

# *Carassius gibelio* in Greece: the dominant naturalised invader of freshwaters

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Received: 23 December 2010 / Accepted: 7 April 2011 / Published online: 5 May 2011  
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**Abstract** Ichthyofauna in the Hellenic freshwaters is quite diverse consisted of 161 species (including 28 non-natives), out of the 546 native species in Pan-European level. However, the status of many aquatic ecosystems is currently degraded as a result of a variety of anthropogenic impacts. This has direct reflection on the conservation status of the indigenous and native fish species whose populations are in many cases declining in favor of the invasive ones. Prussian carp (*Carassius gibelio*) is probably the most dominant invasive species and currently is considered as naturalized in about 26 lake and river basins. Its successful adaptation and proliferation is mainly attributed to its dual reproductive mode (allogynogenetic and gonochoristic), the opportunistic-omnivorous feeding habits and the ability to withstand and flourish in adverse ecological conditions. Accordingly, it exerts competitive, as well as destructive effects upon the indigenous fish species (sperm parasitism, antagonism for food, spawning grounds and spawning substrates) and therefore, efforts are needed to sustain a relative balance of the populations. This review aims to critically discuss the status

of *C. gibelio* in Greece, the intrinsic causes of establishment and the observed impacts on ecosystems. Finally, reasonable actions are proposed related to exploitation of *C. gibelio* stocks and a path model for the protection of native fish species and their ecosystems.

**Keywords** *Carassius gibelio* · Distribution · Ecological impacts · Greece · Invasive species · Prussian carp

## Introduction

*Carassius gibelio* has attracted much of attention from aquatic biologists, especially during the last decade. It is an invasive species with widespread distribution via introductions and translocations throughout most of the European countries, possesses an unique reproduction mode involving either allogynogenetic and/or gonochoristic biotypes (or bioforms) and its robustness allows it to withstand particularly adverse environmental conditions. Accordingly, it exerts negative ecological impacts towards the indigenous ichthyofauna (Kottelat and Freyhof 2007) and this trend is expected to develop further in the future given that 37% of the indigenous species are threatened in Greece (IUCN 2010; Legakis and Maragou 2009).

*Carassius gibelio* has been recorded in Greece since at least the late 1970s (Tsoumani et al. 2006)

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and currently, distributes in many continental freshwaters (lotic and lentic ecosystems), in transitional coastal waters of low salinity and even in one lake on the island of Crete (Economou et al. 2007). One of the well-studied populations is that of the Lake Pamvotis in north-western Greece, where its proliferation was apparent since the mid 1990s and followed closely the rapid degradation of ecological quality and the alteration of trophic complexes of the system (Perdikaris et al. 2005; Leonardos et al. 2008a). This situation is sadly typical in most lake ecosystems in the country, coinciding with the displacement of indigenous fish species by *C. gibelio*, due to competition for spawning grounds and feeding resources and sperm parasitism (Paschos et al. 2004). Accordingly, landings of commercially appreciated fish species dwindle steadily, affecting significantly the fishing communities and the related local societies (Perdikaris et al. 2005).

The aim of the present work was to review the status of *C. gibelio* in Greece and to suggest possible initiatives to reduce its negative ecological impacts.

### **Taxonomic status, origin and distribution of *C. gibelio*: Europe and Greece**

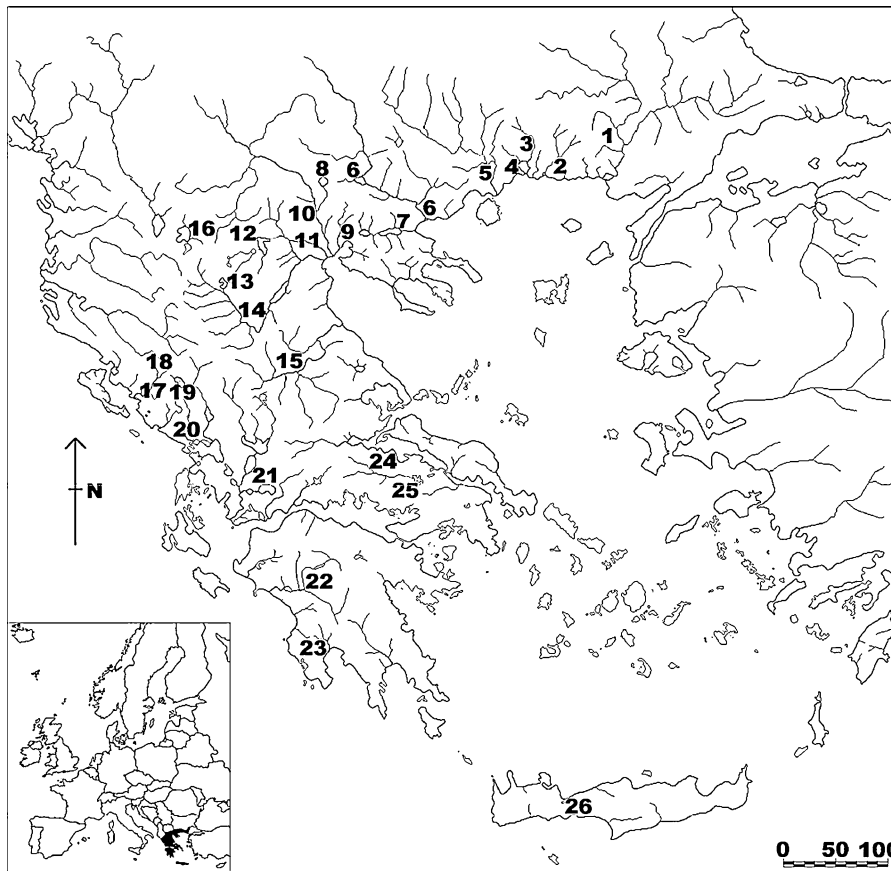
The origin and taxonomic status of *C. gibelio* is still in dispute due to its complex reproduction mode, extensive introductions and translocations, morphological similarity with the brown variety of goldfish (*Carassius auratus*), crucian carp (*C. carassius*) and the presence of hybrid *C. carassius* × *C. auratus* (Pelz 1987; Vasilieva and Vasiliev 2000; Kottelat and Freyhof 2007). It has been proposed that ancient hybridization between female goldfish and male common carp (*C. carpio*) gave rise to the triploid bioform (or biotype) of *C. gibelio* (Chun et al. 2001). Concerning taxonomy, Peñáz et al. (1979) recommended the sub-specific division of goldfish in two forms (*C. a. auratus* and *C. a. gibelio*) and Lelek (1987) described *C. gibelio* as a variety of goldfish. Only recently, *C. gibelio* was recognized as a separate species (Kottelat 1997), but confusion still exists on the common names used in the literature: Prussian carp (e.g., Lamatsch and Stöck 2009), silver crucian carp (e.g., Zhou et al. 2000), crucian carp (e.g., Fan and Liu 1990), gibel carp (e.g., Copp et al. 2005) and European or wild goldfish (e.g., Bobori

et al. 2001; Tsipas et al. 2009), even though Prussian carp is the valid common name (Kottelat and Freyhof 2007).

Regarding its origin, *C. gibelio* is either considered as native from central-eastern Europe to Siberia (Libosvasky 1961) since it fits to a description made by Gessner in 1558, before any known introduction from Asia (Holopainen et al. 1997), or introduced from eastern Asia (Asian taxon according for instance to Copp et al. 2005). Nevertheless, imports of goldfish from the Chinese aquaculture during the period 1611–1691 (Valenciennes 1829–1848) were probably linked to the initial introduction of *C. gibelio* in Portugal and subsequently in England, France and Spain during the seventeenth century (Lever 1996). The second phase of spread apparently took place in the Lower Danube (Romania) during 1912, via natural dispersal down the Danube (Pojoga 1977; Manea 1985). Eventually, its further invasion in Danube was linked to and coincided with the introduction of Chinese carps (Holcik 1980; Navodaru et al. 2002) probably via the Soviet Union during the 1950s, along with transfers of fish from Bulgaria to Hungarian ponds in 1954 to fill a ‘vacant niche’ beside the common carp (Tóth et al. 2005). Expansion in Czech Republic (in the Elbe catchment area) was recently attributed to escapes from aquaculture facilities (as an admixture to common carp fry) and not to upstream auto-migration or spontaneous reproduction (Slavík and Bartoš 2004). Currently, its distribution pattern is almost Pan-European, due to the anthropogenic breakdown of biogeographic barriers, especially in southeastern Europe and the species is considered as naturalized.

*C. gibelio* is present in all Balkan countries neighboring to Greece: Albania (Rakaj and Flloko 1995; Shumka et al. 2008), Former Yugoslavian Republic of Macedonia (FYROM) (Talevski et al. 2009), Bulgaria (Stefanov 2007), Turkey (Kalous et al. 2004; Oezulug et al. 2004; Innal and Erk’akan 2006; Ozcan 2007) and practically in most of the transboundary inland waters (Rivers Evros, Nestos, Strymonas and Axios and Lakes Doirani and Prespes) (Economou et al. 2007) (Fig. 1).

It was suggested that the species was initially introduced in the Hellenic freshwaters during the late 1970s (Tsoumani et al. 2006) or during the 1980s from Hungarian hatcheries (Economidis et al. 2000). However, more recent studies reported that the



**Fig. 1** Distribution of *C. gibelio* in the freshwater ecosystems of Greece (1 R. Evros, 2 R. Filiouris, 3 R. Kompsatos (reported but unconfirmed presence), 4 L. Vistonida, 5 R. Nestos, 6 R. Strymonas and L. Kerkini, 7 L. Volvi (including Koronia), 8 L. Doirani, 9 R. Gallikos, 10 R. Axios, 11 R. Loudias, 12 L. Vegoritida (including the Lakes Zazari, Petron, Chimatitida), 13 L. Kastoria, 14 R. Aliakmonas, 15 R. Pinios, 16 L. Prespes, 17 R. Kalamas, 18 L. Zaravina, 19 L. Pamvotis, 20 R.

Louros, 21 R. Acheloos (including the Lakes Trichonida, Lycimachia, Ozeros and Amvrakia), 22 R. Alfios, 23 R. Parnassos (reported but unconfirmed presence), 24 R. Kifissos, 25 L. Yliki, 26 L. Kourna (R river; L lake; data compiled from Economidis et al. 2000; Tsoumani et al. 2006; Economou et al. 2007; Papadimitriou et al. 2010; Tsipas et al. 2009; hydrographic background modified from Economidis 1995; scale in km)

species was either translocated from the Lake Kerkini to the Lake Pamvotis or introduced from Italy to the same lake during the 1950s or a bit later (Leonardos et al. 2008a). It has been even proposed that the populations originate from China via the Albanian waters (Liasko et al. 2010). The species was also reported with cautiousness as self-recruiting in the north-eastern part of the country (Economidis et al. 2000) and particularly in the River Strymonas (artificial Lake Kerkini) and Rivers Evros and Kompsatos (Economou et al. 2007). According to Economou et al. (2007) “the status of *C. gibelio* with respect to its being native in Greece is still unresolved and controversial”. In a recent study,

the genetic diversity of lake populations of *C. gibelio* in western Greece was assessed using mitochondrial genetic markers (Tsipas et al. 2009). It was actually found to be low, even though two genetically distinct populations were identified, suggesting that the founder populations might be of non-native origin. Nevertheless, the origin issue requires extensive molecular work to be resolved.

The species apparently has established self-recruiting populations in at least 24–26 hydrographic basins (lentic and lowland lotic systems), representing about 19% of catchments throughout continental Greece, including the island of Crete (Fig. 1). Accordingly, the species is rated as top 3rd introduced—

translocated species in the country (Economou et al. 2007), only after Eastern mosquitofish (*G. holbrooki*) and rainbow trout (*O. mykiss*); however, on the grounds of adaptability, capability of establishment and invasiveness, *C. gibelio* is at least equally efficient to pumpkinseed (*L. gibbosus*), pseudorasbora (*P. parva*) and eastern mosquitofish (Zenetos et al. 2009).

The lag phase of range expansion was evident during the last 2–3 decades along with frequent translocations and transfers of cyprinids (mainly common carp) for aquaculture purposes and (re)stocking enhancement [e.g., transfer of common carp fry from Plovdiv (Bulgaria) to Macedonia and Thrace in Greece during the 1980s and 1990s (Hubenova pers. comm. 2010); see also Economidis et al. (2000) for relevant data on the introductions and releases of common carp, goldfish, Chinese carps and tench (*T. tinca*) in the Hellenic fresh waters]. This expansion is still on-going in most invaded aquatic environments, where *C. gibelio* now flourishes.

### Physiological adaptations and biological strategies: keys to dominance

Dominance of *C. gibelio* is attributed to the wide environmental tolerance and flexible/adaptable biological strategies such as: omnivorous feeding habits [opportunistic feeding on detritus and zoobenthos (Peñáz and Kokes 1981; Specziár et al. 1997) and particularly on gastropods, dipterans, cladocerans, copepods and ostracods (Balik et al. 2003)], exploitation of variable habitats (slow running lotic, lentic and transitional systems with low salinity), intense reproductive activity, complex reproductive modes including sperm parasitism and finally active antagonism for food, spawning grounds and spawning substrates (Paschos et al. 2004; Leonardos et al. 2008a, b). The fact that the species has practically minimal commercial value makes it a marginally desirable fishing target and fishing pressure is inevitably directed to other sympatric species.

#### Environmental tolerance

*Carassius gibelio* species are able to survive and thrive in adverse and frequently eutrophic environmental conditions, where other species rarely

succeed, showing remarkable hypoxia-anoxia (through metabolic depression; Lushchak et al. 2001) and ammonia tolerance. Under experimental conditions, *C. gibelio* continues to exhibit growth (0.91% SGR) at ammonia concentrations of 8 mg l<sup>-1</sup> and mortality is not evident even at concentrations as high as 12.5 mg l<sup>-1</sup> (at pH 8.6) (Nathanailides et al. 2003). The species successfully withstands degraded conditions as it survives during extreme episodes/periods of dense cyanobacterial blooms threatening all forms of aquatic life. It actually accumulates microcystins at concentrations up to 902 ng g<sup>-1</sup> primarily in the liver (due to the *first pass effect*) and secondarily in other tissues such as the kidney, intestine, muscle, ovaries and brain (Gkelis et al. 2006; Kagalou et al. 2008; Papadimitriou et al. 2010), showing resistance to intoxication. Concerning temperature, *C. gibelio* exhibits rapid growth and development under favourable thermal conditions and is able to withstand extremes from close to freezing up to 30°C (Antonova 2010). Hibernation and fasting close to the bottom of lakes has been proved for crucian carp in Northern Europe (Holopainen et al. 1997) and it is also a possibility in Greece, especially when the lakes are covered with ice during extreme cold winter temperatures. Overwintering is followed rapidly by intense feeding activity and gonadal growth before the beginning of the spawning period in early spring in the Hellenic climatic conditions (Paschos et al. 2001; Leonardos et al. 2001).

#### Reproductive peculiarities

*Carassius gibelio* exhibits fast growth during the first 2–3 years of life which slows down when puberty starts (Leonardos et al. 2001, 2008b). In the Hellenic conditions, it reaches maturity during the second year of its life, from March to the end of July in the southern parts of the country, and its maximum age were recorded at 6 years in Lakes Lysimachia and Chimaditida (Leonardos et al. 2001, 2008b). In the case of Lake Pamvotis, spawners approach the peripheral shallow spawning grounds at temperature range of 12–14°C (March and April) and leave them for deeper waters at temperatures above 14°C and below 10°C (Paschos et al. 2001). This period does not overlap (or marginally overlaps according to Liasko et al. 2010) with the spawning period of common carp (end of May at 16–18°C), but coincides

with the presence of Acheloos roach (*R. panosi*) spawners, goldfish, and possibly with the critically endangered tsuma (*P. epiroticus*) (Paschos et al. 2004; Liasko et al. 2010).

Its unique reproduction mode among teleosts is due to the coexistence of sexuality (gonochoristic or bisexual reproduction) and asexuality (unisexual gynogenetic reproduction) (Fan and Liu 1990; Fan and Shen 1990; Gui et al. 1993a; Gui 1996, 1997). All other unisexual species (at least 50 in lower vertebrates; Vrijenhoek et al. 1989) reproduce either sexually or asexually (by gynogenesis or hybridogenesis) and never both.

Revealed karyotypes are rather diverse even within the same ploidy levels ( $2n = 94$ ;  $3n = 141$ – $162$ ;  $4n = 200$ – $214$ ). Some populations or biotypes were early identified as diploids of both sexes (Cherfas 1966). Other populations consist of diploids and reduced number of tetraploids of both sexes (Gui et al. 1993b), often together with triploid females and many populations are consisted of all-female allogynogenetic triploids or most frequently of skewed female allogynogenetic triploids (Peñáz et al. 1979; Zhou and Gui 2002; Flajshans et al. 2007) along with triploid and less frequently allotetraploid males (Liasko et al. 2010). In the case of Lake Pamvotis for instance, three different gynogenetic clones have been identified with distinct morphological features, growth, age structure, proportions of males in each clone, heterogeneity, peak-time of approaching to the spawning grounds and overall clone prevalence among the population of *C. gibelio* (Moutsaki et al. 2006; Liousia et al. 2008). Collectively, females were triploids ( $n = 156$ ,  $158$  or  $162$ ) and males were either triploids ( $n = 156$  or  $158$ ) or tetraploids ( $n = 200$ – $214$ ), the later in a 4.3:5.7 ratio (Liasko et al. 2010).

Allogynogenesis is a striking case of gynogenesis observed only in *C. gibelio* and the degree of paternal contribution to the progeny in triploid biotypes varies significantly. It has been experimentally demonstrated that female triploids are sperm parasites capable of using sperm from common carp, goldfish, crucian carp, roach (*R. rutilus*), Acheloos roach (*R. panosi*), ide (*L. idus*) and bream (*A. brama*) (Yu 1982; Jiang et al. 1983; Paschos et al. 2004; Lusková et al. 2010) to trigger embryogenesis (typical gynogenesis). The heterologous sperm was thought to be practically unable in contributing to the phenotype of

the gynogenetic offspring (Jiang et al. 1983; Zhou et al. 2000), leading to genetically identical triploid all-female offspring (clones). However, in few cases micro-chromosomes of paternal origin were recently detected in the offspring, leading to phenotypic similarity (Yi et al. 2003), as well as the entire paternal haploid set of chromosomes [Zhu and Gui 2007; Liasko et al. (2010) for allotetraploid males].

In the Lake Pamvotis, a minor portion (<1–4%) of males has been reported (Paschos et al. 2001; Tsoumani et al. 2006; Liousia et al. 2008; Liasko et al. 2010) of both triploid and tetraploid status (Liasko et al. 2010). Low proportions of males have been also recorded in the Lakes Koronia (6%) and Doirani (7.8%) in northern Greece (Tsoumani et al. 2006), similarly but a bit lower compared to reports from China (up to 20% males; Jiang et al. 1983; Gui et al. 1997) and Europe (Lusková et al. 2010). It is hypothesized that intaspecific sperm contribution (as a supply source) is overall minimal (Paschos et al. 2004), although males are present in the spawning grounds and actively participated to the fertilization process (Liasko et al. 2010). Controlled reproduction experiments with homologous sperm (i.e., from the same species) showed great variability in sperm fertility (fertilization rate) and all progeny produced were females (Liasko et al. 2010). Contrary to that, males occurred in the offspring reproduced by inseminating eggs from gynogenetic females with homologous sperm in Chinese clones (Jiang et al. 1983). Therefore, genetic recombination (contribution of homologous sperm) may take place (*allogynogenesis*), similarly to gonochoristic reproduction (Zou et al. 2001). Accordingly, production of genetically diverge offspring is also possible in natural populations of biased sex ratio. Apparently, this skewed sex ration is maintained in the offspring due to imprinting or ploidy effects (Zhou et al. 2000). Alternatively, production of triploid males in the offspring may involve environmentally-socially-related sex determination mechanisms (Devlin and Nagahama 2002; see also relative discussion in Liasko et al. 2010). Nevertheless, *C. gibelio* is able to explore a variety of mating options from unisexual (allogynogenetic using heterologous sperm with or without paternal gene flow), to ‘typical’ bisexual reproduction. The above modes do not exclude each other in the same habitat and probably for the same clone(s) (or even for the ova of a single specimen)

and they seem to co-evolve quite flexibly. Actually, a transformation process from single-sex to mixed population type has been observed in the case of Dyje-Morava population of *C. gibelio* in Czech Republic (Lusková et al. 2010), from 0% in 1990 to up to about 29% in 2004 and at the same period, ploidy status also changed in favour of the diploid specimens. The advantages of this duality are rather significant since pure gynogens have the advantages of rapid growth and massive spawning and at the same time the deleterious effects of harmful mutations are ameliorated and genetic variation is secured by gonochoristic reproduction and allogynogenetic reproduction with various degrees of paternal contribution.

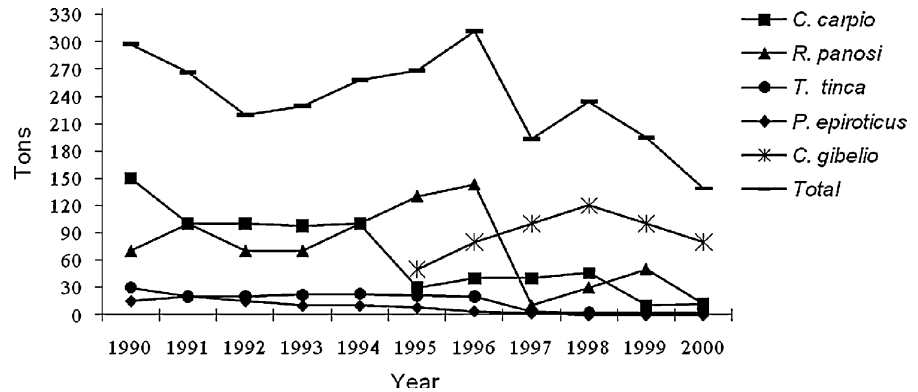
### Impacts on ecosystems

Since invasion is in many cases a long process of overcoming barriers (geographic, environmental, reproductive and dispersal; Richardson et al. 2000), *C. gibelio* can be characterized as one of the most successful aquatic invader. Man-made intervention helped *C. gibelio* in many cases to overcome the boundaries between drainage basins (e.g., translocation of *C. gibelio* from Lake Doirani to Lake Chimatidida in the mid-1980s; Leonardos et al. 2008b), especially in Greece where hydrographic interconnections between different drainages are limited, compared for example to central Europe. Moreover, *C. gibelio* is particularly aggressive in occupying new areas, exerting competitive, as well as destructive, effects upon the indigenous ichthyofauna (e.g., Gaygusuz et al. 2007). It has been accused for rapid changes in biodiversity and alteration of the trophic chain complexity (Leonardos et al. 2008a). Reported declines of crucian carp in north-western parts of the country were suspected to happen due to competition by *C. gibelio* (Economidis et al. 2000), similarly to what happened to the Danubian stocks of crucian carp. Actually, its presence suggests widely observed shifts, from clear to turbid water preferring species in many aquatic ecosystems and alteration of nutrient flows. At the same time, declines of top predators/piscivorous fish such as native trout species and European catfish (*S. glanis*) and reduced competition for food by the rest of the species may further favored the explosion of *C. gibelio* populations in

Greece, as it was reported in Esthonia (Vetemaa et al. 2005), given the intrinsic adaptive advantages of the species. According to Zenetos et al. (2009), the introduction of *C. gibelio* has caused severe problems to fisheries in several lakes in Greece, because of altered community structure and net-clogging. The practically uncontrolled trade and movements of fish (Economidis et al. 2000; Zenetos et al. 2009) and various aquatic animals (e.g. crayfish; Koutrakis et al. 2007) pose additional serious threats to the biological integrity of the freshwater ecosystems. In the case of Lake Pamvotis, *C. gibelio* already dominates in fisheries landings (e.g. 120 tons in 1998, representing 57% of the total landings; Perdikaris et al. 2005), while species of commercial interest such as common carp, European eel (*A. Anguilla*) and tench have seriously declined and the indigenous species are currently rare [Pamvotis chub (*S. pamvoticus*) and strossidi (*L. albanicus*); Leonardos et al. 2008a] or close to extinction (*P. epiroticus*; Perdikaris et al. 2003, 2005; Leonardos et al. 2007, 2008a) (available data are presented in Fig. 2). According to the most recently available unpublished data for 2011 in the Lake Pamvotis, *P. epiroticus*, *L. albanicus* and tench catches are non-existent and daily catches for common carp are about 2 kg. However, even *C. gibelio* is directly and strongly involved to this changing structural pattern in the aquatic community, this cannot be exclusively attributed to its presence. It is primarily a result of a long process of environmental degradation due to human generated pressures (e.g. irrigation, agrochemical runoffs, sewage disposal and industrial pollution), over-fishing during the spawning season, significant reduction of inflow of spring water and degradation of spawning habitats, fluctuations of water level, proliferation of the reed zone (*Phragmites* sp.) and reduction of submerged macrophytes (Kagalou et al. 2001; Paschos et al. 2004; Kottelat and Barbieri 2004).

Accordingly, the observed 'retreat' of native species is expected to be exploited by the already present robust aliens, including *C. gibelio* (Perdikaris et al. 2010), although there is evidence that the reduction of large zooplankton forms in hypereutrophic shallow lakes also negatively affects the growth of *C. gibelio*, compared to less eutrophic systems (Tsoumani et al. 2006). The number of threatened species sympatric to *C. gibelio* range from 50 to 100% out of the total number of native species

**Fig. 2** Annual fisheries landings in Lake Pamvotis during 1990–2000, including *C. gibelio* (modified from Perdikaris et al. 2005)



in 5 basins (Prespes, Pamvotis, Kifissos, Yliki and Kourna) from 25 to 39% in 9 basins (Kompsatos, Kastoria, Pinios, Kalamas, Zaravina, Louros, Acheoos (including the Lakes Trichonida, Lycimachia, Ozeros and Amvrakia), Alfios and Pamissos) and 7.7–22% in 12 basins (Evros, Filiouris, Vistonida, Nestos, Strymonas (including the Lake Kerkini), Volvi (including the Lake Koronia), Doirani, Gallikos, Axios, Loudias, Vegoritida (including the Lakes Zazari, Petron, Chimatitida) and Aliakmonas) (Fig. 3). Moreover, in Lake Pamvotis for instance, the similarity value of fish fauna between 1920s (undisturbed fish fauna) and 2005 was calculated at 14% (Leonardos et al. 2008b) and this trend is expected to develop further in the future, since 25 freshwater teleost species are critically endangered in Greece, including eight cyprinid species (Economou et al. 2007; Kottelat and Freyhof 2007; Legakis and Maragou 2009).

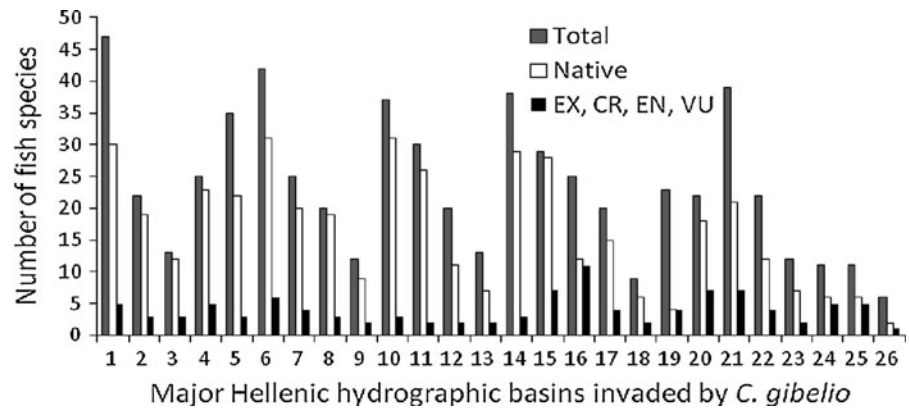
In financial terms, the annual economic losses due to habitat alterations and various impacts on native fish species and other aquatic biota has not been yet estimated in Greece. The various costs of the 138 recorded exotic fish species in the United States were estimated annually at \$5.4 billion (Pimentel et al. 2005). In general, the cumulative cost of invasive species to agriculture, forestry, fisheries and other water uses, utilities, buildings and natural areas (including control spending) of the previous country for the period 1906–1991 was estimated to between \$97 and 137 billion (Lovell and Stone 2005). Finally, in the mid run, climate changes is expected to overtake the effects of non-climatic anthropogenic disturbances (Daufresne and Boët 2007) and further stress the populations of endangered freshwater fish species with deteriorating status, fragmented

and limited distribution and narrow ecological preferences.

## Discussion

The increasingly documented negative impacts of alien species on native fish and ecosystems has led the scientific community to develop risk assessments tools for species introductions, establishment possibilities, expansion, biodiversity threats and ecological impacts (Copp et al. 2009; Mastitsky et al. 2010). Beyond this, in the case of an established species such as *C. gibelio*, any possible direct measure is welcomed aiming to sustain a relative balance of the populations. Selective intensive fishing efforts both in the shallow parts during the spawning period and in the deeper parts of the lakes during the rest of the time have been proposed (Paschos et al. 2004). This practice was recently adopted by fishermen in Lake Pamvotis, who export large amounts of *C. gibelio* to the Romanian market (at least 1.5 tons are exported at a daily base only from the Lake Pamvotis). This practice was also adopted in many lakes of northern Greece, where landings practically depend on *C. gibelio* and at the same time a dramatic decline of all other commercially valuable species is evident. Another ecologically sound measure would be the exploitation of fully mature *C. gibelio* for the extraction of their pituitaries which have been proved valuable to the induction of spawning in cyprinids [potency and hormonal compatibility were recently demonstrated in common carp (Kosti et al. 2008; Perdikaris et al. 2007) and in goldfish (Vavatsikos 2009)]. Other options such as small scale fish meal, on-farm fish feed, livestock and pet feed and fish

**Fig. 3** Native and threatened fish species in the Hellenic aquatic ecosystems invaded by *C. gibelio* [*x*-axis refer to basins of Fig. 1; *EX* extirpated, *CR* critically endangered, *EN* endangered; *VU* vulnerable; data compiled from Economou et al. (2007); IUCN (2010); Legakis and Maragou (2009)]



silage production (Tatterson and Windsor 2001) should be examined. In any case, both forage fish populations and the pet food industry would be benefited from such an alternative protein source currently underexploited (for example, domestic cats consume more fish (13.7 kg year<sup>-1</sup>) than the average Australian person (11 kg year<sup>-1</sup>); data cited in De Silva and Turchini 2008).

Since eradication is virtually impossible in established species and mitigation measures in most cases doubtful, efforts should be targeted primarily to prevent the importation of new aliens, avoid further translocation of existing ones and protection-restoration of native species and their habitats. Action plans including environmental costs to protect threatened species and their habitats and policy enforcement accompanied by adequate economic resources should take place (Bobori et al. 2001). Strict application of recent legislative tools such as the 708/2007 (EC) directive for the use of alien and locally absent species in aquaculture would further control imports and movements of fish, including *C. gibelio*. These are particular urgent for the most of Hellenic inland waters given the fact that Water Framework Directive (2000/60/EC) requires “good ecological status” and “good chemical status” of surface and ground waters by the year 2015. In the case of lakes, most of them are currently disturbed in Greece (i.e., fall into the ‘poor’, ‘bad’ or ‘moderate’ water quality classes based on pH, chlorophyll-*a* concentration, Secchi depth, total phosphorus, high proportion of cyanobacteria in phytoplankton communities and limited macrophyte coverage).

A path model for the protection of native species and their habitats is urgently needed (e.g., Saunders et al. 2002), including continuous monitoring of the

distribution of alien, naturalized and native species, habitat restoration, re-establishing efforts for extirpated native populations, designation of species protection areas (SPAs), no-go areas and ark sites. Indirect measures such as environmentally-friendly crop farming methods and sound water management for irrigation purposes (Kagalou and Leonardos 2009), as well as a system-specific application of biomanipulation methods (particularly from ‘top to down’ control practices using for example top predatory species such as the European catfish) would be particularly beneficial. Moreover, reducing extreme water level fluctuations in lake ecosystems, increasing spring water inflows, protecting spawning grounds and submerged vegetation, controlling escapes of alien farmed species and translocation of livestock facilities from the catchment basins would reduce current pressures. Finally, public education and environmental sensitization, closer co-operation between scientists, policy makers, administrative staff, local societies and fishermen, thorough re-evaluation of the national legislation framework for aquatic organisms-ecosystems, integration of different sector common EU policies (agricultural, fisheries, environmental, etc.) and interstate co-operation should be involved in a mid-long term plan.

Conclusively, *C. gibelio* presents a serious threat to native and particularly to endangered freshwater fish species in Greece and should be taken under consideration in a broader strategy aiming to control the spread and the impacts of invasive aquatic species and ultimately to protect and restore inland ecosystems. This does not imply that any reduction of *C. gibelio* populations will restore the ecosystems, however, its presence contributes to degradation in a decisive way. Accordingly, the presence of *C. gibelio*



should be realized both as a warning alert and a reliable bioindicator of ecological status, particularly in lakes.

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