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Alien fish and crayfish species in Hellenic freshwaters and aquaculture

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Abstract

The diversity of ichthyofauna in Hellenic freshwaters is highlighted by the presence of 161 species. This actually represents 27.8% of the total fish species recorded in European freshwater, including both native and introduced species, suggesting that Greece represents a 'hot spot' for biodiversity. The introduction of alien species for restocking, the aquarium trade and aquaculture was responsible for the deliberate or accidental release of alien specimens into open waters and in some cases for establishing populations. In contrast, commercially valuable alien species (e.g. salmonids, cyprinids and more recently sturgeons) generated significant income to individuals, companies and to the national economy. This paper aims to review the situation regarding the presence of alien fish and crayfish species in Hellenic freshwaters and in particular in aquaculture and to flesh out issues concerning their aquaculture potential.

Key words: alien crayfish species, alien fish species, exotics, freshwater aquaculture, Greece, Hellenic freshwaters.

Introduction

Twenty-eight alien (exotic) fish species out of 161 species (17.39%) have been recorded in Hellenic freshwaters in recent checklists (Economou *et al.* 2007; Zenetos *et al.* 2009). The number, however, is actually greater because some aquaculture-related species were not included in the above lists; nevertheless, the respective percentage in pan-European level is by far lower (5.69%) (33 introduced and 546 native species in the watersheds) based on data provided by Kottelat and Freyhof (2007). The opposite pattern is evident in other important aquaculture species, such as freshwater crayfish, where the percentage of endemism recorded in the freshwater ecosystems is generally higher in Greece (75%; one alien species out of four in total) compared with the European situation of 38.46% (eight alien species out of 13 in total) (Perdikaris 2009).

Alien species are considered valuable for aquaculture, fisheries, recreation and hobbyists and species such as rainbow trout have been domesticated in farming conditions for many decades, following a global trend. Major groups are considered important for generating income through aquaculture, commercial and sport fisheries (e.g. salmonids, cyprinids and more recently sturgeons); however, introductions and intrastate translocations have occasionally resulted in interspecific competition, genetic introgression or even extirpation of self-recruiting species. Translocations between ecosystems are largely responsible for rapid changes in biodiversity (e.g. Prussian carp (*Carassius gibelio* (Bloch, 1782)); Paschos *et al.* 2004; Tsoumani *et al.* 2006; and see the review by Economidis *et al.* 2000a). Overall, the Global Invasive Species Database of the IUCN (GISD 2010) includes data for only six alien freshwater fish species in Greece and the Food and Agriculture Organization Database of Introductions of Aquatic Species (FAO 2009) includes 14 freshwater fish and one freshwater crayfish species, which in both cases are far fewer than the actual situation.

The present paper aims to review the status of alien fish and crayfish species in Hellenic freshwaters (Fig. 1), with particular reference to freshwater aquaculture, and to discuss their aquaculture importance and prospects against possible negative impacts. Thirty fish species belonging to ten families and two crayfish species belonging to two families will be discussed in the order that they appear in Table 1.

Acipenseridae

There are considered to be four native sturgeon species in Greece: stellate sturgeon (*Acipenser stellatus* Pallas, 1771),

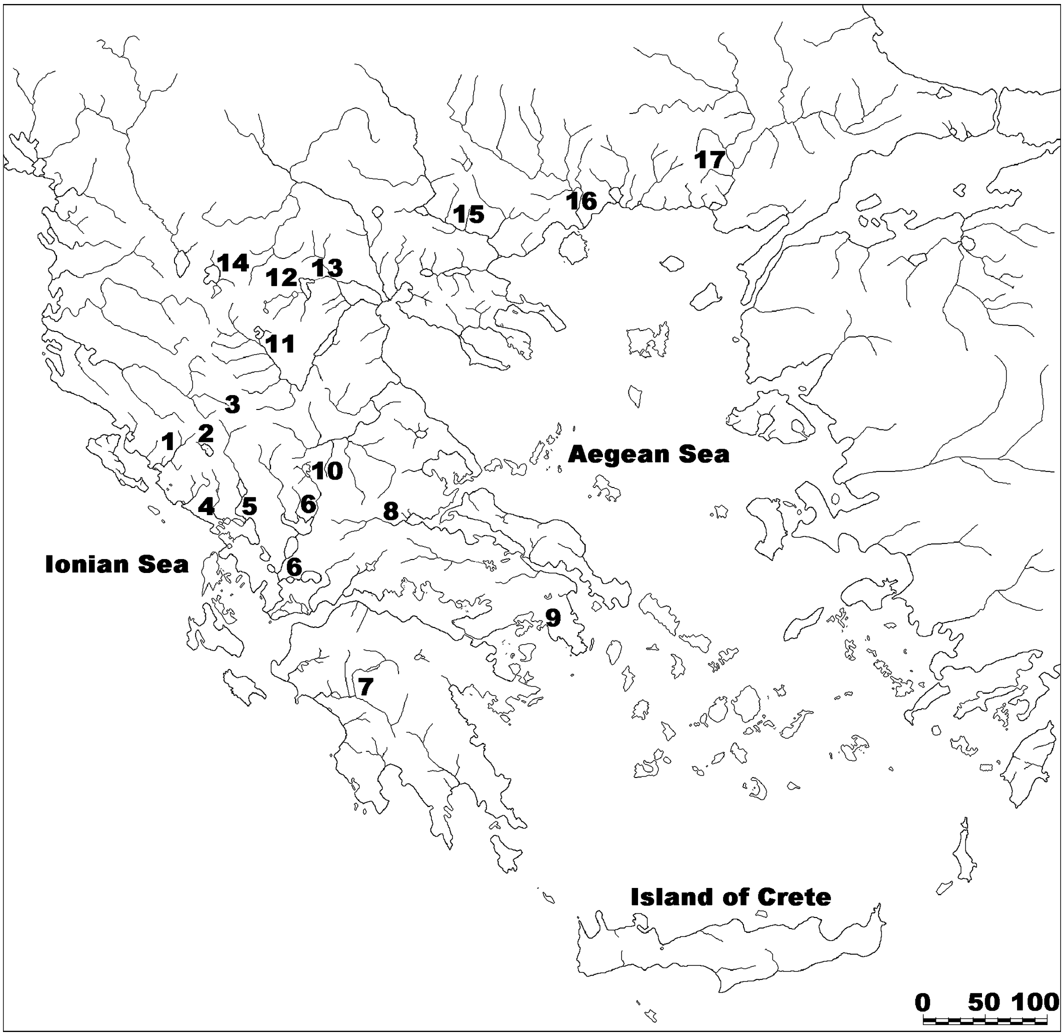

Figure 1 Hydrographic network of Greece including the river systems, lakes and dams associated with the alien fish and crayfish species introductions discussed in this review (background modified from Economidis *et al.* 2000a; scale in km). 1, River Kalamas; 2, Lake Pamvotis (= Ioannina) and Municipal Hatchery of Ioannina Lake; 3, River Aoos and adjacent dam; 4, River Louros and State Hatchery of Terrovo; 5, River Arachthos; 6, River Acheloos; Lake Lysimacheia and Kremasta dam; 7, River Alfios; 8, River Spercheios and Thermopyles; 9, Lake Vouliagmeni; 10, Tavropos dam; 11, River Aliakmonas and Lake Kastoria; 12, Lake Vegoritida; 13, River and Lake Agras and State Hatchery of Edessa; 14, Lakes Prespes (Mikri and Megali Prespa); 15, River Strymonas and Lake Kerkini; 16, River Nestos; 17, River Evros.

Atlantic sturgeon (*Acipenser sturio* L.), Adriatic sturgeon (*Acipenser naccarii* Bonaparte, 1836) and beluga (*Huso huso* L.) (Economidis *et al.* 2000b; Paschos *et al.* 2008). However, the status of the last two species has been questioned because historical data and preserved specimens are virtually absent and recent catches of *H. huso* specimens in the coastal area of the river Evros (Thrace, north-east Greece) (as well as *A. stellatus* and the Russian sturgeon *Acipenser gueldenstaedtii* Brandt & Ratzenburg, 1833) were attributed to aquaculture escapes from Bulgaria (Koutrakis & Economidis 2006). Eggs, fry or even broodstock of eight species (Siberian sturgeon (*Acipenser baerii* Brandt, 1869), *A. gueldenstaedtii*, *A. naccarii*, sterlet (*Acipenser ruthenus* L.), white sturgeon (*Acipenser transmontanus* Richardson, 1836), *H. huso*, paddlefish (*Polyodon spathula* (Walbaum, 1792)) and *A. stellatus*) and the 'bester' hybrid (*A. ruthenus* × *H. huso*) were imported from 1992 to 2004 from Hungary, the Russian Federation, the USA or Italy by the pioneering Municipal Hatchery of Ioannina Lake (D.E.L.I. S.A.) and a few fish farms (Paschos *et al.* 2008). The restocking success of the River Kalamas (north-west Greece) with *A. naccarii* (Paschos *et al.* 2003) has not yet been evaluated, and neither has the deliberate release of *A. gueldenstaedtii* in two

Table 1 Alien fish and crayfish species in Hellenic freshwaters and aquaculture

Families and species	Established in freshwater	Remarks
1. Acipenseridae	Unsuccessful for all species,	It is questionable whether
Acipenser baerii Brandt, 1869 (H)	but *A. naccarii* status	*A. naccarii* and *H. huso*
Acipenser gueldenstaedtii Brandt & Ratzenburg, 1833 (H)	needs evaluation in the River Kalamas	are self-recruiting
Acipenser naccarii Bonaparte, 1836 (M)		
Acipenser ruthenus L. (H)		
Acipenser transmontanus Richardson, 1836 (H)		
Huso huso (L. 1758) (H)		
Bester hybrid (*A. ruthenus* × *H. huso*) (H)		
Polyodon spathula (Walbaum 1792) (H)		
2. Anguillidae	Expected unsuccessful	Confirmed escapes. Concern
Anguilla japonica Temminck & Schlegel, 1846 (L)		over *Anguillicola crassus* infection of Hellenic eel natural stocks
3. Cyprinidae		Controversial origin of
Carassius auratus (L.) (H)	Expected successful	*C. gibelio*. *C. gibelio* and
Carassius gibelio (Bloch, 1782) (L)	Successful	*P. parva* are rapidly
Ctenopharyngodon idella (Valenciennes, 1844) (L)	Unsuccessful	spreading against
Hypophthalmichthys molitrix (Valenciennes, 1844) (L)	Unsuccessful	self-recruiting species
Hypophthalmichthys nobilis (Richardson, 1845) (L)	Unsuccessful	
Parabramis pekinensis (Basilewsky, 1855) (N)	Expected unsuccessful	
Pseudorasbora parva (Temmnick & Schlegel, 1846) (N)	Successful	
4. Ictaluridae	Unsuccessful	
Ictalurus punctatus (Rafinesque, 1818) (L)		
5. Clariidae	Unsuccessful	Excellent potential in
Clarias gariepinus (Burchell, 1822) (M)		geothermal waters
6. Coregonidae	Probably successful	
Coregonus cf. *lavaretus* (L. 1758) (L)		
7. Salmonidae	Unsuccessful for all species	Recently reported natural
Oncorhynchus kisutch (Walbaum, 1792) (L)	except *Salmo* cf. *trutta*	spawning of *O. mykiss* in Austria,
Oncorhynchus mykiss (Walbaum, 1792) (H)		Slovenia, Switzerland and Italy
Salmo letnica (Karaman, 1924) (N)		
Salmo salar L. 1758 (N)		
Salmo cf. *trutta* L. 1758 (N)		
Salvelinus fontinalis (Mitchill, 1814) (N)		
8. Poecilidae	Successful	Competition of *G. holbrooki*
Gambusia holbrooki Girard, 1859 (N)		with critically endangered species
Poecilia cf. *latipinna* Lesuer, 1821 (L)	Successful	*Valencia letourneuxi*
9. Centrarchidae	Successful	Negative ecological impacts on
Lepomis gibbosus (L. 1859) (L)		cyprinids
Micropterus salmoides (La Cepéde, 1802) (L-M)	Probably successful in the future	
10. Cichlidae	Successful	Excellent potential in geothermal
Oreochromis niloticus (L. 1758) (M-H)		waters. This species is able to overcome winter conditions in Greece
11. Astacidae (freshwater crayfish)	Successful	'Plague-free' population
Pacifastacus leniusculus (Dana, 1852) (M-H)		
12. Parastacidae (freshwater crayfish)	Probably successful for future	This species is probably able
Cherax quadricarinatus (von Martens, 1868) (M-H)	escapees	to overcome winter conditions in Greece

The aquaculture importance and potential of the species are qualitatively scored in parentheses: N, negligible; L, low; M, medium; H, high. The vernacular and scientific names of the species follow Kottelat and Freyhof (2007).

dams (Paschos *et al.* 2008). Overall, reintroduction or release plans require careful planning in terms of strategy, species and ecosystems because damming, overfishing (both in coastal areas and in river bodies), pollution, poaching and loss of possible spawning sites may seriously undermine such efforts.

In contrast, there is good potential for sturgeon farming in Greece (Vardakas *et al.* 2005) because of suitable climatic conditions, expertise in artificial reproduction, rearing techniques and non-invasive sex determination methods and, most importantly, because of available natural resources (dams, springs and lakes) (Paschos 2004). Moreover, the initial domesticated broodstock groups in most of the highly appreciated commercial species have been apparently secured. Current annual flesh production is estimated to be approximately 30 tonnes, with the potential for 200 tonnes over the coming years, and caviar production has started in low quantities (Paschos *et al.* 2008). Market demand for freshwater fish is relatively strong in the northern parts of Greece, in various restaurants and also on islands visited by tourists from Eastern Europe (e.g. Russian Federation and countries of the former Yugoslavia); these consumers search for 'new' species, particularly sturgeons. In addition, sturgeons are already exported to Italy and demand shows an increasing trend, as does the global demand for caviar. Finally, *A. baeri* (particularly the albino 'variety') (Coppens International 2007) and *P. spatula* are increasingly popular ornamental species.

Anguillidae

Eel farming is based on the European eel *Anguilla anguilla* (L.) and has existed in Greece since 1986, but until the early 1990s annual production was <100 tonnes. Mean annual production increased to 538 tonnes over the period 1997–2006 (Ministry of Rural Development and Food 2009). Farms mainly import glass eels and elvers from the UK and France. Strong competition from China for glass eels and the respective sky-high cost of imports, the dramatic decline in natural stocks (ICES 2008) and the enforcement of Council Regulation (EC) 1100/2007 requiring strict national management plans are expected to further push the profitability of the sector to its limits. Moreover, infestation by the swim-bladder nematode *Anguillicola crassus* (Kuwahara, Niimi and Itagaki 1974) has been blamed for mortalities in farmed stocks. This nematode was imported with the alien Japanese eel (*Anguilla japonica* Temminck & Schlegel, 1846) in 1988 (Moravec 1992; Zenetos *et al.* 2009) and specimens escaped from farms to the Ionian coast (Corsini-Foka & Economidis 2007). European eel farms exist in six areas, but three farms in Arta, Preveza and Fokida (western Greece) produce the bulk of production. Restocking with *A. anguilla* was carried out in Lake Pamvotis with glass eels and adult specimens originating from the estuaries of western Greece (Economidis *et al.* 2000a) and in the River Kalamas (Costas Perdikaris, unpubl. data, 2007). These eels are regarded as the most desired product from the extensive farming systems (estuaries and lagoons); however, production from these systems has dropped to <100 tonnes over the past decade (Ministry of Rural Development and Food 2009).

Cyprinidae

The common carp *Cyprinus* carpio (L.) is native to central and northern parts of Greece and for this reason is not discussed in the present review. However, fingerlings were initially introduced from Italy into many lakes in western Greece, in Peloponnesus (Lake Stymphalia) and in central Greece (Lake Yliki) (Stephanidis 1939a,b and relevant data in Economidis *et al.* (2000a)). Moreover, mirror, scaly and leather varieties were introduced to farms from either Israel or Hungary during the 1980s and many translocations have taken place.

Goldfish (*Carassius auratus* (L.)) were initially imported during the 1930s by the Italians to the islands of Syros, Paros and Skiathos (Aegean Sea) for the purpose of farming in irrigation tanks (Crivelli 1995; Paschos 2004). Farming was organized on a systematic basis during the 1990s in the Municipal Hatchery of Ioannina Lake (D.E.L.I. S.A.), when 6–7 varieties were successfully bred. Specimens have been caught in three places (Halkidiki (northern Greece), Lake Pamvotis and River Acheloos (western Greece)) and it is also possible that they are present in Lake Prespa (north-west Greece) and in the western part of the island of Crete (Economou *et al.* 2007). According to Economidis *et al.* (2000a) the species was introduced accidentally into Lake Lysimacheia (western Greece). *Carassius auratus* is one of the most popular aquarium species; however, only approximately 5% of the demand is satisfied by domestic production and far-east countries dominate imports. Hormone-mediated reproduction and natural reproduction in aquaria and tanks are routinely carried out at the Department of Aquaculture and Fisheries, Technological Educational Institute of Epirus (north-west Greece).

Prussian carp has dramatically increased its distribution range (Tsoumani *et al.* 2006) mainly through unintentional translocations and in some cases this species has played a significant role in the decline of self-recruiting species (e.g. as a competitor of various cyprinids in the eutrophic and deteriorated Lake Pamvotis in north-west Greece; Perdikaris *et al.* 2005). Populations are mainly female triploids (see Liousia *et al.* 2008 for details about the Lake Pamvotis population) and it has been experimentally demonstrated that female triploids are sperm parasites and reproduce through gynogenesis (using sperm from the common carp *C. auratus*, Acheloos roach (*Rutilus panosi* Bogutskaya & Iliadou 2006) and bream (*Abramis brama* (L.)) (Paschos *et al.* 2004;

Kottelat & Freyhof 2007). This species is regarded to be self-recruiting in the north-eastern part of the country (Economidis *et al.* 2000a), particularly in the Rivers Evros, Strymonas (artificial Lake of Kerkini) and River Kompsatos (Economou *et al.* 2007), but there is debate because the original distribution pattern is 'masked' by introductions, translocations, complex modes of reproduction and species confusion (Kottelat & Freyhof 2007). From an aquaculture point of view, this trash fish could be exploited as a pituitary donor for the artificial reproduction of cyprinids as its pituitary potency and hormonal compatibility were recently demonstrated in *C. carpio* (Perdikaris *et al.* 2007; Kosti *et al.* 2008) and in *C. auratus* (Vavatsikos 2009).

Grass carp (*Ctenopharyngodon idella* (Valenciennes, 1844)), silver carp (*Hypophthalmichthys molitrix* (Valenciennes, 1844)) and bighead carp (*Hypophthalmichthys nobilis* (Richardson, 1845)) were introduced for biocontrol purposes in the 1970s and 1980s (Welcomme 1988; Crivelli 1995). The Municipal Hatchery of Ioannina Lake (D.E.L.I. S.A.) played a major role in sustaining continuous fry supplies of all three species. *Ctenopharyngodon idella* and *H. molitrix* and to a lesser extent *H. nobilis* were introduced into several lakes and large rivers from the mid-1980s onwards (Economidis *et al.* 2000a; Economou *et al.* 2007). Their role in controlling phytoplankton, zooplankton and excessive submerged aquatic vegetation, respectively, have been regarded as positive for the ecosystems in general, without the risk of natural reproduction outside their natural distribution range (Paschos 2004); however, the impact of *C. idella* on aquatic vegetation has been blamed as a major trophic complexity reducing factor (Leonardos *et al.* 2008). Direct aquaculture exploitation for Chinese carps in Greece could only be related to polyculture with other more commercially appreciated species.

White amur bream (*Parabramis pekinensis* (Basilewsky, 1855)) was introduced to Lake Mikri Prespa either by the Albanians in 1959 (Rosecchi *et al.* 1993; Crivelli 1995; Economidis *et al.* 2000a) or was introduced in Albania for aquaculture purposes and some specimens escaped to the lake (Kottelat & Freyhof 2007). Nevertheless, it appears that it has not become established as has not been caught for many years.

Pseudorasbora (*Pseudorasbora parva* (Temmnick & Schlegel, 1846)) is probably the most invasive freshwater species in Greece and throughout Europe (Bianco 1988; Economidis *et al.* 2000a; Economou *et al.* 2007; Kottelat & Freyhof 2007), together with *C. gibelio*, owing to its antagonistic and dominant behaviour towards self-recruiting species (Pinder *et al.* 2006). It was accidentally introduced and subsequently spread through *C. idella* fry stocking. There is virtually no farming interest for these two species.

Ictaluridae and Clariidae

The African catfish *Clarias gariepinus* (Burchell, 1822) was imported from the Netherlands for farming purposes during 1993 and 1994, but efforts stopped in 1996 (Economidis *et al.* 2000a; FAO 2002). The ecological consequences of escapes are generally regarded as severe, which is why Germany banned its trade. However, the well-established know-how of farming in closed recirculated systems in Europe, as well as in remote watershed farming systems fed with geothermal waters (e.g. in Hungary) is a future option because the geothermal capacity of Greece is significant and under exploited. Moreover, the species potential could be preferentially exploited in the warmer southern parts of the country (e.g. on the island of Crete). With regard to marketing prospects, African catfish fillets could replace the fish fillets that are currently imported and sold by large fast food chains.

The presence of the channel catfish *Ictalurus punctatus* (Rafinesque, 1818) has not yet been confirmed in the River Arachthos close to the town of Arta (north-west Greece) (Economou *et al.* 2007), although it was imported to a fish farm in the past decade; however, it is possible because this species has formed reproductively autonomous populations in Spain, Italy and in the Rivers Kuban and Don (Kottelat & Freyhof 2007). Its aquaculture prospects are limited in favour of *C. gariepinus*.

Coregonidae and Salmonidae

Taxonomically debated whitefish (*Coregonus* cf. *lavaretus* (L.)) are present in Lake Vegoritida (western Macedonia) and in the rivers Aliakmonas (north-west Greece) and Acheloos (western Greece) (Economou *et al.* 2007). Broodstock is currently reserved in the state hatchery of Edessa (western Macedonia) (Nikos Georgiadis, pers. comm., 2008). According to Economidis *et al.* (2000a) fertilized eggs were imported from Switzerland in the 1950s and the species was introduced into Lake Vegoritida and later into the artificial Lake Tavropos (central Greece). Baltic cisco (*Coregonus* cf. *albula* (L.)) from the Baltic basin and peled (*Coregonus* cf. *peled* (Gmelin, 1789)) from Siberia have been introduced to the Bulgarian part of the River Nestos (northern Greece) (Economou *et al.* 2007) and may possibly be found in the Greek part of the river in the future. *Coregonus* cf. *lavaretus* is highly desirable for angling purposes and its neutral ecological attributes (non-aggressive or dominant behaviour towards other native species and feeding based on small crustaceans; Economidis *et al.* 2000a; Kottelat & Freyhof 2007) make it suitable for restocking high altitude lakes and dams.

Coho salmon (*Oncorhynchus kisutch* (Walbaum, 1792)) eggs from Canada were imported to the state hatchery of Edessa and to various rainbow trout farms in the River Sperchios (central Greece), as well as to a cage farm in Lake Vegorotida (Holcik 1991; Economidis *et al.* 2000a). This species has been released into a small number of lakes and rivers (Economidis *et al.* 2000a; Economou *et al.* 2007), but its ability to form autonomous populations is debatable, although autonomous populations exist in France, Belgium and possibly Sweden and Latvia. Aquaculture interest for this species is rather low and farming efforts have been abandoned throughout Europe.

Rainbow trout (*Oncorhynchus mykiss* (Walbaum, 1792)) eggs from Switzerland were initially imported to the state hatcheries of Terrovo (north-west Greece) and Edessa during the 1950s as part of the Marshall Plan economic aid program (1948–1952). Subsequently, fry were released into large numbers of rivers and oligotrophic lakes (Economidis *et al.* 2000a). To date, there is no solid evidence of natural spawning in Greece, although spawning was reported by Welcomme (1988); however, it appears that this species is starting to adapt to European waters because populations have become established in alpine rivers in Austria, Slovenia, Switzerland and Italy (Kottelat & Freyhof 2007). Rainbow trout is the basic farmed species in Hellenic freshwaters (Paschos 2004) and annual production from approximately 100 primarily small/medium scale farms is estimated to be 5000 tonnes. Adult golden rainbow trout (mutated colour variant of *O. mykiss*) originating from Canada have also been observed in one farm close to the Greek–Albanian border (Prefecture of Thesprotia, north-west Greece) (Costas Perdikaris, pers. obs., 2004). Mariculture in cages is not a realistic option because of increased water temperatures during the summer period in the Ionian and Aegean seas.

The Pestani trout *Salmo letnica* (Karaman, 1924) has been introduced into Lake Prespes (Crivelli *et al.* 1997). This species is a desirable target for anglers; however, the main problem is the risk of hybridization with the native Prespa trout *Salmo peristericus* Karaman, 1938.

Atlantic salmon (*Salmo salar* L.) eggs were imported from Sweden after 1985 to the state hatchery of Edessa and to four farms with closed recirculating systems (Economidis *et al.* 2000a; Economou *et al.* 2007). However, this species is not a viable candidate for the Greek aquaculture sector because of adverse temperature conditions and there is no possibility of establishing natural stocks.

The taxonomically debated Atlantic trout (*Salmo* cf. *trutta* L.) was introduced into Lake Vegoritida and into the River Alfios (Peloponnesus) and varieties from European hatcheries have been stocked in freshwaters close to rainbow trout farms (Economou *et al.* 2007). This species is registered as an alien because it is virtually absent from the Mediterranean Sea (Kottelat & Freyhof 2007). Nevertheless, the species is highly desired by anglers. The risk of hybridization may be a serious problem for the genetic integrity of native trout stocks in the future.

Brook charr (*Salvelinus fontinalis* (Mitchill, 1814)) eggs were imported during the 1980s to the state hatchery of Edessa. Fry were released into Lakes Vegoritida and Tavropos (Economidis *et al.* 2000a) and into the Rivers Evros (Thrace, north-east Greece) and Acheloos (western Greece) (Economou *et al.* 2007). Established populations in Greece cannot be excluded in the future because they are present in Corsica, Italy, the Czech Republic and southern Germany (Kottelat & Freyhof 2007).

Poecilidae

Eastern mosquitofish (*Gambusia holbrooki* Girard, 1859) were released to control malaria in numerous coastal, islandic and continental swamps in Greece after importation from Italy and France from 1927 to 1937 (cited as *Gambusia affinis* (Baird & Girard, 1853) by Economidis *et al.* (2000a)). However, negative impacts were recorded as a result of feeding competition and aggression towards the native Greek valencia (*Valencia letourneuxi* (Sauvage, 1880)) (Kalogianni *et al.* 2009).

Sailfin molly (*Poecilia* cf. *latipinna* Lesuer, 1821) was recently recorded in Lake Vouliagmeni (suburb of Athens) (Chintiroglou *et al.* 2004) and release of this species possibly occurred through aquarium enthusiasts.

Centrarchidae

Pumpkinseed (*Lepomis gibbosus* (L.)) is a popular aquarium species and was accidentally(?) introduced into some trans-boundary river systems in central Macedonia and Thrace (northern Greece) (Holcik 1991; Economidis *et al.* 2000a; Giapis 2003), as well as into Lake Kastoria, Prespes (north-west Greece), River Alfios (Peloponnesus) (Economou *et al.* 2007) and Lake Tavropos (central Greece) (Bobori *et al.* 2006).

Largemouth bass (*Micropterus salmoides* (La Cepéde, 1802)) have been caught in the Ionian Sea (Corsini-Foka & Economidis 2007) and in the River Acheloos (Economou *et al.* 2007). There are negative ecological consequences from the presence of both species, particularly from *M. salmoides*, because they are aggressive towards cyprinids and their presence has led to population declines in Spain (Kottelat & Freyhof 2007). The aquaculture potential of *M. salmoides* is significant for recreational purposes and as a food fish (e.g. it has been stocked extensively and has formed established populations in dams in the Republic of Cyprus).

Cichlidae

The Nile tilapia *Oreochromis niloticus* (L.) was introduced into a thermal spring at the historical site Thermopyles and into the Kremasta dam of the River Acheloos (western Greece) (Economou *et al.* 2007). Moreover, specimens originating from Israel and Scotland have been imported several times since 1980 to farms close to the cities of Varda, Epidavros (Peloponnesus), Arta (western Greece) and to a monastery close to the city of Nafpaktos (western Greece) (Economidis *et al.* 2000a). The only known established population is located in the lower part of River Arachthos (north-west Greece) and this species overwinters and survives in deep ditches (Costas Perdikaris, unpubl. data, 2010). Moreover, tilapia fry originating from the previous location were unsuccessfully introduced into Lake Pamvotis and into the Aoos dam (north-west Greece) (Athanasios Chantzaropoulos, pers. comm., 2010). Recently, controlled reproduction methods in tanks have been developed at the Department of Aquaculture and Fisheries, Technological Educational Institute of Epirus (north-west Greece) and seed production is readily available. Nile tilapia is farmed throughout Europe in small quantities in warm-water recirculated systems and its potential for small-scale farming is currently under evaluation in the UK (Grady *et al.* 2005). In Greece, Nile tilapia is expected to be a new candidate species for diversification of conventional warm-water aquaculture production (i.e. through integration during the summer grow-out period or in geothermal waters), although the negative impacts of escapees on self-recruiting species can be serious because of inter-specific competition, stunting high density populations and dominant behaviour at the spawning grounds.

Astacidae and Parastacidae

The only known satellite population of the signal crayfish *Pacifastacus leniusculus* (Dana, 1852) exists in the artificial lake of the River Agras (western Macedonia) and it is likely that the population was introduced from Germany (Koutrakis *et al.* 2007; Perdikaris 2009). The population is considered to be 'plague free' because it co-occurs with the native stone crayfish *Austropotamobius torrentium* (Schrank, 1803), which is susceptible to crayfish plague. The aquaculture potential of this species is very promising because market demand cannot be satisfied by natural harvests. There is no aquaculture production of any crayfish species in Greece.

Equal prospects as a food source and as an ornamental species are in place for redclaw (*Cherax quadricarinatus* (von Martens, 1868)), which is available in the aquarium trade (Perdikaris 2009). However, aquaculture exploitation of alien crayfish should be considered with care because uncontrolled imports pose serious threats to stocks of native noble crayfish (*Astacus astacus* (L.)), *A. torrentium* and to the narrow clawed crayfish *Astacus leptodactylus* Eschscholtz, 1823. The release of unidentified gynogenetic crayfish of *Procambarus* spp. in Germany and Holland (Scholtz *et al.* 2003) and its projected invasiveness to watersheds is a recent high-profile example of the intercontinental spread of alien crayfish through the aquarium trade.

Discussion

Globally, 16% of the total finfish aquaculture production from 2000 to 2004 was based on alien species (De Silva *et al.* 2009). The current contribution and future potential of alien fish species in Hellenic inland aquaculture is difficult to quantify precisely and varies greatly from negligible to significant (see the first column in Table 1 for qualitative scoring). For example, commercial species such as rainbow trout, goldfish and to a lesser extent sturgeons are highly appreciated by farmers, markets and hobbyists. Other species with promising future prospects, such as the Nile tilapia and African catfish, could be placed in the middle of this scale. Nevertheless, most alien species are of less interest to aquaculturists, although Atlantic trout, whitefish and pumpkinseed are popular angling targets. In terms of production, the inland aquaculture sector in Greece is hugely dependent on alien species because it has been dominated from the beginning by rainbow trout production. The only indigenous species farmed in low quantities is the common carp, but the origin of the farmed stocks is mostly alien (mainly Hungarian). This is in line with the general trend in Europe (Turchini & De Silva 2008) and contrasts with the situation observed in the Hellenic mariculture sector, which is based primarily on native species and to a lesser extent on introduced stocks (i.e. 'Spanish' sea bream and 'French' sea bass).

From the list of the 30 fish species presented in Table 1, nine alien species (30%) have acclimatized to freshwater after free release in the past (*C. auratus*, *C. gibelio*, *P. parva*, *C. lavaretus*, *S. trutta*, *G. holbrooki*, *P. latipinna*, *L. gibosus and O. niloticus*). However, aquaculture is directly responsible for the establishment of only *P. parva* (via stocking of Chinese carps), *S. trutta* and *O. niloticus*, although imports of *A. japonica* are blamed for indirect harm of *A. anguilla* stocks. Established populations of *C. auratus*, *P. latipinna* and *L. gibosus* probably originated from aquarium or pond stocks. Finally, *C. lavaretus* and *G. holbrooki* were intentionally released for angling purposes and for malaria control, respectively. Nevertheless, the most important introduction pathways for the 270 alien aquatic species recorded in Greece (vertebrates, invertebrates and aquatic plants in all types of aquatic ecosystems) are via trade and aquaculture (Zenetos *et al.* 2009).

Acclimatization success is expected to increase in the future because the impacts of climate change are already present in the ichthyofauna in many places of the world and in many ecosystems (see review by Corsini-Foka and Economidis (2007) on Lessepsian fish immigrants in Hellenic marine and estuarine waters). Mediterranean countries are expected to suffer increased drought periods in the near future (Handisyde *et al.* 2007). This scenario emerges as a major threat for endangered and critically endangered species, particularly in freshwaters (Cochrane *et al.* 2009). Population collapses of species with restricted distribution patterns and narrow ecological requirements are evident in western Greece in the recent past, for example, in *Pseudophoxinus epiroticus* (Steindachner, 1896) in Lake Pamvotis (Perdikaris *et al.* 2005) and *V. letourneuxi* in the River Kalamas system (Kalogianni *et al.* 2009), and the 'retreat' of self-recruiting species is expected to be exploited by already present robust alien species.

Escapes from aquaculture facilities are practically unavoidable in open culture systems. For example, annual catches of rainbow trout have been reported to be equivalent to 2.5–5% of the caged biomass (data cited in Beveridge 1996); however, sound site, species and system selection, the use of triploids as well as effluent control may greatly minimize the ecological impacts. In contrast, there is always a risk of spreading diseases and parasites, therefore translocations of alien specimens between ecosystems should be avoided and further imports must be strictly controlled or at least quarantined for as long as necessary to prove their disease-free status. In particular, the aquarium trade is basically uncontrolled and efforts should be targeted to record imports and distribution within the country. Nevertheless, alien species of desirable aquaculture traits (Nile tilapia and African catfish) may help to diversify inland aquaculture sector production and, moreover, the techniques and methods applied in aquaculture (particularly in the field of hormonal manipulation and artificial propagation) may be valuable in restoring enhancement programmes of self-recruiting species or even in farming efforts of selected indigenous species with aquaculture-desired performances.

Finally, as far as crayfish are concerned, the major threat to self-recruiting species is crayfish 'plague' (*Aphanomyces astaci* Schikora, 1906), which is associated with North American species that are asymptomatic carriers of the mycosis (Alderman 1996). With regard to the 'Australian' parastacidae species, their susceptibility to crayfish 'plague' makes them less threatening to native stocks; however, the largely unpredictable nature of possible impacts (such as the spread of diseases and parasites, rapid growth in increased temperatures and antagonism for food and shelter) require thorough assessment of future imports based on adapted codes of practice (see the flowchart in De Silva *et al.* 2009). Otherwise, aquaculture initiatives should be based either on the three native species or on the 'plague-free' population of signal crayfish that already exists in the country.

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