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ORIGINAL ARTICLE

A review on the animal xenodiversity in Sicilian inland waters (Italy)

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ABSTRACT

This paper reviews the available knowledge about faunal xenodiversity in Sicilian inland waters (Italy). The aim is to provide an updated checklist and bibliography of those non-indigenous species (NIS) which occur in the island, and to identify possible threats to its native biological diversity. Data were collected through an extensive literature search which encompassed also local journals, books, congress abstracts, and other grey literature. All the collected data were critically revised and, when possible, verified by consulting available collections or through dedicated sampling surveys. Only those data contained in reports indicating precise occurrence localities, which were confirmed by our own observations and\or by at least two independent sources including at least a peer-reviewed publication, were considered as certain. Data in literature that did not meet these criteria were considered doubtful and reported separately as unverified data. The information provided by websites has been excluded as it often contains unfounded and\or erroneous data. The fauna of Sicilian inland waters host at present 31 confirmed NIS. In addition, the presence of further 11 taxa is dubious. Among the *verified data*, invertebrate and vertebrate taxa are nearly equally represented, with 15 and 16 taxa, respectively. With 16 species, the phylum Chordata is by far the most represented, followed by Mollusca (8 species) and Arthropoda (6 species). Most of these species were detected in the last 30 years due to the lack of previous regular studies on Sicilian freshwaters. With few exceptions (*e.g.*, the recent introduction of *Xenopus laevis,* the African clawed frog), NIS' effects on native biota have not extensively studied in the island yet. Although the top-down effects caused by introduced vertebrate taxa are known to deeply modify the native structure of the biota, little information is available on the impacts caused by invertebrate taxa, especially the microscopic ones. The presence in Sicily of 11 non-native species of bony fish is probably the most impacting threat to autochthonous fauna through predation, competition and hybridisation. The results shown in the paper highlight the importance and the urgency of more exhaustive investigations on NIS in Sicilian inland waters with special regard to less charismatic taxa whose effects on the native biota have never been evaluated yet.

Key words: Biological invasions; Mediterranean biodiversity; non-indigenous species; translocated species; parautochthonous taxa; allochthonous taxa.

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INTRODUCTION

Biological invasions, *i.e.*, the successful establishment of non-indigenous species (NIS) in a given area, are long known to be one of the most serious threats to the conservation of the world biological diversity. In fact, NIS are known to threat the survival of indigenous species, populations, and communities through hybridisation, competition, parasitism, predation, and the structural changes they cause to the colonised habitats (Ehrenfeld, 2010; Simberloff *et al.*, 2013). Furthermore, they are also known to cause substantial economic damages, and can be harmful for human health (Pimentel *et al.*, 2005, Keller *et al.*, 2011). Although biological invasions are a pervasive global phenomenon which widely interests all the existing ecosystems, some evidences suggest that inland waters are especially prone to be invaded (Gherardi, 2007; Chandra and Gerhardt, 2008). This is possibly due to the pronounced dispersal abilities of most of inland-water taxa (Incagnone *et al.*, 2015), to the naiveté of lakes and other inland water ecosystems to the effects of invaders owing to their evolutionary isolation (Cox and Lima, 2006), and, eventually, to the pivotal importance that these habitats have always had for the human civilisation. Anthropogenic alterations of the pre-existing biocoenoses, both in terrestrial and marine environments, are in fact known to have likely facilitated the establishment of several opportunistic *newcomers* (Chytrý *et al.*, 2008; Airoldi *et al.*, 2015; see also Boggero *et al.*, 2014). Moreover, freshwater ecosystems are globally experiencing the highest loss of biodiversity due to human activities (Naiman and Dudgeon, 2011).

In spite of some early warnings (Elton, 1958), and of the sound evidences of the impacts that non-indigenous species have on the indigenous biota, little efforts were paid to take a census and to monitor non-indigenous species in European inland waters till the end of the XX century; in some instances, confronting alien species was even suspected to be a form of xenophobia (Simberloff, 2003). Such a delay in approaching biological invasions

interested even those countries with a longer tradition in limnological studies, and only recently national and international studies on invasion biology have been conducted. These have led to the creation of dedicated checklists and databases, available on the web, aimed at providing a complete census of the non-indigenous biota of the continent (*e.g.*, DAISIE: *Delivering Alien Invasive Species Inventories for Europe*, www.europe-aliens.org, or *Aquatic alien species in German inland and coastal waters*, http://www.aquatic-aliens.de/). However, the completion of an exhaustive census of the NIS is intrinsically difficult given the dynamic nature of the phenomenon, and it is especially hard for those less-charismatic taxa and\or small-bodied organisms, which are more difficult to notice or to correctly identify. Furthermore, the recent evidences that cryptic species or lineages often are the protagonists of widely overlooked cryptic invasions (Saltonstall, 2002; Marrone *et al.*, 2011; Van Bocxlaer *et al.*, 2015), stress the need for the implementation of molecular identification tools when dealing with biological invasions (Blanchet, 2012).

Based on all these hindering factors, the known distribution of non-indigenous species often reflects the distribution of researchers interested in invasion biology and\or taxonomists, rather than that of the organisms themselves. Such is the case of the non-indigenous biota of Sicilian inland-waters, which was to date understudied, with sparse data, often published in scarcely accessible literature. As a consequence, even in the most recent reviews addressed to the non-indigenous biota of European and Italian inland waters, Sicily has often been considered jointly with Sardinia (Nocita and Zerunian, 2007; Tricarico *et al.*, 2010; Bianco, 2014); this approach reflects the paucity of data available for the two islands rather than any theoretical, biological, or historical reason. In some cases, Sicilian NIS were even not included in the analyses at all (Marr *et al.*, 2013; Boggero *et al.*, 2014). Moreover, due to the aforementioned constraints, those few studies where Sicily was considered as an independent region (Gherardi *et al.*, 2008) show rather fragmentary checklists.

The lack of comprehensive data on NIS makes their management and control difficult. Actually, not all the introduced NIS are able to successfully establish populations in the invaded areas, and even less prove to be actually invasive (*i.e.*, noxious to the native biota - see the *tens rule*, cf. Williamson, 1996). However, when the invasiveness of a certain taxon becomes evident, it is often too late to control or eradicate it in spite of the efforts invested. Accordingly, it has been suggested that the NIS are to be considered *guilty until proven otherwise*, and that a *quick and dirty* response, aimed at eliminating the NIS at their very first colonisation outset is strongly advisable and, possibly, the only way to solve the problem (Gherardi, 2006). A detailed and timely monitoring of the current xenodiversity and of the ongoing biological invasions is thus needed when facing the challenge of protecting the indigenous species and ecosystems from biotic homogenization.

The present paper collects and reviews all the available literature on the NIS occurring in the fauna of Sicilian inland waters, with the explicit aim to provide sound and updated baseline data for future studies and desirable management activities.

METHODS

Definitions and study area

In this paper we describe the animal xenodiversity, *i.e.*, the diversity of the non-indigenous fauna, occurring in Sicilian inland waters (cf. Leppäkoski *et al.*, 2002). Inland waters are here defined according to the Water Framework Directive (Directive 2000/60/EC): all standing or flowing waters on the surface of the land.

In contrast with some published papers dealing with Italian xenodiversity (Gherardi *et al.*, 2008; Tricarico *et al.*, 2010; Boggero *et al.*, 2014), we are hereby considering NIS (non-indigenous species) all those taxa which are occurring outside of their natural distribution range and dispersal potential, and which were introduced to Sicily by human activities (IUCN, 2000); we are therefore here including also the *translocated species*, *i.e.*, those species which are native (autochthonous) to the Italian peninsula or Sardinia but that would be naturally absent in Sicily. Within the NIS, we distinguish among those taxa introduced before the year 1500, called *parautochthonous taxa*, and those which were introduced in Sicily after that date, *i.e.*, the *allochthonous taxa* (Gazzetta Ufficiale della Repubblica Italiana, 2015).

A further important partition is between those taxa which are present in Sicily with self-sustaining breeding populations (*established species*) and those which are present on the island, but whose successful breeding was not observed and that might thus not be able to constitute self-sustaining populations; the non-occasional presence of the latter is due to an ongoing introduction of specimens in the wild (*sporadic species*). Among the NIS, we here consider *invasive species* those widespread non-indigenous species that have adverse effects on the invaded habitats (cf. Gherardi, 2006).

To date, no data on the occurrence of NIS on the small-circum-Sicilian islands are available; accordingly, the present paper focuses on the Sicilian mainland only.

Bibliographical review

A checklist of the NIS reported to occur in Sicily was compiled from an extensive literature search through journals, books, congress abstracts, and other grey literature. Unfortunately, given the difficulties in exhaustively tracing

the grey literature, we cannot exclude that some information might have been missed. All collected data were critically revised and, when possible, checked by consulting available collections or through dedicated sampling surveys. In the frame of this paper, we considered as *verified data* those reports indicating precise occurrence localities, which were confirmed by our own observations and\or by at least two independent sources, including at least a peer-reviewed publication. The information which did not meet these criteria was here considered doubtful and the taxa were reported separately as *unverified*. The information provided by websites has been excluded as it often contains anecdotic and\or erroneous data.

RESULTS

Updated checklist and origin of the NIS occurring in Sicilian inland waters

The updated checklist of the NIS occurring in Sicilian inland waters is reported in Tabs. 1 to 3. Overall, 31 NIS were confirmed to be positively present in Sicily (Tabs. 1 and 2). Another group includes 11 taxa whose presence in Sicily is dubious and\or whose non-indigenous status in Sicily is nowadays considered controversial (Tab. 3). By taking into account only the *verified data*, invertebrates and vertebrates are nearly equally represented, with 15 and 16 taxa respectively. The phylum Chordata is by far the most represented, with 16 species, followed by Mollusca (8 species) and Arthropoda (6 species) (Fig. 1). Overall, the commonest source for the NIS in Sicilian inland waters is the Nearctic region, followed by the West- and East-Palaearctic subregions; only single taxa colonised Sicily from the Neotropical, Afrotropical, Oriental or Australian regions (for more details see Tabs. 1 and 2; Fig. 2). In good accordance, the vast majority of the NIS occurring in Sicily are allochthonous taxa introduced after the XVI century, with only a single mammal species being a parautochthonous taxon (*i.e.*, the brown rat), and three taxa with no data on their first introduction (*i.e.*, the isopod *Proasellus banyulensis*, and the fish *Perca fluviatilis* and *Carassius auratus*, cf. Tabs. 1 and 2).

Unfortunately, nearly no information is available on how deliberate were the introductions of most of the NIS in the inland waters of Sicily, with a few exception as the one of *Gambusia holbrooki* introduced in Sicily between 1925 and 1927 to keep under control malaria-spreading mosquitoes (Consoli, 1928; Veronesi *et al.*, 1997). However, a markedly different pattern is scored between invertebrate and vertebrate taxa. With the only exception of the brown rat, *Rattus norvegicus*, all the remaining vertebrate taxa were likely the object of intentional introductions for ornamental, fishing, or sanitary purposes; conversely, the opposite pattern is scored among the invertebrates, which are mostly inconspicuous species unintentionally released in the wild along with intentionally-introduced aquatic vertebrate species and\or ornamental plants (Mazza *et al.*, 2015).

Invertebrate NIS and putative NIS

All the invertebrate NIS listed in Tab. 1 are known to be successfully established in Sicily, being present with locally abundant, self-sustaining populations. Among them, the oldest records are those referring to the gastropod *Haitia acuta*, whose arrive in Sicily dates back at least to the XIX century (Sowerby, 1873-1874), followed by the crustaceans *Daphnia ambigua, D. parvula*, and *Proasellus banyulensis*, all of them first collected in Sicily in the '80s (Calvo *et al.*, 1993; Stoch *et al.*, 1996; Marrone *et al.*, 2005). All the other taxa were reported to be present on the island only in the XXI century or are even still unpublished records (Tab. 1), thus suggesting a recent significant increase in the rate of successful invasions by invertebrate NIS in Sicilian inland waters.

Among the putative NIS whose presence in Sicily is inferred from unverified data, the reports of the gastropod *Helisoma anceps* and of the crustacean *Moina affinis* are likely based on the misidentification of congener species known to occur on the island, while the report of the bivalve *Corbicula fluminea* from western Sicily is possibly to be ascribed to the mislabelling of a museum specimen (Tab. 3). Finally, the non-indigenous status for the gastropod *Galba truncatula* in Sicily is questioned by recent studies (Liberto *et al.*, 2010) which suggest that this taxon might in fact be autochthonous on the island.

Vertebrate NIS and putative NIS

Most of the vertebrate NIS occurring in Sicily are present with established, widespread populations (Tab. 2). However, there are some exceptions: the rainbow trout, *Oncorhynchus mykiss*, for instance, is a sporadic species, known to be unable to breed in Sicilian inland waters. The presence of this species in the rivers of the island is to be ascribed to the ongoing release of specimens for recreational fishing. To date, no evidences of the presence of reproducing populations of the locally abundant red-eared slider, *Trachemys scripta elegans*, in Sicily are available, although the species is known to successfully breed in Italy and might find in Sicily suitable bioclimatic conditions for its reproduction (Ficetola *et al.*, 2009). Finally, the case of *Emys orbicularis* s.l. is quite peculiar as, although no pure populations of this non-indigenous species are known to occur on the island, there are evidences of the introduction of single *E. orbicularis galloitalica* Fritz, 1995 specimens in Sicilian localities inhabited by the endemic Sicilian pond turtle, *Emys trinacris* Fritz, Fattizzo, Guicking, Tripepi, Pennisi, Lenk, Joger *and* Wink, 2005 (Lenk *et al.*, 1999);

this has led to the genetic introgression of *E. orbicularis* genes in eastern-Sicilian populations of *E. trinacris* (Vamberger *et al.*, 2015).

The identity of some non-indigenous fish species reported to be present in Sicily is still to be ascertained (Tabs. 2 and 3); this is the case of the pike (*Esox* cf. *lucius*), whose taxonomical identity has to be carefully checked in the light of the relatively recent description of the southern pike, *Esox cisalpinus* Bianco and Delmastro, 2011, and of the chub (*Squalius* cf. *cephalus*), for which

Tab. 1. List of the non-indigenous invertebrate animal species known to occur in Sicilian inland waters.

Taxon	Category allochthonous *vs* parautochthonous	Origin	Introduction intentional *vs* unintentional	Status established *vs* sporadic	Source(s)
NEMATODA					
Secernentea					
Spirurida					
Anguillicolae					
Anguillicola crassus Kuwahara, Niimi *and* Itagaki, 1974	A	Southeast Asia	U	E	4, 12
MOLLUSCA					
Gastropoda					
Hydrobiidae					
Potamopyrgus antipodarum (J.E. Gray, 1843)	A	New Zealand	U	E	6, 12
Lymnaeidae					
Radix auricularia (Linnaeus, 1758)	A	Eurasia	U	E	6, 13
Physidae					
Haitia acuta (Draparnaud, 1805)	A	North America	U	E	6, 9
Planorbidae					
Ferrissia fragilis (Tryon, 1863)	A	North America	U	E	14
Helisoma duryi (Wetherby, 1879)	A	North America	n.a.	E	2, 11, 12
Thiaridae					
Melanoides tuberculata (O.F. Müller, 1774)	A	Tropical Africa and Asia	n.a.	E	9, 11
Bivalvia					
Dreissenidae					
Dreissena polymorpha (Pallas, 1771)	A	Ponto-Caspian region	n.a.	E	16
Unionidae					
Sinanodonta woodiana (Lea, 1834)	A	East Asia	n.a.	E	16
ARTHROPODA					
Crustacea					
Branchiopoda					
Anomopoda					
Daphniidae					
Daphnia ambigua Scourfield, 1947	A	North America	U	E	1, 7, 8, 12
Daphnia parvula Fordyce, 1901	A	North America	U	E	7, 8
Copepoda					
Cyclopoida					
Ergasilidae					
Neoergasilus japonicus (Harada, 1930)	A	Asia	U	E	19
Malacostraca					
Isopoda					
Asellidae					
Proasellus banyulensis (Racovitza, 1919)	n.a.	Europe	U	E	3, 8
Decapoda					
Cambaridae					
Procambarus clarkii (Girard, 1852)	A	North America	I	E	5, 10, 17, 18
Hexapoda					
Insecta					
Diptera					
Culicidae					
Aedes albopictus (Skuse, 1894)	A	Southeast Asia	U	E	15

A, Allochthonous; P, parautochthonous; I, intentional; U, unintentional; E, established; S, sporadic; n.a., not available; 1, Calvo *et al.*, 1993; 2, Manganelli *et al.*, 1995; 3, Stoch *et al.*, 1996; 4,Weidema, 2000; 5, D'Angelo and Lo Valvo, 2003; 6, Zettler and Richard, 2003; 7, Marrone *et al.*, 2005; 8, Ruffo and Stoch, 2006; 9, Cianfanelli *et al.*, 2007; 10, Naselli-Flores *et al.*, 2007; 11, Reitano *et al.*, 2007; 12, Gherardi *et al.*, 2008; 13, Liberto *et al.*, 2010; 14, Marrone *et al.*, 2011; 15, Carminade *et al.*, 2012; 16, Colomba *et al.*, 2013; 17, Di Leo *et al.*, 2014; 18, Bellante *et al.*, 2015; 19, Alfonso and Marrone, *upublished data*.

no specimens collected in Sicilian inland waters were, to our knowledge, ever studied or described and whose presence itself in the island is to be considered dubious.

The only aquatic bird ever reported as a NIS for Sicily is the mute swan, *Cygnus olor* (Gmelin, 1789) (Scalera, 2001). However, the specimens overwintering in Sicily are likely coming from the southern Balkans, where the species is autochthonous as breeding as well as wintering bird, and should therefore be considered autochthonous in Sicily (B. Massa, *personal communication*).

DISCUSSION

The animal xenodiversity of Sicilian inland waters

When comparing the checklists reported in Tabs. 1 to

Tab. 2. List of the non-indigenous vertebrate animal species known to occur in Sicilian inland waters.

Taxon	Category allochthonous *vs* parautochthonous	Origin	Introduction intentional *vs* unintentional	Status established *vs* sporadic	Source(s)
CHORDATA					
Osteichthyes					
Perciformes					
Centrarchidae					
Micropterus salmoides Lacépède, 1802	A	North America	I	E	7, 12, 16, 17, 18, 21, 25
Percidae					
Perca fluviatilis Linnaeus, 1758	n.a.	Eurasia	I	E	2, 18, 25
Cypriniformes					
Cyprinidae					
Carassius auratus (Linnaeus, 1758)	n.a.	Asia	I	E	2, 3, 6, 7, 8, 16, 17, 18, 21, 25
Cyprinus carpio (Linnaeus, 1758)	P*	Eurasia	I	E	2, 3, 6, 7, 16, 17, 18, 21, 22, 25, 27
Rutilus rubilio Bonaparte, 1837	A	Southern Italy	I	E	4, 6, 7, 8, 12, 16, 17, 18, 28
Tinca tinca (Linnaeus, 1758)	P	Europe	I	E	2, 3, 6, 7, 16, 17, 25
Siluriformes					
Ictaluridae					
Ameiurus melas (Rafinesque, 1820)	A	North America	I	E	6, 7, 12, 17, 18, 21, 25
Cyprinodontiformes					
Poecilidae					
Gambusia holbrooki Girard, 1859	A	North America	I	E	1, 3, 6, 7, 8, 9, 15, 16, 17, 18, 21, 22, 25, 27, 29
Esociformes					
Esocidae					
Esox cf. *lucius*[§]	A	n.a.	I	E	6, 7, 12, 16, 17, 25
Salmoniformes					
Salmonidae					
Oncorhynchus mykiss Walbaum, 1792	A	North America	I	S	6, 7, 16, 17, 18, 21
Salmo trutta Linnaeus, 1758	A	Europe	I	E	7, 16, 17, 18, 21, 25, 26
Amphibia					
Anura					
Pipidae					
Xenopus laevis (Daudin, 1802)	A	Africa	I	E	14, 19, 20, 21, 23, 24
Reptilia					
Testudines					
Emydidae					
Emys orbicularis s.l.	A	Peninsular Italy	I	n.a.	11, 30
Trachemys scripta elegans (Wied, 1839)	A	North America	I	S	19, 22
Mammalia					
Rodentia					
Myocastoridae					
Myocastor coypus Molina, 1872	A	South America	I	E	17, 19, 21
Muridae					
Rattus norvegicus Berkenhout, 1769	P	Asia	U	E	10, 13, 17, 19, 21

A, Allochthonous; P, parautochthonous; I, intentional; U, unintentional; E, established; S, sporadic; n.a., not available or not applicable; *its parautochthony considered dubious by Gherardi *et al.* (2008, and references therein); [§]no sound information on the identity of the pikes introduced in Sicily is available (see text); 1, Consoli, 1928; 2, Faranda *et al.*, 1977; 3, Tigano, 1983; 4, Tigano and Ferrito, 1986; 5, Lo Valvo *et al.*, 1993; 6, Ferrito and Tigano, 1995; 7, Tigano and Ferrito, 1996; 8, Russo *et al.*, 1997; 9, Veronesi *et al.*, 1997; 10, Sarà, 1998; 11, Lenk *et al.*, 1999; 12, Russo *et al.*, 1999; 13, Scalera, 2001; 14, Lillo *et al.*, 2005; 15, Duchi, 2006a; 16, Duchi, 2006b; 17, Ruffo and Stoch, 2006; 18, Nocita and Zerunian, 2007; 19, AA.VV., 2008; 20, Faraone *et al.*, 2008; 21, Gherardi *et al.*, 2008; 22, Termine *et al.*, 2008; 23, Lillo *et al.*, 2011; 24, Lillo *et al.*, 2013; 25, Bianco, 2014; 26, Duchi, 2014a; 27, Duchi, 2014b; 28, Duchi, 2014c; 29, Duchi and Miceli, 2014; 30, Vamberger *et al.*, 2015.

3 with the information currently available in literature (Scalera, 2001; Ruffo and Stoch, 2006; Nocita and Zerunian, 2007; Cianfanelli *et al.*, 2007; Gherardi *et al.*, 2008; Bianco, 2014), a certain decoupling is obvious, with the latter lacking some taxa which are actually present in Sicily, or conversely including others whose presence is dubious or to be excluded for the island. This is to be ascribed to the shortage of studies explicitly focused at investigating Sicilian xenodiversity, with the few existing data scattered among often difficult-to-get pieces of literature. Furthermore, most of the whole-country-scale reviews are focusing on allochthonous taxa only, leaving aside the parautochthonous and translocated species, which are possibly difficult to single out when working on large geographical scales, but which can be easily identified when the study area is of limited extension and geographically well-defined as the present case-study.

The case of bony fishes is emblematic: although they

Tab. 3. Checklist of the taxa whose presence in Sicily and\or whose non-indigenous status is uncertain.

Taxon	Origin	Notes	Source(s)
MOLLUSCA			
Gastropoda			
Lymnaeidae			
Galba truncatula (O.F. Müller, 1774)	Europe	The species is considered autochthonous by Liberto *et al.*, 2010	5
Planorbidae			
Helisoma anceps (Menke, 1830)	North America	It might have been confused with the congener *H. duryi* (cf. Cianfanelli *et al.*, 2007)	5
Bivalvia			
Corbiculidae			
Corbicula fluminea (O.F. Müller, 1774)	Southeast Asia	The report is based on a single specimen stored in the Mollusc Collection of the Hebrew University of Jerusalem	2
CRUSTACEA			
Branchiopoda			
Anomopoda			
Moinidae			
Moina affinis Birge, 1893	North America	Possibly a misidentification for the congener species *Moina salina* or *M. brachiata* (cf. Marrone *et al.*, 2005)	1
CHORDATA			
Osteichthyes			
Cypriniformes			
Cyprinidae			
Carassius carassius Linnaeus, 1758	Europe	Taxon reported for Sicily without providing precise locality data nor relevant references	6
Squalius cf. *cephalus* [§]	n.a.	Taxon reported for Sicily without providing precise locality data nor relevant references	4
Pseudorasbora parva (Temminck *and* Schlegel, 1846)	Asia	Taxon reported for Sicily without providing precise locality data nor relevant references	7, 8
Perciformes			
Centrarchidae			
Lepomis gibbosus (Linnaeus, 1758)	North America	Taxon reported for Sicily without providing precise locality data nor relevant references	7, 8, 9
Siluriformes			
Ictaluridae			
Ameiurus nebulosus (Lesueur, 1819)	North America	Taxon reported for Sicily without providing precise locality data nor relevant references	7, 8, 9
Reptilia			
Testudines			
Geoemydidae			
Mauremys cf. *sinensis* (Gray, 1834)	Asia	No evidences on the occurrence of the species in the wild are available	10
Aves			
Anseriformes			
Anatidae			
Cygnus olor (Gmelin, 1789)	Eurasia	The individuals overwintering in Sicily might come from the Balkans, where the species is autochthonous. They should thus not be considered NIS in Sicily (B. Massa, *pers. comm.*)	3, 4

[§]No sound information on the species-level identity of the taxon\taxa possibly introduced to Sicily is available; n.a., not available or not applicable; 1, Faranda, 1977; 2, Mienis, 1991; 3, Lo Valvo *et al.*, 1993; 4, Scalera, 2001; 5, Zettler and Richard, 2003; 6, Duchi, 2006b; 7, Nocita and Zerunian, 2007; 8,Gherardi *et al.*, 2008; 9, Bianco, 2014; 10, Panzeri *et al.*, 2014.

are by far the most represented non-indigenous taxon occurring in Sicily, only south-eastern Sicilian inland water bodies have been investigated (Ferrito and Tigano, 1995; Duchi, 2006b, and references therein) to date, and nearly no information is available for most of Sicilian inland waters (but see Russo *et al.*, 1999; Duchi, 2014c). As a consequence, no updated local reviews are available, and the Italian lists are rather incomplete or include some taxa whose actual presence in the island is dubious or can be excluded (Ruffo and Stoch, 2006; Nocita and Zerunian, 2007; Gherardi *et al.*, 2008; Tricarico *et al.*, 2010; and, partly, Bianco, 2014). Furthermore, five out of the 11 fish species reported in Tab. 2 are likely translocated taxa from Peninsular Italy, where they are autochthonous, and thus partly or completely overlooked by Nocita and Zerunian (2007), Gherardi *et al.* (2008), and Bianco (2014). When dealing with biological invasions, the translocation of fish and other animals among different freshwater ecosystems within the region should also be considered. Quite often we actually observed fish introductions in temporary ponds where they can significantly alter and threaten the structure of the native biota (Naselli Flores and Barone, 2012).

The strong predominance of vertebrate over invertebrate taxa in Tabs. 1-3 is likely an artefact due to the high visibility of the former, and to the inadequate number of taxonomists present in Sicily for several aquatic invertebrate taxa. It is quite evident that the presence of a single non-indigenous insect species (*i.e.*, the Asian tiger mosquito, *Aedes albopictus*) in the list here presented has to be ascribed to the paucity of information currently available on Sicilian inland water insect communities rather than to the actual presence of a single NIS belonging to this important and species-rich taxon. More accurate information is available for inland water molluscs and crustaceans, two among the best-studied invertebrate taxa in Sicily; conversely, no information is available for other important taxa as Porifera, Cnidaria, or Annelida, which include several species known to be introduced in Italian and European inland waters and that might well be present in Sicilian inland waters as well.

In spite of the patent incompleteness of the currently available NIS checklist, seven out of the 31 NIS positively present in Sicilian inland waters are listed among the *100 of the world's worst invasive alien species* (Lowe *et al.*, 2000), *i.e.* one mollusc (the zebra mussel, *D. polymorpha*), one insect (the Asian tiger mosquito, *A. albopictus*), three fish (the brown trout *S. trutta*, the carp *C. carpio*, the large-mouth bass *M. salmoides*), one reptile (the red-eared slider, *T. scripta elegans*), and one mammal (the coypu, *M. coypus*). At least two other heavily invasive species should be added to this list, *i.e.* the eastern mosquito-fish, *Gambusia holbrooki*, and the African clawed frog, *Xenopus laevis*, whose impact on native biotas is largely known and also verified for Sicilian inland waters (Lillo *et al.*, 2011; Duchi and Micieli, 2014). Overall, at least nine highly invasive species threatening the native inland water biota are present in Sicily.

Unfortunately, only few studies have been to date addressed to the evaluation of the impact of NIS on Sicilian native species and ecosystems, and these are mostly dealing with fish (Ferrito and Tigano, 1996; Russo *et al.*, 1999; Duchi, 2006a; Duchi and Micieli, 2014; Duchi *et*

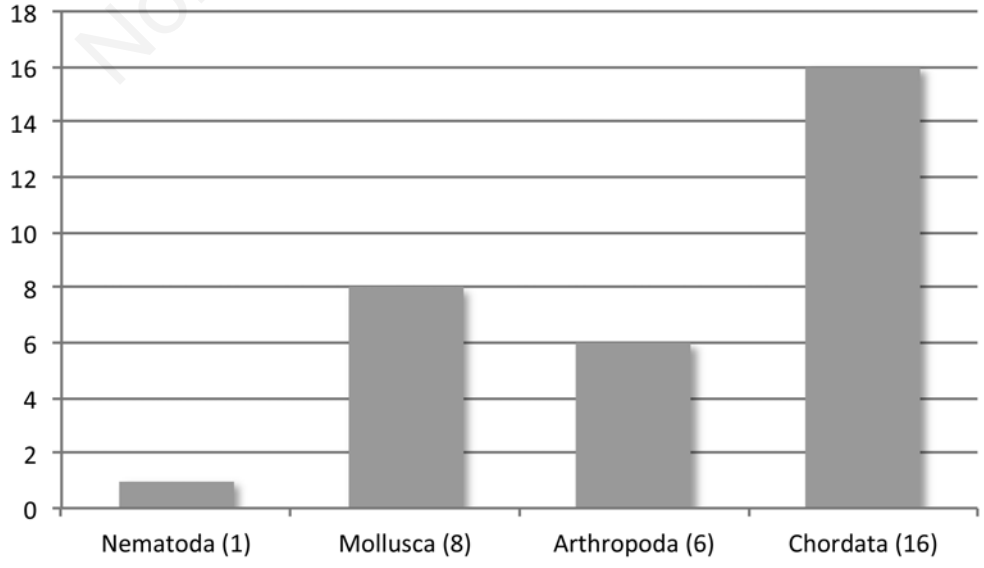

Fig. 1. Histogram of the NIS in Sicilian inland waters by Phylum. Among brackets the number of confirmed species in the island.

al., 2014a); however, some information on the potential negative role of the red swamp crayfish (*P. clarkii*) in Sicilian ecosystems as a vector for toxins and heavy metals is available (Naselli-Flores *et al.*, 2007; Bellante *et al.*, 2015), as well as sound evidences on the threats exerted by the African clawed frogs on native amphibians (Faraone *et al.*, 2008; Lillo *et al.*, 2011) (Tab. 4).

Is Sicily a hot-spot for inland water xenodiversity?

Gherardi *et al.* (2008) and Tricarico *et al.* (2010), based on a dataset including only those species which are allochthonous at the whole-country-level (*i.e.*, without considering the parautochthonous and the translocated species), pointed out that Northern Italy is the hot-spot of Italian inland water xenodiversity. Conversely, Boggero *et al.* (2014), based on a different dataset aimed at exploring the susceptibility to invasions of different habitats and regions, found out that the number of alien species (considering only the allochthonous taxa, according to the definitions used in this paper) is a correlate of temperature, so that sites in warmer areas host in average more alien species than those located in colder ones, which is likely due to a more intense touristic frequentation of the former.

The apparent contrast among these results is due to the lacking or inadequacy of sampling surveys and published data for the southern regions of the country: when the mere number of different NIS known to occur in different regions is compared, the best-studied areas (*i.e.*, the central and northern Italian ones) show the higher number of NIS, which is in fact a function of the sampling and publishing efforts rather than a faithful mirror of the actual xenodiversity distribution pattern. Conversely, when a balanced subset of soundly comparable study sites is in-

Tab. 4. Published data on the impact of NIS on the Sicilian autochthonous inland water biota.

Taxon	Recorded impact on the indigenous biota	Source
Procambarus clarkii	Vector of toxins and heavy metals to higher trophic levels	Naselli-Flores *et al.*, 2007; Bellante *et al.*, 2015
Micropterus salmoides	Predation on *Salaria fluviatilis*	Russo *et al.*. 1999
Gambusia holbrooki	Competition with *Aphanius fasciatus*	Duchi, 2006a; Duchi *and* Micieli, 2014
Salmo trutta	Hybridization with *Salmo cettii*	Duchi, 2014a
Xenopus laevis	Predation on indigenous amphibians	Lillo *et al.*, 2011

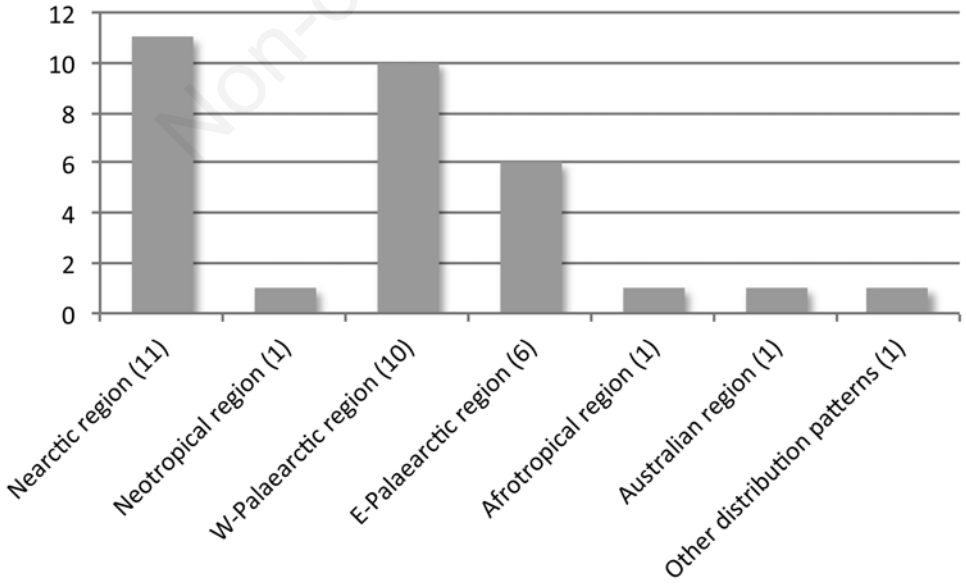

Fig. 2. Histogram of the biogeographical regions of origin for the NIS confirmed in Sicilian inland waters. Among brackets the number of species originating from any biogeographical region. *Melanoides tuberculata* native range lies in both Afrotropical and Palaearctic regions, and is here reported under the bar named Other distribution patterns.

vestigated, the result is exactly the opposite, with the warmer southern Italian regions being more prone to be successfully invaded than the central and northern ones. Such a perspective makes even more urgent the need of properly investigating southern Italian and Sicilian inland water biota, possibly an actual but overlooked hot-spot of inland water animal xenodiversity in Europe.

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