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A regional fish inventory of inland waters in Northern Italy reveals the presence of fully exotic fish communities

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Abstract

The aim of the study is to present a complete and updated fish inventory of inland waters of the Emilia-Romagna region, Northern Italy, and to highlight the presence of fully exotic fish communities. Overall, based on 208 sampling locations, the observed fish fauna consisted of 45 species, 22 native and 23 exotics. A significant element of the inventory is the identification of xenodiversity hotspots (spatially clustered sites, one lowland and one upland region), where a complete substitution of native species by exotic species was observed (in total seven sites in the lowland and two sites in the upland with no native species presence). These xenodiversity hotspots were found to host specific combinations of exotic species, which may be able to constitute balanced exotic communities. The hotspots of the lowland region are located in the northeast lowland part of the territory, hosting exotic species combinations mainly composed by wels catfish (*Silurus glanis* Linnaeus, 1758, a large predator), common carp (*Cyprinus carpio* Linnaeus, 1758, a large benthivore), crucian carp (*Carassius* spp., a small-bodied generalist) and other less dominant exotic species. The hotspots in the upland region were located in the southwest part of the territory and were dominated by only one exotic species (rainbow trout, *Oncorhynchus mykiss* (Walbaum, 1792)). A difference between these xenodiversity hotspots is that in the lowland the introductions were mostly unintentional and are not continued, while in the upland the introduction of rainbow trout is intentional and currently carried out by local fishermen.

Keywords: *Invasional meltdown, hotspots, spatial distribution, fish inventory*

Introduction

The increase in exotic fish species invasions is alarming, creating an important threat for freshwater ecosystems (Leprieur et al. 2008). Exotic species can promote habitat deterioration/alteration such as decline of aquatic vegetation, increase of turbidity and nutrients release due to sediment resuspension, increase of phytoplankton blooms and eutrophication, genetic alterations within populations, spreading of pathogens and parasites, competition with, and predation of, native species (Dibble & Kovalenko 2009; Leunda 2010; Ribeiro & Leunda 2012; Castaldelli et al. 2013). Among European nations, one of those most impacted by exotic species invasions is Italy (see e.g. Bianco & Ketmaier 2001; Bianco 2014), with the Po River basin being one of the most invaded areas. The severity of the invasions has already reached critical limits, especially in the lowland areas near the estuary, where at least 10 native fish species faced local extinction while many exotic ones

showed a population explosion during the period 1991–2009 (Castaldelli et al. 2013).

The first aim of this study is to present a complete and updated inland water fish inventory of the Emilia-Romagna region in Northern Italy. The Emilia-Romagna region belongs to the southern side of the Padanian-Venetian ichthyogeographic district (see Bianco 1995) and hosts a number of native fish species of great conservational interest (e.g. twaite shad *Alosa fallax* (Lacépède, 1803), Italian barbel *Barbus plebejus* Bonaparte, 1839, or Italian nase *Chondrostoma soetta* Bonaparte, 1840) according to the EU Habitat Directive (92/43/EEC). Arising from the inventory, a significant element is the identification of xenodiversity hotspots, where there was a complete substitution of native species by exotic species (Castaldelli et al. 2013). These xenodiversity hotspots were found to host specific combinations of exotic species, which were

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able to constitute fully exotic communities. A discussion on the structure and attributes of these communities was the second aim of this study. A fish inventory including specific information on the distribution of exotic species could be relevant for managers, as it would be most useful to prioritize concrete conservation actions for native biodiversity.

Materials and methods

The study area is located in Northern Italy and it is defined by the administrative boundaries of the Emilia-Romagna Region with total coverage of 22,446 km² (Figure 1). It is naturally bound north and south by the Po River and the Apennine Mountains, respectively. The study region has a Mediterranean continental climate. Altogether, data from 208 river monitoring sites were analyzed in this study (Figure 1), covering a wide range of inland water habitats at different altitudinal zones. The samplings were performed in natural rivers (e.g. Po, Trebbia, Taro, Secchia, Panaro, Reno, Lamone, Fiumi Uniti, Bevano, Marecchia, etc.) and in large artificial irrigation canals which are mainly located in the lowlands (e.g. Po di Volano, Po di Primaro, Canal Bianco, Canale Circondariale, etc.).

Fish data were collected from sampling stations that were homogeneously positioned in 64 waterways of the region (Figure 1), away from recreationally managed sites, and with their section width ranging from 8 to 350 m (the maximum value corresponds to the Po River). The samplings were conducted during the warm season (from April to September) of the period 1998–2004 as part of the institutional regional monitoring program for the compilation of the official Fish Inventory of the

Emilia-Romagna Region (Pascale et al. 2004, 2006; Castaldelli & Rossi 2008).

Fish sampling was performed by electrofishing, adapting the standard guidelines to the particular conditions of waterway typologies (Backiel & Welcomme 1980; Reynolds 1983). Electrofishing was performed thoroughly with a direct current at 400–600 V and 4–5 A (Reynolds 1983; Godinho & Ferreira 2000) once during daylight, in an upstream zigzag direction by wading, when depth was less than 1 m, and by boat in deeper waters. The transect lengths were equivalent to 10 times the river width, ensuring that the range of present macrohabitats of each site was fully surveyed (Hankin & Reeves 1988; Godinho & Ferreira 2000). The duration of sampling was therefore quite variable, ranging from half an hour to more than 2 hours, as in the case of the Po River. Electrofishing is considered the best quantitative method for fish sampling in shallow waters, up to a maximum of 1 m (Zalewski & Cowx 1990) but its efficacy may be low in deeper waters, with high conductivity, or in the presence of big and mobile specimens. Such special conditions occurred in almost all the lower stretches of rivers and in the large canals of the lowlands. For this reason, electrofishing in these sites was verified by sampling using a standard set of nets, composed and operated as follows: three sinking trammel nets (50 m long and 1.80 m high), composed of two external panels with knot-to-knot mesh size of 70 mm and an internal one of 300 mm, and three sinking gill nets (50 m long and 1.80 m high) with knot-to-knot mesh sizes of 40, 20 and 10 mm, respectively. The presence of young-of-the-year specimens was assessed by using 2 × 2 m drop nets with a 5-mm mesh size in parallel with the other nets. Fishing with nets was performed immediately after electrofishing sessions, with the

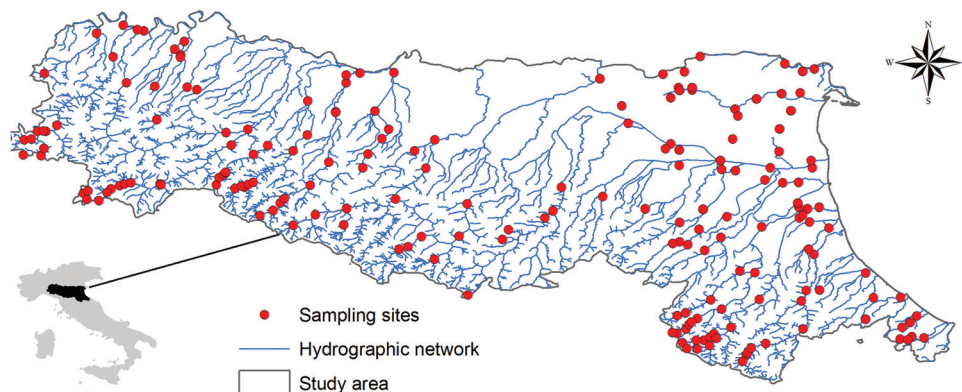


Figure 1. Study area (data source: <http://gadm.org>), hydrographic network of main rivers and streams (data source: <http://www.eea.europa.eu/data-and-maps/data/european-river-catchments-1>) and location of sampling sites.

support of professional fishermen, and the duration was approximately 1 hour for the trammel nets and half an hour for the gill nets, in order to avoid mortality or damage of captured specimens. Fish species were identified according to Kottelat and Freyhof (2007) and Bianco (2014) and attributed either native or exotic status, relative to the Padanian-Venetian ichthyo-geographical district. Sampling sites were then grouped according to the presence/absence of native and exotic fish species.

Results

Overall, the observed fish fauna from the sampling sites consisted of 45 species, 22 native and 23 exotic, belonging to 12 families (Table I). Since a profound discussion on the *Salmo trutta* complex has been undertaken after the surveys, it was not possible to resolve whether the sampled individuals of this complex were native or exotic. Regarding Gobioninae, *Gobio gobio* (Linnaeus, 1758) should be added among the aliens due to its invasions in all waters of the Padano-Venetian district. *Gobio benacensis* (Pollini, 1816) is placed among the natives with a question mark as its presence was not certainly detected.

In a total of nine sampling sites, only exotic species were present. These xenodiversity hotspots were distributed in two main groups (one with seven sites in the lowlands, and one with two sites at higher elevation) which are shown in Figure 2. Table II summarizes the exotic species communities found in these sites.

Overall, it was possible to identify three different groups of sampling sites, based on the presence/absence of native and exotic species:

- A group of nine sites populated solely with exotic species, mostly located in the lowlands. These xenodiversity hotspots showed different combinations of 14 out of the 23 exotic species detected in the region (the missing ones were European barbel *Barbus barbus* (Linnaeus, 1758), roach *Rutilus rutilus* (Linnaeus, 1758), asp *Leuciscus aspius* (Linnaeus, 1758), channel catfish *Ictalurus punctatus* (Rafinesque, 1820), largemouth black bass *Micropterus salmoides* (Lacépède, 1803) and pond loach *Misgurnus anguillicaudatus* (Cantor, 1842) (see Table II).
- A group of 92 sites hosting both native and exotic species, located from the lowlands to the foothills. These sites showed different combinations of native and exotic species, where all 23 exotic species were present, while from the 22 native species only three were missing (Italian nase, bullhead *Cottus gobio* Linnaeus, 1758, Eurasian minnow *Phoxinus phoxinus* (Linnaeus, 1758)).

- A group of 107 sites where only native species were present, located mostly at higher altitudes. These sites showed different combinations of 16 out of 22 native species (the missing ones were twaite shad, tench *Tinca tinca* (Linnaeus, 1758), Italian rudd *Scardinius hesperidicus* Bonaparte, 1845, Southern pike *Esox cisalpinus* Bianco & Delmastro, 2011, thinlip grey mullet *Liza ramada* (Risso, 1827), flat-head grey mullet *Mugil cephalus* Linnaeus, 1758, and European flounder *Platichthys flesus* (Linnaeus, 1758), the latter three typical of salt water but often found in inland waters.

Discussion

The existence of xenodiversity hotspots indicates that exotic fish species might be able to constitute fully exotic communities. These xenodiversity hotspots are surrounded by sites where the presence of native species is extremely low, at least in the lowlands. As fish surveys employed redundant sampling methods, it is unlikely that native species were not detected accurately. It is clear that other anthropogenic drivers (e.g. hydrologic alteration, habitat degradation) are also at play in the area and could favor exotic species, at least in the lowlands (Castaldelli et al. 2013). Therefore, it is likely that these xenodiversity hotspots could arise from species interactions occurring in altered environmental conditions. Unfortunately, because there are no long-term records of the fish communities for all these sites, it is impossible to completely disentangle the exact mechanism of interaction with native fishes.

The presence of fish xenodiversity hotspots is particularly alarming, because there have been few documented cases of non-isolated freshwater systems with high interconnectivity where native fish communities have been completely substituted by exotics. It is well known that exotic species can cause the displacement of natives, by outcompeting natives for spatial and trophic niches (Mooney & Cleland 2001); however, reports that prove complete multiple local fish extinctions as a result of exotic fish species invasions are relatively scarce, and sometimes questionable for reasons explained in Gurevitch and Padilla (2004). The case of direct predation by brown trout (*Salmo trutta* Linnaeus, 1758) causing extinction of galaxiids fishes in New Zealand is one of the very few examples of these (Townsend 1996), while the case of Nile perch (*Lates niloticus* (Linnaeus, 1758)) in Lake Victoria is more controversial (e.g. Kitchell et al. 1997; Witte et al. 2000). Predatory interactions can only explain a limited part of the native species decline found in our study area,

Table I. Observed fish species in the freshwater systems of the Emilia Romagna region. The reported status of each species refers to the Emilia Romagna region (within the Padanian hydrographical district).

Family	Species	Common name	S†	N‡
Anguillidae	<i>Anguilla anguilla</i> (Linnaeus, 1758)	European eel	Ns	17
Clupeidae	<i>Alosa fallax</i> (Lacépède, 1803)	Twaite shad	Ns	8
Cyprinidae	<i>Sarmarutilus rubilio</i> (Bonaparte, 1837)	South European roach	Ns	23
	<i>Leucis aula</i> (Bonaparte, 1841)	Italian red-eye roach	Ns	6
	<i>Squalius squalus</i> (Bonaparte, 1837)	Cavedano chub	Ns	85
	<i>Squalius lucumonis</i> (Bianco, 1982)	Toscana stream chub	Es	2
	<i>Telestes muticellus</i> (Bonaparte, 1837)	Italian riffle dace	Ns	55
	<i>Phoxinus phoxinus</i> (Linnaeus, 1758)	Eurasian minnow	Ns	4
	<i>Tinca tinca</i> (Linnaeus, 1758)	Tench	Ns	1
	<i>Scardinius hesperidicus</i> Bonaparte, 1845	Italian rudd	Ns	30
	<i>Alburnus arborella</i> (Bonaparte, 1841)	Italian bleak	Ns	81
	<i>Chondrostoma soetta</i> Bonaparte, 1840	Italian nase	Ns	2
	<i>Protochondrostoma genei</i> (Bonaparte, 1839)	South European nase	Ns	47
	<i>Gobio benacensis</i> (Pollini, 1816) ?	Italian gudgeon	Ns	20
	<i>Barbus plebejus</i> Bonaparte, 1839	Italian barbel	Ns	76
	<i>Barbus tyberinus</i> Bonaparte, 1839	Tiber barbel	Es	9
	<i>Barbus barbus</i> Linnaeus, 1758	European barbel	Es	3
	<i>Carassius</i> spp.	Crucian carp	Es	71
	<i>Cyprinus carpio</i> Linnaeus, 1758	Common carp	Es	82
	<i>Abramis brama</i> (Linnaeus, 1758)	Common bream	Es	31
	<i>Blicca bjoerkna</i> (Linnaeus, 1758)	White bream	Es	5
	<i>Rutilus rutilus</i> Linnaeus, 1758	Roach	Es	1
	<i>Rhodeus sericeus</i> (Pallas, 1776)	Bitterling	Es	27
	<i>Pseudorasbora parva</i> (Temminck & Schlegel, 1846)	Stone moroko	Es	74
	<i>Ctenopharyngodon idella</i> (Valenciennes, 1844)	Grass carp	Es	3
	<i>Leuciscus aspius</i> (Linnaeus, 1758)	Asp	Es	6
Cobitidae	<i>Misgurnus anguillicaudatus</i> (Cantor, 1842)	Pond loach	Es	1
	<i>Cobitis bilineata</i> Canestrini, 1865	Italian spined loach	Ns	27
Siluridae	<i>Silurus glanis</i> Linnaeus, 1758	Wels catfish	Es	48
Ictaluridae	<i>Ameiurus melas</i> (Rafinesque, 1820)	Black bullhead	Es	20
	<i>Ictalurus punctatus</i> (Rafinesque, 1820)	Channel catfish	Es	4
Esocidae	<i>Esox cisalpinus</i> Bianco & Delmastro, 2011	Southern pike	Ns	1
Salmonidae	<i>Salmo trutta</i> complex	Brown trout	Ns/Es	70
	<i>Oncorhynchus mykiss</i> (Walbaum, 1792)	Rainbow trout	Es	3
Poeciliidae	<i>Gambusia holbrooki</i> Girard, 1859	Eastern mosquitofish	Es	6
Cottidae	<i>Cottus gobio</i> Linnaeus, 1758	Bullhead	Ns	1
Centrarchidae	<i>Micropterus salmoides</i> (Lacépède, 1803)	Largemouth black bass	Es	9
	<i>Lepomis gibbosus</i> (Linnaeus, 1758)	Pumpkinseed	Es	26
Percidae	<i>Perca fluviatilis</i> Linnaeus, 1758	European perch	Es	3
	<i>Gymnocephalus cernua</i> (Linnaeus, 1758)	Ruffe	Es	10
	<i>Sander lucioperca</i> (Linnaeus, 1758)	Zander or pike-perch	Es	29
Mugilidae	<i>Mugil cephalus</i> Linnaeus, 1758	Flathead grey mullet	Ns	1
	<i>Liza ramada</i> (Risso, 1827)	Thinlip grey mullet	Ns	3
Gobiidae	<i>Padogobius bonelli</i> (Bonaparte, 1846)	Padanian goby	Ns	43
Pleuronectidae	<i>Platichthys flesus</i> (Linnaeus, 1758)	European flounder	Ns	1

†S: status; Ns is for native and Es is for exotic species.

‡N: number of sampling sites where the species is present.

as the exotic fish communities comprise several species with a wide spectrum of eco-functional traits. The analysis of these traits, and how the combination of the specific exotic species may lead to fully exotic populations, should be the subject of future investigations.

The original native communities composed mostly by ciprinids such as Italian bleak *Alburnus arborella* (Bonaparte, 1841), Italian rudd, and exocids such as

southern pike were locally extinct within the lowlands xenodiversity hotspots (Table II), where exotic communities were mainly composed by wels catfish *Silurus glanis* (a large predator), common carp *Cyprinus carpio* (a large benthivore) and crucian carp *Carassius* spp. (a small-bodied generalist). These constitute the backbone of the fish communities in most xenodiversity hotspots. Biogeographical origin could partly explain this composition: the main exotic species in these sites

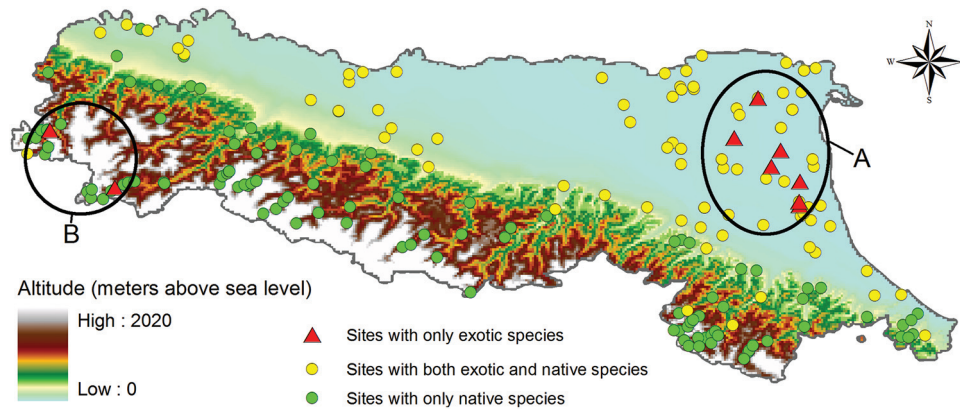


Figure 2. Altitude (data source: <https://ita.cr.usgs.gov/GTOPO30>) and separation of sampling sites based on the presence/absence of native and exotic species.

Table II. Exotic species present in the nine positions belonging to the xenodiversity hotspots where native species were absent (Figure 2).

Site	Lowland region							Upland region		Total
	1	2	3	4	5	6	7	8	9	
Crucian carp	x		x	x			x			4
Common carp	x	x	x	x			x	x		6
White bream							x			1
Common bream	x									1
Bitterling	x									1
Stone moroko	x	x	x				x			4
Grass carp							x			1
Wels catfish	x	x		x	x			x		5
Black bullhead	x			x						2
Eastern mosquitofish			x							1
Pumpkinseed	x	x	x							3
Pike-perch	x		x							2
Ruffe								x		1
Rainbow trout									x	2
Total number of exotic species	9	5	5	4	3	3	3	1	1	

(e.g. common bream *Abramis brama* (Linnaeus, 1758) and wels catfish) come from the same area, the Danube River, where they likely co-evolved and developed mechanisms of niche partitioning and coexistence (Castaldelli et al. 2013). The large size attained by some of these species (e.g. common carp or grass carp *Ctenopharyngodon idella* (Valenciennes, 1844)) and the deep body of others (e.g. common bream, crucian carp) could also partly explain their coexistence with predators. A notable exception to Danube River species are the pumpkinseed *Lepomis gibbosus* (Linnaeus, 1758), a North American centrarchid, and the black bullhead *Ameiurus melas* (Rafinesque, 1820), a North American ictalurid, which are both exotic species introduced over a century ago (Bianco

1998). These species seem able to constitute small populations within these sites, probably due to their well-known trophic and ecologic flexibility (Wainwright et al. 1991).

The xenodiversity hotspots in the lowlands of our study area could provide a valuable example of invasional meltdown in fish communities. Invasional meltdown is the mutual facilitation of invasion by different species (Simberloff & Von Holle 1999). Albeit not a new hypothesis, it still remains controversial (Simberloff 2006) and very few examples of it are known from fish communities (e.g. the opposite effect found in Britton et al. 2010). The ecosystem engineering capabilities of some of these exotic species could explain why these communities thrive. Common and crucian carp, for example, have been known to increase water turbidity and reduce macrophytes through their feeding actions (e.g. Richardson et al. 1995; Bonneau & Scarnecchia 2015). While their invasion in Western Europe was completed long ago, they are capable of continued effects on the environment. Furthermore, grass carp have been shown to be established in the area (Milardi et al. 2015) and feed directly on macrophytes, increasing the positive feedback on turbidity. Increased water turbidity can favor predators such as wels catfish or pike-perch, which are particularly adapted for predation in turbid waters, over native predators such as southern pike, which largely rely on sight and do not have special adaptations. Moreover, the interactions between exotic and native species are likely magnified by hydrologic alteration, as already hypothesized by Castaldelli et al. (2013). Native fish are mostly riverine-adapted species, contrary to exotics which are more lacustrine in origin; therefore, the natives survive in streams or torrents on hills or sub-mountain zones, which should be considered sanctuaries for their survival, as previously discussed by Bianco and Ketmaier

(2001). Ultimately, further studies are needed to confirm whether our study area shows clear signs of invasional meltdown.

The xenodiversity hotspots at higher elevations (Table II) were located in the upper reaches of the Taro River and in a smaller stream (Rio Castello) feeding into the Trebbia River. These sites did not show significant habitat degradation or hydrologic alteration; however, the community was not composed by native trout and gobies or cottids, but rather solely composed by rainbow trout (*Oncorhynchus mykiss*). This species was previously reported to establish in different areas of Italy (Stanković et al. 2015), even if many more populations are known but not yet reported (Milardi, unpublished data), but its interactions with native fish and invertebrates are still largely unexplored. Candiotto et al. (2011) hypothesized that rainbow trout could colonize mainly river stretches where no other fish were present. Our data suggest that in the Taro River and the Trebbia River, a population of rainbow trout can exist well within systems where other natives are present both up- and downstream (suggesting also that it could occasionally effectively displace native species, at least locally). Even though surveyed sites are far from sites where recreational stocking occurs, it is probable that stocking of rainbow trout for recreational fisheries could strongly contribute to the distribution pattern of this species in sites at higher altitudes.

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