

Non-native and translocated freshwater fish species in Turkey

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SUMMARY

Turkey is a hotspot of freshwater fish diversity and endemism, holding a unique ichthyofauna containing distinct European and Asian elements. Currently, 78 endemic species are recognised from Turkey, 65 of which are classified as Critically Endangered or Endangered. Habitat degradation, pollution, and the introduction of non-native fishes are the greatest threats to this unique ichthyofauna. We compiled data on the introduction and distribution of freshwater fishes in Turkey, both non-native and translocated, based on historical accounts and recent surveys. Thirty fish species have been introduced, 11 of which are translocations within Turkey. The overall establishment success was 64% (44% for non-natives and 100% for translocated species). New species continue to be introduced at a rate of 4.8 species per decade, of which 3.1 species establish per decade. Fisheries and aquaculture are two main vectors of deliberate introduction, but the contaminant of stockings is the primary pathway for secondary spread, in particular for *Carassius gibelio*, *Pseudorasbora parva* and *Lepomis gibbosus*. Natural dispersion of species introduced into neighbouring countries through trans-boundary river systems is highlighted as the most likely pathway for future species introductions. We discuss the management options available and outline how these can be incorporated into freshwater fish conservation and non-native fish management programmes. Education, public awareness and information are central components to reduce current rate of fish introductions in Turkey.

Keywords: non-native, freshwater fish, conservation, management, biological invasions, fisheries

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INTRODUCTION

Freshwater ecosystems are particularly affected by non-native species introductions (Stiassny, 1998; Dudgeon *et al.*, 2006), yet freshwater fish continue to be introduced despite their documented ecological and economic impacts (Cambray, 2003; Lintermans, 2004; Cucherousset & Olden, 2011; García-Berthou & Moyle, 2011). These introductions are strongly associated with international shipping, ornamental fish trade, aquaculture, biological control of mosquitoes and water plants, development of new fisheries, irrigation schemes, and inter-basin transfers (Allan & Flecker, 1993; Maitland, 1995; Ruesink, 2005; Jeschke & Strayer, 2006; Stohlgren *et al.*, 2006; Rahel, 2007; Tricarico, 2012). Although a small proportion of non-native species may have neutral, or even beneficial, effects on native biota and ecosystems (Cope & Winterbourn, 2004; Johnson *et al.*, 2009), others become invasive and establish spreading populations that negatively impact the recipient environment and its biota (Mack *et al.*, 2000). Freshwater fish are the most frequently introduced aquatic animal group (Gozlan, 2008), exhibiting higher establishment rates than many other taxa (Jeschke & Strayer, 2006), with introductions generally being irreversible (Cucherousset & Olden, 2011). Further, current technologies available to eradicate established populations can detrimentally impact the native species (Myers *et al.*, 2000) with relatively few long-term success stories. Understanding the multi-faceted process of aquatic invasions is important for the management and conservation of freshwater ecosystems. Identifying the primary vectors and pathways for species introductions is therefore key to reduce the risk of future introductions (Simberloff *et al.*, 2005; Hulme, 2006) and manage the secondary spread of species already present (Vander Zanden & Olden, 2008).

Turkey is a hotspot of freshwater fish diversity and endemism (Fricke *et al.*, 2007), having a distinct ichthyofauna that contains unique elements from both Europe

and Asia (Balık, 1995; Smith & Darwall, 2006; Cuttelod *et al.*, 2009). In Turkey, 11 freshwater ecoregions *sensu* Abell *et al.* (2008) are recognised incorporating three major habitat types: xeric and endorheic basins with large and small lakes and small streams (Central Anatolia and Lake Van – saline and soda lakes), temperate floodplain rivers and wetlands (Upper Dicle (Tigris) and Fırat (Euphrates) and Kura - Southern Caspian Drainages) and temperate coastal rivers (Trakya (Thrace), Western Anatolia, Southern Anatolia, Northern Anatolia, Western Transcaucasia and Asi (Orontes)). The temperate coastal rivers vary between the large meandering rivers of Northern and Western Anatolia to the shorter steep rivers of Southern Anatolia and Asi (Orontes). Northern Anatolia also has fewer lakes than Western and Southern Anatolia. Most rivers, streams, wetlands and lakes in Turkey are heavily polluted and/or eutrophic (Fricke *et al.*, 2007) with numerous dams having been constructed creating artificial lakes (reservoirs), particularly in the major river systems. Additional threats to freshwater habitats include the draining of wetlands, construction of dams, weirs and barrages, over abstraction of water and gravel extraction from river beds (Balık, 1995; Fricke *et al.*, 2007).

A total of 248 native freshwater fish species have been recorded from Turkey, comprised mostly of the families Cyprinidae, Balitoridae and Cobitidae (Fricke *et al.*, 2007). Of these, 78 species are endemic (31.5 % of the total native freshwater fish fauna), 51 % of which are classified as Critically Endangered and 32 % as Endangered (Fricke *et al.*, 2007). Turkey's geographical location and large trans-boundary river systems increases the risk of introduction of non-native fishes from both Asia and Europe (Fig. 1). Despite recent recognition of the impacts of non-native species on native fish communities in Turkey (Gaygusuz *et al.*, 2007; Aydın *et al.*, 2011; Tarkan *et al.*, 2012b), information on the introduction vectors and distribution pathways of non-native fishes remains limited, or buried in obscure reports. The major vectors for the introduction of non-native fishes to Turkey

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have been government authorized aquaculture and stocking programmes to establish and support cage aquaculture, and commercial fisheries (Innal & Erk'akan, 2006). In addition, native species have been translocated within Turkey, many of which may have exerted detrimental impacts on the recipient fish (Innal & Erk'akan, 2006).

To date, only two studies have examined the introduction and translocation of freshwater fishes in Turkey; Innal and Erk'akan (2006) and Innal (2012). However, these works contain contentious data and lack analysis of the distribution, introduction history, success and spread of non-native and translocated species. This study aims to fill these gaps by: (i) providing an updated record of non-native and translocated freshwater fishes in Turkey; (ii) determining the major vectors and pathways for the introduction and secondary spread of non-native and translocated fish species; and (iii) proposing a management framework to provide adequate protection for the native fishes and permit the utilization of non-native and translocated species while limiting the risk of future introductions and the secondary spread of introduced species.

METHODS

A history of freshwater fish introductions in Turkey was compiled from published (e.g. Anonymous (DSI), 1988, 2001; Wildekamp *et al.*, 1997; Van Neer *et al.*, 1999; Çıldır, 2001; Innal and Erk'akan, 2006; Innal, 2012) and grey literature (e.g. reports, unpublished manuscripts, theses, and books), supported by personal communications with fellow researchers (See supplementary Appendix A for a full list of references used). In Turkey, government authorized freshwater fish introductions are controlled by the Ministry of Agriculture and Rural Affairs and the General Directorate of State Hydraulic Works. Both bodies independently collect and report fish stocking and occurrence data at a national level. Native species recorded outside their historical distribution ranges were considered to be translocated. Translocated spe-

cies, although strictly non-native where introduced, were treated separately from the non-native species because they are native at a national level. Translocated species are, however, included in the overall analysis of introduced species.

For both non-native and translocated species, their present status in Turkey was assessed to determine whether the introduction had been successful. The success of the introductions were evaluated following the categorization scheme of Blackburn *et al.* (2011): **C0** - Individuals released into the wild (i.e. outside of captivity or cultivation) in location where introduced, but incapable of surviving for a significant period; **C1** - Individuals surviving in the wild in location where introduced, no reproduction; **C2** - Individuals surviving in the wild in location where introduced, reproduction occurring, but population not self-sustaining; **C3** - Individuals surviving in the wild in location where introduced, reproduction occurring, and population self-sustaining; **D1** - Self-sustaining population in the wild, with individuals surviving a significant distance from the original point of introduction; **D2** - Self-sustaining population in the wild, with individuals surviving and reproducing a significant distance from the original point of introduction; and **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. An introduction was considered to have been successful where the species had recruiting populations in the recipient environment, i.e. classification C2 or higher. We excluded species that had been imported into Turkey by aquaculture research stations at universities and research hatcheries, but never released into the natural environment e.g. *Acipenser baeri* and *Ictalurus punctatus*; the latter incorrectly reported as released into the wild by Innal and Erk'akan (2006). Copp *et al.* (2009) incorrectly reported that *Hemiculter leucisculus* had been introduced into Turkey; the Khauz-Khanskoye Reservoir is in Turkmenistan. Species recently recorded in Turkish waters but for which no recruitment had been recorded were classified as C1 but car-

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ry the caveat that these populations should be monitored annually to evaluate recruitment success.

Detailed Analysis of Six Watersheds

We selected six watersheds for which good data of fish introductions were available to analyse the trends in fish introductions: Sakarya, Aksu, Menderes, Meriç, Kızılırmak and Asi (Orontes) (Fig. 1). The introduction rate was calculated as the average number of new species introduced per decade following Ribeiro *et al.* (2009). The Zoogeographic Index, and indication of the

intensity of introductions in a specific watershed, was calculated as the number of native species expressed as a fraction of the total number of species present in each watershed following Bianco (1991) as implemented by Elvira (1995). The index ranges from 0 for a community containing only non-native species to 1 for a community containing only native species. The percentage successful introductions of non-native and translocated species were calculated for each watershed. We then evaluated the introduction density per 1000 km² watershed area and fitted a power regression.

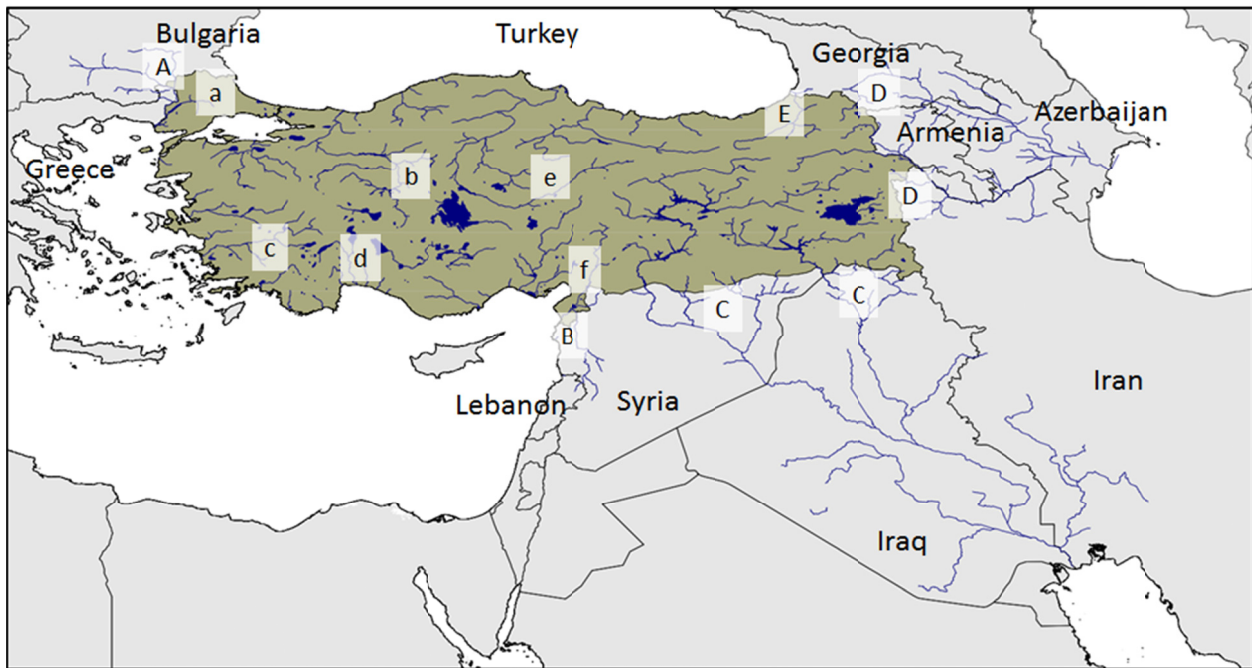


FIGURE 1. Map of Turkey showing (in capital letters) the five trans-boundary river systems: A) Meriç (Evros in Greece and Marista in Bulgaria) shared with Bulgaria and Greece; B) Asi (Orontes) shared with Syria and Lebanon; C) Dicle-Fırat (Tigris-Euphrates) shared with Syria, Saudi Arabia, Jordan, Iraq and Iran; D) Kura-Aras shared with Iran, Armenia, Azerbaijan and Georgia; and the E) Çoruh shared with Georgia. The six rivers included in the detailed assessment are: a) Meriç, b) Sakarya, c) Menderes, d) Aksu, e) Kızılırmak and f) Asi (Orontes).

Vectors and Pathways

The vectors for the introduction of fish species were determined based on our comprehensive literature review. We identified six vectors for the introduction of fish species into Turkey: aquaculture; develop-

ment of fisheries; bio-control of mosquitos or aquatic plants; ornamental fish (release of unwanted fish or escape from ornamental ponds/aquaria); unaided (natural dispersion of species introduced into neighbouring countries) and as a contaminant of imported

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stocks (Hulme *et al.*, 2008). Each species introduced into the freshwaters of Turkey was allocated to the most probable vectors for the introduction. The success of each vector was determined by whether the species established in the recipient water body. Where the species had arrived in Turkey through more than one vector, the vectors of subsequent introductions were noted.

We then evaluated the most probably pathways for the secondary spread of species in Turkey. Species that were recorded from more than one locale were classified according to three pathways for secondary spread: deliberate introductions, contaminants of deliberate introductions, and accidental introductions (mostly the release of unwanted ornamental fish).

RESULTS

We recorded 30 freshwater fish species introduced into Turkish freshwaters

including 11 of which have been translocated within Turkey (making the assumption that *Cyprinus carpio* were native to some portion of Turkey). Nineteen of the introduced species have established self-sustaining populations (Table 1, Fig. 2), although ten of these have restricted ranges, found at ten or fewer locations, have not expanded beyond their point of introduction, or become abundant there. The oldest recorded introduction was *Gambusia holbrooki*, introduced for the biological control of mosquitos in the 1930s (Geldiay & Balık, 1988), with the most recent recorded introduction *Heteropneustes fossilis*, first recorded in Turkish headwaters of Fırat River (Euphrates) in 2011 (Ünlü *et al.*, 2011) putatively from introductions in neighbouring countries. *Cyprinus carpio*, *Carassius gibelio*, *G. holbrooki* and *Pseudorasbora parva* are the most widespread introduced species, followed by *Atherina boyeri* and *Lepomis gibbosus* (Fig. 3).

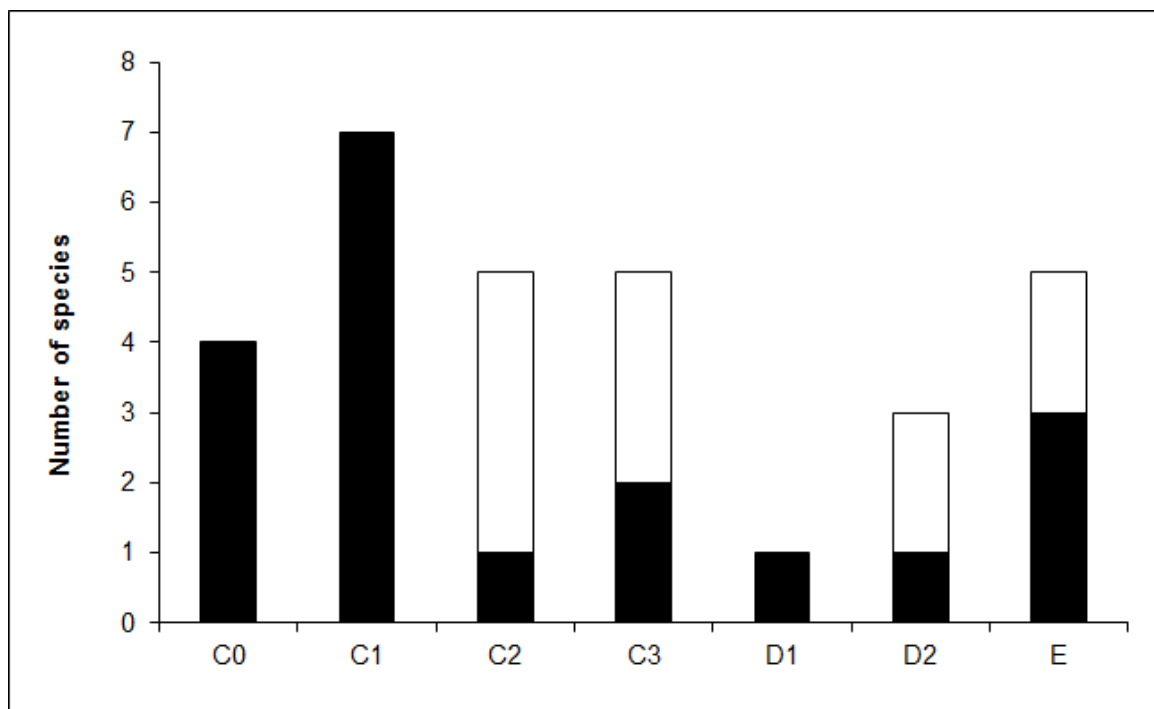


FIGURE 2. Number of non-native and translocated freshwater fish species introduced into Turkish waters using the introductions codes of Blackburn *et al.* (2011) – see methods. The black portion of the bars represents species not native to Turkey whereas the white portion represents species translocated within Turkey.

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TABLE 1. Checklist of non-native (n) and translocated (t, in bold) fish species presently occurring in Turkish inland waters summarising the decade initial introduction, vectors for introduction and secondary spread, and establishment success according to Blackburn *et al.* (2011) – see methods. Black dots indicate the primary introduction vector whereas the open circles indicate secondary or later introduction vectors.

ORDER	FAMILY	SPECIES	Decade	Origin	INITIAL INTRODUCTION						SECONDARY SPREAD					
					Aquaculture	Fishery	Biocontrol	Contaminant	Neighb. country	Ornamental	Deliberate introd.	Contaminant	Accidental release	Establish. success		
Atheriniformes	Atherinidae	<i>Atherina boyeri</i>	1970	t		•						•			E	
Characiformes	Serrasalminidae	<i>Pygocentrus nattereri</i>	2000	n						•					C1	
Cypriniformes	Cyprinidae	<i>Alburnus chalcoides</i>	1960	t		•						•			C3	
		<i>Alburnus tarichi</i>	1950	t	•							•			C2	
		<i>Carassius auratus</i>	1950	n							•			•	C3	
		<i>Carassius carassius</i>	1990	n				•					•		C2	
		<i>Carassius gibelio</i>	1980	n				•	o				•		E	
		<i>Ctenopharyngodon idella</i>	1980	n			•								C1	
		<i>Cyprinus carpio</i>	1970	t		•							•			E
		<i>Hypophthalmichthys molitrix</i>	2000	n			•								C1	
		<i>Pseudorasbora parva</i>	1980	n					•	o				•		E
		<i>Tinca tinca</i>	1940	t		•							•			D2
Cyprinodontiformes	Cyprinodontidae	<i>Aphanius mento</i>	1990	t				•					•		C2	
		Poeciliidae	<i>Gambusia holbrooki</i>	1930	n			•		o		•	o		E	

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TABLE 1 (cont). Checklist of non-native (n) and translocated (t) fish species presently occurring in Turkish inland waters.

ORDER	FAMILY	SPECIES	INITIAL INTRODUCTION						SECONDARY SPREAD						
			Decade	Origin	Aquaculture	Fishery	Biocontrol	Contaminant	Neighb. country	Ornamental	Deliberate introd.	Contaminant	Accidental release	Establish. success	
Perciformes	Percidae	<i>Sander lucioperca</i>	1950	t		•						•			C3
		<i>Perca fluviatilis</i>	1990	t		•						•			C2
	Cichlidae	<i>Coptodon zillii</i>	1970	n	•										D1
		<i>Oreochromis niloticus</i>	1970	n	•										C3
	Gobidae	<i>Knipowitschia caucasica</i>	1990	t				•					•		C3
	Moronidae	<i>Morone sp.</i>	1990	n	•										C1
	Centrarchidae	<i>Lepomis gibbosus</i>	1980	n					•				•		D2
Salmoniformes	Coregonidae	<i>Coregonus lavaretus</i>	1950	n		•									C0
	Salmonidae	<i>Oncorhynchus mykiss</i>	1960	n	o	•						•			C1
		<i>Salmo salar</i>	1980	n	•										C0
		<i>Salvelinus alpinus</i>	2000	n	•										C0
		<i>Salvelinus fontinalis</i>	1990	n	•										C0
Siluriformes	Clariidae	<i>Clarias gariepinus</i>	2000	t	•										D2
	Heteropneustidae	<i>Heteropneustes fossilis</i>	2010	n						•					C1
	Loricariidae	<i>Pterygoplichthys disjunctivus</i>	2000	n							•				C1
	Siluridae	<i>Silurus glanis</i>	1970	t		•						•			C2

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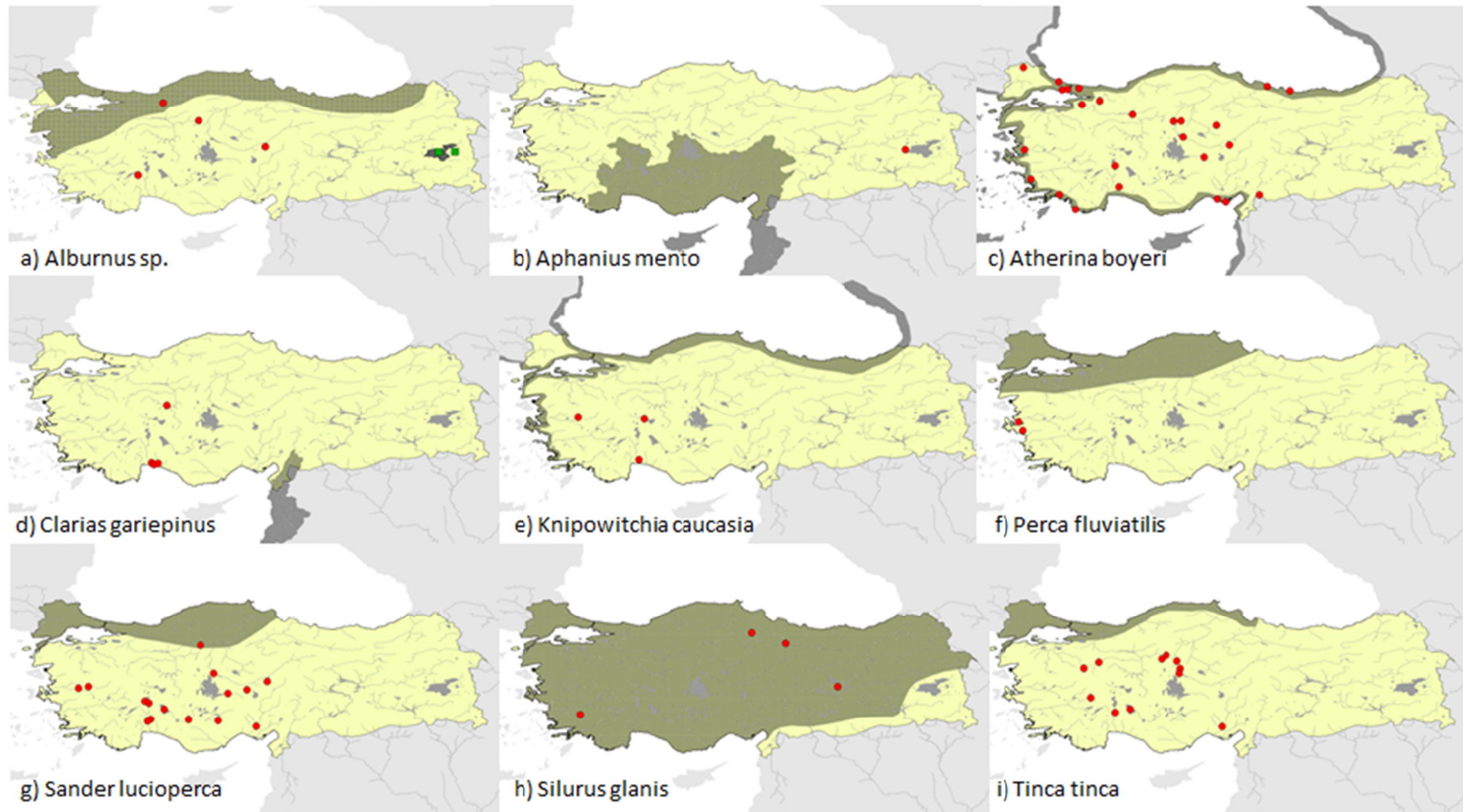


FIGURE 3a. Current distribution of translocated fish species of Turkey. The introductions for *Alburnus chalcoides* (●) and *Alburnus tarichi* (green ■) are included in the same map. The shaded areas represent the natural distribution of the species. For *S. glanis*, some introductions appear to be within its native range but the species had not previously been recorded at these locations.

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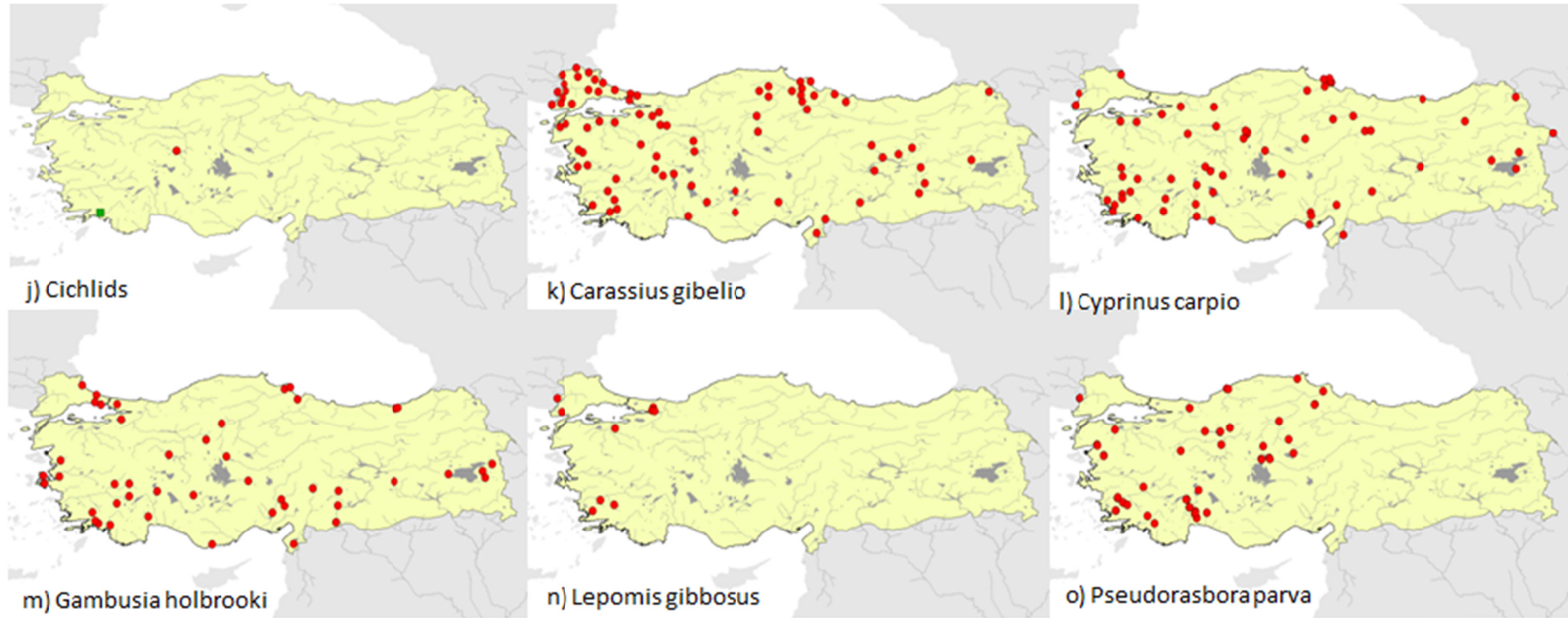


FIGURE 3b. Current distribution of the introduced fishes of Turkey: The introduction locations for Cichlids, *Oreochromis niloticus* (●) and *Coptodon zillii* (green ■), are included on the same map.

Although limited knowledge is available on the detrimental effects of most of the wide-spread non-native fishes in Turkey (Tarkan *et al.*, 2012b), the number of species successfully introduced into Turkey is steadily increasing. The average rate of introduction of new fish species to Turkey since the 1930s is 4.1 species per decade ($R^2 = 0.97$), but increases to 4.8 species per decade ($R^2 = 0.99$) for the period 1950-2010 (Fig. 4). The average rate of new species establishment in Turkey since the 1930s is 2.8 species per decade ($R^2 = 0.98$), but also increases for the period 1950-2010 to 3.1 species per decade ($R^2 = 0.98$) (Fig. 4). The rate of secondary spread of established species is approximately ten new water bodies per decade (Aydın *et al.*, 2011). The overall establishment rate of non-native and translocated fish in Turkey was found to be 64%, 44% for the 19 non-native species and 100% for the 11 translocated species (Table 1). This figure is in line with estimates from similar studies for Greece 52% (Economidis *et al.*, 2000), other European countries 63% (García-Berthou *et al.*, 2005), and worldwide 64% (Ruesink, 2005). For freshwater fish, 63% of intentional introductions are successful whereas <30% of all introduction pathways are successful (García-Berthou *et al.*, 2005). Intentional introductions have higher establishment success (Hulme *et al.*, 2008) largely as a result of the higher propagule numbers and climate matching used in intentional stockings (Lockwood *et al.*, 2005). The high introduction success highlights the role of deliberate introductions in Turkey.

Five species (*C. carpio*, *G. holbrooki*, *A. boyeri*, *C. gibelio* and *P. parva*) have established extensive populations and are considered invasive and problematic (Fig. 3). A further three species, *Clarias gariepinus* (Küçük & İkiz, 2004; Emiroğlu, 2011), *L. gibbosus* (Özcan, 2007; Top, 2011) and *Tinca tinca* (Balık *et al.*, 1997), have established widespread populations in their introduced range and dominate communities in these areas. *Coptodon zilli* (formerly *Tilapia zilli*), however, have established a widespread population but do not dominate communities (Balma *et al.*, 1995). *Carassius*

auratus (İzci, 2004), *Oreochromis niloticus* (Dikel, 1995; Mert & Çiçek, 2010), *Sander lucioperca* (Ekmekçi & Erk'akan, 1997) and *Knipowitschia caucasica* (Van Neer *et al.*, 1999) have established self-sustaining recruiting populations and could potentially start expanding their ranges. Similarly, *Silurus glanis*, *Perca fluviatilis* and *Aphanius mento* (Balma *et al.*, 1995) have established recruiting populations and could become self-sustaining in time, although *S. glanis* and *P. fluviatilis* populations have declined as a result of overfishing. Some species have only been recorded once from a single watershed, e.g. *Pterygoplichthys disjunctivus* (Yalçın Özdilek, 2007) and *H. fossilis* (Ünlü *et al.*, 2011), while others are maintained through escapees from cage aquaculture and fishery stocking programmes, e.g. *Oncorhynchus mykiss* (Anonymous (DSI), 1988). Other species (e.g. *Salvelinus fontinalis*, *Morone* hybrid) are now only found in aquaculture facilities and research facilities at universities, having been extirpated in the wild whereas others (*Ctenopharyngodon idella* and *Hypophthalmichthys molitrix*) appear to have failed to establish self-sustaining populations or have not expanded from their original introduction. Cichlid species were introduced by universities as part of government authorized research programmes, however great uncertainty persists regarding their identification with some authors have reporting several different cichlid species being introduced at a single locality (e.g. Innal and Erk'akan, 2006) when they were, in fact, a single species *C. zilli* (Akın *et al.*, 2005).

Detailed Analysis of Six Watersheds

Of the six watersheds considered, the Sakarya received the highest number of species (19), followed by Meriç and Kızılırmak (14), Menderes (12), Aksu (11) and Asi (Orontes) (5): Table 2. The establishment success of these introductions was highest in Menderes (92%), followed by Aksu (91%), Asi (Orontes) (80%), Meriç (79%), Sakarya (74%) and Kızılırmak (71%). The average rate of species establishment is 1.21 species per watershed per decade; however,

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the rate increases to 2 species per watershed per decade from 1970 to 2010. The rate of introductions peaked at 2.5 species per watershed per decade in the 1970s and 1980s but dropped to 1.17 species per watershed per decade in the 2000s. The Zoogeographic Index ranged between 0.88 Asi (Orontes) to 0.58 in the Aksu, with an overall average of 0.72 for the six watersheds (Table 2). This suggests that some watersheds in Turkey hold on average more than 25% introduced species, similar to water-

sheds in other Mediterranean-climate regions (Leprieur *et al.*, 2008).

Contrary to expectation, we found that introduction and establishment decreased with increasing watershed size (Table 2). A power relationship was found for both introduction and establishment densities (introduction = $5.318 A^{0.755}$ ($R^2=0.912$) and establishment = $4.835 A^{0.784}$ ($R^2=0.917$), where A is the watershed area in 1000 km²).

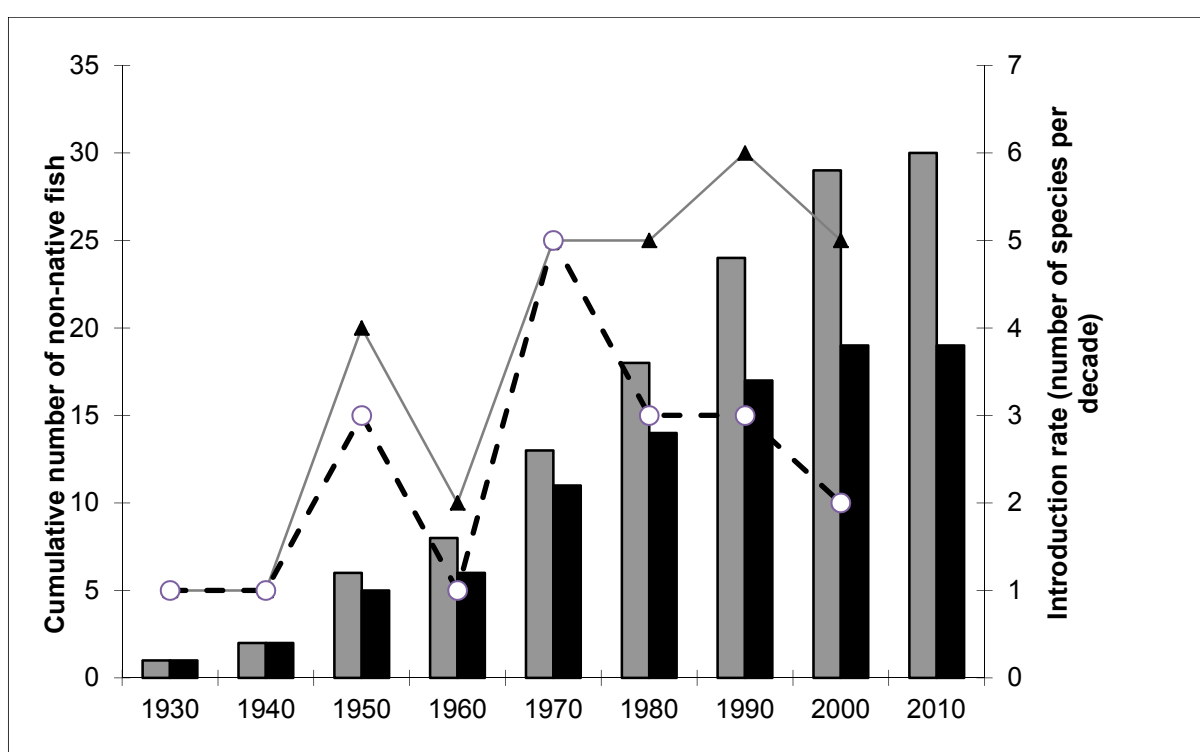


FIGURE 4. Temporal pattern of introduction of non-native fish species into Turkish watersheds: cumulative number of species introduced (grey) and cumulative number of species successfully established (black). The rate of species introduction (▲) and establishment (○) per decade are presented (right axis).

The watersheds recording the highest introduction densities were in southern and western Turkey. These regions have Mediterranean climates and higher population densities than the central, northern and eastern Turkey.

Three species have been successfully introduced to all six watersheds; *C. carpio*, *G. holbrooki* and *O. mykiss*. For this analysis, we considered *O. mykiss* to have successfully established in there watersheds

because their populations are maintained by annual stocking even though they do not appear to reproduce in the wild in Turkey (Çelikkale, 2002). A further five species has been introduced into five of the six watersheds (*C. gibelio*, *S. glanis*, *C. auratus*, *P. parva* and *S. lucioperca*). Of these, only *S. lucioperca* failed to establish in all five watersheds, being extirpated due to overfishing in one watershed, but successfully establishing in other four.

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TABLE 2 Date of detection of non-native and translocated fishes in six watersheds in Turkey. Years in bold represent the earliest date of introduction/detection. The Zoogeographic Index, defined as the number of native species, expressed as a fraction of the total number of species present in each watershed following Bianco (1991).

Species (success/total)	Sakarya	Kızılırmak	Aksu	Menderes	Trakya [#]	Asi [#]
<i>Oncorhynchus mykiss</i>	1970	1980	1983	1985	1985	1992
<i>Gambusia holbrooki</i>	1960	1960	1950	1960	1970	1930
<i>Cyprinus carpio</i>	1970	1970	1990	1970	1980	1999
<i>Silurus glanis</i>	1958	1970	1990	1970	1980	
<i>Carassius gibelio</i>	1988	2003	2000	1990	1982	
<i>Carassius auratus</i>	1970	1980	1999	1985	1970	
<i>Pseudorasbora parva</i>	1999	2000	1992	1990	1982	
<i>Sander lucioperca</i>	1970	1970	1997*	1975	1970	
<i>Atherina boyeri</i>	1970	2000	1995	1970		2005
<i>Tinca tinca</i>	1983	1955			1940	
<i>Lepomis gibbosus</i>	1990			1990	1982	
<i>Carassius carassius</i>	1980	1983*			1975	
<i>Salmo salar</i>	1989*	1988*			1988*	
<i>Ctenopharyngodon idella</i>		2000*		2000*	2000*	
<i>Alburnus chalcoides</i>	1971*	1975*				
<i>Oreochromis niloticus</i>	2009					
<i>Clarias gariepinus</i>	2009		1990			
<i>Knipowitschia caucasica</i>			1996			
<i>Coptodon zillii</i>				1995		
<i>Pterygoplichthys disjunctivus</i>						2007*
<i>Pygocentrus nattereri</i>	2006*					
<i>Salvelinus fontinalis</i>	2000*					
<i>Coregonus lavaretus</i>	1954*					
<i>Hypophthalmichthys molitrix</i>					2000*	
<i>Number of species introduced</i>	19	14	11	12	14	5
Number of introduced species established	14	10	10	11	11	4
Introduction success (%)	73.7	71.4	90.9	91.7	78.6	80.0
Number of native species	33	24	14	22	38	28
Zoogeographic Index	0.70	0.71	0.58	0.67	0.78	0.88
Basin Area (km ²)	58160	78180	4928	24976	14560 [#]	7796 [#]
Established species per 1000 km ²	0.24	0.13	1.62	0.40	0.76	0.64

*Indicates that the species did not establish; # Indicates Turkish portion only.

Vectors and Pathways

The majority of fish introductions in Turkey were the result of intentional releases by government agencies to increase the fishery and aquaculture capacity of selected lakes and reservoirs (Anonymous (DSI), 1988, 2001); see Fig. 5 and Table 1. Species introductions for the establishment and enhancement of fisheries have been 80% successful with eight of the ten species introduced establishing successfully. Escapees from cage aquaculture have been considerably less successful with three of the seven species introduced establishing successfully. A side effect of these introductions has been the unintentional introduction of two invasive species, *C. gibelio*, and *P. parva*, putatively as contaminants in stockings of *C. carpio*. In total five species have been introduced and spread as contaminants of fish stockings, all of which has established successfully. Three species were introduced for biological control purposes (*G. holbrooki*, *C. idella* and *H. molitrix*), of which only *G. holbrooki* has successfully established, although, controlled production of *C. idella* and *H. molitrix* still continues at some aquaculture facilities (Anonymous (DSI), 1988). There is evidence that three ornamental species have been released into Turkish waters (*C. auratus*, *P. disjunctivus*, and *Pygocentrus nattereri*) (Tarkan, 2006; Innal, 2008) with only *C. auratus* establishing. Two species have entered Turkish water through trans-boundary river systems; *L. gibbosus* via the Meriç River (Evros in Greece, Marista in Bulgaria) and *H. fossilis* through the trans-boundary the Dicle-Fırat (Tigris-Euphrates) River system (Al-Hassan & Muhsin, 1986; Ünlü *et al.*, 2011). The success of trans-boundary introductions is currently estimated to be 50%, but could rise to 100% if *H. fossilis* should establish a recruiting population (Bozoğlu *et al.*, 2007). There is evidence that *G. holbrooki*, *C. gibelio*, and *P. parva* also entered Turkish waters from Bulgaria or Greece via the Meriç River (Aydın *et al.*, 2011), but these had previously been introduced by other vectors.

Most species translocations have been carried out legally by the government

agencies for the “enhancement” of fisheries, mostly resulting in successful established populations e.g. *S. lucioperca*, *T. tinca*, *S. glanis*, *P. fluviatilis* (Anonymous (DSI), 1988). However, *A. boyeri* has been dispersed illegally into natural lakes and man-made reservoirs due to its economic value, establishing viable populations in most of them, some of which are expanding rapidly from the introduction locations and becoming invasive (Gençoğlu, 2010).

The two most important pathways for the secondary spread of non-native fishes were identified as the deliberate release of aquaculture and fishery species and the contamination of fishery or aquaculture stockings (Table 1). The remaining pathway identified was the accidental release of ornamental species.

DISCUSSION

In Turkey, the majority of non-native fishes introductions have been intentional (Wildekamp *et al.*, 1997; Aydın *et al.*, 2011), mostly as part of government-sponsored stocking programmes of reservoirs (Tarkan *et al.*, 2012a). As in other Mediterranean countries, the building of reservoirs to provide irrigation, industrial and domestic water provides new opportunities for the establishment of non-native fishes (Collares-Pereira & Cowx, 2004). Recent studies have confirmed that non-native fishes are more successful in artificial water bodies than natural lakes or rivers (Clavero & Hermoso, 2011; Tarkan *et al.*, 2012a; Clavero *et al.*, 2013). Freshwater fish species introductions aimed at improving commercial fisheries in reservoirs have resulted in 80% of the species introduced establishing recruiting populations (Fig. 5). However, all the species that became established as a result of this vector are native to Turkey whereas the two species that failed to establish are both non-native, *O. mykiss* and *Coregonus lavaretus* (Özuluğ *et al.*, 2005), most likely due to their cold water adaptations. Overfishing has, however, resulted in the decline of introduced *S. glanis* and *P. fluviatilis* and

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S. lucioperca populations (FGE, unpublished data). Although the contribution of inland capture fisheries to Turkish freshwater production has remained constant between 1996 and 2009, the composition of the species captured has changed from *C. carpio* (48.0%), *S. glanis* (13.0%), *Gobidae* spp. (11%), *Alburnus tarichi* (6.0%) and *Esox lucius* (4.0%) in 1972 to *C. carpio* (28.0%), *A. tarichi* (27.0%), *A. boyeri* (16.0%), snails (6.0%), *T. tinca* (4.0%) and *S.*

lucioperca (3.0%) in 2009; 84.0% of the total freshwater species catch (Rad & Rad, 2012). Overfishing is a major threat to freshwater biodiversity (Allan *et al.*, 2005), especially larger species (Olden *et al.*, 2007). Many commercial fisheries are reliant on stocking programmes to sustain the harvest (Petr, 1997; Cowx, 1999) although *C. carpio* is the only species exploited by inland capture fisheries in Turkey that is regularly stocked.

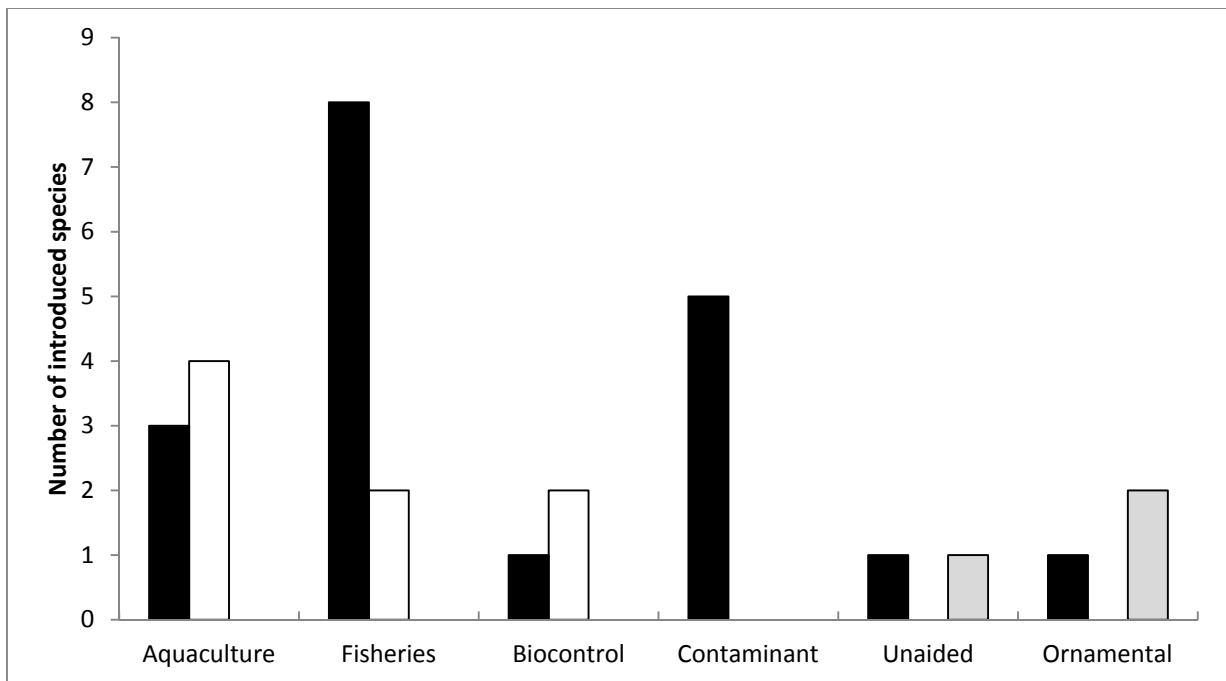


FIGURE 5. Number of non-native fish species introduced into Turkey by introduction vector. Black bars represent species that have successfully established, white bars species that failed to establish, and grey bars species whose establishment is currently uncertain.

The contribution of freshwater species in aquaculture in Turkey has steadily increased from 30% in 1996 to about 65% in 2009 (Rad & Rad, 2012). Aquaculture is the leading vector of aquatic species introductions worldwide (Casal, 2006), with more than 50% non-native species having been intentionally introduced for aquaculture (Casal, 2006; Cook *et al.*, 2008; Gozlan, 2008). In contrast to introductions for fisheries, escapees from research and aquaculture faculties have been less successful with only 43% of the introduced species establishing recruiting populations in Turkey. In

Europe, legislation (Council Regulation 708/2007, of 11 June 2007) establishes guidelines for the use of non-native and locally absent species in aquaculture. Although Turkey is a signatory to various international agreements and the conventions stipulated by European Union (e.g. Water Framework Directive, Council Regulation 708/2007), these have yet to be fully implemented.

Today, *C. carpio* constitutes the bulk of both aquaculture production and stocking programs in Turkey. The spread of *P. parva*

and *C. gibelio* across Europe has been linked to contamination of hatchery stocks (Copp *et al.*, 2005a; Gozlan *et al.*, 2010a). The contamination of *C. carpio* stockings could result from two scenarios: contaminated hatcheries or stocking from compromised wild populations, both of which can be managed by implementing of a stock audit programme (Davies *et al.*, 2013).

As a country industrializes, there is a decrease in the importance of commercial fishing with inland water bodies increasingly, or exclusively, being used as recreational/sport fisheries (Cowx *et al.*, 2010); e.g. Greece, Zenetos *et al.* (2009). Across Europe, non-native species for sport angling have been introduced with devastating impacts on native faunal biodiversity e.g. *S. glanis* (Copp *et al.*, 2009a), *P. fluviatilis* and *S. lucioperca* (Cowx, 1997; Copp *et al.*, 2005a; Küçük, 2012). Once introduced, non-native species are subsequently illegally spread by anglers to neighbouring watershed (García-Berthou *et al.*, 2005). An increase in the popularity of recreational angling could result in an increase in the illegal introduction of popular angling species (Cowx *et al.*, 2010), such as North American *Micropterus* sp., or the translocation of aggressive and large native species e.g. *S. glanis*, *S. lucioperca*, *E. lucius*. Recreational angling groups have requested *E. lucius* introductions for recreational angling, but Turkish authorities have refused such requests having adopted a policy of not introducing piscivorous species. Adoption of stringent policies regarding recreational angling could result in the illegal introduction of “recreational” species, seriously compromising both existing fisheries and conservation programmes (Johnson *et al.*, 2009; Gozlan *et al.*, 2010b).

The translocation of native fish species has been very successful with all 11 species introduced establishing self-sustaining populations. One translocated species reported to have failed to establish, *A. tarichi* a deep-water species endemic to Lake Van, was introduced into Lake Burdur, one of the largest and deepest lakes in Turkey (Akşıray, 1982; Yıldırım *et al.*,

2009). The introduction appeared to be successful until pollution from lakeside factories reduced deep-water oxygen levels (Akşıray, 1982; Yıldırım *et al.*, 2009), resulting in the extirpation of *A. tarichi*. Pollution, rather than biotic or natural environmental factors, resulted in this species failing to establish. However, a second introduction of *A. tarichi* in Lake Erçek in 1990’s has been successful (Çetinkaya, 2006).

Turkey has four major transboundary river systems (Meriç, Asi (Orontes), Dicle-Fırat (Tigris-Euphrates), Kura-Aras and Çoruh: Fig. 1), all of which could allow species introduced into neighbouring countries to naturally extend their ranges into Turkish waters. There is evidence that fish species have entered Turkey via transboundary river systems from Eastern Europe (via Meriç River shared by Bulgaria, Greece, and Turkey) in the northwest (Aydın *et al.*, 2011) and the Middle East (via Asi (Orontes) and Dicle-Fırat (Tigris-Euphrates) rivers) in the south and southeast (Yalçın Özdilek, 2007; Ünlü *et al.*, 2011). Four species (*G. holbrooki*, *C. gibelio*, *L. gibbosus*, and *P. parva*) have entered Turkish waters via Greece and Bulgaria through natural expansion of their introduced ranges in the Meriç River system (Wildekamp *et al.*, 1997; Ekmekçi & Kirankaya, 2006). High numbers of non-native fish species are present in Greece and Bulgaria are high, 25 and 26 species respectively (Economidis *et al.*, 2000; Economou *et al.*, 2007; Uzunova & Zlatanova, 2007), some of which have not previously been recorded in Turkish waters. Similarly, several species have been introduced into Syria, Iran, Iraq, Georgia, Armenia and Azerbaijan that have not previously been recorded in Turkish waters (Coad, 1993; Coad & Abdoli, 1993; Coad, 1996; Gabrielyan, 2001; Coad, 2010, 2013; Salmanov *et al.*, 2013). Recently *H. fossilis* was recorded in the Turkish headwaters of the Fırat (Euphrates) River after having been first recorded in the lower reaches of the Dicle-Fırat (Tigris-Euphrates) River system in the 1950s (Al-Hassan & Muhsin, 1986; Ünlü *et al.*, 2011). It is too soon to determine whether this species has established a recruiting

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population in Turkey, but it may represent the first of many introductions from countries south and east of Turkey. The majority of the species introduced into neighbouring countries have already been introduced into Turkish freshwaters, or are native to Turkey (see Table 3). The species that could have greatest impact in Turkish waters are *Hemiculter leucisculus* and *Percottus glenii*, because both species have detrimentally impacted native fish assemblages elsewhere (Reshetnikov, 2003; Jurajda et al., 2006; Grabowska et al., 2009; Wang et al., 2013). Although both *Micropterus salmoides* and *Lepomis macrochirus* have been recorded as introduced into Iran and Iraq including the Tigris-Euphrates (Coad, 1993; Coad & Abdoli, 1993; Coad, 1996), these species do not appear on recent checklists of introduced fish from either country (Coad, 2010, 2013). Both species have been successfully introduced into other Mediterranean-climate regions (Marr et al., 2010, 2013), significantly impacting native fish assemblages and should be considered as highly undesirable species. Management of trans-boundary river systems is a complex balance of water rights, pollution, species introductions, Turkish water policy, and

trans-boundary agreements (see Kramer et al. 2011). The foundations for developing agreements regarding the introduction of non-native fishes in shared river systems could be developed along the guidelines used to establish the trans-boundary programme between Greece and Bulgaria for the Nestos River (Economidis et al., 2009).

The extent of ornamental fish releases is frequently underestimated (Welcomme, 1992) with about 6% of USA aquarists having admitted to releasing unwanted fish (Gertzen et al., 2008; Strecker et al., 2011). Because of the widespread dispersal of ornamental fish to homes and businesses, these fish can be released into all freshwater habitats (Padilla & Williams, 2004; Copp et al., 2005d; 2010). Three species of ornamental fish have been introduced in Turkey. The majority of ornamental species are from tropical climates and should not be able to reproduce in Turkish conditions. There are, however, a number of ornamental species that have established in Mediterranean Europe (e.g. *Misgurnus anguillicaudatus*) that may establish in Turkey if released in sufficient numbers.

TABLE 3. Freshwater fish species introduced into countries surrounding Turkey that could establish in Turkish waters.

Species	Comments
<i>Hemiculter leucisculus</i>	established in Iran and Iraq (Coad, 2010, 2013) and has been reported from the Tigris-Euphrates River system (Coad & Hussain, 2007)
<i>Mylopharyngodon piceus</i>	introduced into Bulgaria, Armenia, Azerbaijan and Iran (Coad & Abdoli, 1993; Gabrielyan, 2001; Uzunova & Zlatanova, 2007; Coad, 2013; Salmanov et al., 2013) and is reported to have established in at least the Kura-Aras River system in Azerbaijan (Salmanov et al., 2013)
<i>Pimephales promelas</i>	introduced into Iran (Coad & Abdoli, 1993; Coad, 2013)
<i>Ictiobus</i> sp.	introduced into Bulgarian and Greece (Economidis et al., 2000; Economou et al., 2007; Uzunova & Zlatanova, 2007)
<i>Pangasius</i> sp.	recently reported from Iraq (Coad, 2010)
<i>Percottus glenii</i>	introduced into Bulgaria (Uzunova & Zlatanova, 2007)
<i>Oryzias latipes</i>	introduced into Azerbaijan (Salmanov et al., 2013)

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Most of the introduced species, including translocated species, have not been associated with any negative impact on native fauna or flora as they are usually present in low numbers in Turkey. However, several recent studies have provided evidence of the detrimental impact and invasive potential of several non-native fishes in Turkey including: *C. gibelio* (Tarkan *et al.*, 2012a, b), *L. gibbosus* (Özcan, 2007; Top, 2011), *A. boyeri* (Gençoğlu, 2010) and *P. parva* (Ekmekçi *et al.*, 2010). The impact of *G. holbrooki*, in particular, on native ichthyofauna in Turkish waters needs to be evaluated. For example, the decline of killifish (*Aphanius transgrediens*) (Fig. 6) in Lake Acı has been attributed to *G. holbrooki* (FGE, unpublished data). The release of *Gambusia* species to control mosquitoes has

had devastating impacts on native fish assemblages (Pyke, 2008) and has ceased in many countries, although the illegal spread of *Gambusia* species continues (Marr *et al.*, 2010). In Turkey, *G. holbrooki* was deliberately introduced to reduce the risk of malaria, but the species has been spread over the whole country for mosquito control, even in areas not susceptible to malaria. This species may be more widespread than the present study suggests because the habitats frequently surveyed through research and monitoring programmes are not optimal for *Gambusia* and sampling protocols used usually do not target small-bodied species. Some warm water species, such as *C. zilli*, *O. niloticus* and *C. gariepinus*, only survive where the water temperatures are suitable, such as hot springs (Yılmaz *et al.*, 2006).

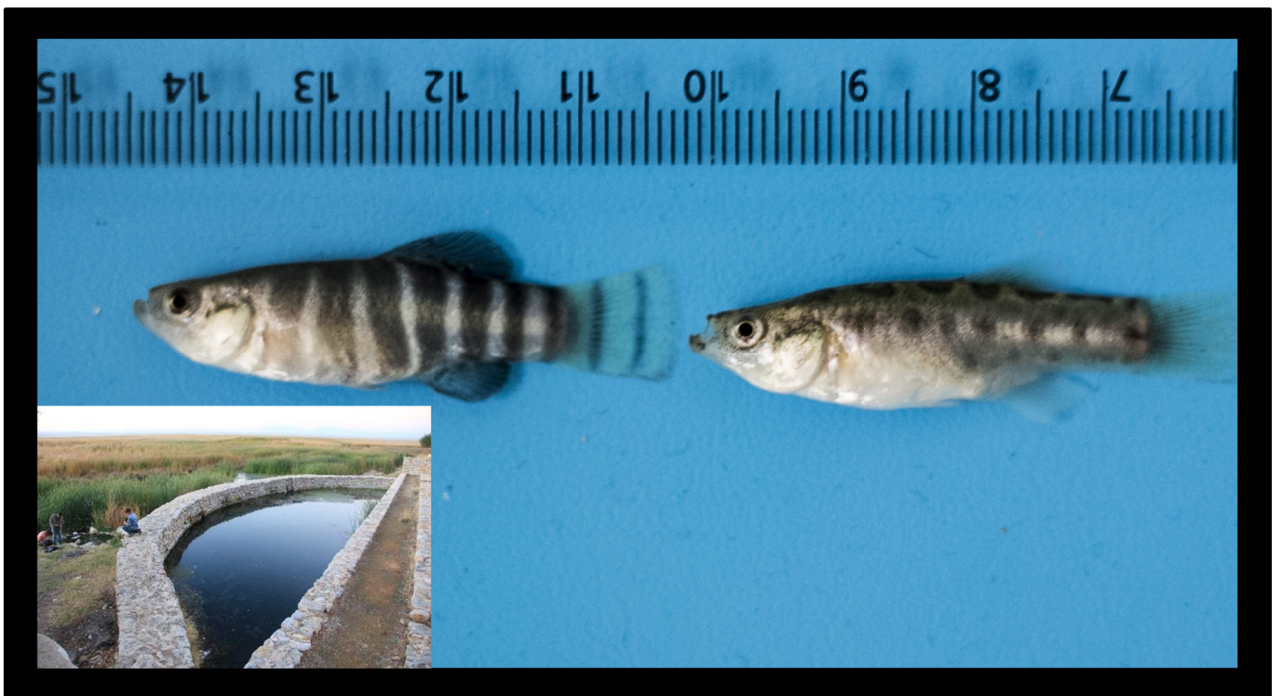


FIGURE 6. Male (left) and female (right) *Aphanius transgrediens*, a Critically Endangered species threatened by the introduction of Eastern mosquitofish (*Gambusia holbrooki*). The inner photographs shows an artificial mosquitofish-free pond built for the conservation of the threatened native species

In 2004, the General Directorate of Protection and Control Department of the Ministry of Food, Agriculture and Livestock instituted penalties for the transport and introduction of non-native species into new environments and the Department of Agriculture and Rural Affairs have declared *C. gibelio* as dangerous species (Circular No: 37/2), promoting its capture throughout the year. These are promising signs but conservation of the unique and highly endangered native fish fauna of Turkey should be prioritized and the precautionary principle applied to all future stockings. Tarkan *et al.* (2014) identified 17 of the 35 species evaluated as having a high risk of potential invasiveness (very high – *C. auratus*, *C. gibelio*, *C. carpio*, *Gambusia affinis*, *G. holbrooki*, *I. punctatus*; high – *Amerius melas*, *C. gariepinus*, *C. idella*, *H. molotrix*, *L. gibbosus*, *Liza haematocheila*, *Oreochromis mossambicus*, *Oreochromis niloticus*, *P. parva*; and medium high – *Oreochromis aureus* and *P. disjunctivus*). Of these, *Gambusia affinis*, *I. punctatus*; *Amerius melas*, *Liza haematocheila*, *Oreochromis mossambicus*, *Oreochromis niloticus*, and *Oreochromis aureus* have not been recorded as introduced in Turkey whereas *C. idella* and *H. molotrix* have been released into natural waters but have not established in Turkey to date. This study did not include species such as *E. lucius*, *Micropterus* sp. and *Misgurnus anguillicaudatus* that have been widely introduced in Europe. The omission of *E. lucius* is regrettable since the introduction of this species has been requested by recreational anglers. Interestingly, species we highlight as potentially invasive (*H. leucisculus*, *H. fossilis* and *P. glenni*) were all classified as medium risk species.

This paper has focussed on non-native and translocated fishes but it should be noted that these are not the only threats to the native fishes of Turkey. Other factors such as pollution, habitat degradation, and unsustainable water abstraction, amongst others, all threaten native fish populations. An example of extreme habitat degradation is the draining of Lake Amik in southern Anatolia from the 1940s to the 1970s resulting in the loss of the entire fish assemblage

(Balık, 1995). In contrast, pollution in the Asi (Orontes) River is threatening the endemic species of this unique freshwater ecoregion (Erk'akan and Ekmekçi, 2000). To date, two global extinctions have been reported from Turkey: *Alburnus akili* Battalgil, 1942 and *Pseudophoxinus handlirschi* (Pietschmann, 1933) in Central Anatolia, both the result of the introduction of piscivorous *S. lucioperca* (Küçük, 2012). Further studies are required to distinguish between the threats exerted by pollution, habitat destruction, and non-native/translocated fish on the native fish populations.

MANAGEMENT MEASURES

Although the presence of non-native species poses a threat to native fish assemblages, it is acknowledged that non-native and translocated fishes are the mainstay of Turkey's freshwater aquaculture and commercial fisheries. A balance must therefore be maintained between the conservation of native taxa and the management of non-native fish (Chadderton, 2003). The management of non-native fishes requires a clear goal to direct the efforts of implementing authorities, funding agencies, and stakeholders towards an agreed outcome (Bomford & Tilzey, 1997; Wittenberg & Cock, 2001; Hulme, 2006). Once a goal has been established management options can be identified and the most appropriate strategies selected to achieve the goal (Bomford & Tilzey, 1997; Wittenberg & Cock, 2001; Hulme, 2006).

Prevention of future introductions is the most effective way of addressing invasion by non-native species (Saunders *et al.*, 2002; Britton *et al.*, 2011a) Council Regulation 708/2007/EC requires an assessment to identify and evaluate the potential risks associated with existing and future non-native species according to their potential to become invasive by instituting adequate decision support tools and risk assessment metrics (Britton *et al.*, 2011a, b), e.g. the Fish Invasiveness Screening Kit (FISK) (Copp *et al.*, 2005c, b). FISK was developed

to provide a screening tool for freshwater fish introductions can become a tool to aid decision- and policy-makers in assessing and classifying freshwater fishes according to their potential invasiveness (Copp *et al.*, 2009b). FISK was recently applied for both non-native and translocated freshwater fish species in Turkey; see Tarkan *et al.*, (2014). Many potentially harmful non-native species have established populations in Turkey, but may be far from achieving their potential geographic distribution. Preventing, or slowing, the secondary spread of known and established non-native species requires different set of goals, strategies, and target audiences than measures required to restrict the import of new species (Vander Zanden & Olden, 2008). Implementation of a stock audit procedure, *sensu* Davies *et al.* (2013), and employing adequate effort by experienced fisheries officials may reduce the extent of stock contamination by undesirable fish species such as *L. gibbosus*, *P. parva* and *C. gibelio*. Capacity at relevant levels (i.e. law enforcement, taxonomic expertise and communication) is critical for prevention programmes to be effective.

No matter how effective the prevention programmes, there is a high probability that further non-native species will be introduced. The precautionary principle requires that action be taken to control or eradicate potentially invasive species as soon as they are detected (Wittenberg & Cock, 2001). Detection of new introductions at low population levels is often difficult, especially in aquatic systems (Collares-Pereira & Cowx, 2004; Mehta *et al.*, 2007) and the costs associated with detection programmes are high (Finnoff *et al.*, 2007). Further, there is often a substantial time lag between introduction and detection. In principle, early detection and rapid response should be straightforward. In practice, for all but economic pests and vectors of disease, the required rapid response is often very slow. Rapid response management includes an assessment of the ecological and economic risks once an introduced species has been detected. An effective rapid response system requires enabling legislation, a sound scientific basis, tools and protocols,

and resources to implement appropriate actions (Thomas *et al.*, 2009). For fish introduction into river networks, early detection is unlikely, or highly improbably (Collares-Pereira & Cowx, 2004). The modular approach outlined by Britton *et al.* (2011a) could be modified for application in Turkey.

Where non-native species have already established, active management needs to focus on reducing their impacts and preventing further spread (Saunders *et al.*, 2002; Britton *et al.*, 2011a). Eradication is more cost-effective than long-term mechanical control (Bomford & O'Brien, 1995; Bomford & Tilzey, 1997; IUCN, 2000), particularly for recent introductions, or where the species has been spatially constrained (Britton *et al.*, 2011a). Eradication of non-native fishes is achieved by chemical treatments, e.g. piscicides, or by draining water-bodies (Collares-Pereira & Cowx, 2004; Finlayson *et al.*, 2005; Britton *et al.*, 2011a). However, the use of piscicides on the Anatolian Peninsula of Turkey needs to be carefully evaluated because the karst formations and ground water systems are susceptible to pesticides. Sustained mechanical removal has been successful only in enclosed systems (small lakes or headwater streams) at small scales (Britton *et al.*, 2011a). Eradication should, however, only be attempted where it is ecologically feasible and has financial and political support (IUCN, 2000). Where eradication is not feasible, control is the next best alternative. Control programmes using mechanical removal techniques (e.g. electro-fishing or netting) are generally effective in suppressing population abundance and reducing their recruitment (Britton *et al.*, 2011a). Eradication and control of non-native fishes remain constrained by their lack of selectivity, and the challenges of treating large spatial scales effectively (Britton *et al.*, 2011a).

Many non-native fishes have established widespread populations and threaten native species. While large-scale eradication of non-native fish is difficult, and rarely implemented, small-scale projects to eradicate non-native fish from priority reaches of small rivers can be successfully completed

with currently available technologies. For example, a piscicide and barrier based conservation management strategy, such as those proposed for the control of non-native fish in the lower Colorado River (Clarkson *et al.*, 2005) and the Cape Floristic Region (Marr *et al.*, 2012), could be implemented. The risk of the illegal release of non-native fish into treated areas must be minimised and new introductions prevented. Education and publicity initiatives with local land-owners and angling bodies could be established, in conjunction with simple and inexpensive monitoring protocols to detect non-native species in restored reaches, to ensure long-term success of conservation programmes (Clarkson *et al.*, 2005). A freshwater fish lobby group similar to the Desert Fish Council (Pister, 1990, 1991) could be established for the conservation of the freshwater fishes of Turkey. The responsibilities of this group would be to identify research needs of freshwater ecosystems in Turkey, detect areas of weakness in freshwater ecosystem conservation, and providing assistance in compensating for bureaucratic inadequacies, and enhancing government conservation programmes.

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AUTHOR CONTRIBUTIONS

AST and FGE developed the initial concepts of the first draft with all authors contributing to the final manuscript

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