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Alien and invasive freshwater fish species in Iran: Diversity, environmental impacts and management

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Abstract: More than 32 alien (exotic) fish species belonging to 10 orders and 12 families (Cyprinidae, Gobiidae, Salmonidae, Anguilidae, Mugilidae, Centrarchidae, Heteropneustidae, Gasterosteidae, Cichlidae, Poecilidae, Adrianichthyidae and Pleuronectidae) were reported from Iran of which 25 species are confirmed by specimens. Some of the alien fishes (e.g., *Cyprinus carpio*, *Carassius auratus*, *Pesudorasbora parva*, *Xiphophorus hellerii* and *Gambusia holbrooki*) have already established breeding populations, acting as invasive species. Some others are regularly stocked by the Iranian Fisheries Company (e.g., *Hypophthalmichthys molitrix*, *Hypophthalmichthys nobilis*, *Ctenopharyngodon idella*) and few others are occasionally recorded from natural waters. *Amatitlania nigrofasciata* and *Tilapia zillii* are two alien cichlids recently reported from Iran. Aquaculture, sport fishing, control of malaria, ornamental purposes, research activities, demonstration in national fairs and accidental introduction are the main reasons for these introductions. *Pseudarasbora parva* was introduced accidentally along with other exotic carps and now is widely distributed in inland waters. The intentional introduction of alien species is an extraordinarily complex issue and requires taking into account a broad number of variables. Understanding the risks that alien species, especially aquatic invasive species (AIS) pose, comparative studies on the ecology and life history strategies of the introduced and invasive species and closely related indigenous species with similar ecological life traits, monitoring the rate of invasion, and the causal relation between population dynamics and species invasion and public awareness, could be effective management strategies to minimize the bio-invasion impacts.

Keywords: Exotic, Threats, Diversity, Management, Iran.

Introduction

Invasive species (IS) are alien (non-native) organisms that have been introduced into an area outside of their natural range, establishing self-sustaining populations and spreading beyond their initial point of introduction, with deleterious impacts on the environment, economy and human health (Kolar & Lodge 2001; Lymbery et al. 2014). Biological invasions are now considered a major environmental issue of public concern (Gozlan et al. 2010). Human population growth, increasing transport capacity and economic globalisation have accelerated the rate of introductions of alien species throughout the world (Vitousek et al. 1997; Sakai et al. 2001; Lymbery et al. 2014). Aquatic invasive species (AIS) and bio-invasions are global environmental issues in marine, brackish and freshwater ecosystems of the world. AIS have been moved across the globe and introduced in totally new environments as an effort to enhance, restore or re-

Table 1. Terminology for alien species (after Lymbery et al. (2014) and Gozlan et al. (2010)).

Term	Definition
Native species	A species occurring within the range it occupies (or could occupy) naturally, independent of human activity
Alien (exotic, non-indigenous) species	A species that has been transported by human activity into an area outside its natural range
Introduced species	Alien species that has been transported by humans into an area outside its natural range, but has not yet established self-sustaining populations in the wild
Established (naturalised) species	Alien species that has been introduced and established self-sustaining populations in the wild
Feral species	Alien species that has been kept in captivity or domestication after introduction, but has escaped or been released to establish self-sustaining populations in the wild
Invasive species	Alien species that has been introduced, become established and is expanding its range, usually with deleterious consequences for native species
Introduction	The deliberate or accidental release into the wild of a non-native species
Translocation	The human-assisted movement of species within a specific region (i.e., movement of fish within rivers, lakes, ponds, etc.)
Dispersal	The natural dissemination (i.e., non-human assisted) of a species from its point of introduction

establish fishery resources.

Similar to trends observed in other countries, the number of aquatic invasive species in Iran has increased considerably over recent decades. These include harmful algal blooms (HAB) caused by *Cochlodinium polykrikoides* (Gymnodiniaceae) in the Persian Gulf in the south (Fatemi et al. 2012), *Mnemiopsis leidyi* blooms (MLB) in the Caspian Sea (Ivanov et al. 2000), *Azolla filiculoides* blooms (AFB) in Anzali wetland (Sadeghi et al. 2013) and invasion of the Oriental River Prawn, *Macrobrachium nipponense* in Anzali wetland (Grave & Ghane 2006) in the north, changing the species diversity and faunistic structure in Iranian water bodies. They have multiple synergistic impacts particularly on the freshwater ecosystem in this country through various ways.

Fishes are one of the aquatic groups which have been widely introduced and translocated. The movement of fishes between countries was reviewed by Welcomme (1981, 1988). Non-native species were primarily introduced into ecosystems in Iran through human activity, either deliberately or unintentionally and is well known, with the introduction of *Gambusia* (Poeciliidae) in the 1920s and *Cyprinus carpio* (Cyprinidae) in the late 1930s when they were introduced to control malaria and to enhance fish production, respectively (Coad 1996; Esmaeili et al. 2007, 2010). Since then, about 30 fish species have been introduced or translocated and some of them are well established in different Iranian water bodies (Coad 1996; Esmaeili et al. 2007; 2010a, b, 2011, 2013; Khaefi 2014).

In this paper, we provide an update on diversity of alien and invasive fishes within Iranian freshwater ecosystems and discuss their possible environmental impacts. We additionally discuss the possible management strategies to protect the native (and endemic) ichthyodiversity in the 17 drainage basins of Iran recognized in Keivany & Ghorbani (2012), Keivany & Esmaeili (2013, 2014), and Keivany et al (2014).

Materials and Methods

This paper is mainly based on our field work data, since 2004 and also on Armantrout (1990), Holčík & Razavi (1991), Coad & Abdoli (1993), Coad (1995, 1996), Teimori (2006), Esmaeili et al. (2007,

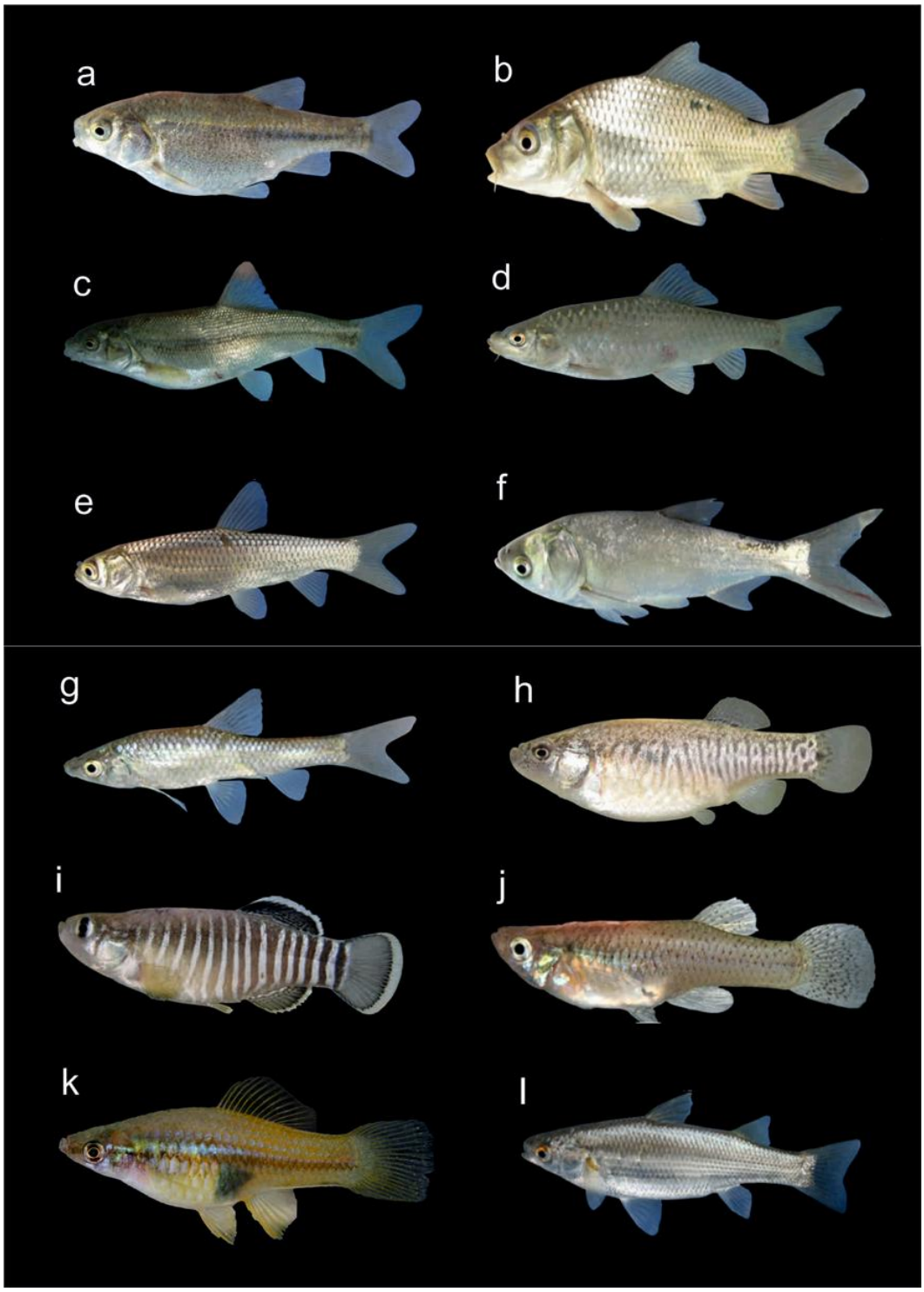

Fig.1. Sympatric native and invasive species in Maharlo basin, except *Xiphophorus hellerii*. a, *Acanthobrama persidis*; b, *Cyprinus carpio*; c, *Capoeta damascina*; d, *Carasobarbus luteus*; e, *Ctenopharyngodon idella*; f, *Hypophthalmichthys molitrix*; g, *Pseudorasbora parva*; h, female *Aphanius farsicus*; i, male *Aphanius farsicus*; j, *Gambusia holbrooki*; k, *Xiphophorus hellerii*; i, C*hela abu*.

2010a,b, 2013, 2014), Hashemi & Ansary (2012), Hashemi et al. (2014), Keivany et al. (2014) and Khaefi et al. (2014). Terminology given by Lymbery et al. (2014) and Gozlan et al. (2010) was followed

Table 2. Alien (exotic) and invasive freshwater fish species of Iran. E=exotic; *=invasive; NC= not confirmed in recent years.

Order	Family	Species	Status	Distribution
Anguilliformes	Anguillidae	*Anguilla anguilla*	E	Caspian Sea
Cypriniformes	Cyprinidae	*Carassius auratus*	E*	Wide distribution
		Carassius carassius	E, NC	Tigris and Caspian
		Carassius gibelio	E	Caspian Sea
		Ctenopharyngogon idella	E	Wide distribution
		Cyprinus carpio	E*	Wide distribution
		Hemiculter leucisculus	E	Caspian Sea/Urmia
		Hypophthalmychthys molitrix	E	Wide distribution
		Hypophthalmychthys nobilis	E	Wide distribution
		Mylopharyngodon piceus	E	Caspian Sea
		Pimephales promelas	E, NC	Namak Lake
		Pseudorasbora parva	E*	Wide distribution
Siluriformes	Heteropneustidae	*Heteropneustes fossilis*	E*	Tigris
Salmoniformes	Salmonidae	*Coregonus lavaretus*	E	Namak Lake
		Oncorhynchus keta	E	Caspian Sea
		Oncorhynchus mykiss	E	Wide distribution
		Salmo trutta	E	Caspian Sea
		Salvelinus fontinalis	E	Namak Lake
Mugiliformes	Mugilidae	*Chelon aurata*	E	Caspian Sea
		Chelon saliens	E	Caspian Sea
		Mugil cephalus	E	Caspian Sea
Beloniformes	Adrianichthyidae	*Oryzias latipes*	E, NC	Tedzhen
Cyprinodontiformes	Poeciliidae	*Gambusia holbrooki*	E *	Wide distribution
		Gambusia affinis	E, NC	?
		Xiphophorus hellerii	E*	Bushehr
Gasterosteformes	Gasterosteidae	*Gasterosteus aculeatus*	E*	Caspian Sea
Perciformes	Gobiidae	*Rhinogobius similis*	E	Harirud
	Centrarchidae	*Lepomis macrochirus*	E, NC	Namak Lake
		Micropterus salmoides	E, NC	Tigris
	Cichlidae	*Amatitlania nigrofasciata*	E	Hormuz
		Tilapia zillii	E	Tigris
Pleuronectiformes	Pleuronectidae	*Platichthys flesus*	E, NC	Caspian Sea

for alien species (Table 1).

Results

In the case of freshwater fishes, the number of reported alien and invasive fishes has reached about 32 species in 10 orders and 12 families (Table 2, Fig. 1) which is about 14.7% of the freshwater ichthyofauna of Iran. However, there are reports (e.g., Coad 1995) of some unconfirmed exotic and transplanted species such as *Carassius carassius* (Linnaeus, 1758), *Pimephales promelas* (Rafinesque, 1820), *Gambusia affinis* (Baird & Girard, 1853), *Oryzias latipes* (Temminck & Schlegel, 1846), *Lepomis macrochirus* (Rafinesque, 1819), *Micropterus salmoides* (Lacèpede, 1802) and *Platichthys flesus* (Linnaeus, 1758). Hence, the confirmed exotic and invasive fishes comprise 25 species. Cyprinidae with 9 species (36% of confirmed non-native species) is ranked the first, and is followed by Salmonidae (5 species, 20%), Mugilidae (3 species, 12%), Cichlidae and Poecilidae each with 2 confirmed species (8%), and 4 families each with only one species (4%). The Neotropical Convict cichlid, *Amatitlania nigrofasciata*, is a new alien fish species which is reported from Iran, the second record of this species from the Middle East and the only known extant wild population in the region (Esmaeili et al. 2013). The exotic cichlid, the

Table 3. Fishes of Shadegan Wetland. N= native; E= exotic; *= invasive.

Order	Family	Species	Status
Clupeiformes	Clupeidae	*Tenualosa ilisha*	N
		Sardinella sindensis	N
	Engraulidae	*Thryssa hamiltonii*	N
Cypriniformes	Cyprinidae	*Acanthobrama marmid*	N
		Alburnoides sp.	N
		Leuciscus vorax	N
		Carassius auratus	E*
		Carasobarbus luteus	N
		Chondrostoma regium	N
		Cyprinion kais	N
		Cyprinion macrostomum	N
		Ctenopharyngogon idella	E
		Cyprinus carpio	E*
		Hypophthalmychthys molitrix	E
		Hypophthalmychthys nobilis	E
		Luciobarbus barbulus	N
		Luciobarbus pectoralis	N
		Luciobarbus xanthopterus	N
		Mesopotamichthys sharpeyi	N
		Tor grypus	N
Siluriformes	Heteropneustidae	*Heteropneustes fossilis*	E*
	Siluridae	*Silurus triostegus*	N
Mugiliformes	Mugilidae	*Chelon abu*	N
		Chelon subviridis	N
		Ellohelon vaigiensis	N
Cyprinodontiformes	Poeciliidae	*Gambusia holbrooki*	E*
Perciformes	Cichlidae	*Tilapia zillii*	E
	Sparidae	*Acanthopagrus arabicus*	N
Synbranchiformes	Mastacembelidae	*Mastacembelus mastacembelus*	N

redbelly tilapia, *Tilapia zillii* (Gervais, 1848), is another new record of an alien fish from natural freshwater bodies in Iran, which was most likely deliberately released to enhance fish production (Khaefi et al. 2014). Exotic and invasive species are distributed in all the 17 drainage basins of Iran and the Caspian Sea basin is ranked first in terms of invasive fish diversity (Table 2). Unfortunately some species have been introduced to fish hot spots of Iran including the Shadegan and Anzali wetlands in south and north of Iran, respectively changing the fish composition in these water bodies (Tables 3, 4). Shadegan wetland is one the largest international wetlands of Iran, situated in the southwest of the country and connecting the Jarahi River to the Persian Gulf. Due to its unique biodiversity, it has been considered as one the wonderful natural landscapes of the world (Hashemi & Ansari 2012). Records of more than 29 fish species including 21 natives and 8 aliens show the high fish diversity of this wetland (Table 3). Introduction of *Tilapia zillii* to this international wetland may have sever affects on native fishes.

Anzali wetland with about 50 native fish species is one of the fish hot spots of Iran. However, during the past few decades about 16 alien fish species (Table 4) have been introduced to this water body changing its fish composition and affecting native fishes. Moreover, additional invaders such as blooms of *Azolla filiculoides* (Sadeghi et al. 2013) and invasion of the Oriental River Prawn, *Macrobrachium nipponense* (Grave & Ghane 2006) in Anzali wetland could have multiple synergistic impacts on this unique freshwater ecosystem.

Table 4. Fishes of Anzali Wetland. N= native; E= exotic; *= invasive.

Order	Family	Species	Status
Petromyzontiformes	Petromyzontidae	*Caspiomyzon wagneri*	N
Acipenseriformes	Acipenseridae	*Acipenser persicus*	N
		Acipenser stellatus	N
Anguiliformes	Anguilidae	*Anguilla anguilla*	E
Clupeiformes	Clupeidae	*Alosa brashnikovi*	N
		Alosa caspia	N
		Alosa knipowitschia	N
		Alosa persica	N
		Alosa kessleri	N
		Clupeonella caspia	N
Cypriniformes	Cyprinidae	*Abramis brama*	N
		Alburnoides eichwaldii	N
		Alburnus chalcoides	N
		Alburnus filippii	N
		Alburnus hohenackeri	N
		Leuciscus aspius	N
		Barbus cyri	N
		Blicca bjoerkna	N
		Capoeta capoeta	N
		Carassius auratus	E*
		Carassius gibelio	E*
		Ctenopharyngogon idella	E
		Cyprinus carpio	E*
		Hemiculter leucisculus	E
		Hypophthalmychthys molitrix	E
		Hypophthalmychthys nobilis	E
		Leucaspius delineatus	N
		Luciobarbus brachycephalus	N
		Luciobarbus capito	N
		Mylopharyngodon piceus	E
		Pelecus cultratus	N
		Pseudorasbora parva	E
		Rhodeus amarus	N
		Rutilus kutum	N
		Rutilus caspicus	N
		Scardinius erythrophthalmus	N
		Squalius cephalus	N
		Tinca tinca	N
		Vimba persa	N
	Cobitidae	*Cobitis faridpaki*	N
		Cobitis keyvani	N
		Sabanejewia aurata	N
		Sabanejewia caspia	N
	Nemacheilidae	*Oxynoemacheilus bergianus*	N
Siluriformes	Siluridae	*Silurus glanis*	N
Salmoniformes	Salmonidae	*Oncorhyncus mykiss*	E
		Salmo caspius	N
		Salmo fario	N
Esociformes	Esocidae	*Esox lucius*	N
Mugiliformes	Mugilidae	*Chelon aurata*	E
		Chelon saliens	E

Table 4. Continued

Order	Family	Species	Status
Atheriniformes	Atherinidae	*Atherina caspia*	N
Cyprinodontiformes	Poeciliidae	*Gambusia holbrooki*	E*
Gasterosteformes	Gasterosteidae	*Gasterosteus aculeatus*	E*
		Pungitius platygaster	N
Syngnathiformes	Syngnathidae	*Syngnathus caspius*	N
Perciformes	Percidae	*Perca fluviatilis*	N
		Sander lucioperca	N
	Gobiidae	*Benthophilus kessleri*	N
		Knipowitschia caucasica	N
		Neogobius melanostomus	N
		Ponticola cyrius	N
		Proterorhinus nasalis	N
		Rhinogobius sp.	N

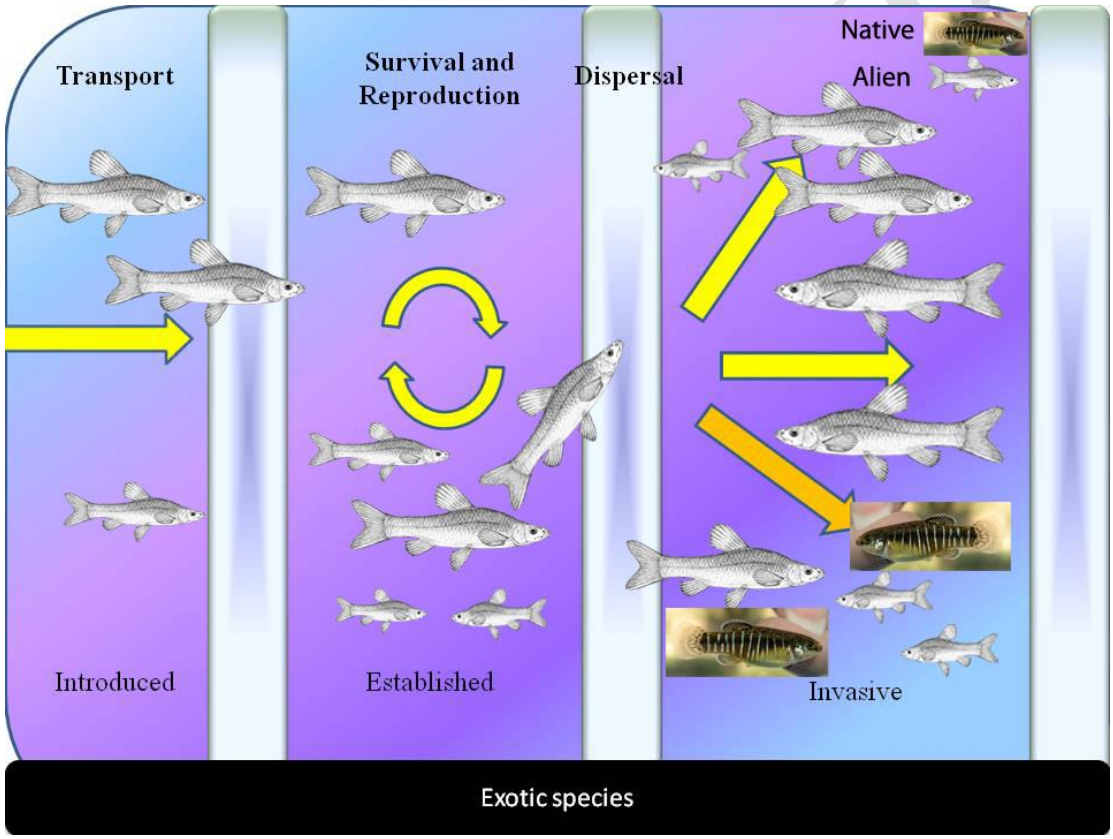

Fig.2. Schematic diagram of processes involved in species invasions (Modified from Lymbery et al. 2014).

The Eastern Mosquitofish, *Gambusia holbrooki* is the most widespread invasive species while *A. nigrofasciata* (in Hormuz basin) and *Xiphophorus hellerii* (Persian Gulf basin) have restricted distributions. Some of the invasive species (e.g., *Cyprinus carpio*, *Carassius auratus*, *Pseudorasbora parva*, *Xiphophorus hellerii* and *Gambusia holbrooki*) have established breeding populations, acting as invaders, while some others are regularly stocked by the Fisheries Department of Iran (e.g., *Hypophthalmichthys molitrix*, *H. nobilis*, *Ctenopharyngodon idella*) and a few others are occasionally recorded from natural waters.

The processes involved in species invasions are

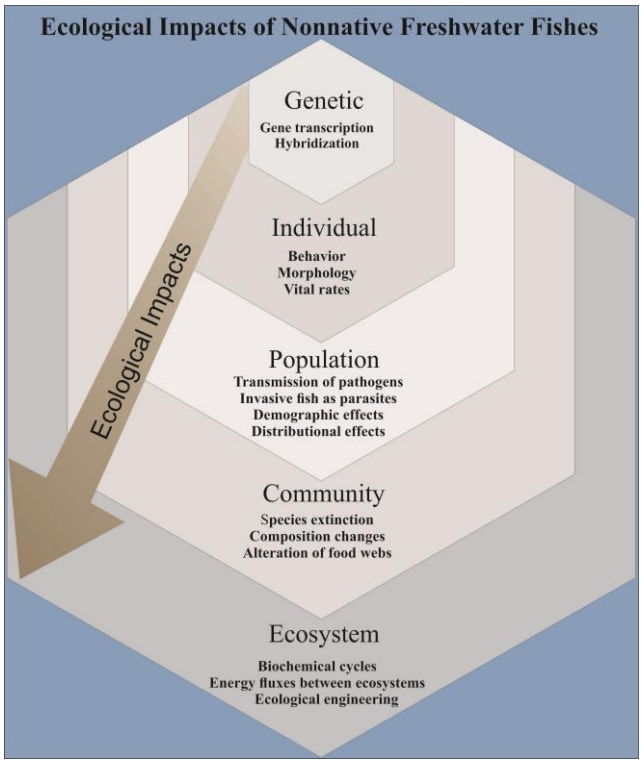

Fig.3. Schematic diagram of ecological impacts of nonnative freshwater fishes. (Modified from Cucherousset & Olden 2011).

almost similar in every biological invasion (Fig. 2). An alien species must surmount geographic barriers to be introduced into a new area, then barriers to survival and reproduction, to become established within the expanded range, and finally barriers to dispersal to become invasive (Blackburn et al. 2011; Lymbery et al. 2014). Due to the nature of the neotropical convict cichlid, *Amatitlania nigrofasciata* and the redbelly tilapia, *Tilapia zillii*, they also may overcome this common framework and act as invasive species in near future.

Discussion

Similar to trends observed in other world regions, the number of non-native fish species introduced and established in Iran has increased considerably over recent decades attaining to 25 confirmed species comprising about 11.5% of the total confirmed freshwater fishes in this country. Aquaculture, sport fishing, control of malaria, ornamental purposes, research activities, demonstration in national fairs and accidental introduction are the main reasons for these introductions (Coad & Abdoli 1993; Esmaeili et al. 2010a, b). Some of them (e.g., *Cyprinus carpio*, *Carassius auratus*, *Pseudorasbora parva*, *Xiphophorus hellerii* and *Gambusia holbrooki*) have been established in natural water bodies acting as invasion species. Fish behavior, minimal resource competition, suitable water temperature, changes in water flow, suitable habitat for spawning, number of release events, species-level factors (such as diet, offspring per year, growth rate, body size, lifespan) and abundant food supply have been recorded to be the main factors promoting establishment of introduced fish species. Whether through accidental introductions or intentional releases, many species attain distributions beyond their natural ranges and form novel interactions with native counterparts (Paterson et al. 2013). Introductions always carry risks for the native biota. The introduction of a non-native species in an ecosystem is always likely to present an ecological risk if the species is able to integrate itself successfully into the ecosystem (Gozlan & Newton 2009), resulting in possible detrimental interactions with native species or even on ecosystem functioning (Gozaln et al. 2010). The ecological consequences of freshwater fish invasions have been reviewed and discussed by Cucherousset & Olden (2011) which are given in Fig. 3. The effects of invaders could be at genetic, individual, population, community and ecosystem levels.

Much of what we know about invaders is based on information on introduced populations in other countries. Results of these past introductions provide perspective on possible outcomes for Iran. The following parameters suggest being the most important impacts of the invasive species on Iranian freshwater fishes (native and endemic).

Competition: Mosquito fish (*Gambusia holbrooki*) prey on the eggs of others fishes; they are aggressive, even attacking fish larger than themselves, thus discouraging feeding and reproduction, and compete directly for food with various cyprinid species, so the mosquito fish has been called "the fish destroyer" by

Myers (1965) and is said to replace native species aggressively (Armantrout 1990). In Iran, the native *Aphanius* species occurs alongside *Gambusia* wherever the latter has been introduced. *Pesudorasbora parva*, competes strongly with other fishes for food and is a predator on their eggs and young.

Effects of redbelly tilapia on native organisms have been well documented. Molnar et al. (2008) considered it as a potential competitor with native fish for food and spawning areas, and it is potentially detrimental to California rice crops. This voracious herbivore constitutes a serious threat to native aquatic plants and the organisms that depend on them. Courtenay in Hogg (1976) called it the most destructive fish to submerged vegetation known next to the grass carp, *Ctenopharyngodon idella*. Due to its feeding habits, the invasive redbelly tilapia eliminated all aquatic macrophytes from the Hyco Reservoir, North Carolina, USA, within a 2-year period, which caused declines in populations of several native fishes; however, because of its ability to switch to alternate food sources, the tilapia populations continued expanding in the absence of macrophytes (Molnar et al. 2008). *Amatitlania nigrofasciata* may cause harm to native fishes as this is an aggressive and territorial species which is well known for its ability to colonize rapidly and it also often carries alien parasites (Wisenden 1994; Bassleer 1997; Martinez et al. 2002).

Habitat change: Some introduced species change the fish habitat. *Gambusia holbrooki* has been shown to have major effects on habitats under experimental conditions (Hurlbert et al. 1972). Grass carp, *Ctenopharyngodon idella* removes the habitat vegetation and decreases the area of refuge for larvae and smaller fish and production of invertebrates on which many native species feed. Carp and goldfish, feed on the bottom and in so doing muddy water.

Genetic changes: Many native species exist in several water bodies in a desert environment and the systematic status of these isolated populations has not been examined (Coad 1995). Movement of taxa between these water bodies may well eliminate a diversity as yet unrevealed. Populations of the bighead (*Hypophthalmichthys nobilis*) in Anzali Wetland of Iran are hybrids with silver carp (*Hypophthalmichthys molitrix*) (Holcik 1989). Hybrids of *Cyprinus carpio* and *Carassius auratus* have been observed in the Caspian Sea basin by K. Abbasi.

Introduction of parasites: Introduced fish species could play a role in the spread of disease or parasites to other animals. As many parasites have been recorded from invasive and native fish species of Iran (see Coad 2014), it seems that the wide distribution range of invasive species may have a significant role in the spread of these parasites. Aquatic invasive species (AIS) have multiple synergistic impacts on the ecosystem through various ways of hybridization, gene pollution, competition, transmission of pathogens and parasites, community level changes, facilitating the introduction of other taxa and elimination and subsequent extinction of endemic species. It can be considerably critical when the invasive species are sympatric to a native (and endemic) species, as it can be seen in the case of several endemic fishes in Iran. A particular example is the cyprinodontid fishes (see above).

Management: The intentional introduction of exotic species is an extraordinarily complex issue that requires taking into account a broad number of variables. Understanding the risks that alien species, especially aquatic invasive species (AIS) pose, requires comparative studies on the ecology and life history strategies of invasive and closely related indigenous species with similar ecological life traits, correct identification of AIS, monitoring the rate of invasion, the causal relation between population dynamics and species invasion, regular checking of

fishes for diseases and parasites, obtaining a more balanced perspective on the ecological impacts of fish invasions across levels of biological organization, improving our understanding of how other facets of environmental change (e.g., habitat degradation, land-use change, climate warming) interact with invasive species, elucidation of the adaptive and evolutionary responses of native species to the presence of invasive species and vice versa (see Cucherousset & Olden 2011), and public awareness, all of which could be effective management strategies to minimize the bio-invasion impacts. Priority may be given to those invasive species that have already been established in the wild and on preventing new infestations.

Finally, as suggested by Gozlan et al. (2010) maps of conservation hot spots should be drawn based on a combination of predictors of future introductions (e.g., human population density, aquaculture activity) and risk level of incurring losses to local– global biodiversity (e.g., number of critically endangered species). This would accelerate prioritization of the areas at national and global levels where risks of future introductions should be minimized, such as those where endemic species are at risk and the intensity of introductions of non-native species has been limited.

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روش تحقیق کمی

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