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## Italian aquaculture and the diffusion of alien species: costs and benefits

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1 Italian aquaculture and the diffusion of alien species: costs and benefits

2

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28 **Abstract**

29 The aim of this review is to clarify the relation between Italian aquaculture and the  
30 introduction on alien species in Italy. In Italy the most common aquatic alien species are  
31 rainbow trout and Manila clam and they represent main economic product of Italian  
32 aquaculture. Wels catfish and red clawed crayfish have been voluntarily or involuntarily  
33 introduced for aquaculture scope and they are now the most invasive alien aquatic  
34 species. Other alien naturalized species, as some salmonid species, are important  
35 economic resources in North Italy for inland professional fishery and are considered  
36 worthwhile of conservation. Thus, aquaculture is directly or indirectly responsible of the  
37 introduction of several alien species in Italy, but its effect on alien species diffusion is  
38 peculiar, as few successfully farmed species have become rapidly common. Until now  
39 conventional aquaculture has played main role in the diffusion of alien species in Italy,  
40 while ornamental aquaculture will be the main source of alien introductions in the  
41 future.

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## 48 **Introduction**

49 Biological invasions are indissolubly related with human society (Simberloff , Martin,  
50 Genovesi, Maris, Wardle, Aronson, Courchamp, Galil, Garcia-Berthou, Pascal, Pysek,  
51 Sousa, Tabacchi & Vila 2013; Bellard, Thuiller, Leroy, Genovesi, Bakkenesk &  
52 Courchamp 2013; Essl, Dullinger, Rabitsch, Hulme, Hülber, Jarošíke, Kleinbauer,  
53 Krausmann, Kühn, Nentwig, Vilà, Genovesi, Gherardi, Desprez-Loustau, Roques &  
54 Pyšek 2011). In particular, in the aquatic ecosystems these invasions are caused by alien  
55 species that are species introduced to areas beyond their natural range of distribution by  
56 humans, directly or indirectly. Aquaculture plays a key role in alien species diffusion at  
57 international level (Casal 2006; De Silva, Nguyen, Turchini, Amarasinghe & Abery  
58 2009; Diana 2009; Turchini & De Silva 2008), FAO database on introductions of  
59 aquatic species (DIAS) shows that aquaculture is worldwide the most often cited reason  
60 for alien fish species introduction (FAO, 2009), (Gherardi, Bertolino, Bodon, Casellato,  
61 Cianfanelli, Ferraguti, Lori, Mura, Nocita, Riccardi, Rossetti, Rota, Scalera, Zerunian &  
62 Tricarico 2008). Aquaculture can also increase the diffusion parasites from reared fish  
63 to wild ones (Krkosek, Gottesfeld, Proctor, Rolston, Carr-Harris, & Lewis 2007). From  
64 the quantitative point of view, aquaculture and restocking activities are the main causes  
65 of introduction of alien species in Europe, as showed by IMPASSE (Impacts of Alien  
66 Species in Aquaculture) project funded by EU Sixth Framework Programme in 2008.  
67 Some alien species were initially reared and successively escaped in the wild, as  
68 goldfish or catfish or red claw crayfish, others unintentionally transferred with target  
69 farmed species as wels catfish, others deliberately released in the natural environment,  
70 as Manila clams. In Italy, the greater part of freshwater alien species have been  
71 introduced primarily for angling and secondarily for aquaculture scopes, while marine  
72 alien species have arrived by international maritime trade or penetration through Suez

73 Canal (lessepsian species) (Andaloro, Falautano, Perzia, Maricchiolo & Castriota 2012).  
74 Consequently, the geographical distribution of aquatic alien species in Italy markedly  
75 differs in marine and freshwater ecosystems. The great number of marine species were  
76 introduced in the 1980s and 1990s in the lagoon of Venice (NE Italy) and in the gulf of  
77 Taranto (SE Italy) that are considered “hot spot” of xenodiversity. These introductions  
78 were mainly caused by the intercontinental naval traffic due to tourism, commerce and  
79 the presence of an Italian Navy base in Taranto (Felline, Caricato, Cutignano, Gorbi,  
80 Lionetto, Mollo, Regoli & Terlizzi 2012; Occhipinti-Ambrogi, Marchini, Cantone,  
81 Castelli, Chimenz, Cormaci, Frogliola, Furnari, Gambi, Giaccone, Giangrande, Gravili,  
82 Mastrototaro, Mazziotti, Orsi-Relini & Piraino 2011). Moreover, it should be  
83 considered that Italy has about 7,000 km of coastline and a central position in  
84 Mediterranean, these facts naturally expose to marine alien species invasion. Between  
85 1945 and 2009, 165 alien marine species have been recorded in Italy, mostly originating  
86 from tropical regions of the world (Occhipinti-Ambrogi *et al.* 2011) while 112  
87 established alien aquatic species have been recorded in inland waters (Gherardi *et al.*  
88 2008). The Italian Ministry of the Environment has published an atlas of Mediterranean  
89 alien species ([http://www.sidimar.tutelamare.it/distribuzione\\_alieni.jsp](http://www.sidimar.tutelamare.it/distribuzione_alieni.jsp)).  
90 Meroplanktonic microscopic larvae naturally favor the spread of aquatic alien species,  
91 both in marine than in inland water ecosystems. Marine species are often transferred  
92 along great distances, principally by means ballast waters and keel fouling. The  
93 voluntary release of fish for recreational fishing or aquaculture, in particular in  
94 freshwater ecosystems, is particularly diffused in Italy where controls on legal and  
95 illegal stocking have been largely ineffective in the past (Gherardi *et al.* 2008).  
96 Moreover, ornamental aquaculture is an emerging sector that has caused several alien  
97 species introduction, particularly in western countries (Rhyne, Tlustý, Schofield,

98 Kaufman, Morris & Bruckner 2012). In Italy, the shortage of clear rules, the increase of  
99 internet trade (Mazza *et al.* 2015) and the continuously increasing number of  
100 ornamental species favors illegal trade and international black market (Mazza,  
101 Tricarico, Genovesi & Gherardi 2013). In general terms, it is very well known that  
102 animal farming is one of the principal direct or indirect cause of diffusion of alien  
103 species, but it should be also remembered the economic relevance of animal farming  
104 and aquaculture (Diana 2009; Perdikaris & Paschos, 2010). Considering the close  
105 relation between the introduction of aquatic alien animal species and aquaculture  
106 activities, this review is principally focused on the clarification of the role of Italian  
107 aquaculture in the diffusion of alien species in Italy.

108

### 109 **Freshwater fish**

110 In general, the most common alien Italian species of freshwater fish is the rainbow trout  
111 (*Onchorynchus mykiss*) (Table 1). It was introduced in the beginning of 20<sup>th</sup> century and  
112 currently is the first species for Italian aquaculture; in 2013 the rainbow trout production  
113 in Italy accounted for 136.5 Mln € (Italian Association of fish farmers, [http://www.api-  
114 online.it/index.cfm/en/home](http://www.api-online.it/index.cfm/en/home)). Rainbow trout doesn't make natural reproduction in Italy,  
115 consequently its presence is exclusively dependent from artificial restocking, with  
116 exception of a population in Trentino region (NE Italy). Its impact on native salmonids  
117 species is related to competition with native species and potential diffusion of diseases.  
118 Salmonids are generally considered high value species in Italy and several introductions  
119 have been attempted in the last decades. Some species of salmonids have been  
120 introduced in the late 60's in some alpine lakes and rivers in North Italy, such as arctic  
121 charr (*Salvelinus alpinus*), native to Artic region and Brook trout (*Salvelinus fontinalis*)  
122 native to North America (Magnea, Sciascia, Paparella, Tiberti & Provenziale 2013).

123 European whitefish, *Coregonus lavaretus* and *C. macrophthalmus*, are zooplanktophagus  
124 salmonid imported in Italy from North Europe at the beginning of 20<sup>th</sup> century and  
125 currently acclimatized in some great lakes in the Italian alpine region (Regione  
126 Lombardia, 2014) (Figure 2). All the catfish currently present in Italy are alien, some  
127 species are naturalized and farmed. Black bullhead catfish (*Ameiurus melas*) and  
128 channel catfish (*Ictalurus punctatus*) native to North America and brown bullhead  
129 catfish (*A. nebulosus*), native to North America, colonized Italian freshwater  
130 ecosystems. Black bullhead catfish and channel catfish and are important species for  
131 aquaculture in Central Italy. Wels catfish (*Silurus glanis*) was reported as accidentally  
132 escaped from angling ponds in 1956 (Gandolfi & Giannini, 1979). After an initial phase  
133 of expansion, in the 1980s it became established in the Po basin in North Italy  
134 (Gandolfi, Zerunian, Torricelli & Marconato 1991) and in the Tiber Arno rivers, in  
135 Central Italy (Figure 1). Several cyprinids have been recently introduced in Italy as the  
136 common bream (*Abramis brama*) and *Pseudorasbora parva* (Volta, Jeppesen, Leoni,  
137 Campi, Sala, Garibaldi, Lauridsen & Winfield 2013). The common roach (*Rutilus*  
138 *rutius*), recently introduced by Danube basin, has stably colonized Maggiore and  
139 Lugano lakes, that are among the bigger Italian lakes (Regione Lombardia, 2012). The  
140 most invasive cyprinid is the asp (*Aspius aspius*) (Zerunian, Goltara, Schipani & Boz  
141 2009), introduced in Italy from central Europe, the only example of carnivorous  
142 cyprinid that stably colonized some areas of Po river basin and currently considered a  
143 species highly appreciated for recreational fishing. Few species of Asian alien ciprinids  
144 are occasionally farmed in Italy: grass carp (*Ctenopharingodon idellus*), bighead carp  
145 (*Hypophthalmichthys nobilis*) and silver carp (*Hypophthalmichthys molitrix*).  
146 Largemouth bass (*Micropterus salmoides*) has been introduced in Italy at the beginning

147 of 20<sup>th</sup> century, it is an active predator that inhabits lentic waters (Marinelli, Scalici &  
148 Gibertini 2007; Zerunian *et al.* 2009).

#### 149 **Marine fish**

150 Due to the mentioned geographical reasons, the situation of alien marine fish species is  
151 radically different from freshwater and there are several alien fish species with low or  
152 unknown impact. Until December 2011, 48 fish alien species have been recorded along  
153 Italian coasts, of which only one species is probably originated by aquaculture  
154 (Occhipinti-Ambrogi *et al.* 2011). Between the alien marine species, some Carangidae  
155 species recently arrived along Italian coasts, as *Seriola carpenteri*, *S. fasciata* and  
156 particularly *S. rivoliiana* (Andaloro *et al.* 2012), are potentially interesting for farming,  
157 similarly to *S. dumerilii*, fish currently farmed in Japan. In other Mediterranean  
158 countries, the presence of some alien species is already considered an opportunity for  
159 aquaculture, for example in Cyprus, where a lessepsian fish, rabbit fish (*Siganus*  
160 *rivulatus*) is actively farmed (Stephanou & Georgiou, 2000). Differently from  
161 freshwaters, marine finfish aquaculture in Italy is based on Mediterranean species:  
162 European sea bass (*Dicentrarchus labrax*) and gilthead sea bass (*Sparus aurata*).

163

#### 164 **Freshwater invertebrates**

165 One of the most invasive alien species recently introduced in Europe and in Italy is the  
166 red swamp crayfish (*Procambarus clarkii*) (Aquiloni *et al.* 2010), that is listed among  
167 the 100 worst invasive alien species (DAISIE 2008). It that has been introduced for  
168 farming in the 1980s from Atlantic coasts of North America (Figure 1). Between  
169 bivalves, a particularly invasive species is zebra mussel (*Dreissena polymorpha*) that  
170 was introduced in Garda lake at the end of '60 and successively had a rapid diffusion in



171 other Italian lakes (Binelli *et al.*, 1997; Lancioni and Gaino, 2006). Asian basket clam,  
172 (*Corbicula fluminea*), native to Southeast Asia has become a serious treat for freshwater  
173 bivalves of North America and successively introduced in Europe (Araujo, Moreno &  
174 Ramos 1993). Similarly to red swamp crayfish, *C. fluminea* is also listed among the 100  
175 worst invasive alien species. It was initially found in the Po River in the late 1990's and  
176 rapidly invaded many waterways in Northern Italy and arrived in the largest Italian  
177 lakes, Garda lake and Maggiore lake (Kamburska, Lauceri, Beltrami, Boggero,  
178 Cardeccia, Guarneri, Manca & Riccardi 2013b). Another freshwater alien bivalve  
179 introduced in Italy is Chinese pond mussel (*Sinanodonta woodiana*) which is an  
180 unionids endemic to China (Colomba, Liberto, Reitano, Grasso, Di Franco & Sparacio  
181 2013; Lancioni & Gaino 2006; Kamburska, Lauceri & Riccardi 2013a). Between  
182 freshwater gastropods, the most invasive species is probably the mud snail  
183 *Potamopyrgus antipodarum*, native to New Zealand, that has colonized all regions of  
184 Italy, except Sardinia (Mazza, Agostini, Aquiloni, Cianfanelli, Tricarico & Gherardi  
185 2011), reaching in some cases densities of 800,000 individuals/m<sup>2</sup>.

## 186 **Marine invertebrates**

187 Marine alien invertebrate species are the largest and diversified group of alien species in  
188 Italy. These include crustaceans, ascidians, ctenophore, bryozoans, cnidarians,  
189 decapods, mollusks and polychaetes for a total number of 401 species (Andaloro *et al.*  
190 2012). The lagoon of Venice is the Italian hotspot for marine invertebrate xenodiversity:  
191 39 species, including 9 mollusks, and 9 crustaceans. Crocetta (2012) stated that marine  
192 mollusks is the group with the highest number of marine alien species in Italy: 35  
193 species including 18 Gastropoda, 16 Bivalvia and 1 Cephalopoda (up to December  
194 2010). Few species of bivalves have been intentionally introduced for aquaculture: the

195 oysters *Crassostrea gigas*, *C. angularis*, *Saccostrea glomerata* and the Manila clam  
196 (*R. philippinarum*).

## 197 **Bivalves**

198 The most common marine alien Italian bivalve is the Manila clam (*R. philippinarum*)  
199 that was deliberately introduced for aquaculture in 1983 in the Venice lagoon and  
200 quickly substituted the Italian clam species (*Venus gallina*) (Chiesa, Nonnis Marzano,  
201 Minervini, De Lucrezia, Baccarani, Bordignon, Poli, Ravagnan & Argese 2011;  
202 Pranovi, Franceschini, Casale, Zucchetta, Torricelli & Giovanardi 2006). Today Manila  
203 clam is the first species for Italian aquaculture in value and in 2011 accounted for 222  
204 Mln €. After its introduction, Manila clams rapidly became an important economic  
205 resource and Italy is first producer country in Europe and second in the world, after  
206 China (Perdikaris & Pascos 2010; Chiesa *et al.* 2011). Its typical farming method is a  
207 capture - based aquaculture and the Manila clam aquaculture is based on harvesting  
208 from naturalized wild population, principally along the coasts of North East Italy,  
209 Veneto and Emilia Romagna regions. Other marine bivalve species introduced for  
210 aquaculture are the Pacific oysters (*Crassostrea gigas*) and (*C. angulata*), but their  
211 diffusion has been not successful as Manila clam and their distribution in the wild is  
212 limited to some areas in northern and central Italy (Macali, Conde, Smeriglio, Mariottini  
213 P Crocetta 2013). The Asian date mussel (*Arcuatula senhousia*), previously known as  
214 *Musculista senhousia* or *Musculista senhousia*, is a alien marine mytilid that was  
215 introduced in the early 1990s in the northeastern Adriatic Sea and currently is spread in  
216 the Po River deltaic area, northeastern Italy (Mistri 2004; Munari 2008). This mussel  
217 sometimes reach densities up 10,000 individuals/sqm in the northern Adriatic, where it  
218 is threatening Adriatic shellfish farms (Crocetta 2012). The soft-shell clams (*Mya*  
219 *arenaria*), a bivalve native of New England coasts, where it is commercially important

220 for fisheries and aquaculture, is considered among the 100 Mediterranean worst  
221 invasive and outcompetes native bivalves (Crocetta & Turolla 2011). Fortunately it is  
222 suitable for human consumption and its harvesting can represent a valid method for  
223 contrasting its diffusion. The rayed pearl oyster (*Pinctada radiata*), commonly known  
224 as pearl oyster, has recently colonized the coasts of a small island in South Italy, Linosa  
225 island (Lodola, Nicolini, Savini, Deidun & Occhipinti-Ambrogi 2013). In Greece, *P.*  
226 *imbricata* was intentionally introduced during the last century for aquaculture purposes  
227 and has established in the wild.

## 228 **Other marine invertebrates**

229 In Italy there are several alien marine species of invertebrates and, between these, the  
230 blue crab (*Callinectes sapidus*) (Thessalou –Legaki, Aydogan, Bekas, Bilge, Boyaci,  
231 Brunelli, Circosta, Crocetta, Durucan, Erdem, Ergolavou, Filiz, Fois, Gouva, Kapiris,  
232 Katsanevakis, Kljajić, Konstantinidis, Konstantinou, Koutsogiannopoulos, Lamon,  
233 Mačić, Mazzette, Meloni, Mureddu, Paschos, Perdikaris, Piras, Poursanidis, Ramos-  
234 Esplá, Rosso, Sordino, Sperone, Sterioti, Taşkin, Toscano, Tripepi, Tsiakkiros &  
235 Zenetos 2012) recently observed in South Italy (Mancinelli, Carrozzo, Costantini,  
236 Rossi, Marini & Pinna 2013) is spreading. The blue crab comes from the Western  
237 Atlantic coast of North America and it was reported for the first time in Mediterranean  
238 in 1931. Its first presence was dated back to 1971 and successively in Venice lagoon  
239 and in Apulia in January 2001 (Florio, Breber, Scirocco, Specchiulli, Cilenti & Lumare  
240 2008). This species has a great economic value along southern U.S. Atlantic coasts  
241 where farming initiatives are starting. Another portunid, the chinese mitten crab  
242 (*Eriocheir sinensis*) has been found also in the Venice lagoon (Mizzan 2005).  
243 Polychaete anellids are introduced unintentionally by ballast waters or for bait trade and  
244 represent a numerous group of marine alien invertebrates, between them *Branchiomma*

245 *bairdi* that has been recently found along Tyrrhenian coasts, reaching very high densities  
246 (c.a. 400 individuals/m<sup>2</sup>), particularly in polluted areas (Arias, Giangrande, Gambi &  
247 Anadon 2013). Another example of invasive sabellid polychaete is *Branchiomma*  
248 *luctuosum*, that outcompetes the Mediterranean native tubeworm *Sabella spallanzanii*  
249 (Occhipinti *et al.* 2011). One species of alien ctenophore jellyfish, recently found along  
250 Italian coasts, is *Mnemiopsis leidyi* that is an effective plankton feeder particularly active  
251 on fish eggs and larvae, native to Atlantic coast of US (Boero 2013).

252

### 253 **Amphibians and aquatic reptiles**

254 Alien amphibians and aquatic reptiles represents a limited phenomenon in Italy and  
255 their presence is almost completely caused by ornamental aquaculture. At least eight  
256 species of alien amphibians and 13 species of aquatic alien reptiles have been  
257 introduced in Italy, but only five species introduced during the last century are  
258 considered invasive (Ficetola, Thuiller & Padoa-Schioppa 2009). Main alien reptiles  
259 diffused in Italy are red-eared slider, (*Trachemys scripta elegans* Wield, 1839) and  
260 yellow-eared slider (*T. s. scripta*), as well as hybrids between them (Agosta & Parolini  
261 1999). Among amphibians, American bullfrog (*Lithobates catesbeianus*) was  
262 introduced in Italy during the 1930s for food. Moreover green frogs (genus *Pelophylax*),  
263 were introduced for farming purposes (Ficetola *et al.* 2009) and their real diffusion is  
264 difficult to assess, being able to hybridize with native green frog species.

265

### 266 **Impact of aquatic alien species**

267 It is widely recognized that the diffusion of alien species result in a loss of biodiversity  
268 and sometimes local extinctions (Diana 2009; Ribeiro & Leunda 2012). In Italy, the  
269 most common alien species among fish and mollusks, *i.e* rainbow trout and Manila  
270 clam, generate a great economic income being the first and second species of Italian  
271 aquaculture for economic value (Italian Association of fish farmers, [http://www.api-](http://www.api-online.it/index.cfm/en/home)  
272 [online.it/index.cfm/en/home](http://www.api-online.it/index.cfm/en/home)) (Table 1). Due to the success of rainbow farming, Italian  
273 inland aquaculture is dominated by alien species, as happens in neighbor countries  
274 (Perdikaris & Pascos 2010; Turchini & De Silva 2008). For instance, in 2011 the 92.3  
275 % of quantity (that corresponded to 84.2% of value) of freshwater fish farmed  
276 production was based on alien species. Naturalized alien salmonids, mainly spread in  
277 northern Italian inland waters (whitefish, arctic char and brook trout) (Figure 2), are  
278 important species for recreational and professional fisheries (Table 1) and did not  
279 apparently affect lake productivity (Zerunian *et al.* 2009). European whitefish is one of  
280 the dominant fish species in the bigger Italian lakes (Garda and Maggiore lakes) and it  
281 is considered a typical product of local gastronomy (Regione Lombardia 2012). Being  
282 unable to make natural reproduction, rainbow trout is occasionally released in controlled  
283 conditions for recreational fishing, without significant effect on autochthonous  
284 salmonids, with the exception of one population in Trentino region that encompass  
285 natural reproduction. Other species as wels catfish (*S. glanis*) and red swamp crayfish  
286 have an tremendous impact on local aquatic fauna and in the freshwater ecosystems.  
287 Wels catfish is an active predator and its presence in Italy caused several problems in  
288 the Po River basin to native species (*i.e.* *Alburnus arborella* and *Scardinius*  
289 *erythrophthalmus*), causing in some cases local extinctions (Castaldelli, Pluchinotta,  
290 Milardi, Lanzoni, Giari, Rossi & Fano 2013; Zerunian *et al.* 2009). Wels catfish  
291 outcompetes native predators, the northern pike (*Esox lucius*) and European perch

292 (*Perca fluviatilis*), that have become extremely rare after its introduction, thus affecting  
293 recreational and professional fishing activities. Wels catfish impact is also evident on  
294 those fish species that lay eggs on bottom vegetation, as tench (*Tinca tinca*) (Milillio,  
295 2012). The diffusion of wels catfish induced also decline in other alien species as the  
296 largemouth bass (*Micropterus salmoides*, Lacépède), black bullhead catfish, (*Ameiurus*  
297 *melas* Rafinesque, 1820) and goldfish, (*Carassius auratus* L.) that were appreciated for  
298 farming or recreational fishing. Red swamp crayfish has a high ecological plasticity and  
299 it reduces biomass and species richness of macroinvertebrates, inducing drastic habitat  
300 changes (Liu, Guo, Ke, Wang & Li 2011; Scalici, Chiesa, Scuderi, Celauro & Gibertini  
301 2010). This species can outcompete the autochthonous crayfish, white-clawed crayfish  
302 (*Austropotamobius pallipes*), and introduced in Italy the crayfish pest, a fungal disease  
303 carried by *Aphanomices astaci*, lethal for European species of crayfish (Aquiloni *et al.*  
304 2010). Red swamp crayfish make burrows in the pond and causes a noticeable physical  
305 impact on freshwater ecosystems (Scalici *et al.* 2010; Garzoli, Paganelli, Rodolfi,  
306 Savini, Moretto, Occhipinti-Ambrogi & Picco 2014; Scalera and Zaghi, 2004; Barbaresi  
307 *et al.* 2004). Some marine alien or lessepsian fish species belonging to Tetraodontids  
308 such as *Sphoeroides pachygaster* and *Lagocephalus sceleratus* are known for their  
309 toxicity due to the neurotoxin tetrodotoxin that may produce paralysis of the diaphragm  
310 and death (Andaloro *et al.* 2012) and they can also introduce pathogens for other fish  
311 species. Uncontrolled harvests of Pacific oysters (*Crassostrea gigas*) eventually  
312 contaminated by toxic algae can lead to diseases in humans. Between freshwater  
313 bivalves, zebra mussel can accumulate biotoxins and sometimes favors the bloom of  
314 *Microcystis aeruginosa*, a toxic microalga (Mazza *et al.* 2013). Similarly to the red  
315 clawed crayfish, alien amphibians can spread fungal diseases as chytridiomycosis and  
316 *Batrachochytrium dendrobatidis*, that can cause autochthonous amphibian decline

317 (Ficetola & Scali 2010). Concerning aquatic reptiles, sliders outcompetes for food and  
318 basking places the autochthonous European pond turtle (*Emys orbicularis*) (Ficetola *et*  
319 *al.* 2009) and, being active predators, sliders have heavy impact on fish and amphibians  
320 species, in particular in those species that lay eggs in shallow waters (Ferri & Soccini  
321 2003).

### 322 **Impact of exotic species and aquaculture: an ecological perspective**

323

324 Dominance and diversity are two key concepts of basic ecology that define the relations  
325 between species in natural ecosystems and in particular they represent the ecosystems  
326 answer to environmental perturbations. These concepts can be adopted in this context in  
327 order to better explain the relation between aquaculture and diffusion of exotic species.  
328 The role of aquaculture has been dual, in fact few successfully farmed species have  
329 become rapidly common, these species can be considered “xenodominant”, while the  
330 species involuntarily introduced are much more numerous, never reach considerable  
331 amounts and increase xenodiversity. The diffusion of species such as tilapia or carps has  
332 been enormously increased for farming purposes (Diana 2009). Conventional  
333 aquaculture (and in an historic perspective, any traditional zootechnic activity) acts as a  
334 kind of key of success for few alien species and in several cases the introductions of  
335 freshwater fish have resulted in great societal benefits (Diana 2009; Gozlan 2008).  
336 Ornamental aquaculture and escaped species increase xenodiversity. Therefore,  
337 xenodominance is the first ecological effect of successful alien species and  
338 xenodominant species have beneficial economic effect on local communities, as the  
339 rainbow trout or Manila clam.

340

## 341 **Management of alien species: status and perspective**

342 Until this moment the main solution proposed for alien invasive species has been the  
343 control of international trade or containment measures against diffusion of alien. Most  
344 common proposed measures regard on one hand rules and international directives that  
345 discipline the import of ornamental species and farmed animals, on the other hand  
346 suggestions on alternative methods against unattended transfers, such as the substitution  
347 of ballast waters in open ocean areas and the removal of fouling organisms, for marine  
348 species. In Italy main conservation efforts and/or management project have been  
349 focused on freshwater ecosystems that are much more fragile (Gherardi *et al.* 2008).  
350 Upon our knowledge, there are not management initiatives on marine fish species.  
351 Freshwater ecosystems lacking native piscivorous fishes, or being highly altered by  
352 humans, appear to be the most vulnerable to biological invasions (Casal 2006;  
353 Castaldelli *et al.* 2013). This vulnerability could also increase in the future, as  
354 consequence of climatic conditions change and it is likely that will favor the spread of  
355 introduced species not only in Europe, but also in northeastern North America, and  
356 Oceania (Bellard *et al.* 2013). In these last two decades, several UE projects in North  
357 Italy, have been focused on freshwater alien species management, in particular targeted  
358 against wels catfish diffusion. Between 2010 and 2012, an intensive fishing activity in  
359 collaboration with local associations of non-professional fisherman produced a  
360 significant harvest of wels catfish biomass.  
361 ([http://www.progettosiluro.altervista.org/opuscolo\\_siluro.pdf](http://www.progettosiluro.altervista.org/opuscolo_siluro.pdf)). Other containment  
362 measures have been adopted for wels catfish as selective fishing and exportation of live  
363 fish toward eastern European markets (Castaldelli *et al.* 2013), exportation in areas  
364 where wels catfish angling is a rooted touristic activity, (as Slovenia) and promoting  
365 direct consumption. Containment strategies have been proposed for red swamp crayfish



366 control (Garzoli *et al.* 2014) and two LIFE projects have been recently funded for this  
367 purpose: RARITY ([http://www.life-rarity.eu/pages/rarity\\_en.htm](http://www.life-rarity.eu/pages/rarity_en.htm)) and SOS TUSCAN  
368 WETLANDS (<http://www.life-sostuscanwetlands.eu/index.php/it/?lang=en>). The  
369 management of alien salmonids is completely different from above mentioned species,  
370 some of these naturalized species are important for local freshwater fishery and  
371 consequently worth of conservation and protection. In Trentino region (NE Italy) the  
372 arctic charr is even protected by a UE disciplinary (Official Journal of the European  
373 Union, September 24<sup>th</sup>, 2013) and it is considered typical product of regional  
374 gastronomy. Re-introduction projects have been carried out in areas where these alien  
375 salmonids decreased, due to over exploitation and environmental pollution.

376 Economic opportunities can arise from alien species presence thus partially  
377 transforming the nuisance into a opportunity such as aquaculture, recreational fishing  
378 and fishing tourism. In Italy fishing tourism is a modern and well known activity  
379 (Alberini, Zanatta & Rosato 2007; Picchi, Scalera & Zaghi 2006; Scalera & Zaghi  
380 2004) and in 2012, in the Lombardy region, a significant increase of fishing tourism  
381 practiced by German fisherman has been noticed, as a consequence of wels catfish  
382 increase. Fisherman often collaborated in conservation projects as happened during  
383 LIFE projects in 2003 and 2004 in Emilia region, but, more interestingly, they are  
384 available to pay extra admission fees in order to do selective fishing in protected areas.  
385 It should be remembered that recreational fishing in Italy regards nowadays almost 2  
386 Mln persons only in freshwaters.

387 Novel products and activities can be developed from alien species, as happens in  
388 France, Croatia and Poland, where wels catfish is farmed (Turchini *et al.*, 2008;  
389 Ulikowski, Szczepkowski & Szczepkowska 2003), or Cyprus where rabbitfish is farmed  
390 in marine cages (Stephanou & Georgiou, 2000). Selective fishing targeted on low-value

391 species as pumpkinseed bass (*Lepomis gibbosus*), can be eventually oriented for the  
392 production of forage/bait fish, following the experience of bluegill sunfish (*Lepomis*  
393 *macrochirus*) farming in southern US states. The recent diffusion of alien blue crab (*C.*  
394 *sapidus*) along Italian coasts could be turned from ecological trouble into opportunity,  
395 by crab farming under controlled conditions, considering that along eastern coasts of  
396 U.S. it is one of most expensive seafood. Freshwater mollusks, when not directly  
397 suitable for human consumption, are potentially utilizable for farmed animal feeds  
398 (Sicuro, Abete, Forneris, Mioletti, Panini & Amedeo 2010). Zebra mussel farming plant  
399 has been proposed as a potential system for a bioremediation project in the Baltic area  
400 (Schernewski, Stybel & Neumann 2012). Chinese pond mussel (*S. woodiana*) in Central  
401 Italy (Tuscany region) was used in 2003 for freshwater pearl production  
402 ([http://prometeo.adm.unipi.it/temp/4\\_Pisa.pdf](http://prometeo.adm.unipi.it/temp/4_Pisa.pdf)). As showed until this point, potential  
403 utilization of exotic species is an attractive option, but it must be handled with care as  
404 potential exploitation could promote the further diffusion of exotic.

405 As regards as reptiles species, the ban to import *T. s. scripta* was imposed by EU since  
406 1997 via the Protection of Species of Wild Fauna and Flora by Regulating Trade. Only  
407 one of the two subspecies of exotic sliders (*T. s. scripta* and *T. s. elegans*) is curiously  
408 considered dangerous, while other species can be legally imported and traded. This fact  
409 has not biological reason as the two subspecies have similar ecological features and  
410 hybrids are fecund and spread in the wild.

## 411 **Conclusions**

412 In Italy several alien aquatic species are currently present and some of them have  
413 documented relevant ecological and economic impact, both negative than positive.

414 From 2009, the adoption of the EU regulation 708/2007, concerning the use of alien and  
415 locally absent species in aquaculture, has disciplined this sector. However, it is not  
416 sufficient to prevent the diffusion of aquatic alien species as Italian aquaculture  
417 encompasses a multiplicity of aspects that include conventional finfish aquaculture,  
418 bivalve aquaculture, ornamental aquaculture and the relation with introduction of alien  
419 species is consequently a multiple facets issue. Basically, there are two main groups of  
420 exotic aquatic species originated by aquaculture: the invasive ones with wels catfish and  
421 Louisiana red swamp crayfish and another heterogeneous group of exotic species that  
422 have beneficial effects. The most common Italian aquatic alien species are rainbow trout  
423 and Manila clams and they represent main economic products of Italian aquaculture.  
424 Moreover other species of naturalized salmonids are important economic resources for  
425 inland professional fishery in North Italy. As regard as ornamental aquaculture,  
426 including aquatic reptiles and amphibians, the consequences on alien species diffusion  
427 are currently more limited, but it should not be underestimated in perspective. The  
428 introduction of new exotic species in Italy is almost completely forbidden by a recent  
429 Italian law (n.1143/2014, applied from January 2015), consequently ornamental  
430 aquaculture will be the main future source of exotic aquatic species diffusion. In this  
431 context, the internet trade (currently uncontrolled) will represent the real challenge of  
432 future. In this moment Italian ornamental aquaculture is almost exclusively based on  
433 alien species, in freshwater and marine species, moreover there are few ornamental  
434 aquaculture farm in Italy and it can be estimated that more than 90% of this sector is  
435 dominated by importation from foreign countries. Advisable solution could be the  
436 encouraging of locally – reared ornamental species farming, that in this moment is not  
437 yet economically convenient in Italy.

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442

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652 Table 1. List of species of Italian aquaculture in 2011 (Italian Association of fish  
 653 farmers, <http://www.api-online.it/index.cfm/en/home>)

Species	tons	Mln €	Origin
Rainbow trout ( <i>Onchorynchus mykiss</i> )	41000	149.7	A
European seabass ( <i>Dicentrarchus labrax</i> )	8700	64	I
Gilthead seabream ( <i>Sparus aurata</i> )	9700	72	I
Gray mullets (mugilids)	3500	9.8	I
Sturgeons (Acipenserids)	1660	14.8	I + A
Eel ( <i>Anguilla anguilla</i> )	1100	11.4	I
Common carp ( <i>Cyprinus carpio</i> )	750	2.9	I
Catfish ( <i>Ictalurus sp.</i> )	550	3.3	A
Arctic charr ( <i>Salvelinus alpinus</i> )	400	1.6	A
Meagre ( <i>Argyrosomus regius</i> )	300	2.1	I
Other fish species	5150	32.4	I + A
Blue mussels ( <i>Mytilus galloprovincialis</i> )	100000	78	I
Manila clams ( <i>Ruditapes philippinarum</i> )	33000	144	A
<b>TOTAL</b>	<b>205810</b>	<b>586</b>	

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655 A, exotic species; I, autochthonous species; I + A autochthonous + exotic species

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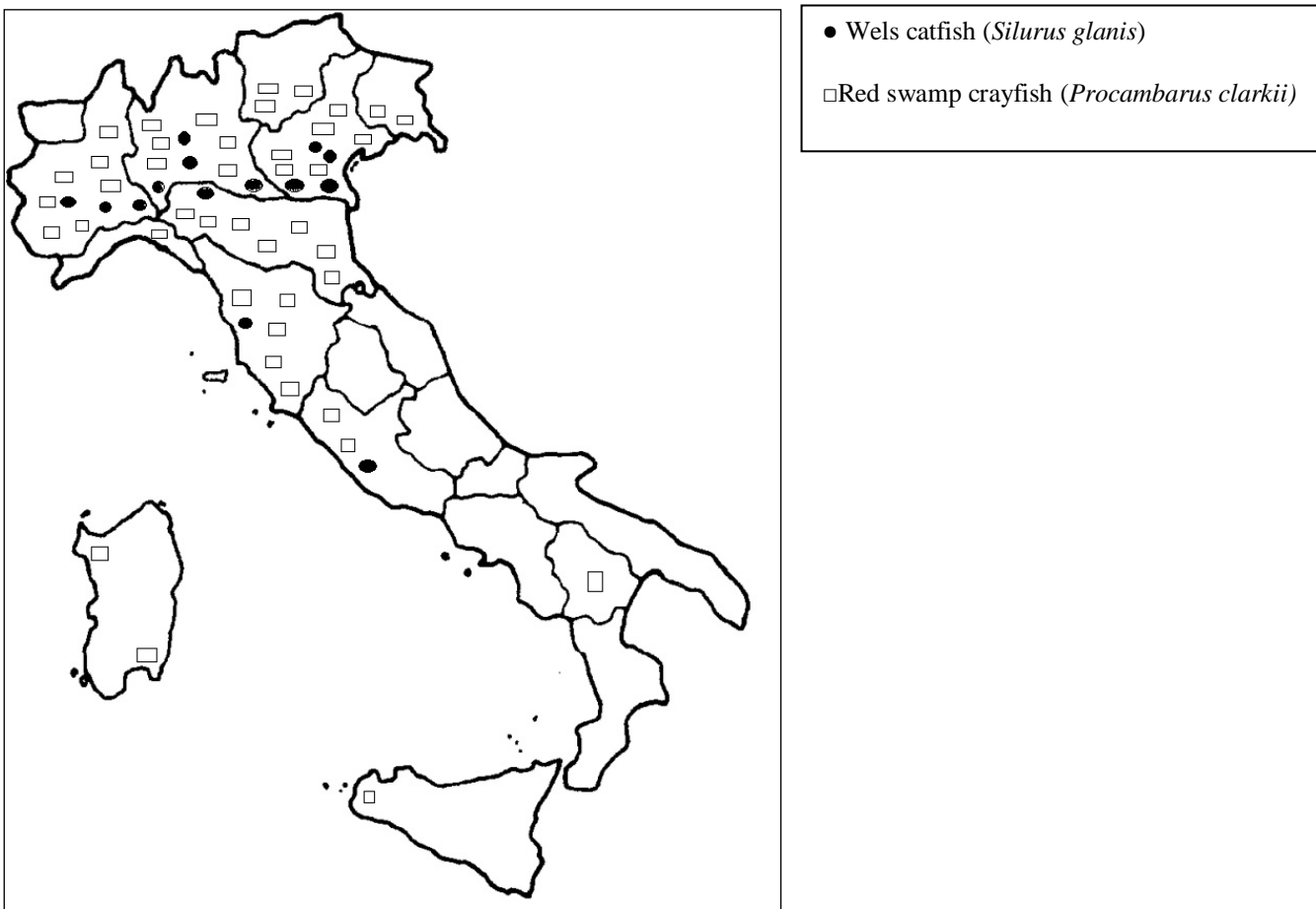
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660 Figure 1. Wels catfish and red swamp crayfish distribution

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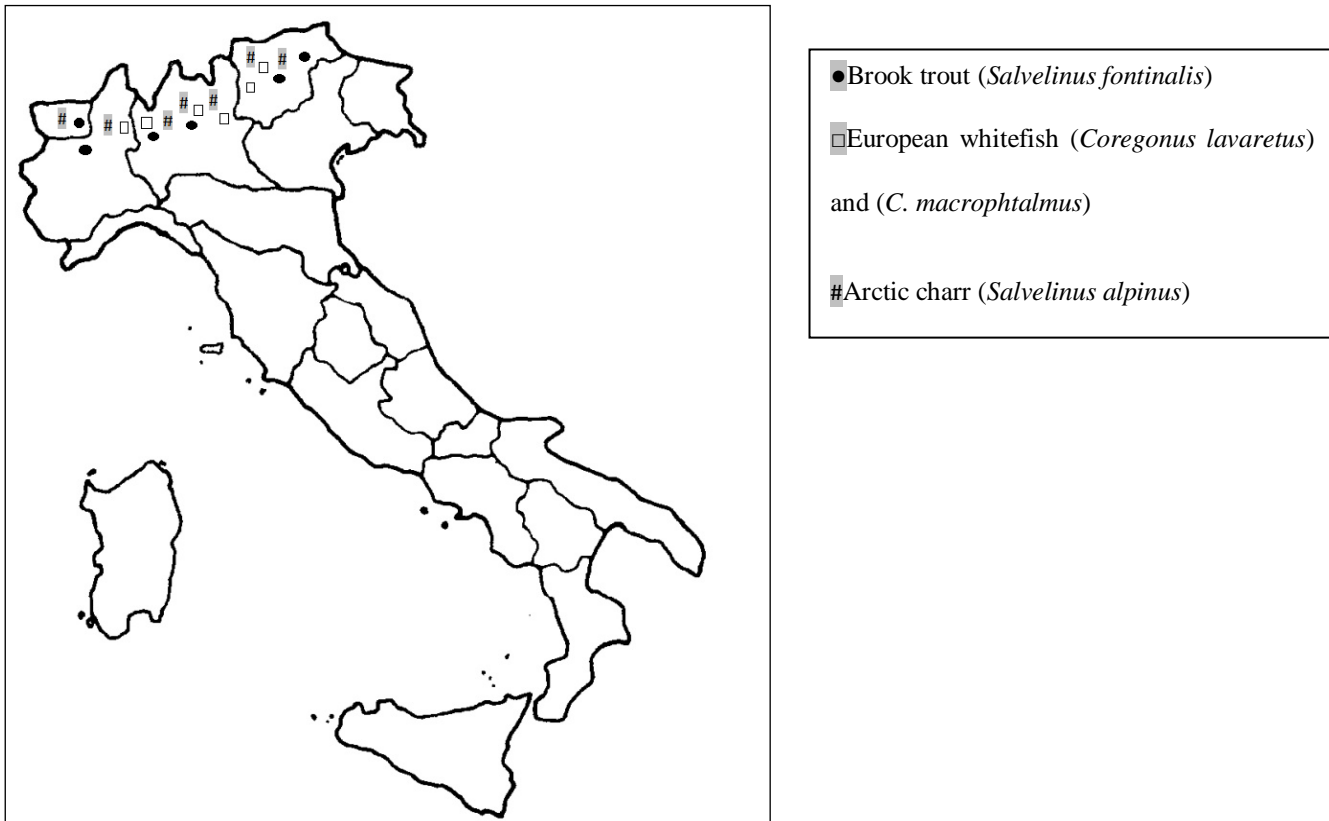
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670 Figure 2. Naturalized exotic salmonid distribution



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