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NON-NATIVE FRESHWATER FISHES OF TURKEY: INTRODUCTION PATHWAYS AND POTENTIAL IMPACTS

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***Abstract.** In recent decades, human induced rapid environmental change has destroyed many ecosystems and threatened biodiversity globally. Currently, in addition to the industrialization and habitat destruction, one of the most important human mediated threatening factors is the introduction of non-native/invasive species into novel ecosystems, where they usually compete with or predate on, and eventually displaced the native biota. In this context, we updated and reviewed non-native freshwater fish species in Turkey with special reference to their introduction pathways and potential impacts. We searched the occurrence data through the global databases and our filed records, and collected case studies including articles published from xxxx to xxxx to demonstrate their potential impacts in Turkish freshwaters.*

*According to our results, a total of 15 non-native freshwater fish species are confirmed for native freshwater ecosystems. Among these, *Gambusia holbrooki*, *Carassius gibelio* and *Pseudorasbora parva* are the most successful and widespread species that has spread almost every major water basin. This spread occurs accidentally or intentionally through aquaculture, ornamental, recreational or commercial fisheries as well as by habitat modifications. Two species (*Pygocentrus nattereri* and *Pangasius sanitwongsei*) are recorded as aquarium escapees which never established viable populations in natural waters, whereas the rest of the species are more or less established successful populations in rivers and lakes. In the published literature, we recognized a huge gap of knowledge on their actual impacts on the native species and ecosystems. We concluded that the more we gain insight into their distribution pattern, the actual impacts and the ecological factors involved, the more able we will be to set particular risk analyses and measure methods, when required.*

***Keywords:** Exotic fish, alien freshwater fish, invasion, fish introduction*

INTRODUCTION

Excessive human population growth, urbanization and industrialization, and massive disturbances caused by human activity have destroyed many ecosystems, threatening the Earth's biodiversity (Primack, 2010). Biological introductions associated with human activities are accepted as a major threat to global biodiversity via reducing species diversity and leading to biotic homogenization at large spatial scales (McKinney & Lockwood, 1999; Villéger et al., 2015; Toussaint et al., 2016). Indeed, spreading of species into new regions is a natural process, but in the past century human activities have been accelerated species invasion in the nature (Lockwood et al., 2007; Ricciardi, 2007). In the past decades, the rate of exotic species introductions has enormously increased worldwide due to excessive human population growth and alteration of the environment. (Williamson & Fitter, 1996; Hulme, 2009; Vilà et al., 2010) and, today non-native species invasions

are considered to be one of the most serious threats to biodiversity and cause of animal extinctions (Vitousek et al., 1997; Clavero & García Berthou, 2005; Primack, 2010). According to Clavero & Garcia-Berthou (2005), invasive species are responsible for extinction of 34 animal species which represents 25% of all extinct species.

Aquatic ecosystems, especially isolated lake and stream systems, are more vulnerable to the introduction of non-indigenous species than other ecosystems (Lodge, 2001). During last decades, many species introductions have occurred via aquaculture, recreational and ornamental fisheries, accidental transport, and biological control in aquatic habitats, and some of these species have become invasive (Primack, 2010).

Species invasion is a complex process and consists of four stages: transport, establishment, spread and impact (Lockwood et al., 2007). Although the great majority of non-indigenous species do not become established in new environments, some percentage of such species do establish themselves, and alter habitat and species diversity due to predation, competition, behavioural interference, hybridization, spread of novel parasites and diseases, disrupt of food webs and modification of biochemical cycles (Welcomme, 1988; Clavero & Garcia-Berthou, 2005; Crivelli, 1995; Gozlan et al., 2005; Caiola & de Sostoa, 2005; Hanfling et al., 2005). Life history traits, such as a short life span, a prolonged reproductive period, diverse diet, and environmental tolerance, can facilitate invasion of freshwater fish in the European bioregion (Grabowska & Przybylski, 2014). Although some non-indigenous species provide new sources of income due to their commercial, recreational, and ornamental value, invasive non-indigenous species eventually result in economic loss, both locally and globally (Pimentel et al., 2005).

Turkey is the only country covered almost entirely by three of the world's 34 biodiversity hotspots: Caucasus, Irano-Anatolian and Mediterranean (Mittermeier et al., 2005) There are many rivers, natural and artificial lakes and ponds of varying ecological properties, which are host to a rich biodiversity of approximately 390 freshwater fish species in Turkey. In addition to over 150 endemic species, Turkey's freshwater ichthyofauna includes Euro-Mediterranean, Syrian-Mesopotamian, and Ponto-Aralo-Caspian species (Freyhof et al., 2014; Çiçek et al., 2018; Froese & Pauly, 2019;). Although Turkey has the richest freshwater ichthyofauna in the Mediterranean Region (Freyhof et al., 2014), its biodiversity is threatened; approximately 33% of the freshwater fish species are threatened and 5 species have already become extinct (Ekmekçi et al., 2013). In addition to pollution, excessive water abstraction, construction of dams and other management activities, overfishing and harvesting of aquatic resources, invasive species all pose a serious threat to Turkey's freshwater fish biodiversity. Recently, many exotic fish species, primarily gibel carp, topmouth gudgeon, rainbow trout, and mosquito fish, have spread to almost all water basins in Turkey (Ekmekçi et al., 2013). This spread occurs accidentally or intentionally via such human activities as aquaculture, and ornamental, recreational, and commercial fisheries.

This study focuses on listing the non-native freshwater fish species of the Turkey, and assessing their introduction pathways and potential impacts. Recent records have confirmed that around 17 fish species are alien for Turkish freshwaters.

NON-NATIVE FRESHWATER FISHES OF TURKEY

Fish introductions into Turkish freshwater systems have a history of approximately 90 years. The oldest deliberate introduction was the mosquito fish as a control agent of mosquitoes in Turkey (Erençin, 1978; Krupp, 1992). Recently, the eastern mosquitofish (*Gambusia holbrooki*) is one of the most widespread exotic species throughout the country (Ekmekçi et al., 2013; Yoğurtçuoğlu & Ekmekçi, 2017). Afterwards, *Coregonus laveratus* was introduced into İznik Lake in 1950s (Nümann, 1954), however the species could not

successfully established and spreaded in the area. Non-native salmonid species were also reported from Turkish inland waters since 1960s (Ekmekçi et al., 2013). Records of exotic fish species introductions in inland waters of Turkey have been increased after 1980s. A list of the non-native fishes and their risk assessment profile according to the latest assessment by Aquatic Species Invasiveness Screening Kit (AS-ISK) (Tarkan et al., 2017) is given in Table 1.

Table 1. Confirmed non-native freshwater fishes and their risk assessment profile in Turkey

Family	Species	Establishment success	AS-ISK outcome
Cyprinidae	<i>Carassius gibelio</i>	Established	High
	<i>Carassius auratus</i>	Established	High
Xenocyprididae	<i>Ctenopharyngodon idella</i>	Not established	High
Gobionidae	<i>Pseudorasbora parva</i>	Established	High
Poeciliidae	<i>Gambusia holbrooki</i>	Established	High
	<i>Poecilia reticulata</i>	Needs confirmation	n.a.
Centrarchidae	<i>Lepomis gibbosus</i>	Established	High
Salmonidae	<i>Oncorhynchus mykiss</i>	Needs confirmation	Medium
Percidae	<i>Gynmocephalus cernua</i>	Established	Medium
Cichlidae	<i>Coptodon zillii</i>	Established	Medium
	<i>Oreochromis aureus</i>	Established	Medium
	<i>Hemichromis letourneuxi</i>	Not established	n.a.
Pangasiidae	<i>Pangasius sanitwongsei</i>	Not established	n.a.
	<i>Pangasius (or Pangasianodon) sp.</i>	Not established	n.a.
Clariidae	<i>Clarias batrachus</i>	Needs confirmation	High
Heteropneustidae	<i>Heteropneustes fossilis</i>	Not established	Medium
Serrasalminidae	<i>Pygocentrus nattereri</i>	Not established	Medium

CURRENT STATUS AND INTRODUCTION PATHWAYS

Like many European, introduction pathways and vectors have not been well documented in Turkey, and thus the origin, pathway or reason for introduction remains unclear for many alien species. Introduction of non-native fish species are usually occurred in two ways caused by human activities: intentionally for aquaculture, commercial and recreational fisheries, biological control, scientific purposes, and unintentionally via natural aquatic networks, fisheries equipment, ship ballast.

Intentional introductions are being frequently made by government institutions, fisheries scientist, locals, and other non-governmental organisations (e.g. fisheries related associations). For example the rainbow trout, which is to native to tributaries of the Pacific Ocean in Asia and North America, has been widely introduced in many streams, lakes and ponds for the purpose of aquaculture and recreational fishery in Turkey by governmental organizations (Anonim, 1988; Uysal & Alpaz, 2002; Kışisel, 2006). Currently, escapees from fish farms have successfully adapted to a wide variety of new habitats, such as streams, rivers, lakes, ponds,

and artificial impoundments, but no self-sustaining population has been recorded yet (Tarkan et al. 2015). The mosquitofish and grass carp have also been deliberately introduced in order to mosquito and aquatic macrophyte biological control, respectively (Erençin 1978; Tarkan et al., 2015; Anonim, 1988; Kişisel, 2006). The mosquitofish is widespread and has self-reproducing populations, whereas no self-reproducing population of the grasscarp was recorded in Turkey (Tarkan et al., 2015).

Aquarium trade is also an important pathway for transportation of non-native species. Some species have been introduced by ornamental purpose. For example, the goldfish (*Carassius auratus*), Piranha (*Pygocentrus nattereri*), the vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*), giant catfish (*Pangasius sanitwongsei*), guppy (*Poecilia reticulata*) and the walking catfish (*Clarias batrachus*) have been recorded as escapees or illegal release for inland water bodies.

Acipenser baeri (Köksal et al., 2000), Cichlid species *Coptodon zilli*, *Oreochromis aureus*, *O. mossambicus*, *O. niloticus* (Sarıhan & Toral, 1982; Sarıhan et al., 1990; Kırgın, 1987; Dikel, 1995; Işık, 1995), *Salmo salar* (Karataş, 1996) *Salvelinus alpinus* (Haliloğlu et al., 2002) ve *Salvelinus fontinalis* (Yılmaz, 1997; Alkan 1997; Başçınar, 2001) were transported for various scientific and fisheries researches in Turkey. Among the above-mentioned species, *C. zillii* and *O. aureus* have been established self-sustaining populations after escape restricted research environment.

Certain fish species such as topmouth gudgeon, (*P. parva*), gibel carp (*C. gibelio*), pumpkenseed (*L. gibbosus*), stinging catfish (*H. fossilis*) have been unintentionally introduced to Turkish freshwaters by natural river networks (Aydın et al., 2011; Ünlü et al., 2011; Ekmekçi et al., 2013; Tarkan et al., 2015). After their introduction, these species except stinging catfish, have been transported to many inland water bodies throughout Turkey in several ways (Aydın et al., 2011; Tarkan et al. 2012; Ekmekçi et al., 2013; Tarkan et al., 2015).

Recently, *P. parva*, *C. gibelio* and *L. gibbosus* are among the most widespread non-native species in the country. *Pseudorasbora parva* is a small gobioid originating from East Asia. It was first recorded from Thrace part of Turkey in 1982 (Erk'akan, 1984), and has rapidly expanded its area of distribution through past three decades (Ekmekçi & Kırankaya, 2006; Tarkan et al., 2015). *Carassius gibelio*, is one of the most problematic and invasive species in Turkish freshwater systems. It has been first recorded from the Thrace part of Turkey in 1986 (Özuluğ et al., 2004). Currently, *C. gibelio* has invaded many lakes, ponds, reservoirs and rivers both in Thrace and Anatolian part of Turkey (Ekmekçi et al., 2013; Yerli et al., 2014; Tarkan et al., 2015). Tarkan et al. (2012) reported that the gibel carp is more successful in artificial water bodies than in natural ones and it can reach excessive populations after introduction due to its gynogenetic reproductive ability (Tarkan et al, 2012). *Lepomis gibbosus*, a centrarchid species native to North America, was first reported in Thrace region of Turkey (Erk'akan, 1983), and expanded its range through western Anatolia within four decades (Ekmekçi et al., 2013; Tarkan et al., 2015).

POTENTIAL IMPACTS

Owing to the high level of endemism and the great conservation value of the Anatolian freshwater fish species, introductions can have severe negative and irreversible impacts on the ichthyodiversity of Turkey (Ekmekçi et al., 2013; Tarkan et al., 2013)

The impact of non-native species can be divided into three concerns: harm to ecological processes, harm to native species and harm to human health and economy. These categories, however, are interdependent; an exotic species which has an ecological impact may also affect native communities and economic concerns.. Non-native species may negatively impact native species in many patterns. The most critical ecological impacts of non-native species are hybridization, predation, competition, habitat alteration (Crivelli, 1995), diseases, and parasites (Welcomme, 1988). Today, *O. mykiss* and *G. holbrooki* were regarded as the world's

100 worst invasive alien species due to their negative impacts on the native species through hybridization, predation and competition. *Carassius gibelio* easily becomes a dominant species in stagnant and slow-running waters and may change the flow of nutrients in the entire ecosystem (Paulovits et al., 1998). *Pseudorasbora parva* can contribute to decrease in abundance of native fish species due to its feeding pressure on juvenile stages of other fish species and transmitting a deadly pathogen (Gozlan et al., 2002; Gozlan et al., 2005).

Today, invasive fish species cause enormous global economic loss. According to Kettunen et al. (2008), annually €12.5 billion is spent in the EU for monitoring, controlling, preventing, and eradicating invasive fish species, and for reversing the damage they cause to fisheries, agriculture, forestry, and public health. On the other hand, decreases in several fish stocks related exotic species have led to the collapse of fisheries, and consequently, commercial viability (Enberg et al., 2009). Collapse of commercially valuable fish stocks has enormous negative social and economic results, and politicians and fishery management institutions have gradually shifted their focus from 'how much to catch' to 'how to make sure there is something to catch' (Enberg et al., 2009).

Information on the economic impacts of the non-native species is very scarce in Turkey. According to fisheries statistics, of the income from common carp (*C. carpio*) fishery has gradually reduced since 2000. Although *C. carpio* is commercially more valuable and demanded than *C. gibelio*, catch ratio of *C. gibelio* is higher, likely due to the decrease in carp populations by the competition with gibel carp (Atalay et al., 2017).

Although there is some national legislation in place that regulates fish and other alien species introductions in the Turkey (Atalay & Toslak, 2013), this legislation is rarely being enforced by the national environmental agencies and are practically ineffective. Furthermore, measures to effectively control the introductions or translocations of alien fish species are still lacking in Turkey. To reduce the negative effects of non-indigenous species, data on their distribution, ecological effects, and control of non-indigenous species are required. Gaps between ecological theory and the practical needs of conservationists, land managers, planners, and policymakers have resulted in the inability to address critical problems caused by invasive non-indigenous species (Byers et al., 2002). A national web collecting that evaluates and compiles data on the distribution and effects of invasive species is urgently needed in Turkey; the governmental organization responsible from fishery management may lead this mission by a project. Detecting invasive species before their establishment stage is a key tool to prevent invasion. Therefore, an early detection mechanism in which, for example, ever-growing citizen science is included, should be popularized and widely implemented.

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