Turkish Journal of Zoology

Volume 46 | Number 1 Article 1

1-1-2022

A review of the alien fishes of Turkish inland waters

ERDOĞAN ÇİÇEK

SOHEIL EAGDERI

SEVİL SUNGUR

TÜBİTAK

Turkish Journal of Zoology

http://journals.tubitak.gov.tr/zoology/

Review Article

Turk J Zool
(2022) 46: 1-13

doi:10.3906/zoo-2109-13

A review of the alien fishes of Turkish inland waters

Erdoğan ÇİÇEK[1,*], Soheil EAGDERI[2], Sevil SUNGUR[3]

[1]Department of Biology, Faculty of Art and Sciences, Nevşehir Hacı Bektaş Veli University, Nevşehir, Turkey
[2]Department of Fisheries, Faculty of Natural Resources, University of Tehran, Karaj, Iran
[3]Health Services Vocational School, Nevşehir Hacı Bektaş Veli University, Nevşehir, Turkey

Received: 12.09.2021 • **Accepted/Published Online:** 19.12.2021 • **Final Version:** 18.01.2022

Abstract: Aquaculture, recreational fishing, restocking, biological control, and the ornamental fish trade have increased the number of nonnative fish in Turkish inland waters. This work reviews the history, current state, and tendencies of fish introductions into Turkish freshwaters. To date, it is known that a total of 34 exotic species (except two marine and three misidentified species) have been introduced deliberately or accidentally into Turkish inland waters, of which, only 19 species have been established in wild ecosystems. A total of five acclimatized species, viz. *Coregonus lavaretus*, *C. macrophthalmus*, *Salmo salar*, *Salvelinus alpinus*, and *S. fontinalis* and four species, viz. *Hypophthalmichthys molitrix, Ictalurus punctatus, Oreochromis mossambicus*, and *Sarotherodon galilaeus* that still live in closed systems were excluded from the ichthyofauna list of Turkey. The current presence of six species, viz. *Acipenser baerii*, *Hemichromis letourneuxi*, *Heteropneustes fossilis*, hybrid *Morone* (*M. chrysops* × *M. saxatilis*), *Pangasius sanitwongsei*, and *Pygocentrus nattereri* needs confirmation as to whether they have been surviving or not in the wild. Some established species, including *Carassius gibelio*, *Gambusia holbrooki*, *Lepomis gibbosus*, and *Pseudorasbora parva* are considered invasive, and *Gymnocephalus cernua* is also spreading into the Trachea region.

Key words: Exotic, introduction, invasive, bioinvasion, Anatolia

1. Introduction

Alien or exotic species are transported by human activity into an area outside of their natural range and can be introduced or established, i.e. those not yet established or established self-sustaining populations in the wild, respectively (Gozlan et al., 2010). Fishes are one group of aquatic organisms that have been widely introduced and translocated (Castaldelli et al., 2013; Esmaeili et al., 2013, 2014, 2017). Introducing nonindigenous fishes probably started with *Cyprinus carpio* for rearing in different regions of the world hundreds of years ago (Balon, 2004). During the last century, the introduction of fishes has increased by human activities all over the world, and the main vectors for these are aquaculture, restocking wild stocks, sport fishing, genetic manipulation, bio-control, bio-manipulation, and releasing ornamental fishes deliberately or unintentionally (Copp et al., 2005). Some of these species are threatening for native and endemic fish species (Top-Karakuş and Tarkan, 2021).

Fish biodiversity in many countries is significantly under threat due to the introduction of exotic fishes. Therefore, a better understanding of such an introduction is important for management and conservation of freshwater ecosystems (Castaldelli et al., 2013; Kiruba-Sankar et al., 2018). The negative outcomes of fish introductions are sometimes disregarded because of the economic importance of the introduced species that enhance aquaculture production. However, they have negative impacts due to habitat degradation, pollution, overfishing, etc. (Moyle et al., 1987; Allendorf, 1991; Holcik, 1991; Welcomme, 1992; Cowx, 1998; Witkowski, 2002). In addition, the decline in biodiversity and/or extinction of native species (especially for endemic) also occurred due to hybridization, competition, predation, transferring parasites, and/or diseases, etc. (Uzunova and Zlatanova, 2007).

Carassius auratus (Deveciyan, 1926) was the first introduced fish into the Turkish inland water, followed by *Gambusia holbrooki* (erroneously given as *G. affinis*) in the 1930s for biological control of mosquitos (Geldiay and Balk, 2007). In previous studies, the introduction of exotic fish species and their distribution in freshwater habitats of Turkey were reviewed (Çetinkaya 2006; Innal and Erkakan, 2006; Innal, 2012; Tarkan et al., 2015), and additionally, recent introductions have been reported by Kuru (2004), Emiroğlu et al. (2016), Yoğutcuoğlu and Ekmekçi (2018), Türkmen (2019), Innal and Sungur (2019), Yerli (2019), Emiroğlu et al. (2020), Çiçek et al. (2021), and Kirankaya

* Correspondence: erdogancicek@nevsehir.edu.tr

and Ekmekçi (2021), extending this inventory to 39 species; however, some of these species need to be excluded from the list. Turkish freshwater ichthyofauna consists of more than 400 species, including nearly 30 exotic species (Kuru et al., 2014; Çiçek et. al., 2015, 2016, 2018, 2020).

Although early reports of an invasive species in a given area are crucial (Holden et al., 2016), systematic surveys on invasive species are rarely performed in Turkey. In this regard, this work aimed to review the history and current state of the fish introductions (i.e. introduction reasons, establishment, success, and economic value in summarized categories) in the Turkish inland waters by providing an updated checklist.

2. Materials and methods

This work is prepared on the basis of our fieldwork data, published sources, and restocking data of freshwater fish species provided by the General Directorate of State Hydraulic Works (DSI) staffs.

The reasons for introduction were divided into five categories as follows:

R1: Aquaculture/research,

R2: Fisheries: enhancement of wild stocks and sports fishing,

R3: Bio-control: to prevent eutrophication, aquatic plants, and pest control,

R4: Ornamental fish industry,

R5: Unknown: Inadvertently introduced by transboundary waterways for no known reason or method.

For establishment success, we partly follow Blackburn et al. (2011):

B1: Individuals have been transported outside of their native range and held in captivity or quarantine,

B2: Individuals have been transported outside of their natural range for cultivation,

B3: Individuals have been transported beyond the limits of their native range and are directly released into the novel environment,

C0: Individuals released into the wild in the location were introduced, but were incapable of surviving for a significant period of time,

C1: Individuals surviving in the wild in the location where they were introduced, but with no reproduction,

C2: Individuals surviving in the wild in the location where they were introduced; reproduction occurs, but the population is not self-sustaining,

C3: Individuals surviving in the wild in the location where they were introduced, reproduction occurring, and the population self-sustaining,

D1: A self-sustaining population in the wild, with individuals surviving a significant distance from the original point of introduction,

D2: A self-sustaining population in the wild, with individuals surviving and reproducing a significant distance from the original point of introduction,

E: Fully invasive species, with individuals dispersing, surviving, and reproducing at multiple sites across a greater or lesser spectrum of habitats and extent of occurrence.

The status of the introduced fishes in the wild was categorized into six groups as follows:

P0: Not found in the wild,

P1: Do not stay in the wild after being released or escaping,

P2: Unknown, needs to be confirmed,

P3: Can be discovered by restocking or fleeing,

P4: Residents of the area,

P5: Widespread,

P6: Invasive.

The establishment success of the previously recorded exotic species can be categorized into four groups as follows:

ES0: Only found in a closed system: never found in the wild, kept only in closed and/or controlled systems (B1, B2),

ES1: Unacclimatized: found in the wild but not reproducing or naturalized (B3, C0),

ES2: Acclimatized: found in the wild, naturalized, not reproducing and self-sustaining, occurrence depends on restocking or escape from closed systems (C1, C2),

ES3: Naturalized (C3, D1, D2),

ES4: Invasive (E).

According to the establishment success status, under the decisions made to be included or excluded from the checklist:

ES0-ES1: Excluded from the ichthyofaunal checklist,

ES2: Questionable to survive in the wild, needs confirmation and therefore excluded from the ichthyofauna checklist but kept on the exotic fish list,

ES3-ES4: There is no doubt about naturalization or continued restocking/escape; they are maintained on exotic and ichthyofauna lists.

To determine economic importance, the categorisation scheme was given as:

E0: Without economic value,

E1: Has economic importance to aquaculture,

E2: Has economic value for stock enhancement, commercial fishing, sport-fishing,

E3: Has economic value for the ornamental fish industry,

E4: Has economic value for bio-control/bio-manipulation,

E5: Has economic value for medical treatment,

E6: Has ecological significance.

3. Results

Previous research has reported that a total of 39 fish species have been reported from Turkey's freshwaters. Of these, two species are marine species, i.e. *Chelon carinatus* and *Planiliza haematocheila* and three others, i.e. *Ameiurus nebulosus*, *Gambusia affinis* were never transferred to Turkey and are misidentified or erroneously listed in checklists and *Tristramella simonis* was reported by Kuru (2004) but without giving any information on where and when it was introduced to Turkey.

The updated list of the alien fishes of Turkish inland waters is summarized in Table 1. The results revealed that there are 34 introduced fish species belonging to nine orders and 14 families in Turkey.

Aquaculture, as the main reason for introducing fish species with a relatively short history in Turkey, began with the farming of rainbow trout (*Oncorhynchus mykiss*) (Ergüden Alagöz et al., 2010).[1] Then other species, viz. *Salmo salar*, hybrid *Morone* (*M. chrysops* × *M. saxatilis*), *Acipenser baerii*, *Ictalurus punctatus*, and six tilapia species, including *Coptodon zillii*, *C. rendalli*, *Oreochromis aureus*, *O. niloticus, O. mossambicus*, and *Sarotherodon galilaeus* were transferred by investors for fish farming, and universities and governmental institutions for research to improve aquaculture production (Altun et al., 2006; Çetinkaya, 2006; Innal and Erkakan, 2006). *Oreochromis niloticus* was imported from Israel by the Adana Fish Breeding Centre of DSI (The General Directorate of State Hydraulic Works), then *C. zillii*, *C. rendalli*, *O. aureus*, and *S. galilaeus* were imported to Çukurova University's fisheries research station (Altun et al., 2006). All of these species were introduced into the wild, first in the Adana Province, and then spread to all the Mediterranean basins of Turkey (Dikel and Çelik, 1998; Çelik and Gökçe, 2003; Gürlek and Turan, 2005; Çiçek, 2021; Arslan et al., 2021). In addition, to promote fishing in natural water bodies, economically valuable species, including *Coregonus lavaretus* and *C. macrophthalmus* (into Lake Iznik in 1954), *Hypophthalmichthys molitrix*, *Salvelinus alpinus*, and *S. fontinalis* were transferred by governmental organizations (Çetinkaya, 2006). Furthermore, eutrophication of the aquatic ecosystems by anthropogenic activities led to the introduction of some herbivorous fishes such as *Ctenopharyngodon idella* and *H. molitrix* by the state (Çetinkaya, 2006). *Carassius auratus* was introduced to Turkey in the 1900s as an aquarium fish (Deveciyan, 1926). In recent years, the occurrence of the ornamental species, including *Clarias batrachus*, *Hemichromis letourneuxi*, *Pterygoplichthys disjunctivus*, *P. pardalis*, *Pygocentrus nattereri*, *Pangasius sanitwongsei*, *Poecilia reticulata*, and *Xiphophorus hellerii*, were reported from the Turkish inland waters (Emiroğlu et al., 2016, Yoğurtcuoğlu and Ekmekçi, 2018; Turkmen, 2019; Innal and Sungur, 2019; Yerli, 2019; Emiroğlu et al., 2020; Kırankaya and Ekmekçi, 2021). The reasons for some introduced species such as *C. carassius*, *C. gibelio*, *Gymnocephalus cernua*, *Heteropneustes fossilis*, *Hypophthalmichthys nobilis* (for Maritza River population), *Lepomis gibbosus*, and *Pseudorasbora parva* are unknown.

Four out of 34 reported exotic fish species in Turkey have still been kept in closed systems and therefore have not been established, and their presence in natural water bodies needs to be confirmed. The other 30 species were introduced to the wild and are already established.

In addition, 11.8% of the exotic fishes in Turkey live in closed systems, i.e. they are not released or have not escaped into the wild, 14.1% are not acclimatized even if introduced into the wild, 11.8% need confirmation whether they still live in the wild, and 55.9% are reported as established.

Aquaculture is a major reason (32.4%) for introducing freshwater fish species into Turkey, and then ornamental fishes (26.5%), followed by stock enhancement (14.7%) and bio-control (8.8%). However, no reason is known for some species that are categorized as unknown (17.6%). Of the 34 exotic species, 5.0% have no economic value. Nearly half of the introduced freshwater fish species with economic value are used in aquaculture (45.0%), followed by fisheries (25.0%), ornamental industry (20.0%), and bio-control (10.0%).

According to the establishment success status, *H. molitrix*, *I. punctatus*, *O. mossambicus*, and *S. galilaeus* are categorised as ES0; however, they have been kept in closed systems in Turkey. *Coregonus lavaretus*, *C. macrophthalmus*, *S. salar*, *S. alpinus*, and *S. fontinalis* are categorised as ES1. The species categorised as both ES0 and ES1 are excluded from the ichthyofauna list of Turkey. In addition, *H. molitrix*, *I. punctatus*, *O. mossambicus*, and *S. galilaeus*. *A. baerii*, *H. fossilis*, *H. letourneuxi*, *P. sanitwongsei* and hybrid *Morone* (*M. chrysops* × *M. saxatilis*) are categorised as ES2, and excluded from the ichthyofauna list of Turkey. However, they are kept on the exotic fish list of Turkey for further confirmation by specimens.

4. Discussion

Since the last century, the introduction and translocation of fish species have altered the composition of the fish fauna of Turkish freshwater bodies (Çiçek et al., 2020). The economy of Turkey has achieved outstanding performance with its steady growth over the last four decades, and in line with this development, many dams have been constructed

[1] FAO (2005). National Aquaculture Sector Overview Turkey. Food and Agriculture Organization of the United Nations, Fisheries and Aquaculture Department, http://www.fao.org/fishery/countrysector/naso_turkey/en

Table 1. Chronologic exotic fish list of Turkey with their economic importance, the reason for introduction, establishment success, population and establishment success status. All definitions of abbreviation are explained in the materials and methods section.

Orders	Families	Species	Year	Authors	Listed in CABI/ DIAS	Economic importance	Reasons of introduction	Establishment success	Population status	Establishment success status
Cyprinodontiformes	Poeciliidae	*Gambusia holbrooki* Girard, 1859	1930's	1,2,3,4,5	X	E4	R3	E	P6	ES4
Cypriniformes	Cyprinidae	*Carassius auratus* (Linnaeus, 1758)	1950's	1,2,3,4,5	X	E3	R4	D2	P5	ES3
Salmoniformes	Salmonidae	*Coregonus lavaretus* (Linnaeus, 1758)	1954	1,2,3,4,5		E2	R2	C0	P0	ES1
Salmoniformes	Salmonidae	*Coregonus macrophthalmus* Nüsslin, 1882	1954	2,4		E2	R2	C0	P0	ES1
Salmoniformes	Salmonidae	*Oncorhynchus mykiss* (Walbaum, 1792)	1969	1,2,3,4,5,20	X	E1-E2	R1	C1	P3	ES2
Cypriniformes	Cyprinidae	*Ctenopharyngodon idella* (Valenciennes, 1844)	1972	1,2,3,4,5,15		E1-E4	R3	C1	P3	ES2
Cichliformes	Cichlidae	*Oreochromis niloticus* (Linnaeus, 1758)	1974	1,2,3,4,5,18,23	X	E1	R1	D2	P5	ES3
Cichliformes	Cichlidae	*Coptodon zillii* (Gervais, 1848)	1975	1,2,3,4,5,19,23	X	E1	R1	D2	P5	ES3
Cichliformes	Cichlidae	*Coptodon rendalli* (Boulenger, 1897)	1978	1,2,3,4,19,23		E1	R1	D2	P5	ES3
Cichliformes	Cichlidae	*Sarotherodon galilaeus* (Linnaeus, 1758)	1978	2,4,19		E1	R1	B1	P1	ES0
Cypriniformes	Cyprinidae	*Pseudorasbora parva* (Temminck Schlegel, 1846)	1982	1,2,3,4,5,13	X	E0	R5	E	P6	ES4
Perciformes	Centrarchidae	*Lepomis gibbosus* Linnaeus, 1758	1982	1,2,3,4,5,13	X	E0	R4	E	P6	ES4
Cypriniformes	Cyprinidae	*Carassius gibelio* (Bloch, 1782)	1987	3,4,5,14	X	E1	R5	E	P6	ES4
Salmoniformes	Salmonidae	*Salmo salar* Linnaeus, 1758	1988	1,2,3,4,5	X	E1	R1	C0	P1	ES1
Cichliformes	Cichlidae	*Oreochromis aureus* (Steindachner, 1864)	1989	1,2,3,4,19,23	X	E1	R1	D2	P5	ES3
Cypriniformes	Cyprinidae	*Hypophthalmichthys molitrix* (Valenciennes, 1844)	1990	1,2,3,4,5,15,22	X	E1-E4	R3	B1	P0	ES0
Cypriniformes	Cyprinidae	*Hypophthalmichthys nobilis* (Richardson, 1845)	1990	1,2,4,15,27	X	E1	R5	D2	P4	ES3
Siluriformes	Ictaluridae	*Ictalurus punctatus* (Rafinesque, 1818)	1990	1,2,3,4	X	E1-E2	R1	B1	P0	ES0
Cypriniformes	Cyprinidae	*Carassius carassius* (Linnaeus, 1758)	1990's	1,2,3,4,5		E2	R5	D2	P5	ES3
Acipenceriformes	Acipenceridae	*Acipenser baerii* Brandt, 1869	1997	2,3,4,16,28		E1	R1	C2	P2	ES2
Moroniformes	Moronidae	Hybrid *Morone* (*Morone chrysops* (Rafinesque, 1820) × *Morone saxatilis* (Walbaum, 1792))	1999	1,2,3,4,5,17		E1	R1	C2	P2	ES2
Salmoniformes	Salmonidae	*Salvelinus alpinus* (Linnaeus, 1758)	1999	1,2,3,4,5		E1-E2	R2	C0	P1	ES1
Salmoniformes	Salmonidae	*Salvelinus fontinalis* (Mitchill, 1814)	1999	1,2,3,4,5	X	E1-E2	R2	C0	P1	ES1
Cichliformes	Cichlidae	*Oreochromis mossambicus* (Peters, 1852)	2000's	1,3,4	X	E1	R1	B1	P0	ES0
Characiformes	Serrasalmidae	*Pygocentrus nattereri* Kner, 1858	2006	4,5,21		E3	R4	C1	P2	ES2
Siluriformes	Heteropneustidae	*Heteropneustes fossilis* (Bloch, 1794)	2006	4,5,12		E2	R5	C3	P4	ES3
Siluriformes	Loricariidae	Hybrid *Pterygoplichthys* (*Pterygoplichthys disjunctivus* (Weber, 1991) × *Pterygoplichthys pardalis* (Castelnau, 1855))	2006	4,5,6,11		E3	R4	C3	P4	ES3

Table 1. (Continued).

Cichliformes	Cichlidae	*Hemichromis letourneuxi* Sauvage, 1880	2017	8		E3	R4	C1	P2	ES3
Siluriformes	Pangaciidae	*Pangasius sanitwongsei* Smith, 1931	2017	7		E3	R4	C1	P2	ES2
Cyprinodontiformes	Poeciliidae	*Poecilia reticulata* Peters, 1859	2019	9		E3	R4	C3	P4	ES3
Salmoniformes	Salmonidae	*Coregonus albula* (Linnaeus, 1758)	2019	10		E2	R2	C3	P4	ES3
Siluriformes	Clariidae	*Clarias batrachus* (Linnaeus, 1758)	2020	24		E3	R4	D2	P4	ES3
Perciformes	Percidae	*Gymnocephalus cernua* Linnaeus, 1758	2021	25		E2	R5	D2	P5	ES3
Cyprinodontiformes	Poeciliidae	*Xiphophorus hellerii* Heckel, 1848	2021	26		E3	R4	C3	P4	ES3

1) Geldiay and Balık (2007); 2) Çetinkaya (2006); 3) Innal and Erk'akan (2006); 4) Innal (2012); 5) Tarkan et al. (2015); 6) Emiroğlu et al. (2016); 7) Yoğurtçuoğlu and Ekmekçi (2018); 8) Innal and Sungur (2019); 9) Türkmen (2019); 10) Yerli (2019); 11) Yalçın Özdilek (2007); 12) Ünlü et al. (2011); 13) Erk'akan (1983); 14) Baran and Ongan (1988); 15) Erk'akan (1984); 16) Köksal et al. (2000); 17) Kızak and Güner (2014); 18) Sağat[1]; 19) Altun et al., (2006); 20) Uysal and Alpbaz (2002); 21) Tarkan (2006); 22) Celayir et al. (2003); 23) Gürlek and Turan (2005); 24) Emiroğlu et al. (2020); 25) Çiçek et al. (2021); 26) Kırankaya and Ekmekçi (2021); 27) Akan[2]; 28) IHA[3]

[1] Celayir Y (2020). Personnel communication. DSI IXth Regional Directorates, Keban Dam Aquaculture Department, Fish Farming Facilities. Adana, Turkey

[2] Sağat Y (2020). Personnel communication. Retired from DSI VIth Regional Directorates, Fish Farming Facilities. Adana, Turkey

[3] IHA (2021). https://www.iha.com.tr/haber-keban-baraj-golunde-ikinci-defa-goruntulendi-havyari-tam-2-milyon-liraya-alici-buluyor-993883

in all parts of Turkey. Dam construction was accompanied by intensive fish translocation, cage aquaculture, and restocking activities using both native and exotic fish species, with exotics as the dominant group.

Due to the rapid expansion of aquaculture in many countries, the number of consumed species has substantially increased in recent years. Aquaculture is the major vector for half of the introduced exotic fishes in the world (Shelton and Rothbard, 2006), and 34% (nine species) of those in Turkey, with a short history that started in the late 1960s (FAO 2005). The total aquaculture production of Turkey was 76.248 tons in 2009 and rose to 105.118 tons in 2018.[2] Except for *O. mykiss*, other introduced species for aquaculture purposes are not commonly used, e.g., 12 tons of tilapia was produced in 2018 and *A. baerii* (2 tons in 2018) were cultured for caviar production (TUIK, 2019). Except *O. mossambicus*, eight other introduced species for aquaculture purposes are found in the wild. *Oncorhynchus mykiss* has been successfully established but has not been bred naturally, and its presence depends on escapes from trout farms or restocking. Five tilapia species were imported for research purposes to solve aquaculture problems such as acclimatization, feeding, disease, and hybridization by Çukurova University's fisheries research station. The station's rearing systems were connected to the Seyhan River; therefore, specimens from all five species have escaped into the wild. Among them, the presence of *S. galilaeus* is questionable because all specimens were lost because of the inability to keep them alive. Later, *C. zillii*, *C. rendalli*, *O. niloticus*, and *O. aureus* were reported from the waterbodies of Adana, Hatay, Mersin, Antalya, Burdur, and Eskişehir provinces (Dikel and Çelik, 1998; Çelik and Gökçe, 2003; Gürlek and Turan, 2005; Emiroğlu, 2011; Ergüden Alagöz, 2013; Innal and Gianetto, 2017; Innal, 2019; Arslan et al., 2021). Interbreeding between the escaped tilapia species is possible and they have probably produced hybrids, reported as *Tilapia* spp. in the Seyhan River and Köyceğiz Lake (Akın et al., 2005; Buhan et al., 2017). The existence of a *C. carassius* × *C. auratus* hybrid has not been solved yet, along with the origin and validation of *C. gibelio* (Yerli et al., 2014). Recent findings showed a high genetic diversity of *C. gibelio* in Turkish freshwater habitats (Ağdamar and Tarkan, 2019).

The ornamental fish trade is also a source of accidental introductions of alien fish into the wild. The ornamental fish industry has developed in recent years and their introduction into the wild is not reflected in the scientific literature as those aquaculture fishes. The most recent aquarium fish introduced into the Turkish inland waters are *P. disjunctivus*, *P. pardalis*, *P. sanitwongsei, H. letourneuxi*, *P. reticulata*, *C. batrachus*, and *X. hellerii* (Yalçın Özdilek, 2007; Emiroğlu et al., 2016, 2018, 2020; Yoğurtcuoğlu and Ekmekçi, 2018; Innal and Sungur, 2019; Türkmen, 2019; Kırankaya and Ekmekçi, 2021). The number of introduced ornamental fishes is limited, with a few individuals found locally and some of them naturalized in small habitats. The establishment of *P. disjunctivus* and *P. pardalis* in Eskişehir (Emiroğlu et al., 2016), of *P. reticulata* in İzmir and Malatya provinces (Turkmen 2019; Kırankaya and Ekmekçi, 2021), and of *X. hellerii* in Malatya province (Kırankaya and Ekmekçi, 2021) has been reported. However, it is probable that specimens of the genus *Pterygoplichthys* are hybrids of *P. disjunctivus* × *P. pardalis* (Wu et al., 2011). Emiroğlu et al. (2016) reported the presence of hybrid individuals in Eskişehir, likely reported by Godwin et al. (2016). Reevaluation of these established species is suggested to better understand their adaptation processes for further management measures.

Poecilia reticulate and *X. hellerii* are the most popular ornamental fishes in the world. *Poecilia reticulate* was reported from natural freshwaters in the aquifer of Çeşme-Ildır (İzmir) (Türkmen, 2017). Later, both of them were discovered in a hot spring habitat, namely a stream in the Tohma River drainage (Euphrates basin) (Kırankaya and Ekmekçi, 2021). These exotic species cannot tolerate cold waters. Therefore, they have limited distributions because of their thermal tolerance. Hence, it is recommend to eliminate them in the area where they were naturally introduced.

The introduction of grass carp, *C. idella* allows applying the so-called "top-down control" to improve water quality (Uzunova and Zlatanova, 2007). This species is mainly stocked in some dams and irrigation channels in Adana and Gaziantep provinces, the southern parts of Turkey, to prevent aquatic weed growth.[3],[4] Additionally, *H. molitrix* and *H. nobilis* were used as bio-manipulators to prevent eutrophication. Introduction of these two species previously reported, but probably *H. molitrix* transferred by DSI and no information available regarding transferring of *H. nobilis* to Turkey and also their artificial propagation and rearing programs as warm water candidates were unsuccessful.[5] Recently, *H. nobilis* has been caught from the Maritza River (41°06′40.84″N-26°19′54.18″N) by sport fishing.[6] This species was reported from Greece and

[2] TUIK (2019). Turkish Statistical Institute. Fishery Statistics; Available from http://www.tuik.gov.tr/PreHaberBultenleri.do?id=30697, 20.12.2019

[3] Celayir Y (2020). Personnel communication. DSI IXth Regional Directorates, Keban Dam Aquaculture Department, Fish Farming Facilities. Adana, Turkey

[4] Sağat Y (2020). Personnel communication. Retired from DSI VIth Regional Directorates, Fish Farming Facilities. Adana, Turkey

[5] Celayir Y (2020). Personnel communication. DSI IXth Regional Directorates, Keban Dam Aquaculture Department, Fish Farming Facilities. Adana, Turkey

[6] Akan E (2021). Personnel communication. Balik Yurdu. https://www.youtube.com/watch?v=iJnZSppwwI8

Bulgaria as an exotic species (Uzunova and Zlatanova, 2007; Barbieri et al., 2015) and it probably entered the Trachea Region by transboundary waterways.

A total of six salmonid-like species, viz., *C. lavaretus*, *C. macrophthalmus*, *S. alpinus*, *S. fontinalis* for enhancement of fisheries, and *O. mykiss* and *S. salar* for aquaculture purposes, have been introduced (Çetinkaya 2006; Innal and Erkakan, 2006; Innal, 2012; Tarkan et al., 2015). However, except for *O. mykiss*, their successful establishment was not reported, and their current survival has not been confirmed yet by specimens. Furthermore, the establishment of *C. albula* has been reported from the Aktaş Lake, located on the border of Georgia and Turkey (Yerli, 2019), probably introduced accidentally by the Georgian part.

The introduction reasons of *C. carassius*, *C. gibelio*, *G. cernua*, *H. fossilis*, *H. nobilis* (Maritza population), *P. parva*, and *L. gibbosus* are unknown (Özcan, 2007a, Özcan, 2007b; Innal, 2011, 2012; Tarhan et al., 2012, 2015; Özcan and Tarhan, 2019; Çiçek et al., 2021). The first five species have low economic value, and the two latter species have no economic value. *Carassius gibelio* and *P. parva* have been successfully naturalized, extending their distribution range in Turkish inland waters (Özcan, 2007a; Tarkan et al., 2012; Yerli et al., 2014; Özcan and Tarhan, 2019) and probably introduced with the restocking of *C. carpio* or other Chinese carps, i.e. *C. idella*, into dams (Radkhah et al., 2016; Eagderi and Moradi, 2017; Eagderi et al., 2018).

The presence of *G. cernua* has also been documented in several aquatic ecosystems outside of its native range in Europe. This species is considered an efficient invader due to its adaptability to tolerate a high range of environmental conditions related to salinity, eutrophication, temperature, turbidity, etc. (Petriki et al., 2014). Recently, this species was observed in some lakes in the Maritza-Ergene Basin (Çiçek et al., 2021). However, this species was also reported by Deveciyan (1926) as *Acerina cernua*. Therefore, it is debatable whether this species is exotic or natural.

4.1. Effects of introduction

The introduction of some exotic fishes, particularly into inland waters, has had catastrophic ecological and economic consequences such as competition, predation, habitat change, genetic change, and transmission of pathogens (Elvira, 2001; Cambray, 2003; Cucherousset and Olden, 2011; Garcia-Berthou and Moyle, 2011). Introductions of exotic fish are always considered risky for the native fish fauna. Some species such as *C. gibelio*, *P. parva*, and *L. gibbosus* are dominant biomass in some lakes and reservoirs of Turkey (Çetinkaya, 2006; Innal and Erkakan, 2006; Özcan, 2007a, Özcan, 2007b; Innal, 2011, 2012; Tarkan et al., 2012, 2015; Ekmekçi et al., 2013; Yerli et al., 2014; 2019; Mangıt et al., 2018; Kurtul and Sarı, 2019a; Özcan and Tarkan, 2019). Furthermore, they are reported from new localities every year, nearly distributed in all the freshwater basins of Turkey. The wide environmental tolerances of these species are their advantages in this regard. After the introduction and translocation of the exotic fishes, the fish compositions are significantly changed, as seen in the Beyşehir, Eğridir, and Çıldır lakes where *C. gibelio* is the main component of fishing activities in these lakes. In addition, these introductions have increased taxonomic and functional faunal similarity among regions in the Mediterranean climate region (Marr et al., 2013). Studies regarding the impact of introduced fishes on native fishes and fish biodiversity are rare in Turkey, and adverse consequences of exotics have been ignored due to their economic significance in other countries (Elvira and Almodovar, 2001; Cucherousset and Olden, 2011). Peculiarly, despite a great number of the introduced fishes, those with economic values had not established in Turkish freshwater aquatic ecosystems.

Another negative effect of fish introduction is the spread of diseases or parasites. Large-scale international transfers of fish have been proposed as the source of exotic pathogen introduction that have caused enormous ecological and economic impacts in the receptor country. Many new parasites have been transferred and established in native fishes as a result of the introduction of exotic fish species into Bulgarian waters (Uzunova and Zlatanova, 2007; Cikova et al., 2004). There are few studies on this subject in Turkey, e.g., *Sphareothecum destruens*, a generalist pathogen, was reported from *P. parva* in Turkey (Sarıçay River, Milas, SE Turkey) (Gozlan et al., 2009), then transferred to sea bass farms (Ercan et al., 2015).

The introduction of exotic fishes can lead to the extinction of native species (Raikova-Petrova et al., 2004; Apostolos, 2005). The mosquito fish was introduced in various freshwater habitats of Turkey and there are many reports regarding its serious threat to *Aphanius* species (Wildkamp and Valkenburg, 1994; Kurtul and Sarı, 2019a). The negative effects of some exotic species such as *P. parva*, *C. gibelio*, *L. gibbosus*, and *O. mykiss* have been pointed out in some works without any real field experiments (Özcan, 2007a; Tarkan et al., 2012; Ekmekçi et al., 2013; Yerli et al., 2014; Özcan and Tarhan, 2019). Recently, Top-Karakuş and Tarkan (2021) represented the relationship between *Capoeta aydinensis* and *L. gibbosus* in an ex situ growth experiment. They revealed that the specific growth rate of *C. aydinensis* was the lowest, while the number of *L. gibbosus* increased. The possible impact of the introduced fishes in Turkey on the native fish biodiversity is still unknown and needs further studies. A control program has been initiated for *P. parva* in the UK, and bio-manipulation has been found to be a more effective and cheaper way than eradication (Britton et al., 2010). That could be a proper example to conduct in Turkey.

Table 2. Recent status of previously reported exotic freshwater fishes of Turkey.

Species	Exotic fish list	Freshwater ichthyofauna of Turkey	Reason of exclusion
Chelon carinatus	Exclude	Exclude	The species is a pure marine species. Not found in the freshwater.
Planiliza haematocheila	Exclude	Exclude	The species is a pure marine species. Not found in the freshwater.
Ameiurus nebulosus	Exclude	Exclude	Probably never transferred to Turkey. Misidentified by Erençin et al. (1971)
Tristramella simonis	Exclude	Exclude	Probably never introduced to Turkey or misidentified. If introduced not established.
Gambusia affinis	Exclude	Exclude	Never transferred to Turkey. *Gambusia holbrooki* reported as *G. affinis* in the previous studies.
Ictalurus punctatus	Exclude	Exclude	Keep in closed system for research. Never introduced into the wild.
Sarotherodon galilaeus	Exclude	Exclude	Keep in closed system for aquaculture. Probably never introduced in the wild, If introduced not established.
Hypophthalmichthys molitrix	Exclude	Exclude	Not established in the wild. Keep in closed system for research.
Oreochromis mossambicus	Exclude	Exclude	Keep in closed system for research. Never introduced in the wild.
Coregonus lavaretus	Exclude	Exclude	Not established
Coregonus macrophthalmus	Exclude	Exclude	Not established
Salmo salar	Exclude	Exclude	Not established
Salvelinus alpinus	Exclude	Exclude	Not established
Salvelinus fontinalis	Exclude	Exclude	Not established
Acipenser baerii	Questionable	Exclude	Need to confirmation to still alive in the wild
Hemichromis letourneuxi	Questionable	Exclude	Need to confirmation to still alive in the wild
Heteropneustes fossilis	Questionable	Exclude	Need to confirmation to still alive in the wild
Hybrid *Morone* (*M. chrysops* × *M. saxatilis*)	Questionable	Exclude	Need to confirmation to still alive in the wild
Pangasius sanitwongsei	Questionable	Exclude	Need to confirmation to still alive in the wild
Pygocentrus nattereri	Questionable	Exclude	Need to confirmation to still alive in the wild
Carassius auratus	X	X	
Carassius carassius	X	X	
Carassius gibelio	X	X	
Clarias batrachus	X	X	
Coptodon rendalli	X	X	
Coptodon zillii	X	X	
Coregonus albula	X	X	
Ctenopharyngodon idella	X	X	
Gambusia holbrooki	X	X	
Gymnocephalus cernua	X	X	
Hypophthalmichthys nobilis	X	X	

Table 2. (Continued).

Lepomis gibbosus	X	X	
Oncorhynchus mykiss	X	X	
Oreochromis aureus	X	X	
Oreochromis niloticus	X	X	
Poecilia reticulata	X	X	
Pseudorasbora parva	X	X	
Hybrid *Pterygoplichthys* (*P. disjunctivus* × *P. pardalis*)	X	X	
Xiphophorus hellerii	X	X	

4.2. Legislative frames of the exotic fish introductions

There are national and international regulations to prevent the spread of alien fishes, the threat of biological diversity, and the destruction of native fish species' genotypes and genetic resources. Regulations, communications, and other relevant national legislation issued based on the fisheries law, as well as the legislation of the European Union and other international legislation and treaties, are relevant for the control of exotic fish introductions (Atalay and Toslak, 2013) that should be implemented by government institutions. The legal background for the introduction of exotic species into Turkey are; 1) Fisheries and Aquaculture Law (Official Gazette N 13799/04.04.1971), 2) Fisheries and Aquaculture Ordinance (Official Gazette N 22223/10.03.1995), 3) Biodiversity Act (State Gazette N 22860/27.12.1996), and 4) Prevention and Management of the Introduction and Spread of Invasive Alien Species (2013/0307/COD, Proposal for a Regulation of the European Parliament and the Council). Hence, there is an urgent need to prepare a legal regulation regarding the entry of foreign species into Turkey to control and prevent their effects on aquatic ecosystems.

4.3. Range extension

While some exotic species, such as *C. gibelio*, *G. holbrooki*, *L. gibbosus*, and *P. parva*, spread rapidly and colonized aquatic habitats in the Anatolia region, becoming invasive, others, e.g., *S. alpinus*, *S. fontinalis C. lavaretus*, and *C. macrophthalmus* have failed to establish self-sustaining populations. Tilapia are warm-water species naturally distributed in tropical areas. The Mediterranean coast of Turkey is relatively suitable for them to survive, as it is observed that they become invasive in some habitats (e.g. Lake Gölbaşı, Hatay). Previous studies carried out on *L. gibbosus* have shown that invasion success is greatest in warmer environments (Fobert et al., 2013) and further climate change will probably increase the establishment of new populations of the alien fish. Hence, invasive species such as *C. zillii*, *C. rendalli*, *O. niloticus*, *O. aureus*, and *L. gibbosus* in Turkey will also be expected to expand their distribution ranges. Unwanted and uncontrolled expansion of alien fishes in Turkey can be illustrated by *C. gibelio* (Özcan, 2007b; Yerli et al., 2014), *G. holbrooki* (Kurtul and Sarı, 2019a, b), *P. parva* (Özcan and Tarkan, 2019), which are found in all basins of Turkey and *L. gibbosus* distributed in the Marmara and Aegean regions, and they have been spreading to new localities (Özcan, 2007a). Recently, the spread of *G. cernua* into the Trachea region has been reported (Çiçek et al., 2020).

5. Conclusion

As a conclusion, a total of 34 exotic fishes have been reported from Turkey, of which 19 species have successfully established in the wild (Table 2). The establishment success of some species in Turkish freshwater is controversial. Therefore, we decided to provide such a checklist to show further areas that need to be investigated by reevaluating them. In this list, species that have not been introduced into the wild and naturalized species are suggested to be excluded from the ichthyofauna list of Turkey (ES0/ES1). Questionable species need confirmation by specimens (ES2). According to the establishment success status, 20 species are excluded from the list of freshwater ichthyofauna of Turkey, and *A. baerii*, *H. fossilis*, *H. letourneuxi*, *P. nattereri*, *P. sanitwongsei*, and hybrid *Morone* (*M. chrysops* × *M. saxatilis*) are kept on the exotic fish list as questionable until confirmation by specimen. However, two specimens of *A. baerii* were recently caught surprisingly by two different fishermen in Keban Dam Lake and are probably intentionally released from the fish farms. The status of this species should be clarified with further studies.[7]

The introduction of pathogens, habitat shifting, competition, predation, genetic changes, and effects of climate change on exotic species need more research. The introduction of exotic species is an extraordinarily complex issue, and understanding of their risks requires

[7] IHA (2021). https://www.iha.com.tr/haber-keban-baraj-golunde-ikinci-defa-goruntulendi-havyari-tam-2-milyon-liraya-alici-buluyor-993883/

comparative studies. In international organizations, there is a lack of knowledge about the exotic freshwater fishes of Turkey. A total of 17 exotic species have been listed in CABI and GISD.[8,9] However, erroneous reports of some species, e.g., *A. nebulosus* (Le Sueur, 1819) are found in their list. Therefore, country-specific data should be provided to CABI, GISD, Fishbase, and other international organisations. Furthermore, it is suggested that new introductions should not be permitted without any scientific evaluation, particularly those of hotspots. Research, education, and strict control are the key tools to prevent the spread of alien fish species (Uzunova and Zlatanova, 2007).

Acknowledgments
The authors are thankful to Prof. Dr Hamid Reza Esmaeili (Shiraz University), Prof. Dr Deniz Ergüden (Iskenderun Technical University), Prof. Dr Deniz Innal (Mehmet Akif Ersoy University) and Burak Seçer (Nevsehir HBV University) for the valuable suggestions and help provided.

[8] CABI (2020). Invasive Species Compendium, Turkey. https://www.cabi.org/isc/datasheet/108587#tolistOfSpecies

[9] GISD (2020). The global invasive species database. http://www.iucngisd.org/gisd/search.php

References

Ağdamar S, Tarkan AS (2019). High genetic diversity in an invasive freshwater fish species, *Carassius gibelio*, suggests establishment success at the frontier between native and invasive ranges. Zoologischer Anzeiger 283: 192e200. doi:10.1016/j.jcz.2019.10.002

Akın S, Buhan E, Winemiller KO, Yılmaz H (2005). Fish assemblage Structure of Köyceğiz Lagoon- Estuary, Turkey: Spatial and Temporal Distribution patterns in relation to Environmental Variation. Estuarine Coastal and Shelf Science 64: 671-684. doi:10.1016/j.ecss.2005.03.019

Allendorf F (1991). Ecological and genetic effects of fish introductions: synthesis and recommendations. Canadian Journal Fisheries and Aquatic Sciences 48: 178-181. doi:10.1139/f91-318

Altun T, Tekelioğlu N, Danabaş D (2006). Tilapia Culture and its Problems in Turkey. Ege University, Journal of Fisheries Aquatic Sciences 23 (3-4): 473-478.

Apostolos A (2005). The ichthyofauna from the Bulgarian sector of the Mesta River. Acta Zoologica Bulgarica 57: 91-196.

Arslan P, Innal D, Ozeren SC (2021). Notes on the Distribution of the Genus *Oreochromis* in the East Mediterranean Region of Turkey. Commagene Journal of Biology 5 (1): 18-23.

Atalay MA, Toslak C (2013). Fish Stocking, National and International Regulations on Alien and Invasive Fish Species. Journal of Fisheries Aquatic Sciences 28: 39-62.

Balon EK (2004). About the oldest domesticates among fishes. Journal of Fish Biology 65 (Supplement A), 1-27. doi:10.1111/j.1095-8649.2004.00563.x

Baran I, Ongan T (1988). Limnological features, fishing problems and suggestions of Gala Lake. Gala Lake and Its Problems Symposium, Nature Protection Association Scientific Publications Series, Istanbul, 46-54.

Barbieri RS, Zogaris E, Kalogianni M, Th. Stoumboudi Y, Chatzinikolaou S et al. (2015). Freshwater Fishes and Lampreys of Greece: An annotated checklist. Monographs on Marine Sciences No. 8. Hellenic Centre for Marine Research: Athens, Greece. p. 130.

Blackburn TM, Pyšek P, Bacher S, Carlton JT, Duncan RP et al. (2011). A proposed unified framework for biological invasions. Trends in Ecology and Evolution 26: 333-339. doi:10.1016/j.tree.2011.03.023

Britton JR, Davies GD, Brazier M (2010). Towards the successful control of the invasive *Pseudorasbora parva* in the UK. Biological Invasions 12: 125-131. doi:10.1007/s10530-009-9436-1

Buhan E, Doğan HM, Kılıç OM, Yılmaz DS, Buhan SD (2017). Monitoring Tilapia (*Tilapia* spp.) Population in Köyceğiz Lake of Turkey by Thermal Bands of LANDSAT-5 TM and LANDSAT-7 ETM+ Satellite Images. Journal of Agricultural Faculty of Gaziosmanpasa University 34 (3): 237-244. doi:10.13002/jafag4316

Cambray JA (2003). Impact on indigenous species biodiversity caused by the globalisation of alien recreational freshwater fishes. Hydrobiologia 500: 217-230. doi:10.1023/A:1024648719995

Castaldelli G, Pluchinotta A, Milardi M, Lanzoni M, Giari L et al. (2013). Introduction of exotic fish species and decline of native species in the lower Po basin, north-eastern Italy. Aquatic Conservation: Marine and Freshwater Ecosystems 23 (3): 405-417. doi:10.1002/aqc.2345

Celayir Y, Akbay N, Pala M, Yüksel F (2003). DSI Keban Dam Fisheries Branch Directorate Production of silver carp (*Hypophthalmichhys molitrix*, Valenciennes, 1844) preliminary production. XII. National Fisheries Symposium, 2-5 September 2003 Elazığ, Proceedings 463-466.

Cikova V, Uzunova E, Rozdina D (2004). PCR approach in diagnostic of redmouth disease in salmonid fish. Zivotnov¨dni nauki 41: 81-84.

Coad BW (1996). Exotic fish species in the Tigris Euphrates Basin. Zoology in the Middle East 13: 71-83. doi:10.1080/09397140.1996.10637707

Copp GH, Bianco PG, Bogutskaya NG, Eros T, Falka I et al. (2005). To be, or not to be, a non-native freshwater fish? Journal of Applied Ichthyology 21: 242-262. doi:10.1111/j.1439-0426.2005.00690.x

Cowx IG (1998). (ed.) Stocking and introduction of fish. Fishing News Books, Oxford.

Cucherousset J, Olden JD (2011). Ecological impacts of non-native freshwater fishes. Fisheries 36: 215-230. doi:10.1080/03632415.2011.574578

Çelik M, Gökçe MA (2003). Determination of Fatty Acid Compositions of Five Different Tilapia Species from the Çukurova (Adana/Turkey) Region. Turkish Journal of Veterinary and Animal Science 27: 75-79.

Çetinkaya O (2006). Grafted or stocked waters of exotic and indigenous species of fish in Turkey, a preliminary study to show effects of them on farming, fishing, natural populations and aquatic ecosystems. Fisheries and Reservoir Management Symposium Memorandum Book, 07-09 February 2006, T.K.B Akdeniz Fisheries Research, Production and Education Institute Publications, 205-235.

Çiçek E (2021). Recent status of exotic tilapia species in Turkey. Ege Journal of Fisheries and Aquatic Sciences 38 (1): 111-116. doi:10.12714/egejfas.38.1.14

Çiçek E, Birecikligil SS, Fricke R (2015). Freshwater fishes of Turkey; a revised and updated annotated checklist. Biharean Biologists 9 (2): 141-157.

Çiçek E, Birecikligil SS, Fricke R (2016). Addenda and errata of: Freshwater fishes of Turkey: a revised and updated annotated checklist. FishTaxa 1 (2): 116-117.

Çiçek E, Emiroğlu O, Aksu S, Secer B, Başkurt S et al. (2021). Range extension of *Gymnocephalus cernua* Linnaeus, 1758 (Perciformes: Percidae) as a new invasive species for Turkey. Acta Biologica Turcica 34 (1): 26-30.

Çiçek E, Fricke R, Sungur S, Eagderi S (2018). Endemic freshwater fishes of Turkey. FishTaxa 3(4): 1-39.

Çiçek E, Sungur S, Fricke R (2020). Freshwater lampreys and fishes of Turkey; a revised and updated annotated checklist 2020. Zootaxa 4809 (2): 241-270.

Deveciyan K (1926). Pêche Et Pêcheries En Turquie (Türkiye'de Balık ve Balıkçılık). Reprint in Turkish by Aras publishing, 8th edition, October 2020, Istanbul, 574p.

Dikel S, Çelik M (1998). Body and Nutritional Composition of Tilapia (*Tilapia* ssp.) from the Southern Seyhan River. Turkish Journal of Veterinary and Animal Sciences 22: 517-520.

Eagderi S, Moradi M (2017). Range extension of the lake goby *Rhinogobius similis* Gill, 1859 (Teleost: Gobiidae) to Urmia Lake basin in northwestern Iran. Biharean Biologist 11 (2): 123-125.

Eagderi S, Nasri M, Çiçek E (2018). First record of the Amur goby *Rhinogobius lindbergi* Berg 1933 (Gobiidae) from the Tigris River drainage, Iran. International Journal of Aquatic Biology 6 (4): 202-207.

Ekmekçi FG, Kırankaya ŞG, Gençoğlu L, Yoğurtcuoğlu B (2013). Present Status of Invasive Fishes in Inland Waters of Turkey and Assessment of the Effects of Invasion. Journal of Fisheries Aquatic Sciences 28: 105-140.

Elvira B (2001). Identification of non-native freshwater fishes established in Europe and assessment of their potential threats to the biological diversity. Convention on the conservation of European wildlife and natural habitats. Council of Europe T-PVS 6: 35p.

Elvira B, Almodóvar A (2001). Freshwater fish in Spain: facts and figures at the beginning of the 21st century. Journal of Fish Biology 59 (Supp. A): 323-331. doi:10.1111/j.1095-8649.2001.tb01393.x

Emiroğlu Ö (2011). Alien fish species in upper Sakarya River and their distribution. African Journal of Biotechnology 10 (73): 16674-16681. doi:10.5897/AJB10.2502

Emiroğlu Ö, Atalay MA, Ekmekçi FG, Aksu S, Başkurt S et al. (2020). One of the world's worst invasive species, *Clarias batrachus* (Actinopterygii: Siluriformes: Clariidae), has arrived and established a population in Turkey. Acta Ichthyologica et Piscatoria 50 (4): 391-400.

Emiroğlu Ö, Başkurt S, Aksu S, Giannetto D (2018). Standard weight equations of two sub-/tropic nonnative freshwater fish, *Clarias gariepinus* and *Oreochromis niloticus*, in the Sakarya River Basin (NW Turkey). Turkish Journal of Zoology 42: 694-699.

Emiroğlu Ö, Ekmekçi FG, Aksu S, Başkurt S, Atalay MA et al. (2016). Introduction and Establishment of Tropical Ornamental Fish, *Pterygoplichthys* spp. (Actinopterygii: Siluriformes: Loricariidae) in Hot Springs: Aquarium Trade as a Potential Risk for Biodiversity in Turkey. Acta Ichthyologica et Piscatoria 46 (4): 351-356. doi:10.3750/AIP2016.46.4.07

Ercan D, Andreou D, Sana S, Öntaş C, Baba E et al. (2015). Evidence of threat to European economy and biodiversity following introduction of an alien pathogen on the fungal-animal boundary. Emerging Microbes and Infections 4, e52. doi:10.1038/emi.2015.52

Erençin Z, Baran I, Ergüven H (1971). Zwergwelsen in Ostanatolien (*Ameiurus nebulosus* (sic) Le Sueuer, 1890 (sic). Ankara Üniversitesi Veteriner Fakültesi Dergisi 18: 214-218.

Ergüden Alagöz S (2013). Invasive Fish Species and their Probable Effect on the Seyhan Dam Lake. Biodiversity Symposium, 22-23 May 2013, Muğla-Marmaris.

Ergüden Alagöz S, Göksu MZL, Çelikkol Ç (2010). Spring Feeding Habits by Escaped Cage Rainbow trout, *Oncorhynchus mykiss* (Walbaum, 1792) in the Seyhan Dam Lake (Adana/Turkey). Journal of Applied Biological Sciences 4 (3): 7-10.

Erkakan F (1983). The fishes of the Thrace Region. Hacettepe Bulletin Natural Sciences and Enginering 12: 39-48.

Erkakan F (1984). A new Cyprinid fish record for Turkey, *Pseudorasbora parva* from the Thrace region. Doğa Bilim Dergisi 8 (3): 350-351.

Esmaeili HR, Gholamifard A, Sayyadzadeh G, Parsi B, Mirghiyasi S et al. (2013). New record of the convict cichlid, *Amatitlania nigrofasciata* (Günther, 1867), from the Middle East (Actinopterygii: Cichlidae). Aqua, International Journal of Ichthyology 19: 225-229.

Esmaeili HR, Masoudi M, Amini Chermahini M, Esmaeili AH, Zarei F et al. (2017). Invasion of the Neotropical and Nearctic fishes to Iran. FishTaxa 2 (3): 126-133.

Esmaeili HR, Teimory A, Owfi F, Abbasi K, Coad BW (2014). Alien and invasive freshwater fish species in Iran: Diversity, environmental impacts and management. Iranian Journal of Ichthyology 1 (2): 62-72. doi:10.22034/IJI.V1I2.4

Fobert E, Copp GH, Zieba G, Vilizzi L, Godard MJ et al. (2013). Predicting non-native fish dispersal under conditions of climate change: case study in England of dispersal and establishment of pumpkinseed *Lepomis gibbosus* in a floodplain pond. Ecology of Freshwater Fish 22: 106-116. doi:10.1111/eff.12008

Garcia-Berthou E, Moyle PB (2011). Rivers. In Simberloff D, Rejmanek M (eds), Encyclopaedia of Biological Invasions. University of California Press, Berkeley Los Angeles: 609-612.

Geldiay R, Balık S (2007). Freshwater fishes of Turkey (Vth edition). Ege Univiversity Faculty of Fisheries Publications, No: 46, Izmir, 644 p.

Godwin JC, Steen DA, Werneke D, Armbruster JW (2016). Two Significant Records of Exotic Tropical Freshwater Fishes in Southern Alabama. Notes of the Southeastern Naturalist 15 (4): 57-60.

Gozlan RE, Andreou D, Asaeda T, Beyer K, Bouhadad R et al. (2010). Pan-continental invasion of *Pseudorasbora parva*: towards a better understand fish invasions. Fish and Fisheries 11: 315-340. doi:10.1111/j.1467-2979.2010.00361.x

Gozlan RE, Whipps C, Andreou D, Arkush K (2009). Characterisation and geographical isolation of *Sphaerothecum destruens* in Europe. International Journal of Parasitology 39: 1055-1058.

Gürlek, M, Turan, C (2005). Genetic identification of *Tilapia* species living in Cukurova and Hatay regions. Türk Sucul Yaşam Dergisi 575-578.

Holcík J (1991). Fish introductions in Europe with particular reference to its central and eastern part. Canadian Journal Fisheries and Aquatic Sciences 48(Suppl. 1): 13-23.

Holden MH, Nyrop JP, Ellner SP (2016). The economic benefit of time-varying surveillance effort for invasive species management. Journal of Applied Ecology 53 (3): 712-721. doi:10.1111/13652664.12617.

Innal D (2011). Distribution and impacts of *Carassius* species (Cyprinidae) in Turkey: a review. Management of Biological Invasions 2: 57-68. doi:10.3391/mbi.2011.2.1.06

Innal D (2012). Alien fish species in reservoir systems in Turkey: a review. Management of Biological Invasions 3: 115-119. doi:10.3391/mbi.2012.3.2.06

Innal D (2019). Diversity and length-weight relationships of Blenniid Species (Actinopterygii, Blenniidae) from Mediterranean Brackish Waters in Turkey. Aquatic Sciences and Engineering 34 (3): 96-102.

Innal D, Erkakan F (2006). Effects of exotic and translocated fish species in the inland waters of Turkey. Reviews in Fish Biology and Fisheries 16: 39-50. doi:10.1007/s11160-006-9005-y

Innal D, Gianetto D (2017). Age Structure and Length-Weight Relationship of Non-native Redbelly Tilapia *Coptodon zillii* (Gervais, 1848) (Cichlidae) in the Pınarbaşı Spring Creek (Burdur, Turkey), Acta Zoologica Bulgarica 9: 111-116.

Innal D, Sungur S (2019). First record of non-indigenous fish *Hemichromis letourneuxi* (Cichlidae) from Pınarbaşı Creek (Burdur, Turkey). The Journal of Graduate School of Natural and Applied Sciences of Mehmet Akif Ersoy University 10(1): 90-94. doi:10.29048/makufebed.562523

Kırankaya ŞG, Ekmekçi FG (2021). First Record of a Feral Population of Green Swordtail (*Xiphophorus hellerii*) with an Additional Record of Guppy (*Poecilia reticulata*) in Turkish Freshwaters. Hacettepe Journal of Biology and Chemistry 49 (1): 433- 441. doi:10.15671/hjbc.961220

Kızak V, Güner Y (2014). First record of F_2 hybrid striped bass (*Morone chrysops* ♀ × *Morone saxatilis* ♂ × *Morone chrysops* ♀ × *Morone saxatilis* ♂) in Kemer Dam Lake. Turkish Journal of Zoology 38: 637-641. doi:10.3906/zoo-1304-1342

Kiruba-Sankar R, Praveen Raj J, Saravanan K, Lohith Kumar K, Raymond Jani Angel J et al. (2018). Chapter 9 - Invasive Species in Freshwater Ecosystems – Threats to Ecosystem Services. In Editor(s): Chandrakasan Sivaperuman, Ayyam Velmurugan, Awnindra Kumar Singh, Iyyappan Jaisankar, Biodiversity and Climate Change Adaptation in Tropical Islands, Academic Press, pp257-296.

Köksal G, Rad F, Kındır M (2000). Growth performance and feed conversion efficiency of Siberian sturgeon juveniles (*Acipenser baerii*) reared in concrete raceways. Turkish Journal of Veterinary and Animal Sciences 24: 435-442.

Kurtul I, Sarı HM (2019a). Contribution on the Distribution of *Gambusia holbrooki* (Mosquitofish) in Turkey. LimnoFish 5 (3): 170-180. doi:10.17216/LimnoFish.519729.

Kurtul I, Sarı HM (2019b). Length–weight relationships of invasive mosquitofish (*Gambusia holbrooki* Girard, 1859) in 23 river basins of Turkey. Turkish Journal of Zoology 44: 324-334.

Kuru M (2004). Recent systematic status of inland water fishes of Turkey. Gazi Eğitim Fakültesi Dergisi 24 (3): 1-21.

Kuru M, Yerli SV, Mangıt F, Ünlü E, Alp A (2014). Fish biodiversity inland waters of Turkey. Journal of Academic Documents for Fisheries and Aquaculture 3: 93-120.

Mangıt F, Korkmaz M, Yerli SV (2018). Morphological variation of pumpkinseed (*Lepomis gibbosus*) with emphasis on allometry. Turkish Journal of Zoology 42: 53-61. doi:10.3906/zoo-1703-1745.

Marr SM, Olden JD, Leprieur F, Arismendi I, Ćaleta M et al. (2013). A global assessment of freshwater fish introductions in Mediterranean-climate regions. Hydrobiologia 719: 317-329. doi:10.1007/s10750-013-1486-9

Moyle PB, Li HW, Barton B (1987). The Frankenstein effect: impact of introduced fishes on native fishes in North America. 415-426. In: Stroud R.H. (ed.) The role of fish culture in fishery management. American Fishery Society, Bethesda.

Özcan G (2007a). Distribution of the non-native fish species pumpkinseed *Lepomis gibbosus* Linnaeus 1758 in Turkey. Aquatic Invasions 2 (2): 146-148. doi:10.3391/ai.2007.2.2.10

Özcan G (2007b). Distribution of non-indigenous fish species Prussian Carp *Carassius gibelio* Bloch 1782 in the Turkish Freshwater Systems. Pakistan Journal of Biological Sciences 10: 4241-4245. doi:10.3923/pjbs.2007.4241.4245

Özcan G, Tarkan AS (2019). Distribution revisited- fifteen years of changes in the invasion of a freshwater fish, *Pseudorasbora parva* (Temminck and Schlegel, 1846) in Turkey. Transylvanian Review of Systematical and Ecological Research 21 (2): 69-80. doi:10.2478/trser-2019-00013.

Petriki O, Naziridis T, Apostolou A, Koutrakis E, Bobori DC (2014). The spread of the introduced *Gymnocephalus cernua* Linnaeus, 1758 (Perciformes: Percidae) along the transboundary Strymonas (Struma) River basin: First report in Kerkini Dam Lake (Greece). Acta Zooogica Bulgarica 66 (4): 563-566.

Radkhah A, Eagderi S, Mousavi-Sabet H (2016). First record of the exotic species *Hemiculter leucisculus* (Pisces: Cyprinidae) in southern Iran. Limnetica 35 (1): 175-178. doi:10.23818/limn.35.14

Raikova-Petrova G, Hamwi N, Petrov I (2004). Changes in the ichthyofauna of the middle stream of Iskar river (Bulgaria). Forest Science 3: 87-92.

Shelton WL, Rothbard S (2006). Exotic species in global aquaculture - A Review. The Israeli Journal of Aquaculture–Bamidgehi 58 (1): 3-28.

Tarkan AS (2006). The story of a pranha in Lake Sapanca. Av Doğa 41: 75-77.

Tarkan AS, Copp GH, Top N, Özdemir N, Önsoy MB et al. (2012). Are introduced gibel carp *Carassius gibelio* in Turkey more invasive in artificial than in natural waters? Fisheries Management and Ecology 19: 178-187. doi:10.1111/j.1365-2400.2011.00841.x

Tarkan AS, Marr SM, Ekmekçi FG (2015). Non-native and translocated freshwater fish species in Turkey. FiSHMED Fishes in Mediterranean Environments 2015.003.

Top-Karakuş N, Tarkan AS (2021). Does non-native pumpkinseed *Lepomis gibbosus* affect endemic algae-scraping *Capoeta aydinensis* in case of introduction to a small stream? An ex situ growth experiment. Ecology of Freshwater Fish 00, 1-6. doi: 10.1111/eff.12614

Türkmen G (2019). First record of the guppy (*Poecilia reticulata* Peters, 1859) in inlandwaters of Turkey. Journal of Fisheries and Aquatic Sciences 36 (4): 397-400. doi:10.12714/egejfas.36.4.11

Uysal I, Alpbaz A (2002). Comparison of the growth performance and mortality in Abant trout (*Salmo trutta abanticus* Tortonese, 1954) and rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) under farming conditions. Turkish Journal of Zoology 26: 399-403.

Uzunova E, Zlatanova S (2007). A review of the fish introductions in Bulgarian freshwaters. Acta Ichthyologica et Piscatoria 37 (1): 55-61. doi:10.3750/AIP2007.37.1.08

Ünlü E, Çiçek T, Değer D, Coad BW (2011). Range extension of the exotic Indian stinging catfish, *Heteropneustes fossilis* (Bloch, 1794) (Heteropneustidae) into the Turkish part of the Tigris River watershed. Journal of Applied Ichthyology 27: 141-143. doi:10.1111/j.1439-0426.2010.01580.x

Welcomme RL (1992). A history of international introductions of inland aquatic species. ICES Marine Science Symposium 194: 3-14.

Wildekamp RH, Valkenburg K (1994). Notizen über zahnkarpfen-lebensraüme in Anatolien. Die Aquarien und Terrarien Zeitschrift 47 (7): 447-453.

Witkowski A (2002). Introduction of fishes into Poland: benefaction or plague? Nature Conservation 59: 41-52.

Wu L-W, Liu C-C, Lin S-M (2011). Identification of exotic sailfin catfish species (*Pterygoplichthys,* Loricariidae) in Taiwan based on morphology and mtDNA sequences. Zoological Studies 50: 235-246.

Yalçın Özdilek Ş (2007). Possible threat for Middle East inland water: an exotic and invasive species, *Pterygoplichthys disjunctivus* (Weber, 1991) in Asi River, Turkey (Pisces: Loricariidae). Journal of Fisheries and Aquatic Sciences 24 (3-4): 303-306.

Yerli SV (2019). First record of a coregonid fish species, *Coregenus albula* (Linnaeus, 1758) (Salmoniformes: Salmonidae) in Aktaş Lake shared between Turkey and Georgia. Journal of Black Sea/Mediterranean Environment 25 (3): 325-332.

Yerli SV, Mangıt F, Emiroğlu Ö, Yeğen V, Uysal R et al. (2014). Distribution of invasive *Carassius gibelio* (Bloch, 1782) (Teleostei: Cyprinidae) in Turkey. Turkish Journal of Fisheries and Aquatic Sciences 14: 581-590. doi:10.4194/1303-2712-v14_2_30.

Yoğurtcuoğlu B, Ekmekçi FG (2018). First record of the giant pangasius, *Pangasius sanitwongsei* (Actinopterygi: Siluriformes: Pangaiidae), from Central Anatolia, Turkey. Acta Ichthyologica Et Piscatoria 48 (3): 241-244. doi:10.3750/AIEP/02407