


Review

Status of Endemic Freshwater Fish Fauna Inhabiting Major Lakes of Turkey under the Threats of Climate Change and Anthropogenic Disturbances: A Review

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Abstract: Due to its peculiar geographical position and its environmental heterogeneity, Turkey represents an important biodiversity hotspot for freshwater fish fauna. Unfortunately, native fish communities of Turkey, mainly from lentic ecosystems, have been massively altered in the past decades. Furthermore, these species, especially the endemic species, are now threatened by several human activities in addition to the global issue of climatic changes. The aim of this paper is to provide an updated review on the current status of endemic fish species from main lakes of Turkey including major threats affecting fish assemblages. By gathering data from the literature and authors' personal observations, 62 endemic fish species were reported to occur in the considered 37 Turkish Lakes. The presence of non-native species, agriculture activities, climatic drought, and decreasing water level were found to be the threats that most affect the fish communities of the considered Turkish Lakes.

Keywords: Anatolia; IUCN; non-native species; water drought; aquatic biodiversity



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1. Introduction

Due to its crossroads location and the diversity of its geographic features and climatic conditions, Turkey hosts a very rich biodiversity. This richness is also clearly reported by the global map of biodiversity hotspots showing that 3 out of 34 world biodiversity hotspots meet in Turkey: The Mediterranean, Caucasus, and Irano-Anatolian [1]. This unique biodiversity is the result of various biogeographic factors [2] and land-use history [3] that, over the centuries, have shaped the territory. Turkey is also a core of intraspecific diversity given that during the last glacial age it served as the so-called South-Eastern refugium for several European taxa [4,5].

The Asian part of Turkey, also known as Anatolia or Asia Minor (hereinafter referred to as Anatolia), is perhaps one of the richest regions in the world in terms of lakes. The Eastern Anatolian region and north of the Taurus Mountains in the Mediterranean region, also known as the "Lakes Region", hosts the majority of the Turkish lakes. These lakes are the remains of large inland lakes that once covered Central and Eastern Anatolia and often have distinct features deriving from their surrounding soils. For this reason, all these lakes have peculiar water features that make them worthy of worldwide interest. Among them, Lake Van is the world's largest soda lake and also one of the largest of few endorheic lakes located in Eastern Anatolia; Lake Tuz is one of the world's largest hypersaline lakes with a surface and water level that vary seasonally [6]. These lakes are also important wetlands providing breeding, accommodation, and wintering areas for water birds. This is because Turkey is the passage for two major bird migration routes extending from northern Europe to Africa. In more detail, among the Turkish wetland protected areas, 91 to 135 in Turkey are special areas for birds [7].

Despite this richness and these peculiarities, half of these wetland areas are currently threatened by drought. In the last 100 years, about 1.3 million hectares of Turkish wetlands

have completely dried out [8]. The diminution of annual and winter precipitation occurring in Turkey (and principally in the Aegean and Mediterranean regions) in the last decades has led to a gradual degradation of soil moisture and a general decrease in the water level of the Turkish lakes [9,10]. This is mainly due to increasing temperature caused by climate change and the pressure generated by anthropogenic activities, mainly consisting of draining activities for the control of malaria or the creation of new agricultural lands [8]. Also, the alteration of water flows, water pollution, and eutrophication represent the most severe threats to Turkish wetlands [11]. In addition to these, a further degradation of these habitats derives from the overexploitation of marginal vegetation of the lakes by local communities for livestock farming [2,12]. In particular, Türkeş [13] reported that by an examination of the regional and historical changes in precipitation and drought index series in Turkey showed that extreme drought in the southeast and middle Anatolia regions is mostly due to climatic effects, whereas in the Mediterranean and Aegean regions it is principally due to anthropogenic disturbances.

The peculiar characteristics of these aquatic environments are also reflected in their fauna, which, having been isolated for very long time due to the above cited factors, have undergone an original process of speciation. As a result of this isolation, Turkish lakes host several rare species [14]. Moreover, the fauna inhabiting the lakes are particularly vulnerable to climate change because they have limited possibility to disperse in case of rapid environment changes and because, as mentioned above, they are already exposed to numerous human-induced pressures [15]. Among these human-induced threats, the presence of non-native species is reported worldwide as the second main factor threatening aquatic fauna after climate change [16]. Among the non-native species, some become invasive and are able to establish viable populations that can negatively impact the new environment [17,18]. With regard to Turkey, it is known that the composition of the fish communities of Turkish inland waters has been significantly altered in the last decades by a huge number of non-native species that have been introduced, deliberately or accidentally, into inland water, leading to alterations in ecosystem structure and impacting the abundance and composition of native communities [19]. Non-native species can cause detrimental impacts on the environment, not only indirectly because of their impacts on native fauna through predation, competition, hybridization, or disease transmission; they can also be a direct cause of habitat degradation [20–23].

Although several local studies focusing on fish species of some Turkish lakes are available in the literature, there is a lack of a comprehensive summary of the threats posed to them or the endemic fish species inhabiting these valuable ecosystems.

Thus, the aim of this study was to provide an updated review on the current status of endemic fish species from main lakes of Turkey, including the major threats affecting fish assemblages.

2. Materials and Methods

In order to create a complete and exhaustive background, the available literature and published data reported in recent international publications (papers, proceedings, and books from 1990 to 2020) were assembled and supplemented with information accessible from grey literature (theses, project reports) and personal unpublished observations of the authors.

Specifically, 37 lakes located across Turkey and chosen considering those most studied and for which information was available in literature were taken under consideration (Figure 1).

Firstly, a list of the endemic freshwater fish species occurring in the considered Turkish lakes was created taking into consideration the local endemic species (endemic only to a restricted lake or watershed) or regional endemism (species occurring only in several of the selected lakes). For each fish species, all taxonomic information follows FishBase and Eschmeyer's Catalog of Fishes [24,25], and its IUCN Red List Category [26] is also provided.

Thus, for each lake, a detailed list of the major threatening factors was created taking into consideration the following 14 threats organized by impact from highest to lowest:

climatic drought; decreasing water level; presence of non-native species; agricultural activities; water pollution; wastewater discharge; overfishing; urbanization; presence of industrial activities; tourism activities; massive fish death; cutting/burning of the reeds; aquaculture activities; and presence of power plants.

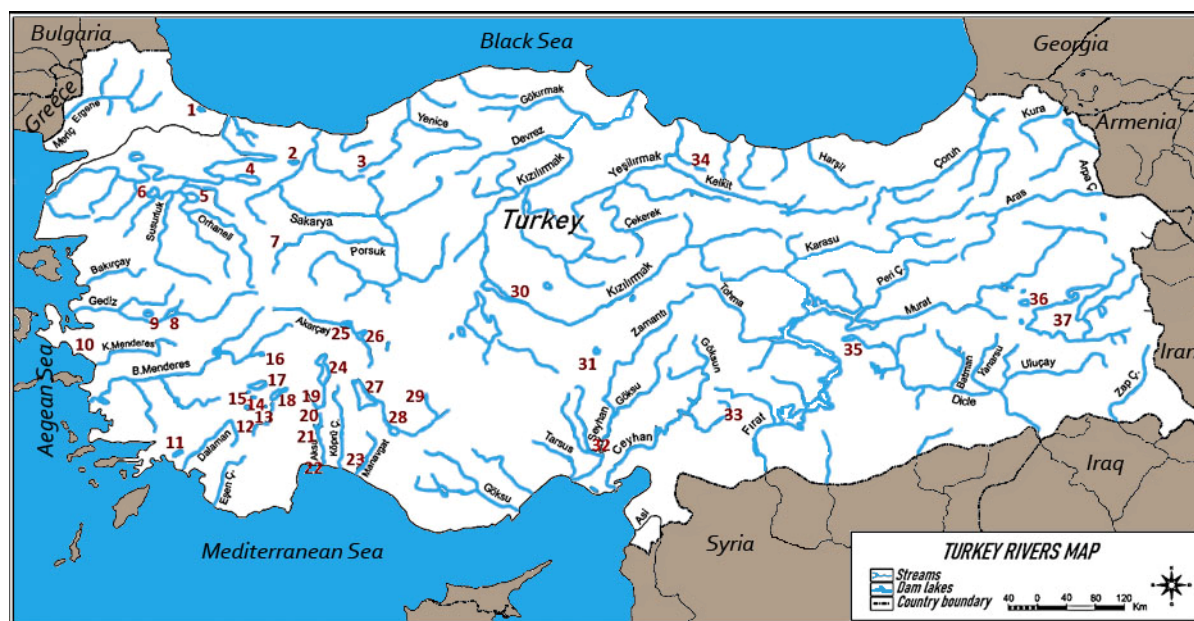


Figure 1. Map reporting the locations * of the 37 lakes in Turkey considered in the study, together with their river systems (*: 1—Lake Durusu, 2—Lake Sapanca, 3—Lake Abant, 4—Lake Iznik, 5—Lake Apolyont (Uluabat), 6—Lake Manyas, 7—Dam Lake Enne, 8—Dam Lake Demirköprü, 9—Lake Marmara, 10—Lake Kocagöz, 11—Lake Köyceğiz, 12—Dam Lake Yapraklı, 13—Lake Gölhisar, 14—Lake Yarışlı, 15—Lake Salda, 16—Lake Işıklı, 17—Lake Acıgöl, 18—Lake Burdur, 19—Lake Gölçük, 20—Dam Lake Onaç, 21—Lake Kırkgöz, 22—Lake Yamansaz, 23—Dam Lake Manavgat, 24—Lake Eğirdir, 25—Lake Eber, 26—Lake Akşehir, 27—Lake Beyşehir, 28—Lake Suğla, 29—Lake Altınapa, 30—Dam Lake Hirfanlı, 31—Marshes Sultan, 32—Dam Lake Seyhan, 33—Lake Gölbaşı, 34—Dam Lake Almus, 35—Lake Hazar, 36—Lake Nazik, 37—Lake Van).

For the threat “presence of non-native species”, specific details on the non-native species are reported for each lake. Specifically, the following categories for introduced species (non-native and translocated) were considered: *Atherina boyeri* Risso 1810, *Carassius gibelio* (Bloch 1782), *Cyprinus carpio* Linnaeus 1758, *Esox lucius* Linnaeus 1758, *Gambusia holbrooki* Girard 1859, *Knipowitschia caucasica* (Berg 1916), *Lepomis gibbosus* (Linnaeus 1758), *Oncorhynchus mykiss* (Walbaum 1792), *Pseudorasbora parva* (Temminck & Schlegel 1846), *Sander lucioperca* (Linnaeus 1758), *Tinca tinca* (Linnaeus 1758), and other species. This last category includes some non-native and translocated species that are reported to occur only in some locations of Turkey (i.e., *Clarias gariepinus* (Burchell 1822); *Coptodon rendalli* (Boulenger 1897); *Coptodon zillii* (Gervais 1848); *Ctenopharyngodon idella* (Valenciennes, 1844); *Oreochromis niloticus* (Linnaeus 1758); *Perca fluviatilis* Linnaeus 1758 and so on).

3. Results and Discussion

Table 1 reports a summary of information about the 37 selected Turkish lakes. Together with physical characteristics (area, water depth, and elevation), information about the river basin and the lake origin is provided (Table 1).

A total of 62 freshwater fish species endemic to Turkey have been reported to occur in the 37 selected Turkish lakes (Table 2). The most represented family was Leuciscidae (26 species), followed by Aphaniidae (9), then Cyprinidae, Cobitidae, and Nemacheilidae (6 each) (Table 2).

Table 1. Details of physical characteristics (area, water depth, elevation), the river basin, and the origin for each of the 37 considered Turkish lakes (N: lake number in Figure 1 from west to east).

Lake	N	River Basin	Area (km ²)	Height from Sea (Altitude) (m)	Maximum Depth (m)	Origin
Abant	3	Western Black Sea	1.28	1335	18	Landslide Set
Acıgöl	17	Burdur (Closed)	92	844	2	Tectonic
Aksehir	26	Akarçay	102	958	4	Tectonic
Almus Dam	29	Yeşilirmak	31.3	817	75	Artificial
Altınapa Dam	5	Konya (Closed)	2.20	1257	30	Artificial
Apolyont	27	Susurluk	135	6	10	Tectonic
Beyşehir	18	Konya (Closed)	656	1125	10	Tectonic–Karstic
Burdur	34	Burdur (Closed)	150	845	61	Tectonic
Demirkopru Dam	8	Gediz	47.7	238	50	Artificial
Durusu Dam	1	Marmara	30.4	2	3.4 (mean)	Coastal set–artificial
Eber	25	Akarçay	120	967	6	Tectonic
Eğirdir	24	Antalya	470	916	13	Tectonic–Karstic
Enne Dam	7	Sakarya	0.94	1001	22	Artificial
Gölbasi	33	Ceyhan	2.19	880	22	Tectonic–Karstic
Gölcük	19	Antalya	1	1360	41	Volcanic
Göhlisar	13	Western Mediterranean	4	946	10	Karstic
Hazar	35	Fırat Dicle	86	1248	210	Tectonic
Hirfanlı Dam	30	Kızılırmak	263	870	40	Artificial
Işıklı	16	Büyük Menderes	65	815	8	Tectonic
Izник	4	Marmara	298	85	65	Tectonic
Kırkgöz	21	Antalya	<2	302	2	Karstic
Kocagöz	10	Küçük Menderes	<1	8	7	Tectonic–Alluvial Set
Köyceğiz	11	Western Mediterranean	52	8	30	Alluvial Set
Manavgat Dam	23	Antalya	8.6	58	30	Artificial
Manyas	6	Susurluk	161	17	5	Tectonic
Marmara	9	Gediz	41	71	7	Alluvial Set
Nazik	31	Van (Closed)	45	1816	48	Lava Set
Onaç Dam	36	Antalya	3.56	838	21	Artificial
Salda	20	Burdur (Closed)	43	1140	180	Tectonic
Sapanca	15	Sakarya	47	34	61	Alluvial Set
Seyhan Dam	2	Seyhan	67.8	10	45	Artificial
Suğla	32	Konya (Closed)	40	1090	2	Tectonic–Karstic
Sultan Marshes	28	Kızılırmak	200	1070	2	Tectonic
Van	37	Van (Closed)	3713	1646	451	Volcanic–Lava Set
Yamansaz	22	Antalya	11	2	5	Karstic
Yapraklı Dam	12	Western Mediterranean	6.5	1070	>20	Artificial
Yarıklı	14	Burdur (Closed)	14	912	2	Tectonic

Table 2. List of the freshwater fish species endemic to Turkey reported ¹ to occur in the main lakes of Turkey (N: lake number in Figure 1 from West to East; IUCN: IUCN category according to [26]; Endemism: LE: local endemic, RE: regional endemic).

Lake	N	Family	Species	English Common Name	IUCN	Endemism
Abant	3	Salmonidae	<i>Salmo abanticus</i> Tortonese, 1954	Abant trout	NE	LE
Acıgöl	17	Aphaniidae	<i>Anatolichthys transgrediens</i> (Ermin 1946)	Acipinar killifish	CR	LE
		Cobitidae	<i>Cobitis phrygica</i> Battalgil 1944	Aci spined loach	NE	RE
Akşehir	26	Gobionidae	<i>Gobio intermedius</i> Battalgil, 1944	Eber gudgeon	EN	RE
		Leuciscidae	<i>Squalius recurvirostris</i> Özulug & Freyhof, 2011	Akşehir chub	VU	RE
Almus Dam	34	Cyprinidae	<i>Barbus anatolicus</i> Turan, Kaya, Geiger & Freyhof, 2018	-	DD	RE
Altınapa Dam	29	Leuciscidae	<i>Squalius anatolicus</i> (Bogutskaya, 1997)	Beyşehir dace	LC	RE
Apolyont	5	Clupeidae	<i>Clupeonella muhlisi</i> Neu, 1934	Apolyont sprat	NE	RE
		Leuciscidae	<i>Alburnus carinatus</i> Battalgil, 1941	Manyas shemaya	EN	RE
Beyşehir	27	Aphaniidae	<i>Anatolichthys iconii</i> (Akşiray 1948)	Konya killifish	NE	RE
		Cobitidae	<i>Cobitis battalgilae</i> Bacescu, 1962	Battalgil spined loach	EN	RE
			<i>Cobitis bilseli</i> Battalgil, 1942	Beyşehir spined loach	EN	LE
		Cyprinidae	<i>Capoeta mauricii</i> Küçük, Turan, Şahin & Gülle, 2009	Longsnout scraper	EN	RE
			<i>Garra kemali</i> (Hankó, 1925)	Ereğli minnow	EN	RE
		Gobionidae	<i>Gobio microlepidotus</i> Battalgil, 1942	Beyşehir gudgeon	VU	RE
		Leuciscidae	<i>Alburnus akili</i> Battalgil, 1942	Beyşehir bleak	EX	LE
			<i>Chondrostoma beysehirense</i> Bogutskaya, 1997	Beyşehir nase	EN	RE
			<i>Pseudophoxinus anatolicus</i> (Hankó, 1925)	Anatolian minnow	EN	RE
			<i>Pseudophoxinus battalgilae</i> Bogutskaya, 1997	Beyşehir minnow	NE	RE
<i>Pseudophoxinus hittitorum</i> Freyhof & Özulug, 2010	Hittitic spring minnow		EN	RE		
Nemacheilidae	<i>Squalius anatolicus</i> (Bogutskaya, 1997)	Beyşehir dace	LC	RE		
Nemacheilidae	<i>Oxynoemacheilus atili</i> Erk'akan, 2012	Beyşehir loach	NT	RE		
Burdur	18	Aphaniidae	<i>Anatolichthys sureyanus</i> (Ney 1937)	Sureyan killifish	EN	LE
Demirköprü Dam	8	Gobiidae	<i>Knipowitschia mermere</i> Ahnelt, 1995	Marmara goby	VU	RE
Durusu	1	Leuciscidae	<i>Alburnus istanbulensis</i> Battalgil 1941	Thracian shemaya	LC	RE
Eber	25	Leuciscidae	<i>Squalius recurvirostris</i> Özulug & Freyhof, 2011	Akşehir chub	VU	RE
		Nemacheilidae	<i>Seminemacheilus lendlii</i> (Hankó, 1925)	Anatolian loach	VU	RE
Eğirdir	24	Aphaniidae	<i>Anatolichthys iconii</i> (Akşiray 1948)	Konya killifish	NE	RE
		Cyprinidae	<i>Garra klatti</i> (Kosswig 1950)	Isparta minnow	EN	RE
			<i>Capoeta pestai</i> (Pietschmann, 1933)	Egirdir barb	CR	RE
		Leuciscidae	<i>Pseudophoxinus egridiri</i> (Karaman, 1972)	Egirdir minnow	EN	LE
<i>Pseudophoxinus handlirschi</i> (Pietschmann, 1933)	Handlirsch's minnow		EX	LE		
Enne Dam	7	Leuciscidae	<i>Alburnus escherichii</i> Steindachner, 1897	Caucasian bleak	LC	RE
Gölbasi	33	Cobitidae	<i>Cobitis erkakanae</i> Freyhof, Bayçelebi & Geiger, 2018	Gölbasi spined loach	NE	RE
Gölcük	19	Aphaniidae	<i>Anatolichthys splendens</i> Kosswig & Sözer 1945	Splendid killifish	EX	LE
		Cyprinidae	<i>Garra klatti</i> (Kosswig 1950)	Isparta minnow	EN	RE
Göhlisar	13	Leuciscidae	<i>Scardinius elmaliensis</i> Bogutskaya, 1997	Antalya rudd	EN	RE
Hazar	35	Aphaniidae	<i>Kosswigichthys asquamatus</i> Sözer 1942	Scaleless killifish	LC	LE
		Leuciscidae	<i>Alburnus heckeli</i> Battalgil, 1944	Hazar bleak	LC	LE
		Nemacheilidae	<i>Oxynoemacheilus hazarensis</i> Freyhof & Özulug, 2017	Hazar loach	NE	LE
Hirfanlı Dam	30	Aphaniidae	<i>Anatolichthys danfordii</i> (Boulenger 1890)	Danford's killifish	CR	RE

Table 2. Cont.

Lake	N	Family	Species	English Common Name	IUCN	Endemism
Işıklı	16	Gobionidae	<i>Gobio maeandricus</i> Naseka, Erk'akan & Küçük, 2006	Işıklı gudgeon	EN	RE
		Leuciscidae	<i>Squalius carinus</i> Özulug & Freyhof, 2011	Chocolate chub	EN	LE
Iznik	4	Leuciscidae	<i>Alburnus nicaeensis</i> Battalgiç, 1941	Iznik shemaya	EX	LE
Kırkgöz	21	Aphaniidae	<i>Paraphanius mentoides</i> (Akşiray, 1948)	-	NE	RE
Kocagöz	10	Gobiidae	<i>Knipowitschia ricasolii</i> (Di Caporiacco 1935)	Ephesus goby	CR	RE
		Gobiidae	<i>Knipowitschia byblisia</i> Ahnelt, 2011	Byblis goby	LC	RE
Köyceğiz	11	Gobiidae	<i>Knipowitschia caunosi</i> Ahnelt, 2011	Caunos goby	LC	LE
		Leuciscidae	<i>Alburnus baliki</i> Bogutskaya, Küçük & Ünlü, 2000	Antalya bleak	EN	RE
Manavgat Dam	23	Leuciscidae	<i>Alburnus carinatus</i> Battalgiç, 1941	Manyas shemaya	EN	RE
		Leuciscidae	<i>Alburnoides manyasensis</i> Turan, Ekmekçi, Kaya & Güçlü, 2013	Manyas spirilin	LC	LE
Marmara	9	Gobiidae	<i>Knipowitschia mermere</i> Ahnelt, 1995	Marmara goby	VU	RE
		Cobitidae	<i>Cobitis joergbohleni</i> Freyhof, Bayçelebi & Geiger, 2018	Sultan spined loach	NE	LE
Marsh Sultan	31	Leuciscidae	<i>Pseudophoxinus elizavetae</i> Bogutskaya, Küçük & Atalay, 2006	Sultan Sazlığı minnow	CR	RE
		Nemacheilidae	<i>Oxynoemacheilus ciceki</i> Sungur, Eagderi & Jalili, 2017	Loach	NE	LE
Nazık	36	Nemacheilidae	<i>Seminemacheilus ahmeti</i> Sungur, Jalili, Eagderi & Çiçek, 2018	Sultan crested loach	NE	LE
		Cyprinidae	<i>Capoeta kosswigi</i> Karaman, 1969	Van barb	DD	RE
Onaç Dam	20	Leuciscidae	<i>Alburnus tarichi</i> (Güldenstädt, 1814)	Van bleak	NT	RE
		Nemacheilidae	<i>Oxynoemacheilus ercisanus</i> (Erk'akan & Kuru, 1986)	Van loach	EN	RE
Salda watersheds	15	Leuciscidae	<i>Pseudophoxinus ninae</i> Freyhof & Özulug, 2006	Onaç spring minnow	CR	RE
		Aphaniidae	<i>Anatolichthys fontinalis</i> (Akşiray 1948)	Burdur killifish	NE	RE
		Aphaniidae	<i>Anatolichthys saldae</i> (Akşiray 1955)	Salda killifish	NE	LE
		Cobitidae	<i>Cobitis phrygica</i> Battalgazi, 1944	Aci spined loach	NE	RE
Sapanca	2	Leuciscidae	<i>Pseudophoxinus burduricus</i> Küçük, Gülle, Güçlü, Çiftçi & Erdogan, 2013	Burdur spring minnow	EN	RE
		Leuciscidae	<i>Squalius fellowesii</i> (Günther, 1868)	Aegean chub	LC	RE
Seyhan Dam	32	Cobitidae	<i>Cobitis emrei</i> Freyhof, Bayçelebi & Geiger, 2018	Sapanca spined loach	NE	LE
Suğla	28	Leuciscidae	<i>Chondrostoma ceyhanensis</i> Küçük, Turan, Güçlü, Mutlu & Çiftçi, 2017	Ceyhan Nase	NE	RE
		Cobitidae	<i>Cobitis battalgilae</i> Bacescu, 1962	Battalgil spined loach	EN	RE
Van	37	Leuciscidae	<i>Pseudophoxinus anatolicus</i> (Hankó, 1925)	Anatolian minnow	EN	RE
		Nemacheilidae	<i>Pseudophoxinus battalgilae</i> Bogutskaya, 1998	Beyşehir minnow	NE	RE
Yamansaz	22	Leuciscidae	<i>Alburnus tarichi</i> (Güldenstädt, 1814)	Van bleak	NT	RE
		Nemacheilidae	<i>Oxynoemacheilus ercisanus</i> (Erk'akan & Kuru, 1986)	Van loach	EN	RE
Yapraklı Dam	12	Leuciscidae	<i>Pseudophoxinus alii</i> Küçük, 2007	Pamphylian spring minnow	EN	RE
Yarışlı	14	Leuciscidae	<i>Alburnus carianorum</i> Freyhof, Kaya, Bayçelebi, Geiger & Turan, 2018	-	EN	RE
		Aphaniidae	<i>Anatolichthys fontinalis</i> (Akşiray 1948)	Burdur killifish	NE	RE

¹ main references: [25,27–46].

Most of the Leuciscidae species belong to the *Alburnus* (9 species) and *Pseudophoxinus* (9 species) genera (72% in total). *Alburnus* was found to be very rich in Turkey, with 20 valid species reported to occur in the country [46,47]. Hrbeek et al. [48] underlined the significant role of central Anatolian plate tectonic events on the diversification and

phylogenetic relationships of the genus *Pseudophoxinus*, which is often co-distributed with *Anatolichthys* (Aphaniidae) in Central Anatolia. Turkey was recognized by Wildekamp [29] and Wildekamp et al. [49] as the center of diversity for the *Aphanius* (now *Anatolichthys*) genus, and Hrbek et al. [50] reported that 6 species and 4 subspecies of the 14 described occur in Anatolia [50]. Nevertheless, these populations are currently in decline due to degradation of habitats, mainly caused by excessive water use for agricultural activities and the presence of non-native species, but there is a lack of knowledge about the status of these species [51].

With regard to Cobitidae, the evolution of the *Cobitis* genus in Anatolia started in the Miocene and led to the formation of a large number of local lineages of this group [28]; to date, 28 species have been reported in Turkey [28], but the taxonomy of the genus is under continuous revision. Among the Nemacheilidae, *Oxynoemacheilus* is the largest genus and in Turkey has a great diversity, with 42 reported species from inland waters (26 endemics) [52–55]. Southwestern Anatolia is also an important biodiversity hotspot for the genus *Knipowitschia* (Gobiidae), with four of the five recorded species being endemic to Turkey (*K. byblisia*, *K. caunosi*, *K. mermere*, and *K. ricasoli*) and reported to occur only in isolated habitats [27,35,56] (Figure 2).



Figure 2. Pictures of some representative species endemic to Turkey: 1: *Pseudophoxinus alii*; 2: *Aphanius transgrediens*; 3: *A. sureyanus*; 4: *Alburnus tarichi*. (Original photos by Deniz Innal.)

Considering the 62 endemic species listed in Table 2 according to their IUCN categories, an alarming result emerged (Figure 3).

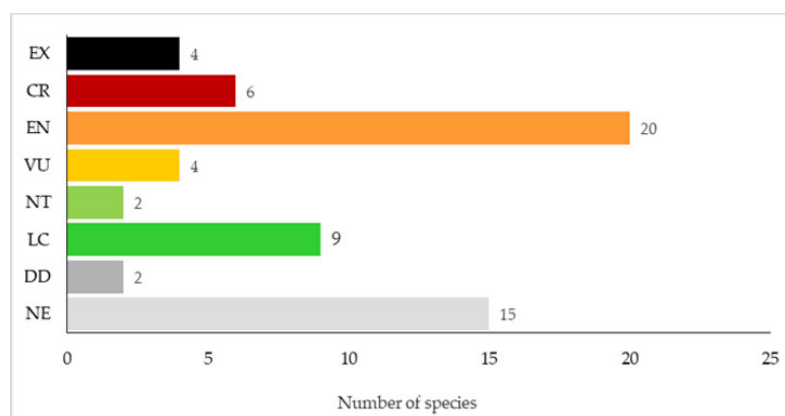


Figure 3. Number of species endemic to Turkish lakes listed in the categories of IUCN (2020) [26].

Among the considered species, four (*A. akili*, *A. nicaeensis*, *A. splendens*, and *P. handlirschi*) are listed as Extinct according to IUCN [26]. *Alburnus nicaeensis* most likely became extinct due to the invasion of non-native and translocated species that were stocked into Lake Iznik to improve fishery yields [57]. Similarly, *A. splendens*, *A. akili*, and *P. handlirschi* are also considered extinct in lakes Gölcük, Beyşehir, and Eğirdir, respectively, given that no individuals have been found in the last decades [58–60]. With regard to Lake Eğirdir, several studies reported that the introduction of zander (*Sander lucioperca*) into the lake in 1955 caused the extinction of some endemic species [61]. Alarmingly, similar collapses of native fish stocks are also underway in Lake Beyşehir [19].

With endemic species often being restricted to only a small and isolated area, they are more sensitive to change in the environment, and threats to their habitat can lead to their disappearance. To give an example, Lake Burdur, one of the saline lakes of Central Anatolia, is known to have undergone a slow decrease in water supply, caused by massive and often uncontrolled water abstraction for agriculture purposes and the construction of dams and reservoirs. Currently, it can be reported that almost no water is left over to feed the lake (authors' personal observation). *Anatolichthys sureyanus* (Figure 2) is strictly endemic to Burdur Lake and it is currently assessed as Endangered, but, given the current status of the lake, it appears that the survival of the species is at a higher risk and that the species requires detailed conservation actions. Although *A. sureyanus* is known to be quite tolerant of the high pollution in Lake Burdur, the species has been observed congregating close to freshwater springs where the salinity is lower, indicating that the increasing salinity of the lake is reaching levels that the species cannot tolerate. Among all the 58 remaining endemic species, 6 are listed as Critically Endangered and 20 are listed as Endangered (Figure 3). In addition, another detail worthy of concern is the high number of species in the categories Not Evaluated and Data Deficient (15 and 2, respectively) (Figure 3). This underlines the lack of information on the biology and ecology of these endemic species and the need for detailed studies to assess their conservation status.

Considering the number of endemic species reported for each lake (Table 2), Lake Beyşehir, the largest freshwater lake in Turkey and in all the Mediterranean basin, is the lake with the highest number of endemic species (13), followed by Lake Eğirdir (5 species).

Salmo abanticus is one of the Salmonidae species endemic to Turkish lakes. Although Kalayci et al. [62] reported the species as a synonym of *S. trutta*, the taxon is still considered as a species and listed as Vulnerable according to IUCN (2019) [63]. In Lake Abant, the population of the species declined due to the introduced *O. mykiss*. Currently, the population is continuously restocked in the lake for fishing purposes, but it is unknown what would happen to the population if stocking was stopped [63]. With regard to Lake Van, only two endemic species have adapted to its hypersodic waters. One of these, *Alburnus tarichi* (Figure 2), is a lacustrine, pelagic species that migrates about 15 km up inflowing rivers to spawn. The population has been in decline due to activities in the spawning streams, illegal fishing, habitat degradation, and wastewater pollution (from domestic and industrial sources). Currently only 12 rivers are available as spawning areas for the species; the other rivers are either too small or are blocked by weirs (with no fish passes).

In Table 3, a detailed list of the main disturbances is reported for each of the lakes studied.

In summary, all the 37 lakes showed exposure to at least five different threats. More specifically, the most disturbed lakes were Lake Seyhan Dam (11 of the 14 threats) followed by Lake Marmara, Lake Demirkopru Dam, Lake Eber, Lake Hazar, and Lake Sapanca (10 of the 14 threats each). On the contrary, those with the lowest number of reported threats (5 of 14) were Lake Kocagöz, Lake Gölcük, and Lake Manavgat Dam. Although this result could sound like good news for these last three cited lakes, it is important to take into consideration that this could also be due to a lack of specific studies focusing on these environments and not an optimistic report of their ecological integrity. Further research focusing on these lakes as well as those showing greater disturbance is therefore suggested. Another result to underline from Table 3 is that Lake Van was the only environment where

Considering the frequencies of occurrence for the 14 examined categories of threats, climatic droughts and decreasing water level (all lakes) were the most reported disturbances, followed by presence of non-native species (36 of 37 lakes) and agricultural activities (35 of 37) (Figures 4–6).

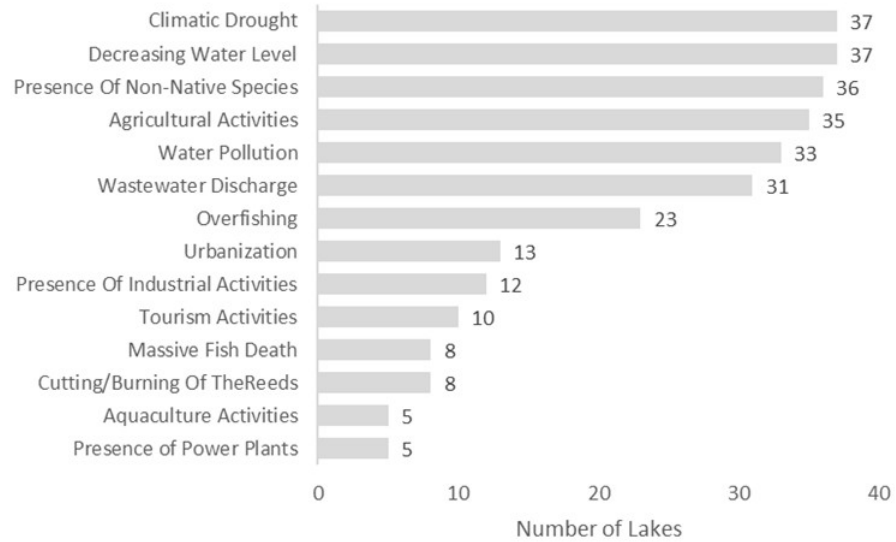


Figure 4. Frequencies of occurrence of the 14 main threats in the examined Turkish lakes.

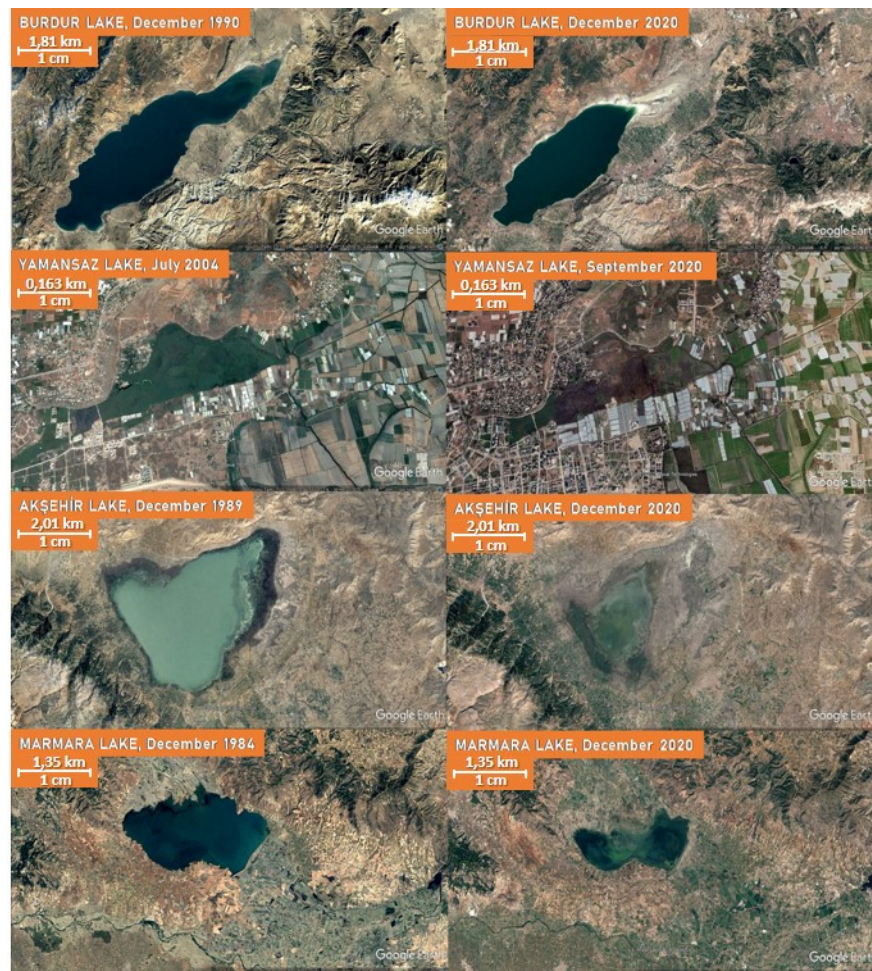


Figure 5. Satellite images from Google Earth showing the trend of water level decrease in the last decades in some Turkish lakes.

Additionally, water pollution, mainly due to domestic and industrial discharges, appears to be quite common and can lead to massive death of fish that, unfortunately, is reported to occur periodically in Turkish lakes (Figure 6).

It is important to underline that threats often work in synergy, and this represents the real “threat” brought about by human activities [64].

Despite the impacts on native species having been widely documented [65,66], the introduction of non-native species continues to be a common practice worldwide. With regard to Turkey, Innal and Erk’akan [67] reported that the major vectors for the introduction of non-native fishes have been government-authorized aquaculture and stocking programs to establish and support cage aquaculture and commercial fisheries. Moreover, several native species have been translocated within Turkey, although it is known that they may have exerted detrimental impacts on the native community of lake fish [67].

From the literature survey, Lake Beyşehir, Lake Eğirdir, and Lake Işıklı were those reporting greater numbers of the considered non-native and translocated species (Table 4).



Figure 6. Pictures reporting some threats in the considered Turkish lakes: 1: Presence of non-native species in Lake Beyşehir; 2: Massive fish death in Lake Onaç Dam; 3: Water extraction for agricultural activities; 4: Tourism activities in Lake Salda.

Table 4. Occurrence of the main introduced (non-native and translocated) species reported * in Turkey in the examined lakes.

Lake	Introduced (Non-Native and Translocated) Species										
	<i>Atherina boyeri</i>	<i>Carassius gibelio</i>	<i>Cyprinus carpio</i>	<i>Esox lucius</i>	<i>Gambusia holbrooki</i>	<i>Knipowitschia caucasica</i>	<i>Lepomis gibbosus</i>	<i>Oncorhynchus cykiss</i>	<i>Pseudorasbora parva</i>	<i>Sander luciperca</i>	<i>Tinca tinca</i>
Abant											
Acıgöl											
Akşehir											
Almus Dam											
Altınapa Dam											
Apolyont											
Beyşehir											
Burdur											
Demirkopru Dam											
Eber											
Eğirdir											
Enne Dam											
Gölbasi											
Gölcük											
Göhlisar											
Hazar											
Hirfanlı Dam											
Işıkli											
Izmit											
Kırkgöz											
Kocagöz											
Köyceğiz											
Manavgat Dam											
Manyas											
Marmara											
Nazik											
Onaç Dam											
Salda											
Sapanca											
Seyhan Dam											
Suğla											
Sultan Marshes											
Van											
Yamansaz											
Yapraklı Dam											
Yarıklı											

*: main references: [45,51,66,68–99].

In Lake Işıkli, located in Central Anatolia in the so-called “Lake District”, together with the non-native species, two translocated species, highly important for the local economy, are known to occur: *E. lucius* and *T. tinca*. However, the abundances of these two species have rapidly decreased in the last years, mostly due to the massive presence of non-native species like *C. gibelio* and water hyper-eutrophication [100]. Similarly, it can be reported that the massive presence of *C. gibelio* in other lakes of the Lake District (Beyşehir, Eğirdir, Suğla, Karataş, Göhlisar, and Kovada) is also creating a huge economic loss for local fisheries. These species are not used by local fishers as a resource, and fishers spend most of their

energy and efforts removing specimens of *C. gibelio* from their nets without any associated economic income.

Carassius gibelio is the non-native species reported to occur in the most Turkish lakes, followed by *G. holbrooki* and *P. parva* (Figure 7).

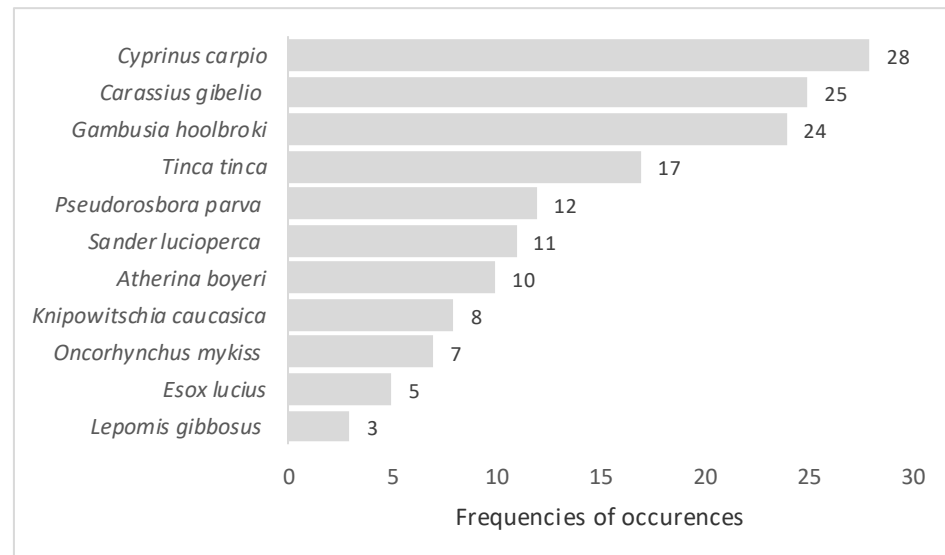


Figure 7. Frequencies of occurrence of the main non-native and translocated species in the examined Turkish lakes.

The wide distribution of these non-native species is of great concern given that they are listed among the 100 worst non-native species in the world [101].

The issue of non-native or translocated species becomes more problematic in the case of those species like *A. boyeri* or *C. carpio* that have a considerable economic value for local fisheries. These species are commonly restocked and translocated by the local institutions in almost every natural lake and reservoir every year.

In this case, the management of these species needs to also take into account the benefit that the species can have for the local economy but always giving priority to preserving the ecological integrity of the aquatic environment for sustainable use of fisheries resources: a disturbed habitat is not able to provide a long-lived economic benefit, as happened in the cited case of Lake Işıklı. However, most of the time, these restocking practices are not supported by a solid scientific background aimed to monitor and control the ecological status of the lake or the success of these activities.

4. Conclusions

Many lakes in Turkey have shrunk considerably over recent years, mainly due to increasing drought and increased ground-water abstraction, leading to profound implications for the whole aquatic ecosystem. The results reported in this study confirm these trends and represent an important point to consider for the future management of these environments.

Forecasted future climatic changes added to the above cited anthropogenic disturbances and changes in land-use would also make the existing conditions progressively worse. Thus, decisions for dealing with the negative impacts of climate change on water resources should include efficient management of existing water and land with forecasting systems to avoid droughts and soil erosion, but also taking into consideration the management of non-native species, which are currently the main reported disturbance in Turkish lakes.

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