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

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.

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 gibbous (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 (km²) | 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                  |
| Altnapa 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                  |
| Dursusu Dam | 1 | Marmara            | 30.4       | 2                             | 3.4 (mean)        | Coastal–artificial          |
| Eber      | 25 | Akarçay             | 120        | 967                           | 6                 | Tectonic                    |
| Eğirdir   | 24 | Antalya             | 470        | 916                           | 13                | Tectonic–Kartıc             |
| Enne Dam  | 7  | Sakarya             | 0.94       | 1001                          | 22                | Artificial                  |
| Gölbasi   | 33 | Ceyhan              | 2.19       | 880                           | 22                | Tectonic–Kartıc             |
| Gölcük    | 19 | Antalya             | 1          | 1360                          | 41                | Volcanic                    |
| Gölhisar  | 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                    |
| Iznik     | 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                 | 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                  |
| Sugla     | 32 | Konya (Closed)      | 40         | 1090                          | 2                 | Tectonic–Kartıc             |
| Sultan Marshes | 28 | Kızırmak         | 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                  |
| Yarıılı    | 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          | Salmo abanticus Tortonese, 1954              | Abant trout         | NE       | LE       |
| Acigöl     | 17 | Aphaniidae          | Anatolichthys transgrediens (Ermin 1946)    | Acipinar killifish  | CR       | LE       |
|            |    | Cobitidae           | Cobitis phrygica Battalgil 1944              | Aci spined loach    | NE       | RE       |
| Aksehir    | 26 | Gobionidae          | Gobio intermedius Battalgil, 1944            | Eber gudgeon        | EN       | RE       |
|            |    | Leuciscidae         | Squalias recurvirostris Özuluğ & Freyhof, 2011 | Aksehir chub        | VU       | RE       |
| Almus Dam  | 34 | Cyprinidae          | Barbus anatolicus Turan, Kaya, Geiger & Freyhof, 2018 | -                   | DD       | RE       |
| Altınapa Dam | 29 | Leuciscidae         | Squalias anatolicus (Bogutskaya, 1997)       | Beysëhir dace       | LC       | RE       |
| Apolyont   | 5  | Leuciscidae         | Alburnus carinatus Battalgil, 1941           | Manyas shemaya      | EN       | RE       |
|            |    | Leuciscidae         | Squalius anatolicus (Bogutskaya, 1997)       | Beysehir dace       | LC       | RE       |
|            |    | Leuciscidae         | Capoeta mauricii Kucuk, Turan, Sahin & Gulle, 2009 | Longsnout scraper   | EN       | RE       |
|            |    | Leuciscidae         | Garra kemali (Hanko, 1925)                   | Eregli minnow       | EN       | RE       |
|            |    | Leuciscidae         | Alburnus akili Battalgil, 1942               | Beysëhir bleak      | EX       | LE       |
|            |    | Leuciscidae         | Chondrostoma beysëhrense Bogutskaya, 1997    | Beysëhir nase       | EN       | RE       |
|            |    | Leuciscidae         | Pseudophoxinus anatolicus (Hanko, 1925)      | Anatolian minnow    | EN       | RE       |
|            |    | Leuciscidae         | Pseudophoxinus battalgilae Bogutskaya, 1997  | Beysehir minnow     | NE       | RE       |
|            |    | Leuciscidae         | Pseudophoxinus hittitorum Freyhof & Ozuluğ, 2010 | Hittitic spring minnow | EN       | RE       |
|            |    | Leuciscidae         | Squalias anatolicus (Bogutskaya, 1997)       | Beysëhir dace       | LC       | RE       |
|            |    | Nemacheilidae       | Oxynoemacheilus atili Erk’akan, 2012         | Beysëhir loach      | NT       | RE       |
| Burdur     | 18 | Aphaniidae          | Anatolichthys sureyanus (Ney 1937)          | Sureyan killifish   | EN       | LE       |
| Demirköprü Dam | 8 | Gobiidae            | Knipowitschia mernere Ahnelt, 1995          | Marmara goby        | VU       | RE       |
| Durusu     | 1  | Leuciscidae         | Alburnus istanbulensis Battalgil, 1941       | Thracian shemaya    | LC       | RE       |
| Eber       | 25 | Leuciscidae         | Squalias recurvirostris Özuluğ & Freyhof, 2011 | Aksehir chub        | VU       | RE       |
|            |    | Nemacheilidae       | Seminemacheilus lendii (Hanko, 1925)         | Anatolian loach      | VU       | RE       |
|            |    | Nemacheilidae       | Oxynoemacheilus hazarensis Freyhof & Ozuluğ, 2017 | Hazar loach        | NE       | LE       |
|            |    | Pseudophoxinus handlirschii (Pietschmann, 1933) | Handlirsch’s minnow | EX       | LE       |
| Enne Dam   | 7  | Leuciscidae         | Alburnus escherichii Steindachner, 1897      | Caucasian bleak     | LC       | RE       |
| Gölbaşı   | 33 | Cobitidae           | Cobitis erkakanæ Freyhof, Bayçelebi & Geiger, 2018 | Gölbaşı spined loach | NE       | RE       |
| Gölcük     | 19 | Aphaniidae          | Anatolichthys splendens Kossowig & Sozer 1945 | Splendid killifish  | EX       | LE       |
|            |    | Cyprinidae          | Garra laëtia (Kossowig 1950)                 | Isparta minnow      | EN       | RE       |
| Gölhisar   | 13 | Leuciscidae         | Scardinsius eleniensi Bogutskaya, 1997       | Antalya rudd        | EN       | RE       |
| Hazar      | 35 | Leuciscidae         | Alburnus heckeli Battalgil, 1944             | Hazar bleak         | LC       | LE       |
|            |    | Nemacheilidae       | Oxynoemacheilus hazarensis Freyhof & Ozuluğ, 2017 | Hazar loach        | NE       | LE       |
| Hirfanlı Dam | 30 | Aphaniidae          | Anatolichthys danfordii (Boulenger 1890)     | Danford’s killifish | CR       | RE       |
| Lake          | N  | Family                      | Species                                   | English Common Name         | IUCN | Endemism |
|--------------|----|-----------------------------|-------------------------------------------|------------------------------|------|----------|
| İskıltı      | 16 | Gobionidae                  | *Gobio maenadricus* Naseka, Erk’akan & Küçük, 2006 | İskıltı gudgeon             | EN   | RE       |
|              |    | Leuciscidae                 | *Squalius carinus* Ozulug & Freyhof, 2011 | Chocolate chub              | EN   | LE       |
| İznil        | 4  | Leuciscidae                 | *Alburnus nicaenis* Battalgil, 1941       | Iznik shemaya               | EX   |          |
| Kırkgöz      | 21 | Aphaniidae                  | *Paraphanius mentosides* (Aksıray, 1948)  |雅纳河虾       | NE   | RE       |
| Kocagöz      | 10 | Gobiidae                    | *Knipowitschia ricoldi* (Di Caporiacco 1935) | Ephesus goby                | CR   | RE       |
| Köyçeğiz     | 11 | Gobiidae                    | *Knipowitschia byblisia* Ahnelt, 2011     | Byblis goby                 | LC   | RE       |
|              |    |                             | *Knipowitschia caunosi* Ahnelt, 2011      | Caunos goby                 | LC   | LE       |
| Manavgat Dam | 23 | Leuciscidae                 | *Alburnus baliki* Bogutskaya, Küçük & Ünlü, 2000 | Antalya bleak               | EN   | RE       |
| Manyas        | 6  | Leuciscidae                 | *Alburnus carinatus* Battalgil, 1941      | Manyas shemaya              | EN   | RE       |
|              |    | Leuciscidae                 | *Alburnoides manyasensis* Turan, Ekmekçi, Kaya & Güçlü, 2015 | Manyas spirlin             | LC   | LE       |
| Marmara       | 9  | Gobiidae                    | *Knipowitschia mermere* Ahnelt, 1995      | Marmara goby                | VU   | RE       |
|              |    | Cobitidae                  | *Cobitis johnbohleri* Freyhof, Bayçelebi & Geiger, 2018 | Sultan spined loach          | NE   | LE       |
|              |    | Leuciscidae                 | *Pseudophoxinus elizaveti* Bogutskaya, Küçük & Atalay, 2006 | Sultan Sazlıgı minnow        | CR   | RE       |
|              |    | Nemacheilidae               | *Oxynoemacheilus ciki* Sungur, Eagederi & Jalili, 2017 | Loach                      | NE   | LE       |
|              |    |                             | *Seminnemacheilus ahmeti* Sungur, Jalili, Eagederi & Çışek, 2018 | Sultan crested loach        | NE   | LE       |
| Marsh Sultan  | 31 | Cyprinidae                  | *Capoeta kosswigi* Karaman, 1969           | Van bar                     | DD   | RE       |
|              |    | Leuciscidae                 | *Alburnus tarichi* (Güldenstädt, 1814)    | Van bleak                   | NT   | RE       |
|              |    | Nemacheilidae               | *Oxynoemacheilus ercisianus* (Erk’akan & Kuru, 1986) | Van loach                  | EN   | RE       |
| Nazik         | 36 | Leuciscidae                 | *Pseudophoxinus ninae* Freyhof & Özulug, 2006 | Onaç spring minnow          | CR   | RE       |
|              |    | Aphanidae                   | *Anatolichthys fontinalis* (Aksıray 1948) | Burdur killifish            | NE   | RE       |
|              |    |                             | *Anatolichthys salae* (Aksıray 1955)      | Saluda killifish            | NE   | LE       |
|              |    | Cobitidae                  | *Cobitis phrygica* Battalgazi, 1944        | Acı spined loach            | NE   | RE       |
|              |    | Leuciscidae                 | *Pseudophoxinus burdarius* Küçük, Gülle, Güçlü, Çiftçi & Erdogan, 2013 | Burdur spring minnow        | EN   | RE       |
| Salda watersheds | 15 | Cobitidae                  | *Squalius fellaevesii* Günther, 1868       | Aegean chub                 | LC   | RE       |
| Onaç Dam      | 20 | Leuciscidae                 | *Pseudophoxinus entrei* Freyhof, Bayçelebi & Geiger, 2018 | Sapanca spined loach        | NE   | RE       |
| Sapanca       | 2  | Cobitidae                  | *Cobitis ceyhanensis* Küçük, Turan, Güçlü, Mutlu & Çiftçi, 2017 | Ceyhan Nase                 | NE   | RE       |
| Seyhan Dam    | 32 | Leuciscidae                 | *Chondrostoma ceyhanensis* Küçük, Turan, Güçlü, Mutlu & Çiftçi, 2017 | Ceyhan Nase                 | NE   | RE       |
| Sugla         | 28 | Cobitidae                  | *Cobitis battalgilae* Bacescu, 1962        | Battalgil spined loach      | EN   | RE       |
|              |    | Leuciscidae                 | *Pseudophoxinus anatolicus* (Hankó, 1925) | Anatolian minnow            | EN   | RE       |
|              |    |                             | *Pseudophoxinus battalgilae* Bogutskaya, 1998 | Beyshehir minnow            | NE   | RE       |
| Van           | 37 | Leuciscidae                 | *Alburnus tarichi* (Güldenstädt, 1814)    | Van bleak                   | NT   | RE       |
|              |    | Nemacheilidae               | *Oxynoemacheilus ercisianus* (Erk’akan & Kuru, 1986) | Van loach                  | EN   | RE       |
| Yamansaz      | 22 | Leuciscidae                 | *Pseudophoxinus alii* Küçük, 2007         | Pamphylian spring minnow    | EN   | RE       |
| Yapraklı Dam  | 12 | Leuciscidae                 | *Alburnus carianorum* Freyhof, Kaya, Bayçelebi, Geiger & Turan, 2018 | -                          | EN   | RE       |
| Yarıslı        | 14 | Aphanidae                   | *Anatolichthys fontinalis* (Aksıray 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]. Hrbek 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](image_url1)

**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 İnal.)

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

![Figure 3](image_url2)

**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 Köcağöz, 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
no non-native species were reported. This is due, as cited above, to the peculiar chemical characteristic of the lake waters that allows the survival of only specialized fish species like *A. tarichi* able to adapt to this hypersodic environment.

**Table 3.** List of the main threats reported to occur in the main lakes of Turkey (N: lake number in Figure 1 from west to east).
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            | Atherina boyeri | Carassius gibelio | Cyprinus carpio | Esox lucius | Gambusia coolebroki | Kiperotia/tea manasticta | Lepomis gibbosus | Oncorhyncus cykiss | Pseudorosbora parva | Sander luciperca | Tinca Tinca | Other Species |
|-----------------|-----------------|-------------------|-----------------|-------------|---------------------|--------------------------|------------------|------------------|---------------------|----------------|-------------|---------------|
| Abant           |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Acıgöl          |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Akşehir         |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Almus Dam       |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Altınpa Dam     |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Apolyont        |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Beyşehir        |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Burdur          |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Demirkopru Dam  |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Eber            |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Eğirdir         |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Enne Dam        |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Gölbaşı        |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Gölük           |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Gölhisar        |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Hazar           |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Hırfanlı Dam    |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Işıklı          |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Iznik           |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Kirkgöz         |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Kocagöz         |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Köyçeğiz        |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Manavgat Dam    |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Manyas          |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Marmara         |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Nazik           |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Onaç Dam        |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Salda           |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Sapanca         |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Seyhan Dam      |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Suğla           |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Sultan Marshes   |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Van             |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Yamansaz        |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Yapraklı Dam    |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |
| Yarıslı          |                 |                   |                 |             |                     |                          |                  |                  |                     |                |             |               |

*: main references: [45,51,66,68–99].

In Lake Işıklı, 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, Gölhisar, 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 \textit{C. gibelio} from their nets without any associated economic income.

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

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure7.png}
\caption{Frequencies of occurrence of the main non-native and translocated species in the examined Turkish lakes.}
\end{figure}

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 \textit{A. boyeri} or \textit{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 IŞIKLı. 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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