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Review

Ecological Interdependence of Pollution, Fish Parasites, and Fish in Freshwater Ecosystems of Turkey

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Abstract: Records of mass fish deaths were found in different data sources for this study. A map of mass fish deaths in Turkey was also realized for the first time. We aimed to present a review of the distribution of mass fish deaths in the freshwater ecosystems of Turkey, mostly present in the Marmara Region and Aegean Sea Region, where there are intensive industrial and agricultural activities. Fish parasites generally occur in equilibrium with their hosts in natural environments. In the freshwater ecosystems of Turkey, which are highly affected by human activities and have extremely rich natural ichthyofauna, the negative effects of pollution on environmental parameters, which can directly affect the fish, and the emergence and overextension of fish parasites can cause a supplementary synergic direct negative effect transposition in mass fish deaths due to the deterioration of host immunity and to the wounds induced in fish where bacterial, viral, and fungal pathogens can be effective. Finally, these factors can influence the fish rate of survival and skew the structure of fish populations. Mass fish deaths have been frequently reported in Turkey, but are usually only explained by pollution as a single accepted anthropogenic stressor. Together with pollution, a supplementary induced bioecological stressor, the qualitative and quantitative characteristics of the fish parasites' association variations should be assessed and monitored as potential complex precursor indicators of fish communities' structural degradation and freshwater ecosystems' dreadful conditions. Fish parasites as biomonitor species should be used to identify the effects of pollution in Turkish ecosystems, and not only in freshwater ecosystems, in the future. An optimum management plan for freshwater ecosystems should include all the physico-chemical factors, fish parasites, and fish elements involved in permanent assessment and monitoring activities.

Keywords: pollution; fish parasites; fish; ecological interdependence; Turkey

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1. Introduction and Background

Biodiversity changes and declining tendencies under human impact represent a planetary process influencing most taxonomical groups and their natural habitats [1–3]. In the context of 21st-century global concern about freshwater as a strategic sustainable natural resource and generator of secondary resources, among increasing stressors, threats, and risks, pollution is a major stressor impacting aquatic ecosystems [4–12]. The directly and indirectly associated freshwater biodiversity is an essential component of the biosphere, without which its proper functioning is impossible. There are a relatively large number of studies on the impacts of pollution, with a high variety of negative effects on different freshwater ecosystem taxa, including fish, revealing the significance and magnitude of the topic worldwide [13–21]. The relatively new climate change context amplifies the human-induced stressors' effects in an accelerated rhythm [22–24]. Although the negative effects of direct pollution on fish have been studied in different circumstances, the possibility of indirect impact through a pollution–parasites–risk interrelation still needs to be addressed, which is the main purpose of this study.

A good ecological status for the protection and conservation of the aquatic environment is of vital importance around the world for the well-being of the related habitats, species, and human societies [23,25–32]. Aquatic environment protection activities have to deal with variable human-induced environmental stressors worldwide, including domestic, industrial, agricultural, water-body hydro-morphological changes, climate change, and natural disasters, which are significantly affecting these ecosystems [20,33,34]. All these human-induced situations and cases are present in Turkey, too [30,35–37].

Fish parasites have been used by various scientists as a biological indicator to determine fish population dynamics and stock trends [38–40]. Fish parasites are ubiquitous, primarily surviving in dynamic equilibrium with their host(s), and they are often overlooked in fish health assessments [41]. Pollution can affect the susceptibility and immune response of fish, exposing them to parasite infection [42,43]. Pollutants can also affect the free-living stages of parasites, directly or indirectly, through the intermediate hosts of the parasite. Hence, it is easier to monitor the changes in the infection values of the parasite in the host than to use the routine methods to determine the pollution [44].

Classical methods used to verify the accumulation of pollutants provide exact quantification but do not reflect the environmental impact on the ecosystem's key end taxa. Moreover, they are not cheaper than biological monitoring [45].

Pollution studies have generally been carried out on the short-term effects of chemicals, namely their acute toxicity [46]. In nature, aquatic organisms are exposed to low concentrations of pollutants over long periods [44]. Therefore, working on bio-indicator species can provide clearer results for the accumulative and synergetic effects of pollution.

There have been many environmental impact studies that aim to understand interactions between parasites and ecological problems such as pollution [44,47–51].

The Middle East is extremely rich in fish diversity. It is a transitional area between three main biogeographical units: the Palearctic, the Afrotropical, and the Oriental regions. However, it is also subject to a major human impact effect [18]. Turkey shows a notable diversity of habitats, with significant variations in altitude, precipitations, temperature, topography, and geological history, which is reflected in its rich biodiversity [25]. Its territory lies at the nexus of Europe, the Middle East, Central Asia, and Africa [26]. It is a hotspot of freshwater fish diversity and also includes endemic species, possessing unique and rich ichthyofauna containing distinct Euro–Asian–African elements. Currently, among the 368 freshwater fish species, 3 are globally extinct, 5 are extinct in Turkey, and 153 species are recognized as endemic, 65 of which are classified as Critically Endangered and Endangered [27]. All of them are affected by high and variable human stressors, which have induced habitat degradation [28,29]. Many stressors plague the Turkish waters, and the contribution of each stressor is difficult to quantify [30]. It is much more difficult to highlight indirect the influence of complex stressor on fish.

A total of 199 parasite species have been reported in freshwater fish in Turkey. In total, 131 of these species (Monogenea—85 species, Digenea—23 species, Cestoda—23 species) belong to Platyhelminthes; 15 species belong to Nematoda; 10 species belong to Acanthocephala; 7 species belong to Annelida; 14 species belong to Ciliophora; 3 species belong to Euglenozoa; 1 species belongs to each of Myzozoa, Metamonada, Choanozoa, and Mollusca; 4 species belong to Cnidaria; and 11 species belong to Arthropoda [52–57].

There are a few published studies on using fish parasites as a bioindicator species in freshwater ecosystems in pollution-related studies in Turkey [58–60]. One of the most visible direct effects of pollution in freshwater is mass fish deaths. This study aims to reveal the role of fish parasites as aquatic ecosystem bioindicators for the freshwater ecosystems' key driving pollution-related stressors in these types of habitats, and to stress the interdependencies among Turkey's freshwater ecosystems' pollution, fish parasites, and fish.

The main aim of this article is to review reports of pollution-related fish deaths in Turkey and to examine the ecological relationships between fish, parasites, and pollutants. This is the first such review to be conducted in Turkey, so it could be a potentially important contribution to the literature in this field. The study draws attention to the pollution situation by associating it with the reported bioindication parasites in the freshwater where mass fish deaths have occurred. The study also highlights a potential interrelation between pollution and the decrease in fish resilience, the facilitation of fish parasites by the reduced biological status of fish, and the decrease in fish ecological status because of pollution and parasite synergistic effects.

2. Material and Methods

The literature on the parasites of freshwater fish in Turkey was prepared from significant specific publications, such as articles, theses, projects, proceedings, and checklists, from 1964 to 2022. Data from 44 water bodies were compiled, and the collected data come from all years of research, regardless of the date of fish death. The names of parasites were checked on databases such as the World Register of Marine Species [61] and FishBase [21]. Reports in several media materials were also used to track these incidents with related information and compile a map of mass fish deaths.

For this study, a map was produced of the localities where mass fish deaths occurred in the freshwaters of Turkey. We also listed fish parasite studies in freshwaters where mass fish deaths occurred. As a result, we interpreted the usability of the related fish parasites as bioindicator species based on current pollution where mass fish deaths occurred and highlighted the pollution–fish and parasites–fish interrelations.

3. Results

3.1. Types of Pollutants

Mass fish deaths are a common disaster in freshwaters. Natural causes, such as oxygen depletion, cyanobacterial blooms, storms, hail, waves, and currents cause mass fish deaths [62]. Infectious agents (viral, bacterial, fungal, parasitic agents, etc.) can also cause mass fish deaths. These agents are present at low levels in equilibrium in fish in natural environments and farms. However, they cause mass deaths in fish because of the deterioration of environmental conditions in the aquatic ecosystem [63].

However, mostly anthropogenic causes are more responsible for mass fish deaths. These causes are: agricultural (manure, pesticides, irrigation, etc.); industrial (mining, petroleum, wood products, chemicals, food, metal, etc.); municipal (sewage, power generation, water supply, etc.); transportation (pipeline, truck, rail, etc.); other (construction, well drilling, etc.); and tourism (thermal spas, boats, etc.) [64].

Mass fish deaths are also seen frequently in the freshwaters of Turkey, such as in the agricultural irrigation pond in Yeni Ziraatli Village of Manyas District, in 2014. These deaths occurred because of the wastewater containing animal pesticides and natural fertilizers released from the cattle farms in the region reaching the pond, as well as a large amount of water being drawn from the pond for irrigation. In the analysis, ammonia and phosphorus values in the waters were found to be relatively high. As a result, wels catfish and carp died there due to lack of oxygen (Figure 1, https://www.youtube.com/watch?v=6FTqOUIrXWg (accessed on 11 August 2022)).

3.2. Indicator Parasites

There are various reviews in which studies are compiled on the determination of the differences in the parasite community and infection values based on changes in water-quality parameters related to pollution, as well as the determination of the pollutant bioaccumulation in the parasites according to the pollution type in the aquatic ecosystems [47,48,50,51,65–70].

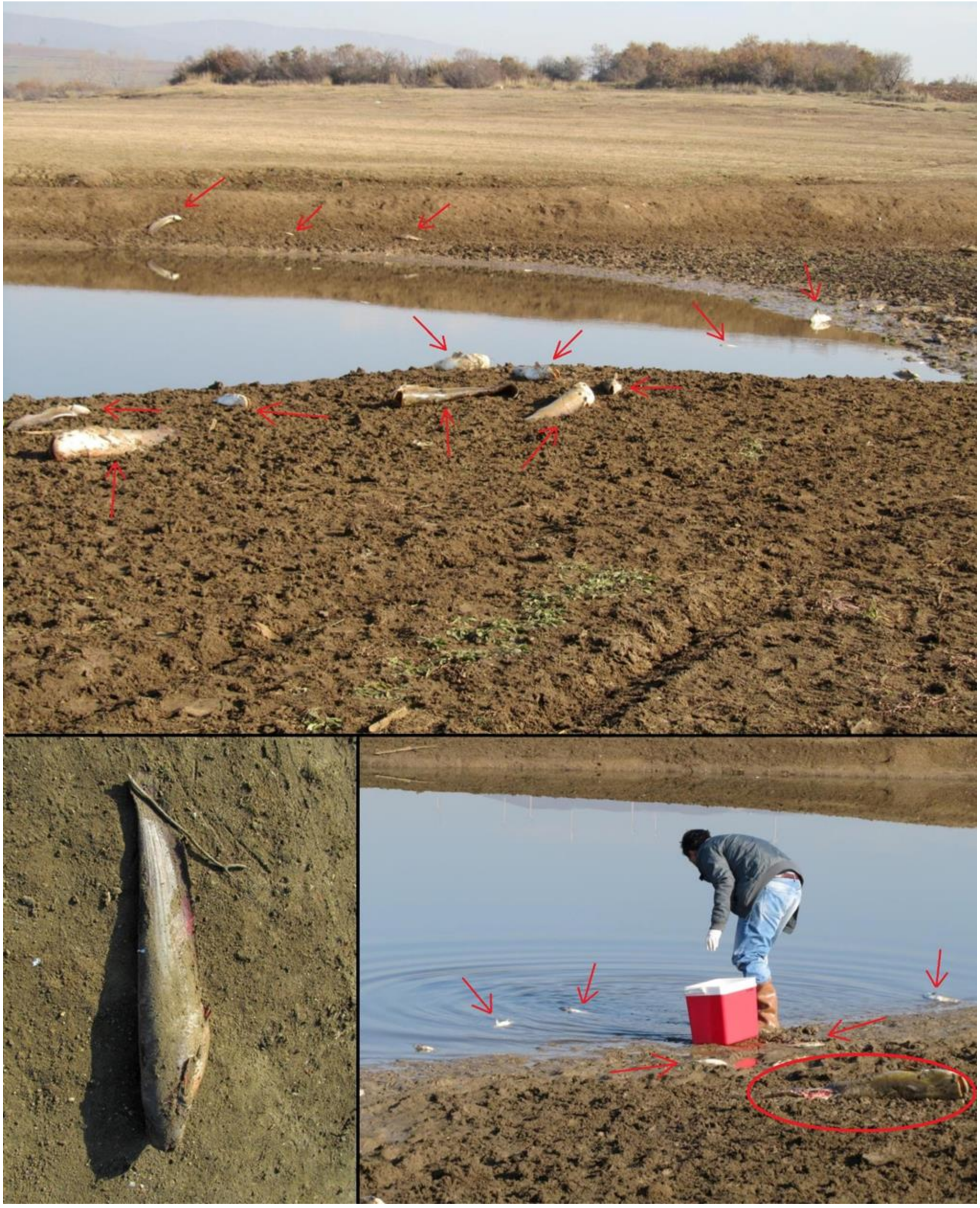

Figure 1. A case of mass fish deaths in an irrigation pond used for agricultural purposes in Bandırma.

3.3. Region

For this review, a distribution map of the localities where mass fish deaths occur in the freshwaters of Turkey was prepared based on the public information available (Figure 2). A fish parasite list was also prepared according to parasite surveys carried out in freshwaters where mass fish deaths occurred (Table 1). In addition, the existing pollution types and causes in these freshwaters where mass fish deaths occurred were examined with reference to the subject. As a result, we interpreted the usability of the related parasites as bioindicator species based on the current pollution in freshwaters where mass fish deaths occurred, and stressed the potential interrelations among the aquatic ecosystems' pollution, fish parasites, and fish.

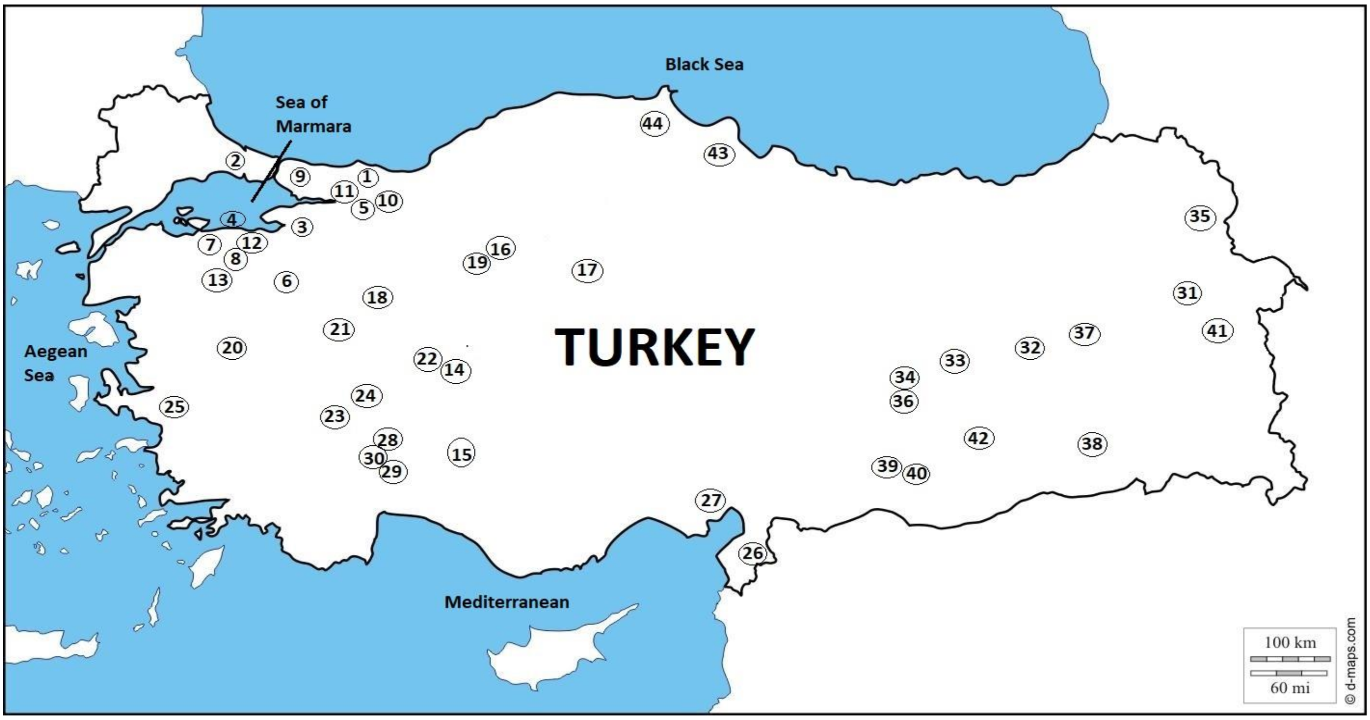

Figure 2. Ecosystems in Turkey where mass fish deaths occurred and parasite surveys were carried out; 1–44 spots names and characteristics are presented in the below Table 1.

Table 1. Mass fish deaths and parasitology studies in some ecosystems in Turkey.

	Location	Host Fish Species: Parasite Species	Reference	Fish Deaths Date	Source
	Marmara Region				
1	Büyükakgöl	***Blicca bjoerkna***: *Tylodelphys clavata, Piscicola geometra*, Glochidia	Altan and Soylu (2018)	2010	https://www.etkihaber.com/akgolde-toplu-balik-olumleri-yasaniyor.-51904h.htm (accessed on 1 November 2022)
2	Büyükçekmece Dam Lake	***Squalius cephalus***: *Paradiplozoon homoion* ***Rutilus rutilus***: *Caryophyllaeus laticeps*	Yardımcı et al. (2018)	2021	https://www.yenisafak.com/video-galeri/gundem/rengi-degisen-buyukcekmece-golunde-olen-baliklar-kiyiya-vurdu-2220804 (accessed on 10 November 2022)
3	İznik Lake	***Rutilus frisii***: *Caryophyllaeus laticeps*, ***Rutilus rubilio***: *Neoechinorhynchus rutili*	Aydoğdu et al. (1997) Aydoğdu et al. (2000)	2020	https://www.tv100.com/bursanin-iznik-ilcesinde-iznik-golunu-besleyen-en-buyuk-dere-olan-cakirca-deresinde-yasanan-toplu-balik-olumleri-vatandaslari-tedirgin-etti-video-499455 (accessed on 23 November 2022)
4	Karacabey Lagoon Lake	***Esox lucius***: *Raphidascaris acus*	Öztürk et al. (2002)	2020	https://www.bursadabugun.com/haber/bursa-karacabey-deki-balik-olumlerinin-arastirilmasi-istendi-1324902.html (accessed on 23 November 2022)
5	Karasu Stream	***Luciobarbus escherichii***: *Pomphorhynchus laevis*	Soylu (1991)	2021	https://www.hurriyet.com.tr/gundem/karasu-nehrinin-ustunu-tamamen-kapladi-yore-halkini-tedirgin-eden-balik-olumleri-41837035 (accessed on 23 November 2022)
6	Kocadere Stream	***R. rutilus***: *Dactylogyrus crucifer, Diplostomum spathaecum*	Selver (2008)	2018	https://kuzeyormanlari.org/2018/09/16/bursa-inegol-kocadereyi-yine-zehirlediler-baliklar-4-kez-topluca-can-verdi/ (accessed on 24 November 2022)
7	Manyas Lake	***R. rutilus***: *Dactylogyrus crucifer, Paradiplozoon homoion, Ligula intestinalis*	Öztürk (2000)	2014	https://www.mynet.com/manyas-golunde-balik-olumleri-180101621484 (accessed on 23 November 2022)
8	Mustafakemalpaşa Stream	***Alburnus alburnus***: *Bothriocephalus acheilognathi*	Aydoğdu and Selver (2006)	2019	https://www.bursadabugun.com/haber/bursa-mustafakemalpasa-daki-balik-olumleri-suruyor-1200184.html (accessed on 27 November 2022)

Table 1. *Cont.*

	Location	Host Fish Species: Parasite Species	Reference	Fish Deaths Date	Source
9	Ömerli Dam Lake	***Alburnus istanbulensis***: *Ergasilus sieboldi*	Şimşek (2013)	2021	https://www.denizhaber.net/omerli-barajindaki-balik-olumleri-korkuttu-haber-102459.htm (accessed on 27 November 2022)
10	Sakarya River	***Abramis brama***: *Caryophyllaeus laticeps*, Glochidia ***E. lucius***: *Raphidascaris acus*	Akmırza and Yardımcı (2014)	2021	https://www.halk54.com/gundem/sakarya-nehri-nde-balik-olumleri-goruldu-h53220.html (accessed on 3 December 2022)
11	Sapanca Lake	***B. bjoerkna***: *Dactylogyrus crucifer, Asymphylodora imitans, Piscicola geometra* ***R. rutilus***: *Dactylogyrus crucifer, D. vistulae, Diplostomum spathaecum, Tylodelphys clavata* ***E. lucius***: *Raphidascaris acus* *Tinca tinca*: *Glochidia*	Soylu (1990), Karabiber (2006), Soylu (2006)	2007	https://www.hurriyet.com.tr/gundem/sapanca-golunde-balik-olumleri-basladi-7575460 (accessed on 15 December 2022)
12	Uluabat Lake	***R. rutilus***: *Dactylogyrus crucifer, Paradiplozoon homoion, Caryophyllaeus laticeps* ***E. lucius***: *Rhipidocotyle fennica, Raphidascaris acus, Acanthocephalus anguillae* ***T. tinca***: *Piscicola geometra*	Öztürk et al. (2000), Öztürk (2005), Öztürk (2002)	2014	https://www.olay.com.tr/yuzlerce-olu-balik-ve-kus-kiyiya-vurdu-337894 (accessed on 15 December 2022)
13	Susurluk Stream	***S. cephalus***: *D. vistulae, Paradiplozoon megan*	Gürkan and Tekin Özan (2012)	2019	https://www.denizhaber.net/susurluk-cayinda-toplu-balik-olumleri-yasandi-haber-91537.htm (accessed on 15 December 2022)
	Central Anatolia Region				
14	Akşehir Lake	***Alburnus nasreddini***: *Pomphorhynchus laevis*	Buhurcu (2006)	2010	https://www.milliyet.com.tr/gundem/aksehir-golunde-kus-olumleri-1287711 (accessed on 15 December 2022)
15	Beyşehir Lake	***T. tinca***: *Proteocephalus torulosus, Acanthocephalus anguillae*	Tekin Özan (2005)	2020	https://www.konhaber.com/haber-beysehir_de_tedirgin_eden_toplu_balik_olumleri-1360411.html (accessed on 15 December 2022)
16	Çayırhan Stream	***Alburnus orontis***: *Ligula intestinalis*	Keskin and Erakan (1987)	2020	https://www.haberler.com/ankara-daki-cayirhan-golu-nde-toplu-balik-olumu-13660519-haberi/ (accessed on 17 December 2022)
17	Eymir Lake	***Alburnus* sp:** *Ligula intestinalis, Pomphorhynchus laevis*	Burgu et al. (1988)	2010	https://www.internethaber.com/eymir-golunde-balik-olumleri-247392h.htm (accessed on 17 December 2022)
18	Porsuk Stream	***A. alburnus***: *Ligula intestinalis*	Yılmaz et al. (1996)	2021	https://www.gazeteduvar.com.tr/su-akisi-duran-porsuk-cayinda-baliklar-toplu-halde-oldu-haber-1529347 (accessed on 17 December 2022)
19	Sarıyar Dam Lake	***Alburnus* sp:** *Ligula intestinalis, Pomphorhynchus laevis*	Burgu et al. (1988)	2020	https://www.cnnturk.com/turkiye/ankarada-barajdaki-balik-olumlerine-inceleme?page=4 (accessed on 17 December 2022)
	Aegean Region				
20	Demirkopru Dam Lake	***Capoeta capoeta***: *Ligula intestinalis*	Keskin and Erakan (1987)	2015	https://www.salihlisektorgazetesi.com/14823/haber/demirkopru-baraji-nda-balik-olumleri-.aspx (accessed on 17 December 2022)
21	Enne Dam Lake	***A. alburnus***: *Ligula intestinalis, Paraergasilus longidigitus* ***Carassius carassius***: *Argulus foliaceus*	Koyun (2001), Koyun et al. (2007)	2018	https://www.mynet.com/kutahyada-toplu-balik-olumleri-110104353108 (accessed on 10 February 2023)
22	Eber Lake	***Cyprinus carpio***: *Argulus foliaceus*	Öztürk (2005)	2017	https://www.sondakika.com/haber/haber-eber-golu-nde-yasanan-toplu-balik-olumleri-9293003/ (accessed on 17 December 2022)
23	Işıklı Dam Lake	***Squalius carinus***: *Dactylogyrus vistulae, Tylodelphys clavata* ***E. lucius***: *Bathybothrium rectangulum*	Soylu et al. (2017), Dişçi (2002)	2017	https://www.denizlihaber.com/denizli/civril/iddialar-cok-vahim-isikliyi-besleyen-kufi-cayi-zirai-ilaclarla-zehirleniyor-balik-olumleri-basladi/ (accessed on 19 December 2022)
24	Örenler Dam Lake	***S. cephalus***: *Dactylogyrus vistulae, Diplostomum spathaecum, Pomphorhynchus laevis*	Kurupınar (2009)	2015	https://www.afyonzafer.net/sandikli/sandikli-orenler-barajindaki-baliklar-telef-oldu-h23431.html (accessed on 17 December 2022)

Table 1. *Cont.*

	Location	Host Fish Species: Parasite Species	Reference	Fish Deaths Date	Source
25	Tahtalı Dam Lake	***C. carpio***: *Lernaea cyprinacea*	Karakişi and Demir (2012)	2012	https://www.etkihaber.com/izmire-icme-suyu-saglayan-tahtali-barajindaki-balik-olumleri-korkuttu-139705h.htm (accessed on 17 December 2022)
	Mediterranean Region				
26	Asi River	***Anguilla anguilla***: *Anguillicola crassus*	Genç et al. (2008)	2021	https://www.trthaber.com/haber/guncel/asi-nehrinde-su-sicakliginin-yukselmesi-ve-kalitesinin-azalmasi-balik-olumlerine-neden-olabilir-601224.html (accessed on 17 December 2022)
27	Ceyhan River	***A. anguilla***: *Anguillicola crassus*	Genç et al. (2005)	2021	https://www.ntv.com.tr/galeri/turkiye/kahramanmarasta-meydana-gelen-balik-olumlerinin-nedeni-arastiriliyor,RIt7rfdox0CHT0ljQDDsKA/4_o5u0oyAUWZNHzq4mqVwA (accessed on 10 February 2023)
28	Egirdir Lake	***Pseudophoxinus egridiri***: *Lernaea cyprinacea*	Akçimen et al. (2018)	2012	https://www.denizhaber.net/egirdir-golunde-toplu-balik-olumleri-haber-41608.htm (accessed on 17 December 2022)
29	Karacaören I. Dam Lake	***Luciobarbus pectoralis***: *Ligula intestinalis*	Kır (1998)	2013	https://www.sondakika.com/haber/haber-ozel-haber-karacaoren-baraji-nda-sazan-olumleri-4798468/ (accessed on 19 December 2022)
30	Kovada Lake	***C. carassius***: *Argulus foliaceus* ***T. tinca***: *Proteocephalus torulosus*	Tekin Özan and Kır (2005), Kır and Tekin Özan (2005)	2014	http://www.egirdirses.com/haber-valimizin-dikkatine-...-7971.html (accessed on 19 December 2022)
	Eastern Anatolia Region				
31	Bendimahi Brook	***C. carpio***: *Bothriocephalus acheilognathi, Caryophyllaeus laticeps, Neoechinorhynchus rutili*	Topçu (1993)	2021	https://www.vansiyaseti.com/van/van-baligi-olumleri-arastiriliyor-h73155.html (accessed on 19 December 2022)
32	Fırat River	***Mastacembellus mastacembelus***: *Diplostomum spathaecum*, Glochidia	Koyun and Çelik (2020)	2021	https://jinepsgazetesi.com/2021/06/milyonlarca-balik-neden-oldu/ (accessed on 19 December 2022)
33	Hazar Lake	***Capoeta umbla***: *Bothriocephalus acheilognathi*	Aksoy (1996)	2020	https://www.gunisigigazetesi.net/elazig-guncel/baliklar-neden-oluyor-h78174.html (accessed on 19 December 2022)
34	Karakaya Dam Lake	***C. umbla, Acanthobrama marmid***: *Bothriocephalus acheilognathi*	Örün et al. (2003)	2021	https://www.ntv.com.tr/galeri/turkiye/karakaya-barajinda-toplu-balik-olumleri,zLDDlyH2lkOtmQZ2sUfj7g/szqvGqbDeUq8xZCOVvluJw (accessed on 19 December 2022)
35	Kars Stream	***C. capoeta, Barbus plebejus***: *Ligula intestinalis*	Arslan et al. (2015)	2021	https://www.trthaber.com/haber/turkiye/kars-cayinda-toplu-balik-olumleri-goruldu-600223.html (accessed on 17 December 2022)
36	Keban Dam Lake	***Chondrostoma regium***: *Bothriocephalus acheilognathi, Ergasilus sieboldi* ***Capoeta trutta***: *Lamproglena pulchella, Ergasilus sieboldi* ***Alburnus mossulensis***: *Neoechinorhynchus rutili, Ergasilus briani* ***Barbus rajanorum***: *Piscicola geometra*	Sağlam (1992), Dörücü and İspir (2005), Kavak and Şeker (2017)	2014	https://www.sondakika.com/haber/haber-keban-baraj-golu-nde-balik-olumlerine-inceleme-6504258/ (accessed on 17 December 2022)
37	Murat River	***Cyprinion macrostomum***: *Lernaea cyprinacea*	Koyun et al. (2015	2019	https://www.denizhaber.net/murat-nehrindeki-balik-olumleri-endiselendirdi-haber-90238.htm (accessed on 17 December 2022)
	South Easten Anatolia Region				
38	Dicle River	***M. mastacembelus***: Glochidia	Koyun and Çelik (2020)	2021	https://www.gazeteduvar.com.tr/diclede-baliklar-neden-oluyor-haber-1522077 (accessed on 20 December 2022)
39	Atatürk Dam Lake	***Planiliza abu, M. mastacembelus, C. carpio, Carasobarbus luteus***: *Argulus foliaceus*	Öktener et al. (2006), Öktener and Alaş (2009)	2019	https://www.haberturk.com/adiyaman-da-kiyiya-vuran-baliklara-inceleme-2526158 (accessed on 20 December 2022)

Table 1. *Cont.*

	Location	Host Fish Species: Parasite Species	Reference	Fish Deaths Date	Source
40	Halil-ür Rahman Lake	***C. luteus***: *C. umbla, Lamproglena pulchella*	Öktener et al. (2008)	2021	https://www.hurriyet.com.tr/gundem/balikligolde-balik-olumleri-raporlastiriliyor-41753569 (accessed on 20 December 2022)
41	Zernek Dam Lake	***C. carpio***: *Bothriocephalus acheilognathi*	Topçu (1993)	2021	https://www.rudaw.net/turkish/kurdistan/1709202114 (accessed on 20 December 2022)
42	Devegecidi Dam Lake	***A. marmid, A. mossulensis***: *Ligula intestinalis*	Başaran and Kelle (1976)	2021	https://www.facebook.com/TigrisHaber/videos/diyarbak%C4%B1r-devege%C3%A7idi-baraj%C4%B1nda-toplu-bal%C4%B1k-%C3%B6l%C3%BCmleri/895500778037894/ (accessed on 20 December 2022)
	Black Sea Region				
43	Bafra Fish Lakes	***Sander lucioperca***: *Tylodelphys clavata, Bothriocephalus acheilognathi* ***C. carpio***: *Ergasilus sieboldi*	Öztürk et al. (2011), Öztürk et al. (2012)	2014	https://www.haberler.com/kizilirmak-deltasi-nda-balik-ve-sulun-olumleri-6450737-haberi/ (accessed on 20 December 2022)
44	Sarıkum Lagoon Lake	***Aphanius chantrei***: *Neoechinorhynchus rutili, Ergasilus sieboldi*	Öztürk (2005)	2018	https://www.ajanssinop.com/koruma-alaninda-balik-katliami-iddiasi/3877/ (accessed on 20 December 2022)

Turkey territory is geographically divided into seven main regions: Central Anatolia, Marmara, Black Sea, Eastern Anatolia, Southeastern Anatolia, Aegean, and Mediterranean [71]. In all of these freshwater ecosystems, one of the most obvious evidence of the presence of pollution is mass fish death events. The existence of 200 natural lakes [72] and 2.214 dam lakes and ponds [73] has been determined in Turkey. In this research, 56 ecosystems containing lakes, streams, and rivers were identified and recognized as places where mass fish deaths occurred, and parasitological studies were carried out in these regions of Turkey.

According to the identified type of pollution, there are domestic wastes and wastewaters in almost all of these freshwaters. Domestic pollutants are followed by pollutants originating from industrial and agricultural activities. There are also pollutants from mining, thermal or spa facilities, fish farms, and tourism sectors in some ecosystems.

4. Discussion

Several studies have shown that the prevalence of *Paradiplozoon homoion* increases in waters where eutrophication and thermal pollution are in effect [74–76]. Nevertheless, it has been found by various researchers that the prevalence of the parasite decreases in lakes where there is effluent and thermal pollution [67,75,77,78]. The prevalence of *Paradiplozoon homoion* was low in various fish, for example, 3.5% on *Squalius cephalus* in Büyükçekmece Dam Lake [79]; 0.8% on *Rutilus rutilus* in Manyas Lake [80]; and 10.4% on *R. rutilus* in Uluabat Lake [81]. *Paradiplozoon megan* was also found in low amounts (22.8%) on *S. cephalus* in Susurluk Stream [82].

Özdemir [83] showed that Büyükçekmece Lake has a mesotrophic character and that nitrogen and phosphorus loads from agricultural and industrial sources increased considerably from 1990 to 2000. Arı [84] emphasized the intensity of excessive eutrophication and showed that the pollution in Manyas Lake is of industrial origin. Kurtoglu et al. [85] determined that the high nitrogen and phosphorus pollution in Uluabat Lake was caused by agricultural, animal, and industrial wastewater carried from Mustafa Kemalpaşa Stream. Manyas, Uluabat Lakes, Büyükçekmece Dam Lake, and Susurluk Stream are mostly threatened by domestic, industrial, and agricultural pollution. Therefore, this may be the main cause of low infection.

The prevalence was reported to be high when examining the ecosystems where *Dactylogyrus crucifer* has been reported in Turkey. Selver [86] reported a 59.3% prevalence on *R. rutilus* from Kocadere Stream; 44% prevalence from Manyas Lake by Öztürk [80]; 87.6%

prevalence from Sapanca Lake by Karabiber [87]; 90.6% prevalence from Uluabat Lake by Öztürk [81]; and 100% prevalence on *Blicca bjoerkna* from Sapanca Lake by Soylu [88].

Crafford et al. [89] detected an increase in the prevalence of *Dactylogyrus* with rising temperature. The reason for the high prevalence of *Dactylogyrus crucifer* in Turkey may be the increase in water temperature. Bagge and Valtonen [77] found an increase in prevalence in waters with effluent pollution, while Dušek et al. [90] found a decrease in the prevalence of *Dactylogyrus* in waters with eutrophication and organic pollution. The presence of pollution caused by domestic, industrial, and agricultural effluents in the ecosystems where *Dactylogyrus* has been reported has been demonstrated by various studies of, for example, Manyas Lake [84], Sapanca Lake [91], Kocadere Stream [92], and Uluabat Lake [85].

In contrast to *Dactylogyrus crucifer*, the prevalence values of *Dactylogyrus vistulae* are low. Gürkan and Tekin Özan [82] reported *Dactylogyrus vistulae* with 30.7% prevalence on *S. cephalus* from Susurluk Stream; 42.7% from Örenler Dam Lake by Kurupınar [93]; and 27.7% on *Squalius carinus* from Işıklı Dam Lake by Halmetoja et al. [94]. In these ecosystems, the decrease in the prevalence of *Dactylogyrus vistulae* may be explained by the presence of eutrophication and organic contamination [93].

Various researchers have shown that there is a decrease in the infection values in the monitoring studies of *Tylodelphys clavata* according to pollution type. Karvonen et al. [78] determined that the *T. clavata* tends to decrease in *Carassius carassius* where organic pollution is high; Valtonen et al. have shown that it tends to decrease in *R. rutilus* in waters where effluent is mixed [67]; and Halmetoja et al. have shown that it tends to decrease in *Perca fluviatilis* in waters with high acidification [94]. This digenea has been reported with infection rates of 6.6% in *B. bjoerkna*, 7.40% in *R. rutilus*, 13% in *S. carinus*, and 1% in *Sander lucioperca* in Turkey, by Altan and Soylu [95], Karabiber [87], and Soylu et al. [94], respectively.

Durmaz [96] determined that heavy metals such as arsenic, mercury, and selenium are at critical levels in Büyük Akgöl Lake due to industrial activities and pesticides. Altuğ [91] found higher levels of zinc, lead, copper, mercury, and cadmium in mussels than in fish samples in Sapanca Lake. She determined that heavy metal levels in fish in Sapanca Lake do not pose a danger to human health. However, she also emphasized that heavy metal pollution started in the lake. Bulut et al. [97] attributed the low dissolved oxygen data in Işıklı Lake to the presence of domestic, industrial, and agricultural wastes. Akbulut et al. [98] explained that eutrophication is very heavy in Bafra Fish Lakes and attributed it to the discharge of agricultural and domestic discharge waters into the lakes without any treatment.

As can be seen, Sapanca Lake and Büyük Akgöl Lakes, where the parasite is reported, are threatened by domestic and industrial pollution, while Işıklı Lake and Bafra Lake are mostly threatened by domestic and agricultural pollution. Therefore, the reason for the low rate of infection in these lakes is compatible with the findings of Valtonen et al. [67] and Altan and Soylu [95].

It has been found that *Rhipidocotyle fennica* in *R. rutilus* show a greater prevalence against pollution in ecosystems where wastewater is mixed [67,99]. Öztürk et al. [100] stated that *Rhipidocotyle fennica* (94%) is one of the dominant parasites in the seasonal distribution of parasites in *Esox lucius* in Uluabat Lake. As mentioned above [84], the mixing of the wastewater of Uluabat Lake has a possible effect on increasing the infection rate of this parasite.

Baruš et al. [101] reported low prevalence of *Bathybothrium rectangulum* in *Barbus barbus* from water containing heavy metals. Işıklı Dam Lake, where Dişçi [102] reported the parasite, is especially affected by agricultural activities including pesticides and fertilization. The detection of such low infection may be due to the heavy metal content of these pesticides.

It has been determined that, while pollution causes a decrease in the prevalence of *Caryophyllaeus laticeps* in lakes polluted by effluent [67,103], it causes an increase in lakes where metal and thermal pollution are present [79,103,104]. Prevalence of *Caryophyllaeus laticeps* was low in various fish; for example, it was 1.9% on *R. rutilus* in Büyükçekmece

Dam Lake [79]; 8.3% on *Abramis brama* in Sakarya River [105]; 4.6% on *R. rutilus* in Uluabat Lake [81]; and 42.1% on *Cyprinus carpio* in Bendimahi River [106]. Pollution of wastewater is effective in Büyükçekmece Dam Lake [83], Sakarya River [107], Uluabat Lake [85], and Bendimahi Brook [108,109]. Therefore, these findings agree with those of Valtonen et al. [67] and Jirsa et al. [103]. The reason for the high level of parasite infection in Iznik Lake may be the wastes from industrial activities and from agricultural fertilizers and pesticides [110].

It has been found that pollution events causes a decrease in the prevalence of *Ligula intestinalis* in waters with heavy metal pollution [111], while it causes an increase in waters with waste pollution [67]. *L. intestinalis* from different ecosystems of Turkey were generally detected at low prevalence. It is reported that the prevalence was 0.8% from Manyas Lake [80], 6.9% from Çayırhan Stream [112], 1.5% from Eymir Lake and Sarıyar Dam Lake [113], 52.2% from Porsuk Stream [114], 6.9% from Demirköprü Dam Lake [112], 10.6% from Enne Dam Lake [115], 22% from Karacaören I. Dam Lake [116], 1.5% and 43.8% from Kars Stream in different years [117], and 18.7% and 7% from Devegecidi Dam Lake in different years [118]. When we compared with the prevalence of *Ligula intestinalis* in Turkey, it is consistent with the research findings of Gabrashanska and Nedeva [111] and Oyoo-Okoth et al. [112]. In these aquatic ecosystems, the pollution caused by the mixing of domestic and industrial wastes has been determined by various researchers, for example, in Manyas Lake [84], Çayırhan Stream [119], Eymir Lake [120], Sarıyar Dam Lake [121], Porsuk Creek [122], Demirköprü Dam Lake [123], Enne Dam Lake [124], Karacaören I. Dam Lake [125], Kars Stream [126], and Devegeçidi Dam Lake [127]. However, these findings do not agree with those of Valtonen et al. [67]. This may be because the distribution of *L. intestinalis* in fish was not examined seasonally, which is the reason for the low infection values of *L. intestinalis* in most of the studies conducted in Turkey.

Shah et al. [128] found an increase in the prevalence of *Bothriocephalus acheilognathi* in waters with organic pollution, while Khalil et al. [129] found a decrease in experimental studies of cadmium toxicity. When examining ecosystems where the parasite have been reported in Turkey, various researchers have shown that wastewaters from domestic, industrial, and agricultural activities negatively affect these ecosystems in such waterbodies as Mustafakemalpaşa Stream [130], Bendimahi Brook and Zernek Dam Lake [131], Hazar Lake [132], Karakaya Dam Lake [133], Keban Dam Lake [134], and Bafra Fish Lakes [98].

When the infection values of this parasite have been examined in Turkey, they have generally been found to be low. The prevalence of *Bothriocephalus acheilognathi* was low in various fish, such as 8.3% on *Alburnus alburnus* in Mustafakemalpaşa Stream [135]; 14% on *C. carpio* in Bendimahi Brook and Zernek Dam Lake [106]; 0.8% on *Capoeta umbla* in Hazar Lake [136]; 1.6 % on *C. umbla* and 20% on *Acanthobrama marmid* in Karakaya Dam Lake [137]; and 23% on *A. marmid* and 10.8 % on *Chondrostoma regium* in Keban Dam Lake [138].

For waters with metal contamination, Morley et al. [139] determined an increase in the prevalence of *Proteocephalus torulosus*, while Valtonen et al. [67] found a decrease in waters where the wastes were mixed. Low prevalence values of *Proteocephalus torulosus* were determined in studies conducted in Beyşehir Lake (3%) and Akşehir Lake (2.8%) [140,141]. According to [142], there are three main types of pollution affecting Akşehir Lake: agricultural fertilizers, medicines, and household wastes, which are wastes from a canned fruit factory. The pollution present in Beyşehir Lake is generated by the streams of domestic waste, pesticides and fertilizers, and factory waste (textiles, rifle factories, fish businesses, etc.) [143]. Therefore, the low prevalence of parasite infection is in line with Valtonen et al.'s [67] findings.

Valtonen et al. [67] and Karvonen et al. [78] determined a decrease in the prevalence of *Neoechinorhynchus rutili* in lakes where waste and organic pollution are present. When the studies conducted in Turkey were examined, generally low infection rates were also found, for example, 6.2% prevalence by Kavak and Şeker [144], 21% prevalence by Topçu [106], 29.2% prevalence by Aydoğdu et al. [145], and 4% prevalence by Öztürk et al. [146]. These lakes are especially threatened by domestic and industrial pollution. When the pollution types of the ecosystems where the parasite is reported were examined, the presence of domestic, agricultural, and industrial wastes was identified by various researchers, for example, in Bendimahi River [131], Keban Dam Lake [134], İznik Lake [110], and Sarıkum Lagoon [147].

A decrease in the prevalence values of *Pomphorhynchus laevis* was determined in the lakes and the experimental studies of heavy metal pollution [103,148–150]. Low infection rates were also reported in the ecosystems where this parasite was reported in Turkey. Burgu et al. [113] reported this parasite from Eymir Lake (0.3%), from Sarıyar Dam Lake (0.3%), and from Örenler Dam Lake (32.7%) by Kurupınar [93]. These lakes are in affected by heavy metal pollutants originating from pesticides and fertilizers from agricultural and animal activities. Soylu [151] reported this parasite with 83.3% prevalence from Karasu Stream, while 61.8% prevalence from Akşehir Lake was reported by Buhurcu [152]. Although both studies found a high percentage of infections, this could be attributed to the lack of seasonal study of parasites.

Filipović Marijić et al. [150] determined that the infection value decreased for *Acanthocephalus anguillae* in *S. cephalus* in the case of heavy metal contamination. Infection values of *Acanthocephalus anguillae* are low: 0.7% on *E. lucius* in Uluabat Lake [100] and 1% on *Tinca tinca* in Beyşehir Lake [140] in Turkey.

While an increase was found in the prevalence of *Raphidascaris acus* in waters with thermal and waste pollution [67,104], a decrease was found in waters with organic pollution [78]. There has been an increase in the infection values of the parasite in Sapanca and Uluabat Lakes, while waste pollution has been found in these lakes [91,153]. Soylu et al. [88] reported this parasite with 65.2% prevalence, while 96.2% prevalence was reported by Öztürk et al. [100]. There is intense organic pollution in Sakarya River and Karacabey Lagoon [107,154]. There was a decrease in the infection values in these ecosystems. This parasite was recorded with 15.7% and 18.1% prevalence by Öztürk et al. [100] and Akmırza and Yardımcı [105], respectively.

It has been determined that ergasilids tend to decrease in waters with eutrophication and organic pollution [75,78,155], effluent pollution [155], acidification [95], and thermal pollution [104]. A similar decrease has been observed in the infection values of ergasilids, even in some lakes in Turkey (Ömerli Dam Lake, Keban Dam Lake, Bafra Fish Lakes, Sarıkum Lagoon Lake). *Ergasilus briani* was recorded with 9.5% prevalence on *Alburnus mossulensis* by Sağlam [156], *Ergasilus sieboldi* with 13.5% prevalence on *Alburnus istanbulensis* by Şimşek [157], and 6.2% prevalence on *C. regium* and 0.5% prevalence on *Capoeta trutta* by Sağlam [156]. Considering the ecosystems where ergasilids have been reported in Turkey, there is the presence of the above-mentioned contaminants, for example, in Ömerli Dam Lake [158], Keban Dam Lake [134], Bafra Fish Lakes [98], and Sarıkum Lagoon [147].

Tuuha et al. [155] determined that the infection value of *Paraergasilus longidigitus* increased in waters with eutrophication and effluent pollution. The infection rate of the parasite in *A. alburnus* in Enne Dam Lake in Turkey was found to be higher (56.7%) than that of other ergasilids. In the Enne Dam Lake, where the parasite is reported, there is thermal pollution in addition to waste pollution [126].

Infection values of the parasitic copepods were generally found to be significantly low. *Lernaea cyprinacea* was reported with 6.4% prevalence on *C. carpio* (Tahtalı Dam Lake) by Karakişi and Demir [159]; 5% on *Cyprinion macrostomum* from Murat River by Koyun et al. [160]; 31.3% on *Pseudophoxinus egridiri* from Egirdir Lake by Akçimen et al. [161]; and *Lamproglena pulchella* was reported with 28.5% on *C. trutta* from Keban Dam Lake by Sağlam [156].

In Tóro et al.'s [162] laboratory study, it was determined that oil and petroleum waste caused a decrease in the prevalence of *Lernaea cyprinacea*, while Galli et al.'s [66] field study determined the limiting effect of pollution on *Lamproglena pulchella*.

When the pollution status of the lakes where *Lernaea cyprinacea* are reported was examined, pollution from industrial, mining, and oil exploration activities was found [163–165]. Similarly, domestic and agricultural contamination has been identified in Keban Dam Lake, where *Lamproglena pulchella* was previously reported.

A decrease in the prevalence of *Argulus foliaceus* was found in a lake where organic pollution was present, by Karvonen et al. [78], and in an experiment on metal pollution by Pettersen et al. [166]. When the infection values of the parasite were examined in Turkey, low infection rates were observed. Öztürk [167] reported argulus with 6.5% prevalence on *C. carpio*, while 10.7% was reported on *C. carassius* by Tekin Özan and Kır [141]; 1.3% on *Planiza abu* and 14.3% on *Mastacembelus mastacembelus* by Öktener et al. [168]; and 19.1% on *C. carpio* and 11.1% on *Carasobarbus luteus* by Öktener and Alaş [169]. These lakes are under the influence of both organic pollution and metal pollution.

Altan and Soylu [95] found a decrease in the infection values of *Piscicola geometra* in inland waters with acidification, and Jirsa et al. found the same in waters with effluent pollution [103]. When the ecosystems where *Piscicola geometra* has been reported were examined, the infection values of the parasite were reported to be low. A prevalence of 4.9% on *B. bjoerkna* was reported by Altan and Soylu [95]; 1.2% on *R. rutilus* was found by Karabiber [87]; 2.1% on *Barbus rajanorum* was found by Sağlam [156]; and 1.4% on *T. tinca* was reported by Öztürk [80]. The presence of wastewater pollution in the mentioned lakes (Büyük Akgöl, Sapanca, Keban Dam, Uluabat) has been identified by the researchers mentioned above. Therefore, these findings from Turkey overlap with those of Altan and Soylu [95] and Jirsa et al. [103].

Karvonen et al. [78] reported that the prevalence value of glochid in fish tends to decrease in waters with eutrophication and organic pollution, and Pettersen et al. [166] found the same in waters with metal pollution. In these aquatic environments, where glochids are reported in Turkey, there is intense pollution, as stated above. Altan and Soylu [95] reported glochid prevalence with 21.3% on *B. bjoerkna*; 18.1% on *A. brama* was reported by Akmırza and Yardımcı [105]; and 8.8% on *T. tinca* was found by Akbeniz [170].

There are few studies on the accumulation of pollutants in parasites in determining the pollution in freshwaters in Turkey. Tekin Özan and Kır [58] pointed out that *Ligula intestinalis* (Cestoda) might be a suitable biomonitor species in the determination of heavy metal pollution in their study of Kovada Lake, while, in two studies conducted in Beyşehir Lake, it was stated that it was not useful as a biomonitor species [60]. Tekin Özan and Kır's [59] study on pike reported that *Raphidascaris acus* (Nematoda) is a reliable species in the determination of heavy metal pollution in Işıklı Lake. Genç et al. [60] described *Anguillicola crassus* (Nematoda) as a useful species in the determination of heavy metal pollution in their study on parasites of European eel in the Asi River.

5. Conclusions

Fish parasites generally occur in equilibrium with their hosts in natural environments. In the freshwater ecosystems of Turkey, which are highly affected by human activities and which have extremely rich natural ichthyofauna, the negative effects of pollution on environmental parameters, which can directly affect fish, and the emergence and overextension of fish parasites can cause a supplementary synergic direct negative effect transposition in mass fish deaths due to the deterioration of host immunity and to the induced wounds in fish where bacterial, viral, and fungal pathogens can be effective. Finally, they can influence the fish rate of survival and skew the structure of fish populations.

Mass fish deaths have been frequently reported in Turkey, but are usually explained only by pollution as a single accepted anthropogenic stressor. Together with pollution, a supplementary induced bioecological stressor, the qualitative and quantitative characteristics of the fish parasites' association variations should be assessed and monitored as potential complex precursor indicators of fish communities' structural degradation and freshwater ecosystems' dreadful conditions.

There are many studies across the world on the use of fish parasites as biomonitors in the determination of pollution in aquatic ecosystems. Classical laboratory methods are generally used to determine the pollution in freshwaters in Turkey. Fish parasites as biomonitor species should be used to identify pollution in freshwaters in the future. An optimum freshwater ecosystem management plan should contain all the physico-chemical factors, and fish parasite and fish elements should be involved in permanent monitoring, analysis, and management activities.

This type of research approach is inchoate, opening a new research field of interest. What is required in the future is to be able to identify and indicate individually which parasites and which ecological circumstances are good indicators of a specific or complex case of contamination. It should also be stressed that the interrelated causes and effects should create synergic situations, and one cause should not be attributed to one specific contamination effect.

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