005b; Emiroğlu, 2011).

Anthropochore movements of host population are important in the dispersal of their helminth parasites in new habitats (Kennedy et al., 1991; Kennedy, 2006). Intensive modern aquaculture caused increased introduction and translocation of infectious pathogens, considered to be serious threats to aquatic biodiversity and management of fisheries (Gozlan et al., 2006; Reading et al., 2011). The colonization, establishment, and pathogenicity of introduced parasites are influenced by numerous biotic and abiotic factors (Kennedy, 1994).

A variety of alien and translocated fish species have been introduced into inland waters of Turkey in the past (Çetinkaya, 2006; Innal and Erk'akan, 2006). Tarkan et al. (2015) postulated that Turkey introduced 30 fish species, of which 11 species represent translocations. The main reason for introduction of aquatic species in Turkey is for the purpose of aquaculture, followed by ornamental fish production, recreational fisheries, and fisheries improvement. There have been reports concerning the release of many aquarium fishes into spring water and the severe impact on native biota (Emiroğlu et al., 2016).

There is still limited information in the studied area about the parasite fauna of non-native fish species introduced in new habitats. Öktener (2014a, b) provided a list of freshwater and marine fish parasites from Turkey, excluding parasitic helminths and crustaceans. Some alien parasite species such as Asian fish tapeworm, *Schyzocotyle acheilognathi*, and Eel swimbladder nematode, *Anguillicoloides crassus*, are widespread and have been recorded on native fish species (Genç, 2005; Çolak et al., 2012; Innal et al., 2016; Innal et al., 2018; Hansen and Alarcón, 2019). This research provides an overview of the current state of knowledge on various groups of parasites with different origin recorded in alien fish species living in Turkish freshwater bodies.

MATERIAL AND METHODS

This study scanned the scientific data of the inland waters of Turkey. The following systems were considered: closed (laboratory), farm in creek, dam lake, or natural lake. A checklist comprising parasite species, alien fish host species, native range, and species authorship was compiled based on available scientific literature. For those taxa for which sufficient data regarding the origin of the parasite and their status was uncertain, the checklist includes "unknown" or "limited data". The mentioned parasites belong to alien species living in natural waters, and some parasites have been detected under aquaculture conditions. Some parasites of *Oncorynchus mykiss* (Walbaum, 1792) and *Salvelinus fontinalis* (Mitchill, 1814) have been reported from the marine environment. Some references are used in the regulations on taxonomy of fish parasites (Bunkley-Williams and Williams, 1994; Woo et al., 1995; Kirjušina and Vismanis, 2007; Wootten, 2012; Colorni et al., 2014). The scientific and common names for fish species were given according to Fishbase (Froese and Pauly, 2021).

RESULTS AND DISCUSSION

The systematic status and name of fish hosts are listed in table 1, while the check list of parasites of alien fish in Turkey is presented in table 2.

Table 1: Systematic status of non-indigeneous host fish species in Turkey.

No.	Species	Common name	Family
1.	*Lepomis gibbosus* (Linnaeus, 1758)	Pumpkinseed	Centrarchidae
2.	*Oreochromis aureus* (Steindachner, 1864)	Blue tilapia	Cichlidae
3.	*Oreochromis niloticus* (Linnaeus, 1758)	Nile tilapia	Cichlidae
4.	*Sarotherodon galilaeus* (Linnaeus, 1758)	Mango tilapia	Cichlidae
5.	*Coptodon rendalli* (Boulenger, 1897)	Redbreast tilapia	Cichlidae
6.	*Coptodon zillii* (Gervais, 1848)	Redbelly tilapia	Cichlidae
7.	*Carassius auratus* (Linnaeus, 1758)	Goldfish	Cyprinidae
8.	*Carassius gibelio* (Bloch, 1782)	Prussian carp	Cyprinidae
9.	*Pseudorasbora parva* (Temminck and Schlegel, 1846)	Topmouth gudgeon	Gobionidae
10.	*Morone saxatilis* (Walbaum, 1792)	Striped bass	Moronidae
11.	*Morone chrysops* × *Morone saxatilis*	Hybrid bass	Moronidae
12.	*Gambusia holbrooki* (Girard, 1859)	Eastern mosquitofish	Poeciliidae
13.	*Oncorynchus mykiss* (Walbaum, 1792)	Rainbow trout	Salmonidae
14.	*Salvelinus fontinalis* (Mitchill, 1814)	Brook trout	Salmonidae
15.	*Ctenopharyngodon idella* (Valenciennes, 1844)	Grass carp	Xenocyprididae

Parasites occur in alien freshwater fishes both in natural water systems and in aquaculture environments. Parasite species were reported from the following 15 alien fish hosts: *Carassius auratus* (Linnaeus, 1758), *Carassius gibelio* (Bloch, 1782), and *Ctenopharyngodon idella* (Valenciennes, 1844) introduced for the weed control, *Gambusia holbrooki* (Girard, 1859), hybrids of *Morone chrysops* (Rafinesque, 1820) × *Morone saxatilis* (Walbaum, 1792), *Morone saxatilis*, *Lepomis gibbosus* (Linnaeus, 1758), *Oreochromis aureus* (Steindachner, 1864), *Oreochromis niloticus* (Linnaeus, 1758), *Oncorynchus mykiss* (Walbaum, 1792) introduced in many dam lakes, *Pseudorasbora parva* (Temminck and Schlegel, 1846), *Salvelinus fontinalis* (Mitchill, 1814) introduced in fish farming in the Black Sea region, *Sarotherodon galilaeus* (Linnaeus, 1758), *Coptodon rendalli* (Boulenger, 1897) and *Coptodon zillii* (Gervais, 1848).

Some parasite species of these alien fish hosts have been found in aquaculture systems and potentially pose a threat towards species of natural water systems.

According to the present bibliographical research, both protozoans and metazoans major groups of parasitofauna are recorded in non-indigenous fish species of Turkey, as follows: ciliates (eight genera), flagellates (three genera), mixozoans (one species), monogeneans (five genera), cestodes (three genera), digeneans (five genera), acanthocephalans (two genera), nematodes (six genera), annelids (one species), bivalve mollusks (*Glochidium larvae*), and crustaceans (three genera).

In addition to these categories, for the parasitofauna of non-indigenous ichthyofauna representatives in Turkey it can also be mentioned *Sphaerothecum destruens*, a mesomycetozoean fish pathogen (Arkush et al., 2003).

Based on previous published records, the highest numbers of parasites taxa (24) were reported in salmonid *Oncorhynchus mykiss*.

On the other hand, the highest numbers of infected fish hosts (6) related to a specific parasites species were observed in protozoans *Chilodonella piscicola* and *Ichthyophthirius multifiliis.*

While the majority of parasitofauna in freshwater fish of Turkey has an Asian origin (originated mainly in China), seven taxa have an Eurasian origin (*Ichthyobodo necator*, *Chilodonella cyprini*, *Ichthyophthirius multifiliis*, *Apiosoma piscicolum*, *Dactylogyrus minutus*, *Trichodina acuta*, and *Piscicola geometra*, and *Lernaea cyprinacea*), six species are native in Europe (*Trichodina claviformis*, *Trichodina domerquei*, *Ligula intestinalis*, *Crepidostomum farionis*, *Schulmanela petruschewskii*, and *Argulus foliaceus*), and only one parasite species has an North American origin (*Onchocleidus similis* syn. *Urocleidus similis*).

Overall, the most frequently found parasites in freshwater alien fish of Turkey were protozoans. Among them, *Ichyophthirius multifiliis*, *Ichthyobodo necator*, and *Trichodina* spp., are the most important and common in all aquatic systems (Kayış et al., 2013). *I. necator* represents a detrimental species that economically affects the cultured *Oncorhynchus mykiss* (Ogut and Akyol, 2007).

Although the parasites of non-native species are introduced in a new range, it has been hypothesized that native parasites could also infect the non-native fishes (Sheath et al., 2015). Yuryshynets et al. (2019) noted that is difficult to assess whether it is about a co-introduction with the fish host or an acquisition in the new environment, as long as parasites remain unidentified to species level. Sometimes it could be possible that non-indigenous fish invading a local ichthyofauna have transmitted fewer parasite species than they have received from the native hosts (Rauque et al., 2018).

Anguilla anguilla (Linnaeus, 1758) is a threatened species of brackish water systems in Turkey. It is native and has an economic value. Some alien parasite such as *Anguillicoloides crassus* Kuwahara, Niimi and Itagaki 1974 affect the health status of this fish species, producing inflammations and hemorrhages in the swimbladder. The nematode *A. crassus* arrived from Asia to Mediterranean countries at the beginning of 1980s, with Japanese eel, *Anguilla japonica* (Innal et al., 2018). Moreover, in estuarine habitats of Turkey, another Asian parasite, namely the monogenean *Pseudodactylogyrus anguillae* (Yin and Sproston, 1948) Gusev, 1965 was reported on the gills of *A. anguilla* (Çolak et al., 2012).

Another highly invasive parasite species that cause massive fish kills is *Schyzocotyle acheilognathi* (Yamaguti, 1934), a cestode introduced from China with the grass carp *Ctenopharyngodon idella* (Valenciennes, 1844), used for weed control of the aquatic systems (Innal et al., 2016). After its discovery in Turkey in the 1970s, *S. acheilognathi* has negative implications for the populations of native and endemic fish species (Innal et al., 2016).

The monogenean *Onchocleidus similis* Müller, discovered in 1936, is also considered an alien parasitic species of ichthyofauna in Turkey (Çolak, 2013). It has been recorded on the host *Lepomis gibbosus* (Soylu, 2014), a North American freshwater fish. In Turkey, *Lepomis gibbosus* is one of the most successful alien fish species, with an increasing dispersal area (Innal, pers. obs.).

Infecting multiple organs within its host, the fungus-like parasite *Sphaerothecum destruens*, originated in China, belongs to Mesomycetozoea class (Sana et al., 2017). In Turkey, it is found in the cyprinid species *Pseudorasbora parva* (Ercan et al., 2015), a fish native to East Asia.

Also, the parasitic copepod *Neoergasilus japonicus* (Harada, 1930) (Ergasilidae), native to East Asia, was observed in inland water systems of Turkey. It was reported from the native fish species *Scardinius erythrophthalmus* (Soylu and Soylu, 2012).

Table 2a: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Mesomycetozoea				
Sphaerothecum destruens Arkush, Mendoza, Adkison and Hedrick, 2003	*Pseudorasbora parva*	Sarıçay stream, Muğla	Ercan et al. (2015)	China
	Lepomis gibbosus			
Euglenozoa, Kinetoplastida				
Ichthyobodo sp.	*Oncorhynchus mykiss*	Aquaculture	Soylu (1985)	ld/u
			Altunay (2006)	
			Altunay and Yıldız (2008)	
			Balta et al. (2019)	
Ichthyobodo necator (Henneguy, 1883) Pinto, 1928	*Oncorhynchus mykiss*	Aquaculture	Soylu (1996)	Eurasia
			Burgu et al. (1988)	
			Kayiş (2006)	
			Ögüt and Akyol (2007)	
			Balta et al. (2008)	
	Salvelinus fontinalis	Aquaculture	Kayiş (2006)	
			Balta et al. (2008)	
Metamonada, Trepomonadea				
Hexamita salmonis (Moore, 1922)	*Oncorhynchus mykiss*	Aquaculture	Öğüt and Akyol (2005)	ld/u
			Ögüt and Akyol (2007)	
			Balta et al. (2018)	
Spironucleus salmonicida Jørgensen and Sterud (2006)	*Oncorhynchus mykiss*	Aquaculture	Balta et al. (2019)	ld/u

Table 2b: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Ciliophora, Oligohymenophorea				
Ambiphrya sp.	Hybrid bass	Aquaculture	Tokşen (2006)	ld/u
	Morone saxatilis	Aquaculture	Tokşen (2006)	
	Oncorhynchus mykiss	Aquaculture	Özçelep (2009)	
Apiosoma piscicolum Blanchard, 1885	*Oncorhynchus mykiss*	Aquaculture	Ögüt and Akyol (2007)	Eurasia
Apiosoma sp.	*Oncorhynchus mykiss*	Aquaculture	Burgu et al. (1988)	ld/u
			Altunay (2006)	
			Altunay and Yıldız (2008)	
			Özçelep (2009)	
Epistylis sp.	*Morone saxatilis*	Aquaculture	Tokşen (2006)	ld/u
	Oncorhynchus mykiss	Aquaculture	Ögüt and Akyol (2003)	
			Altunay (2006)	
			Altunay and Yıldız (2008)	
			Özçelep (2009)	
	Hybrid bass	Aquaculture	Tokşen (2006)	
Ichthyophthirius multifiliis Fouquet, 1876	*Ctenopharyngodon idella*	Aquaculture	Uzbilek and Yıldız (2002)	Eurasia
	Salvelinus fontinalis	Aquaculture	Balta et al. (2008)	
	Hybrid bass	Aquaculture	Tokşen (2006)	
	Morone saxatilis	Aquaculture	Tokşen (2006)	
	Oncorhynchus mykiss	Aquaculture	Burgu et al. (1988)	
			Ögüt et al. (2005)	
			Ögüt and Akyol (2007)	
			Balta et al. (2008)	
			Çevrimel and Soylu (2017)	
			Özer et al. (2010)	
			Balta et al. (2019)	
			Tokşen (2002)	
			Uzbilek and Yıldız (2002)	
			Tabakoğlu (2004)	
			Mefut et al. (2007)	
			Özçelep (2009)	

Table 2c: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Ciliophora, Oligohymenophorea				
Ichthyophthirius sp.	*Oncorhynchus mykiss*	Aquaculture	Soylu (1996)	ld/u
Trichodina acuta Lom, 1961	*Oreochromis niloticus*	Aquaculture	Cengizler and Can (1999)	Eurasia
Trichodina claviformis Dobberstein and Palm, 2000	*Oncorhynchus mykiss*	Aquaculture	Ögüt and Akyol (2007)	Europe
Trichodina domerquei (Wallengren, 1897)	*Oncorhynchus mykiss*	Aquaculture	Burgu et al. (1988)	Europe
			Ince and Uslu (2017)	
Trichodina sp.	*Ctenopharyngodon idella*	Aquaculture	Uzbilek and Yıldız (2002)	ld/u
	Morone saxatilis	Aquaculture	Tokşen (2006)	
	Oncorhynchus mykiss	Aquaculture	Burgu et al. (1988)	
			Soylu (1996)	
			Altunay (2006) Altunay and Yıldız (2008)	
			Çevrimel and Soylu (2017)	
			Balta et al. (2008)	
			Balta et al. (2019)	
			Özçelep (2009)	
			Ögüt and Akyol (2003)	
	Salvelinus fontinalis	Aquaculture	Balta et al. (2008)	
Trichodina nigra Lom, 1960	*Oncorhynchus mykiss*	Aquaculture	Özer et al. (2010)	Eurasia
			Burgu et al. (1988)	
			Dal (2006)	
Trichodinella sp.	*Oncorhynchus mykiss*	Aquaculture	Burgu et al. (1988)	ld/u
Tripartiella sp.	*Oncorhynchus mykiss*	Aquaculture	Altunay (2006)	ld/u
			Altunay and Yıldız (2008)	

Table 2d: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Ciliophora, Phyllopharyngea				
Chilodonella cyprinid (Moroff, 1902) Strand, 1928	*Oreochromis aureus*	Aquaculture	Cengizler and Can (1999)	Eurasia
	Oreochromis niloticus	Aquaculture	Cengizler and Sarıhan (1992)	
			Cengizler and Can (1999)	
	Sarotherodon galileus	Aquaculture	Cengizler and Sarıhan (1992)	
	Tilapia rendalli	Aquaculture	Cengizler and Sarıhan (1992)	
	Tilapia zilli	Aquaculture	Cengizler and Sarıhan (1992)	
	Oncorhynchus mykiss	Aquaculture	Burgu et al. (1988)	
			Soylu (1996)	
			Ögüt and Akyol (2007)	
Chilodonella sp.	*Ctenopharyngodon idella*	Aquaculture	Uzbilek and Yıldız (2002)	ld/u
	Oncorhynchus mykiss	Aquaculture	Altunay (2006)	ld/u
			Altunay and Yıldız (2008)	
			Balta et al. (2019)	
			Özer et al. (2010)	

Table 2e: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Myxozoa				
Eimeria truttae (Leger and Hesse, 1919) Stankovitch, 1924	*Oncorhynchus mykiss*	Aquaculture	Sağlam and Pala (2008)	ld/u
Platyhelminthes, Monogenea				
Dactylogyrus anchoratus (Dujardin, 1845) Wagener, 1857	*Carassius auratus*	Enne Dam Lake	Koyun (2001)	Asia
		Enne Dam Lake	Koyun and Altunel (2007)	
		Emre Dam Lake	Öztürk (2011)	
	Carassius gibelio	Ömerli Dam Lake	Kırcalar (2013)	
		Seyitler Dam Lake	Öztürk (2010)	
		Karacaören II Dam Lake	Kır and Samancı (2012)	
		Sığırcı Lake	Çolak (2013)	
		Gala Lake	Soylu (2014)	
		Emre Dam Lake	Öztürk (2011)	
		Marmara Lake	Demir and Karakişi (2016)	
Dactylogyrus baueri Gussev, 1955	*Carassius gibelio*	Ömerli Dam Lake	Kırcalar (2013)	Japan
		Sığırcı Lake	Çolak (2013)	
		Gala Lake	Soylu (2014)	
Dactylogyrus inexpectatus Isjumova, 1955	*Carassius gibelio*	Ömerli Dam Lake	Kırcalar (2013)	Southeast Asia
		Sığırcı Lake	Çolak (2013)	
		Gala Lake	Soylu (2014)	
Dactylogyrus minutes Kulwièc, 1927	*Carassius gibelio*	Karacaören II Dam Lake	Kır and Samancı (2012)	Eurasia
Dactylogyrus sphyrna Linstow, 1878	*Oncorhynchus mykiss*	Aquaculture	Ince and Uslu (2017)	Eurasia

Table 2e: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Myxozoa				
Dactylogyrus vastator Nybelin, 1924	*Carassius gibelio*	Sığırcı Lake	Çolak (2013)	Asia
		Gala Lake	Soylu (2014)	
	Oreochromis niloticus	Aquaculture	Cengizler and Can (1999)	
Dactylogyrus sp.	*Ctenopharyngodon idella*	Aquaculture	Uzbilek and Yıldız (2002)	ld/u
	Oncorhynchus mykiss	Aquaculture	Burgu et al (1988)	
	Carassius gibelio	Ömerli Dam Lake	Kırcalar (2013)	
Diplozoon paradoxum von Nordmann, 1832	*Tilapia zilli*	Tigem Pond	Zeren (2008)	Asia
Gyrodactylus carassii Malmberg, 1957	*Carassius gibelio*	Seyitler Dam Lake	Öztürk (2010)	Europe
Gyrodactylus elegans von Nordmann, 1832	*Carassius auratus*	Karagöl Lake	Geldiay and Balık (1974)	Asia
Gyrodactylus katharineri Malmberg, 1964	*Carassius auratus*	Enne Dam Lake	Koyun and Altunel (2007)	Asia
Gyrodactylus sp.	*Carassius auratus*	Emre Dam Lake	Öztürk (2011)	ld/u
	Carassius gibelio	Ömerli Dam Lake	Kırcalar (2013)	
		Gala Lake	Soylu (2014)	
		Sığırcı Lake	Çolak (2013)	
		Marmara Lake	Demir and Karakişi (2016)	
	Oncorhynchus mykiss	Aquaculture	Ögüt and Akyol (2007)	
	Lepomis gibbosus	Sığırcı Lake	Çolak (2013)	
Tetraonchus sp.	*Tilapia zilli*	Tigem Pond	Zeren (2008)	ld/u
Onchocleidus similis syn. *Urocleidus similis* Mueller, 1936	*Lepomis gibbosus*	Sığırcı Lake	Çolak (2013)	North America
		Gala Lake	Soylu (2014)	
	Carassius gibelio	Gala Lake	Soylu (2014)	

Table 2f: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Platyhelminthes, Cestoda				
Caryophyllaeus fimbriceps Annenkova-Chlopina, 1919	*Carassius gibelio*	Gala Lake	Soylu (2014)	Ponto-Caspian region
Ligula intestinalis (Linnaeus, 1758)	*Ctenopharyngodon idella*	Aquaculture	Uzbilek and Yıldız (2002)	Europe
	Pseudorasbora parva	Hirfanlı Dam Lake	Benzer (2020)	
Schyzocotyle acheilognathi (Yamaguti, 1934)	*Ctenopharyngodon idella*	Aquaculture	Uzbilek and Yıldız (2002)	Asia
	Carassius gibelio	Bafra fish lakes	Öztürk and Özer (2014)	
	Gambusia holbrooki			
Platyhelminthes, Digenea				
Clinostomum complanatum (Rudolphi, 1814) Braun, 1899	*Oncorhynchus mykiss*	Aquaculture	Burgu et al (1988)	ld/u
	Lepomis gibbosus	Sığırcı Lake	Çolak (2013)	
Crepidostomum farionis (Müller, 1780) Lühe, 1909	*Oncorhynchus mykiss*	Aquaculture	Dörücü (2000)	Europe
Diplostomum sp.	*Carassius gibelio*	Ömerli Dam Lake	Kırcalar (2013)	ld/u
	Oncorhynchus mykiss	Aquaculture	Çevrimel and Soylu (2017)	
	Carassius gibelio	Gala Lake	Soylu (2014)	
		Sığırcı Lake	Çolak (2013)	
	Lepomis gibbosus	Sığırcı Lake	Çolak (2013)	
		Gala Lake	Soylu (2014)	
Tylodelphys clavata (von Nordmann, 1832) Diesing, 1850	*Lepomis gibbosus*	Sığırcı Lake	Çolak (2013)	Eurasia
Tetracotyle spp.	*Lepomis gibbosus*	Sığırcı Lake	Çolak (2013)	ld/u

Table 2g: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Acanthocephala				
Acanthocephalus sp.	*Lepomis gibbosus*	Gala Lake	Soylu (2014)	ld/u
Pomphorhynchus laevis (Zoega in Müller, 1776) Porta, 1908	*Carassius auratus*	Enne Dam Lake	Koyun (2001)	Ponto-Caspian region
	Oncorhynchus mykiss	Aquaculture	Burgu et al. (1988)	
		Aquaculture	Çevrimel and Soylu (2017)	
Nematoda				
Contracaecum sp.	*Carassius auratus*	Enne Dam Lake	Koyun and Altunel (2007)	ld/u
	Carassius gibelio	Marmara Lake	Demir and Karakişi (2016)	
Contracaecum rudolphii Hartwich, 1964	*Carassius gibelio*	Karataş Lake	Innal et al. (2020)	ld/u
Eustrongylides excisus Jägerskiöld, 1909	*Lepomis gibbosus*	Gala Lake	Soylu (2014)	ld/u
	Carassius gibelio	Marmara Lake	Demir and Karakişi (2016)	
Hysterothylacium aduncum (Rudolphi, 1802)	*Carassius gibelio*	Karacaören II Dam Lake	Kır and Samancı (2012)	ld/u
	Oncorhynchus mykiss	Aquaculture	Pekmezci and Umur (2015)	ld/u
Hysterothylacium sp.	*Carassius auratus*	Enne Dam Lake	Koyun (2001)	ld/u
Pseudocapillaria tomentosa (Dujardin, 1845) Moravec, 1987	*Carassius gibelio*	Marmara Lake	Demir and Karakişi (2016)	ld/u
Raphidascaris acus (Bloch, 1779)	*Carassius gibelio*	Büyükçekmece Dam Lake	Yardımcı et al. (2018)	Ponto-Caspian region
Schulmanela petruschewskii (Shulman, 1948)	*Oncorhynchus mykiss*	Aquaculture	Pekmezci and Umur (2015)	Europe
Annelida, Hirudinea				
Piscicola geometra (Linnaeus, 1761)	*Carassius gibelio*	Uluabat Lake	Arslan and Emiroğlu (2011)	Eurasia

Table 2h: Updated list of identified parasite species of alien fish from freshwater bodies of Turkey (ld/u = limited data/unknown).

Parasite/pathogen taxon and species	Host fish species	Fish origin	Author and record in Turkey	Parasite's area of origin
Mollusca, Bivalvia				
Glochidia (larvae)	*Lepomis gibbosus*	Gala Lake	Soylu (2014)	Asia
	Carassius gibelio	Gala Lake	Soylu (2014)	
Crustacea, Maxillopoda				
Argulus foliaceus (Linnaeus, 1758)	*Carassius auratus*	Aquarium conditions	Yıldız and Kumantaş (2002)	Europe
		Emre Dam Lake	Öztürk (2012)	
	Carassius gibelio	Emre Dam Lake	Öztürk (2012)	
		Aquaculture condition	Tabakoğlu (2006)	
	Oncorhynchus mykiss	Aquaculture	Öktener and Ünal 2020	
Crustacea, Copepoda				
Lernaea cyprinacea (Linnaeus, 1758)	*Carassius gibelio*	Karacaören II Dam Lake	Kır and Samancı (2012)	Asia
		Marmara Lake	Demir and Karakişi (2016)	
		Onaç Reservoir	Innal (2020)	
		Çanaklı Reservoir		
		Soğanlı Reservoir		
		Karataş Lake		
		Beyşehir Lake		
	Gambusia holbrooki	Kundu River Estuary	Innal and Avenant-Oldewage (2012)	
		Düger Creek	Innal et al. (2017)	
	Lepomis gibbosus	Gala Lake	Soylu (2014)	
	Pseudorasbora parva	Onaç Reservoir	Innal (2020)	
	Oncorhynchus mykiss	Aquaculture	Tokşen et al. (2015)	
		Sarı Mehmet Dam Lake	Urku and Onalan (2018)	
Ergasilus sp.	*Carassius gibelio*	Büyükçe-kmece Lake	Yardımcı et al. (2018)	ld/u

CONCLUSIONS

The data of the present survey suggest that human activities, particularly aquaculture have led to the introduction of non-indigenous fish along with their parasites which could negatively influence the native and endemic ichthyofauna of Turkey. Some parasites such as *Anguillicoloides crassus*, *Schyzocotyle acheilognathi*, and *Onchocleidus similis* have increased in dispersal areas and nowadays affect the native hosts.

Chilodonella cyprini, identified in six alien fish species, and *Ichthyophthirius multifiliis*, found in five species, are believed to be the most generalist parasites; both of these protozoan parasites are of Eurasian origin. For a large number of parasites related to non-native fish species, there are still limited data on their area of origin.

Oncorhynchus mykiss was the alien host with the highest number of reported parasites, including protozoans, mixozoans, digeneans, acanthocephalans, nematodes, and crustaceans. Since there are so many parasite species reported for trout rearing, aquaculture owners should concentrate more on management strategies.

As the invasive fish species continues to have a major impact on the diversity of indigenous fish populations of Turkey, careful monitoring of their parasites is required in further studies, especially for the alien species, originated in Asia or North America. However, it is worth noting that non-indigenous fishes may be infected with native Eurasian parasites.

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