Different Invasibility of Permanent and Temporary Water Bodies in a Semi-arid Mediterranean Island

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Abstract

Non-indigenous species (NIS) represent a threat to aquatic biodiversity worldwide. However, freshwater ecosystems in drylands are potentially more prone to biological invasions than those located in temperate regions due to the higher number of artificial waterbodies generally occurring in these areas, which might act as invasions hub for NIS. In this paper we review the available information about NIS in Sicilian water bodies, discuss the role exerted by artificial lakes and ponds in facilitating the establishment of NIS in arid and semi-arid areas, and compare the invasibility of permanent and temporary water bodies in drylands. Artificial waterbodies increase the target-area effect for disperser and provide a cosy environment to NIS due to their recent origin and to the lack of efficient biological filters against newcomers, thus acting as bridgeheads and invasion hubs favouring invasive species. Finally, we propose a few actions to attenuate the threaten caused by NIS to the sensitive native biota of aquatic ecosystems in drylands.

Keywords: NIS, dryland limnology, artificial lakes, biological invasions, Sicily

Disclosure statement: The authors declare no conflict of interest

Introduction

Biological invasions, i.e. the successful establishment of non-indigenous species (NIS) in a given area, are considered one of the most serious threats to biodiversity conservation, both at local and global scale (e.g. Gherardi 2007; Havel et al. 2015). Invasive species may threaten the survival of native populations and communities through hybridisation, competition, parasitism, and predation, and, more in general, they cause structural changes to the native communities of invaded habitats (Ehrenfeld 2010; Strayer 2010; Simberloff et al. 2013); furthermore, they can exert a negative impact on economic activities, and impair human health (e.g. Pimentel 2011).

Apart from reports on the occurrence of single NIS, synoptic data on the animal xenodiversity occurring in the inland waters of arid and semi-arid areas are scarce, and most of the available literature focuses on temperate regions, where a longer limnological tradition exists and more data are available (e.g. Gherardi 2007; Nentwig 2007; Leuven et al. 2017). This is unfortunate, since freshwater ecosystems in drylands are potentially more sensitive to biological alteration than those located in more humid, temperate regions. Actually, the cyclic nature of the climate-driven disturbances they are subjected to (mainly water-level and salinity fluctuations) is unpredictably altered by human impacts and global changes which can reshape the composition of their biota (Jeppesen et al. 2015). Moreover, temporariness and small dimensions further contribute to the deliberate destruction of these natural aquatic ecosystems in arid and semi-arid areas (Fig. 1), in spite of their disproportionately high biodiversity value (Naselli-Flores and Barone 2012). The disappearing or the rarefication of these aquatic ecosystems may alter the connectivity among the local communities, and ultimately impair the metacommunity dynamics by favouring local extinctions (Naselli-Flores et al. 2016). The vanishing of small natural water bodies is generally accompanied by the building of larger artificial reservoirs to fulfil agriculture (e.g. Ollivier et al. 2018), energetic (e.g. Zarfl et al. 2015), and domestic needs. The mix of human alterations, direct destruction of small natural ecosystems and their substitution with newly built reservoirs has a significant impact on the composition and structure of the native biota of inland waters and can likely offer, especially in semi-arid zones, new colonization opportunities to NIS.

Artificial lakes are actually known to facilitate the settlement of newcomers under a variety of climatic conditions (Johnson et al. 2008; Alfonso et al. 2010; Havel et al. 2015), and this can be particularly true for man-made lakes and ponds in drylands, due to their placement on the territory, to their higher cumulative surface compared to that of natural ecosystems, to the human-promoted disturbance they are subjected, and to the lack or to the weakness of those biological filters that can hinder a successful establishment of newcomers (Naselli-Flores 2003; Incagnone et al. 2015; Stoch et al. 2016).

In the present paper, based on data gathered in Sicily, we i) describe the xenodiversity in Sicilian inland waters and attempt a chronology of its biological invasions; ii) discuss the potential role of man-made aquatic ecosystems as bridgeheads facilitating the establishment and spreading of NIS; iii) analyse the different susceptibility to the establishment of NIS in natural aquatic ecosystems characterised by a permanent vs. a temporary hydroperiod.

A brief account on the inland waters of Sicily

The Mediterranean Basin, located between 32° and 42° latitude N, covers portions of three continents (Europe, Africa and Asia) and, since about 3 million years, is subjected to a peculiar semi-arid climate characterized by a strong seasonality of rainfall and air temperature, which are out of phase and determine the alternance of rainy, cool (winter) and dry, warm (summer) periods (Naselli-Flores 2011). The length of the dry period can vary, and recurrent periods of prolonged drought and water shortage are also typical. Thousands of islands, with a surface ranging from 25,711 km^2 to a few hectares, are scattered in the

Mediterranean Sea and have been hosting human populations since thousands of years. In these islands, natural streams and ponds (including temporary ones) were often insufficient to fulfil the needs of the human populations and man-made canals and standing water collections were therefore built since at least 3,000 years ago (Zahar 2011). However, human impacts on natural freshwaters were quite limited until about 10 centuries ago. Since then, a progressive change in agriculture all around Europe brought to the intensification of cereal production and to the capillary diffusion of watermills, even in the largest islands of the Mediterranean Sea (Bresc and Di Salvo 2001). The higher food availability further fuelled human growth and contributed to change the characteristics of European inland waters. Watermills, in particular contributed to create ponds and lakes where none had existed before, and these lentic artificial ecosystems favoured the transfaunation of several aquatic species across Europe (for an historical account of the transformation experienced by European inland waters in the Medieval Period see Hoffman 1995).

Sicily is the largest and most populated island of the Mediterranean Sea. It represents a paradigmatic example of Mediterranean island due its prevailing climate ranging from semi-arid to temperate-dry conditions, with temperate-humid and humid zones limited to the highest mountain ranges (Naselli-Flores 2011). Sicilian landscape shows a physiography dominated by a hilly landscape (61%) and a fair amount of mountain range (25%, including the Mount Etna, the highest European volcano), the remaining surface (14%) being characterized by lowlands. Aquatic lotic ecosystems in this region include a river network mainly formed by torrent-like systems, and a few permanent lowland rivers whose discharge is strictly dependent on precipitation. Several of these streams are temporary and/or saline due to the presence of evaporite outcrops dating back to the Messinian salinity crisis.

As regard natural lentic waters, permanent and temporary brackish waterbodies are mainly located along the southern coast of the island, with the exception of the endorheic

Lake Pergusa, the largest Sicilian natural lake (surface 1.4 km^2), which is located in the middle of the island. Permanent, shallow freshwater lakes and ponds are generally found at elevation above 1,000 m a.s.l. Conversely, freshwater temporary ponds, i.e. those waterbodies alternating a wet and a totally dry phase, represent the most common type of natural aquatic ecosystem in this, as well as in the others, Mediterranean island (Marrone et al. 2006a; Marrone et al. 2019). These ecosystems host quite a peculiar aquatic biota, adapted to overcome complete desiccation, and representing the bulk of Sicilian inland waters native biodiversity (Marrone et al. 2006a; 2009).

In Sicily, until the beginning of the XX century, man-made reservoirs were mainly represented by small tanks made of stones, cement and lime collecting a few cubic meters of water, locally called “ggèbbia” (Alvarez-Cobelas et al. 2005). After the World War II, several much larger reservoirs, with a storing capacity higher than 10^6 m^3, were built by damming natural, often temporary, streams all around the island. In addition, both the Regional and the Italian governments have been encouraging the building of thousands of smaller artificial lakes to promote agriculture development (e.g. Guggino Picone et al. 1960; Uzzani 2012). The effects that these newly built aquatic ecosystems exert on the autochthonous aquatic biota have never been carefully evaluated.

Altogether, natural lentic ecosystems (both the permanent and temporary ones, excluding the small ground and rock pools), although abundant and widespread (≈2,000 according to a rough estimate), generally show small dimensions (surface area ranging between less than 10 m^2 to a few hectares; average depth between 0.1 and 2 m), a quite limited cumulative surface (≈5 km^2), and store a relatively limited amount of water (≈5.5 Mm^3). These values represent a small fraction of those shown by the 29 major dam reservoirs and the ≈20,000 agriculture ponds built in the island in the last 60 years (total surface ≈140 km^2; water stored ≈1 km^3) (Calvo et al. 1993; Naselli-Flores 1999; Naselli-Flores and Lugliè

2014). These artificial lakes were mainly built in the hilly part of the island and in the lowlands, where most of the agriculture activities are concentrated, and where the need for an easy-to-access and abundant source of freshwater was more pronounced. At the same time, due to the lack of any awareness of the biological importance of these natural aquatic ecosystems, several temporary ponds lying in these areas have been drained, incorporated in the cultivated areas, and eventually replaced by brand-new, agriculture reservoirs (Fig. 1), more conveniently located at the side of the cultivated fields (Stoch and Naselli-Flores 2014).

[Figure 1 near here]

Occurrence and habitat preferences of NIS in Sicilian inland waters

A checklist of the NIS occurring in Sicilian inland waters was compiled based on literature data; conversely, the NIS occurring on small circum-Sicilian islands and on the Maltese Islands are not discussed here. Google Scholar (https://scholar.google.com/), PubMed (https://www.ncbi.nlm.nih.gov/pubmed/), and the "Biodiversity Heritage Library" (http://www.biodiversitylibrary.org/) were used as the main source of information. The used keywords were "NIS", "Non indigenous species", "Invasive species", "biological invasions" "allochthonous species" "Sicily", "inland waters", "reservoirs" "ponds" and different combinations of them. The search was carried out in Italian and English. Moreover, grey literature (local journals, theses, congress abstracts and websites) was explored as well. Attention was paid to review all the references that include relevant systematics, as well as biogeographical and distributional data. All obtained occurrence data were critically revised and, when possible, checked through dedicated sampling surveys. The checklist produced by Marrone and Naselli-Flores (2015) was used as a baseline dataset, which was critically reviewed and implemented with the available new records. The nomenclature applied to the reported NIS has been checked and amended according to the most updated available literature, so that following Vecchioni et al. (2017), the planorbid gastropod reported as *Ferrissia fragilis* (Tryon, 1863) by Marrone et al. (2011) is here reported as *Ferrissia californica* (Rowell, 1863), and the gastropod reported as *Haitia acuta* (Draparnaud, 1805) by Marrone and Naselli-Flores (2015) is here ascribed to the genus *Physella* following the opinion of Vinarski (2017). Following Miracle et al. (2013), the cyclopoid copepod reported as *Acanthocyclops trajani* Mirabdullayev and Defaye, 2004 by Schifani et al. (2019) is here ascribed to *A. americanus* (Marsh, 1893).

In comparison with the checklist produced by Marrone and Naselli-Flores (2015), the checklist of Sicilian NIS is here pruned from the brown rat *Rattus norvegicus* Berkenhout, 1769, which is not strictly aquatic, and from the European pond turtle *Emys orbicularis* (Linnaeus, 1758), which did not establish self-sustaining populations on the island (but see Vamberger et al., 2015). Conversely, new occurrence localities were published for the red swamp crayfish *Procambarus clarkii* Girard, 1852 (Faraone et al. 2017; Deidun et al. 2018), and three new NIS were reported for the island: the crayfish *Cherax destructor* Clark, 1936, the copepod *Acanthocyclops americanus*, and the jellyfish *Craspedacusta sowerbii* Lankester, 1880 (Deidun et al. 2018; Schifani et al. 2019). Since the possible non-native status of the leech *Placobdella costata* (Fr. Müller, 1846) and the apicomplexan *Haemogregarina stepanowi* Danilewsky, 1885 has not been ascertained to date (see Arizza et al. 2016; Marrone et al. 2016), these taxa are not included in the present work. [Table 1 near here]

Some emydid taxa belonging to the genera *Trachemys* and *Pseudemys* occur in aquatic ecosystems throughout the island. Although no data are currently available on the actual occurrence of successful breeding events in Sicily, *Trachemys scripta* (Thunberg in Schoepff, 1792) is known to regularly breed in southern peninsular Italy (e.g. Ficetola et al. 2009; Crescente et al. 2014) and was observed to breed in the Botanical Garden of the University of Palermo and other open-air private ponds, so that its establishment in the wild in Sicily is likely. Accordingly, we here opted to include the family Emydidae (excluding *Emys trinacris* Fritz et al., 2005) among the non-native taxa occurring in Sicily, although we refrain from indicating which taxa actually breed in the wild on the island. These new observations bring the total number of animal NIS occurring in Sicily to 32 (Table 1). The Chordata are the most represented taxon, followed by arthropods and molluscs, and the vast majority of the recorded NIS are of Palearctic origin.

Among the 18 invertebrate NIS up to now recorded in Sicily, 3 were exclusively found in lotic environments, 9 exclusively in lentic ones, and 6 were able to colonise both standing and flowing waters (Table 1). The three species only found in rivers and streams [i.e. *Anguillicola crassa* Kuwahara, Niimi and Itagaki, 1974, *Melanoides tuberculata* (Müller, 1774), and *Cherax destructor*] were exclusively observed in natural ecosystems. Conversely, the 13 species occurring in lentic environments were all observed in artificial lakes, whereas only 8 of them are also occurring in natural, permanent ponds. More in general, no species was found to occur exclusively in natural lentic aquatic ecosystems and, with the exception of *Physella acuta*, no species proved to be able to colonise natural temporary waters.

Vertebrate taxa, with the exception of the rainbow and brown trouts, which only occur in natural rivers, proved to be able to colonize any type of permanent aquatic ecosystem in the island originating from the reservoirs they were originally introduced into.

A tentative chronology of the biological invasions in Sicilian inland waters

No precise data are available on the date of first introduction of each NIS in Sicily; however, a coarse-grained time frame could be produced (Tab. 1).

Among the NIS recorded on the island, only few species occurred in Sicilian inland waters earlier than the XX century (Table 1); the tench, *Tinca tinca* (Linnaeus, 1758), is the first NIS known to be introduced in Sicily. This fish was likely introduced in Medieval times as a source of food (Bresc 1986; Duchi 2018). Among the invertebrates, the gastropods *Radix auricularia* (Linnaeus, 1758) and *Physella acuta* were introduced on the island possibly along with ornamental aquatic plants in the XIX century, or even earlier. In fact, in the first half of the XIX century, *R. auricularia* specimens were collected in the Botanical Garden of Palermo and at the mouth of the River Simeto, close to Catania (Liberto et al. 2010). *P. acuta* was reported to be present in streams close to Syracuse by Philippi (1844, sub "*Physa rivularis*"; see also Vinarski 2017).

In the second half of the XX century, man-made water bodies were intensively built throughout the island (Naselli-Flores 1999) and, due to the paucity of autochthonous freshwater fish, they were routinely stocked with non-indigenous fish for recreational or utilitarian purposes (Faranda 1977). About 70% of the fish species currently present in the inland waters of the island (excluding the diadromous taxa) are NIS, which were introduced in the course of the XX century (Gandolfi et al. 1991; Marrone and Naselli-Flores 2015). As an example, at the end of the second decade of the last century, land reclamation works were accompanied by the massive, intentional introduction of the eastern mosquitofish, *Gambusia holbrooki* Girard, 1859, to fight malaria in those few wetlands that had escaped reclaiming (Consoli 1928); this North American Poeciliidae, quite effective in controlling mosquitos' larvae, but also notorious for its detrimental impact on native biodiversity (Margaritora et al. 2001; Vannini et al. 2018), has been later on deliberately introduced in the majority of agriculture lakes and dam-reservoirs and is nowadays among the most widespread fish in Sicilian waterbodies. Along with non-native fishes, their parasites [e.g *Neoergasilus japonicus* (Harada, 1930)*, Anguillicola crassa,* possibly *Sinanodonta woodiana* (I. Lea, 1834) glochidia), and some 'hitchhiker' invertebrates [e.g. *Daphnia* spp., *Acanthocyclops americanus*, possibly *Dreissena polymorpha* (Pallas, 1771) veliger larvae] were likely introduced (see Duggan and Pullan 2017), although the occurrence of some of these taxa was overlooked until the XXI century (Giannetto et al. 1990; Calvo et al. 1993; Marrone et al. 2005; Marrone and Naselli-Flores 2015, and references therein). Several other zooplanktic species strictly linked to the open waters of permanent, deep lakes occur in Sicily only in the largest man-made reservoirs, and it is likely that the branchiopods *Daphnia cucullata* Sars, 1862, *D. galeata* Sars, 1864 and *Diaphanosoma* spp., which are autochthonous in Peninsular Italy, might in fact represent recently introduced elements in the Sicilian fauna. However, getting data on the pattern of molecular diversity of these species is necessary in order to clarify the local status of these taxa, which are thus here conservatively excluded from the list of Sicilian NIS. Finally, the rodent *Myocastor coypus* (Molina, 1782) and the clawed frog *Xenopus laevis* (Daudin, 1802) are known to occur on the island since the XX century, the first being escaped from farming (Petralia 2008) and the second one possibly imprudently released in the wild from laboratories or hobby breeders (Lillo et al. 2005; Lillo 2008a).

The most recent wave of biological invasions, which is currently underway, is taking place in the XXI century: in less than 20 years, 12 taxa (11 invertebrates and 1 vertebrate, see Table 1) were released by, or escaped from, hobby or professional breeders, likely thanks to the increased global trade of aquarium pets (e.g. Padilla and Williams 2004; Nunes et al. 2015; Maceda-Veiga et al. 2014; Duggan et al. 2018).

The role of man-made waterbodies on biological invasions in Sicily

The first large Sicilian dam-reservoir (32.8 Mm^3) was impounded in 1923 and several others followed after the World War II (Calvo et al. 1993). All these water bodies were built in a context where the only existing natural permanent water bodies were a few brackish coastal shallow lakes and some high-altitude ponds located on the mountain chains. These natural permanent ecosystems hosted no or few “pure lacustrine” invertebrate species and were rather inhabited by local “pond species”, which opportunistically colonized these sub-optimal environments (see Alfonso et al. 2010). Analogously, the few autochthonous non-diadromous fish in Sicily are typical of flowing or of well oxygenated standing waters (Gandolfi et al. 1991), and most of the autochthonous Sicilian amphibians are not able to successfully breed in fish-inhabited water bodies (Lo Valvo et al. 2017). A scarce contingent of autochthonous taxa, none of them well adapted to this habitat typology, was therefore able to colonize the eutrophic and highly astatic Sicilian reservoirs.

Unsaturated and poorly structured biological communities as these ones are characterized by scarce resistance and resilience against biological invasions (Shurin 2000; Havel et al. 2005), and Sicilian reservoirs could thus be readily colonized by both vertebrates and invertebrate NIS. Soon after, most of the introduced fish species (e.g. *Rutilus rubilio* Bonaparte, 1837, *Perca fluviatilis* Linnaeus, 1758, *Ameiurus melas* Rafinesque, 1820, and others) spread from dam reservoirs to the upstream river network, further enlarging their distribution range in the island. Moreover, both passively and actively dispersing invertebrates, once established their first populations in the invaded water bodies likely benefited from the increased availability of aquatic surface area provided by the building of artificial lakes and ponds. Actually, in arid and semi-arid landscapes, the prevailing occurrence of water bodies in open habitats enhances the so-called target-area effect (Lomolino 1990). In these areas, the realized dispersal was actually found to be more efficient than in areas characterized by higher habitat complexity (see Korn et al. 2010; Stoch et al. 2016).

A further, more recent, mechanism entailing the introduction and spreading of aquatic NIS in Sicily is the intentional release of ornamental and aquarium organisms: several gastropods, cnidarians, and isopods are known to having been introduced following this route (e.g. see Patoka et al. 2016; Vecchioni et al. 2017; Duggan et al. 2018), and there are evidences of multiple independent releases of NIS in distantly-located Sicilian man-made water bodies (e.g. Faraone et al. 2017).

The evidences collected until now on NIS chronology and distribution in Sicilian inland waters thus suggest that the largely unsaturated biological communities of man-made ponds and lakes in Sicily were easily invaded by NIS, and artificial water bodies effectively acted as bridgeheads for their establishment and spreading throughout the region through both autogenous and man-facilitated dispersal events.

Different susceptibility of permanent and temporary natural ecosystems to the establishment of NIS

In Sicily, the few existing natural permanent water bodies have been steadily colonized by NIS, so that they currently host a xenodiversity comparable to that observed in artificial water bodies. Conversely, based on available data (Table 1), seasonal ponds and streams proved to be nearly immune to such invasions. Actually, only two invertebrate species are to date known to occur in Sicilian temporary ponds and pools, i.e. the dipteran *Aedes albopictus* Skuse, 1894, occurring in artificial pools only (e.g. flowerpot dishes, abandoned exhausted tires and containers), and the gastropod *Physella acuta*, which is quite common in long-lasting natural temporary ponds. This obvious higher resistance of temporary water bodies against biological invasions has to be ascribed both to abiotic and biotic factors. First, the wide seasonal oscillations of all the physical and chemical parameters of temporary waters, along with the actual presence of a dry phase, seem to act for several taxa as an efficient barrier to the colonization of these water bodies. Then, temporary water bodies in the Mediterranean Basin can efficiently resist against biological invasions thanks to their ancient, species-rich and diversified biological communities (e.g. the communities of the "*Hemidiaptomus* ponds", see Sahuquillo and Miracle 2013; Alfonso et al. 2016), which represent an effective biological hindrance against the establishment of newcomers (Incagnone et al. 2015). Interestingly, the resistance against invasion of the native animal communities inhabiting temporary water bodies is so high that it is also exerted against "foreign" conspecific evolutionary lineages, which are not allowed to establish themselves in those water bodies where conspecific lineages are already present, generating the so-called dispersal-gene flow paradox (De Meester et al. 2002; Incagnone et al. 2015). As a rule, such mechanisms generate a pronounced beta diversity at a regional level (e.g. Stoch et al. 2016), and an unexpectedly high genetic structuring even at very small geographical scale (e.g. Ketmaier et al. 2012, Marrone et al. 2013; Ventura et al. 2014; but see also Kappas et al. 2017 for a contrasting evidence).

However, although most invasive species are unable to permanently colonize temporary water bodies, they are able to temporarily exploit them for trophic reasons. In Sicily, this is the case of the amphibian *Xenopus laevis* and the fish *Gambusia holbrooki*. Both these species take advantage of the ephemeral contacts between permanent and temporary wetlands, which open them new feeding opportunities (F. Marrone and L. Naselli-Flores, *pers. obs.*). This opportunistic behavior severely affects local communities which have not developed adaptations against these vertebrate predators. In other semi-arid areas, *Procambarus clarkii* specimens coming from populations inhabiting permanent waters are known to have a significant effect on temporary water ecosystems, altering the structure and functioning of the pre-existing communities (e.g. Peréz-Bote et al. 2004; Meineri et al. 2013). The higher ecological resistance against NIS shown by temporary ponds could be therefore breached in a given area depending on the proximity and number of artificial waterbodies which potentially increase invaders' pressure.

Conclusions

In semi-arid areas, artificial lakes and ponds are nowadays much more abundant than natural ones (Oertli 2018). The relatively recent origin and the poor community structure of these environments implicate a weak effect exerted by biological filters and facilitate the successful establishment of NIS (Alfonso et al. 2010; Duggan and Payne 2017). Moreover, their number and placement on the territory likely increase the biological connectivity among aquatic habitats through the higher target surface they provide for dispersing organisms, thus further facilitating NIS local dispersal. The increased number of artificial aquatic habitats can also favour the spreading of some native species, and a positive effect in the distribution of insects, amphibians and birds has been reported under more humid climatic conditions (Ruggiero et al. 2008; Deacon et al. 2018); however, in semi-arid areas only the more euryecious and widespread macroinvertebrates with a high dispersal capacity were found to successfully colonize artificial waterbodies (e.g. Abellan et al. 2006). In fact, in Sicily, the distribution of some autochthonous taxa such as the copepods *Copidodiaptomus numidicus* (Gurney, 1909) and *Calanipeda aquaedulcis* Kritschagin, 1873, the cladoceran *Daphnia longispina* O.F. Müller, 1776 or, among vertebrates, the amphibian *Bufo bufo* (Linnaeus, 1758), were favoured by the building of permanent man-made reservoirs (Calvo et al. 1993; Marrone et al. 2005; Sicilia and Turrisi 2008; Alfonso et al. 2010; Vecchioni et al. 2019); these species are nowadays much commoner in Sicilian man-made water bodies than in the natural ones. Conversely, the more specialized invertebrate species or those typical of Mediterranean temporary and permanent ponds were not able to colonize artificial lakes, and are currently exiled in the natural ponds which survived to date (Marrone et al. 2006a, 2006b).

In Sicily, the building of artificial water bodies is driven by an alleged economic development, which does not take in account its impact on native biodiversity. However, it is now clear that the presence and numbers of artificial water bodies in arid and semi-arid areas might have profound impacts on the local aquatic biota; these impacts are multi-faceted, bringing direct advantages to NIS and to a few euryecious native taxa, but being noxious for the majority of the more specialized native biota. As described above, the building and spreading of such man-made ecosystems constitute an actual threat to the preservation of local biodiversity due to their function as bridgeheads that facilitate biological invasions and generate a significant pressure of NIS on natural ecosystems.

Furthermore, it has to be considered that ornamental and aquarium organisms trading (mainly involving fish and aquatic plants) is a fast growing, billionaire industry (e.g. Padilla and Williams 2004; Prathvi et al. 2014). This trading moves hundreds of species, a huge amount of money, and potentially represents one of the most effective pathways for NIS introduction, facilitating an easy exchange of species among distant regions of the world (see Allen et al. 2017 for a comprehensive account). In fact, along with fish and/or aquatic plants, several "hitchhikers" are likely transported into the water or on the traded organisms, and eventually released in the environment (Marrone and Naselli-Flores 2011). To prevent this risk, recommendations have been made to all countries in order to control the import and export of species that may become invasive (Convention on Biological Diversity – COP 6 Decision VI/23 - https://www.cbd.int/decision/cop/?id=7197 last accessed May 20, 2019). However, these recommendations are often disregarded by policymakers of most countries and the import and transport of NIS is still largely unregulated (Allen et al. 2017).

As highlighted by Oertli (2018), the physical characteristics of artificial lakes and ponds and their placement in a given area should be carefully planned in order to facilitate the colonization by autochthonous species (and thus their "naturalization"), and to effectively inhibit the establishment of NIS. As an example, the possibility of scientifically-supervised inoculation of the newly created artificial waterbodies with propagules from the local native biota should be investigated as a possible approach to speed-up the process of "naturalization" of man-made waterbodies. Such procedure should be thus addressed at inhibiting the colonization of NIS through the establishment of invasion-resistant, native assemblages.

Moreover, restricting the access to invasion hubs proved to effectively work in the control of an invasive vertebrate in arid Australia (Letnic et al. 2015).

In order to achieve the goal of a successful coexistence of economic development and nature conservation, political decisions should be taken to make aware both the land-owners and the relevant stakeholders of the risks and opportunities linked with the building of artificial water bodies. Early-warning observatories on the occurrence and distribution of alien species should be established, so that the arrival of new NIS could be faced and controlled in the early stage of invasion, before they spread on the territory becoming difficult or impossible to eradicate.

References

Abellan P, Sanchez-Fernandez D, Millan A, Botella F, Sanchez-Zapata JA, Gimenez A. 2006. Irrigation pools as macroinvertebrate habitat in a semi-arid agricultural landscape (SE Spain). Journal of Arid Environments 67: 255–269. DOI 10.1016/j.jaridenv.2006.02.009.

Agenzia Regionale per la Protezione dell'Ambiente Sicilia, 2008. Atlante della Biodiversità della Sicilia. Vertebrati terrestri. Studi e Ricerche 6, ARPA Sicilia, Palermo, pp. 533.

Alfonso G, Belmonte G, Marrone F, Naselli-Flores L. 2010. Does lake age affect zooplankton diversity in Mediterranean lakes and reservoirs? A case study from southern Italy. Hydrobiologia 653: 149-164. DOI 10.1007/s10750-010-0350-4.

Alfonso G, Beccarisi L, Pieri V, Frassanito A, Belmonte G. 2016. Using crustaceans to identify different pond types. A case study from the Alta Murgia National Park, Apulia (South-eastern Italy). Hydrobiologia 782: 53-69. DOI 10.1007/s10750-016-2669-y.

Allen PE, Barquero MD, Esteban Bermúdez E, Calderón JC, Hilje B, Pineda W, Saborío-Rodríguez G, Arguedas V, Chacón-Madrigal E. 2017. Calling for more accurate information in aquarium trade: analysis of live-fish import permits in Costa Rica. Management of Biological Invasions 8: 533-542. DOI 10.3391/mbi.2017.8.4.08.

Alvarez-Cobelas M, Rojo C, Angeler D. 2005. Mediterranean limnology: current status, gaps and the future. Journal of Limnology 64: 13-29. DOI 10.4081/jlimnol.2005.13.

Aradas A, Maggiore G. 1842. Catalogo ragionato delle conchiglie viventi e fossili di Sicilia esistenti nelle collezioni del Dottor Andrea Aradas e dello estinto Abbate D. Emiliano Guttadauro. Atti della Accademia Gioenia di Scienze Naturali, Ser. I, Mem. V, 17(2): 163-205.

Arizza V, Sacco F, Russo D, Scardino R, Arculeo M, Vamberger M, MARRONE F. 2016. The good, the bad and the ugly: *Emys trinacris*, *Placobdella costata* and *Haemogregarina stepanowi* in Sicily (Testudines, Annelida and Apicomplexa). Folia Parasitologica 63: 029. DOI 10.14411/fp.2016.029.

Bella S, Russo A, Suma P. 2018. Monitoring of *Aedes albopictus* (Skuse) (Diptera, Culicidae) in the city of Catania (Italy): seasonal dynamics and habitat preferences. Journal of Entomological and Acarological Research 50: 7217. DOI 10.4081/jear.2018.7217

Berrebi P, Caputo Barucchi V, Splendiani A, Muracciole S, Sabatini A, Palmas F, Tougard C, Arculeo M, Marić S. 2018. Brown trout (*Salmo trutta* L.) high genetic diversity around the Tyrrhenian Sea as revealed by nuclear and mitochondrial markers. Hydrobiologia 826: 209–231. DOI 10.1007/s10750-018-3734-5.

Bresc H. 1986. Un monde méditerranéen: économie et société en Sicile (1300-1450). Bibliothèque des Écoles françaises d'Athènes et de Rome 262: 1-981.

Bresc H, Di Salvo P. 2001. Mulini ad acqua in Sicilia. Edizioni L’Epos, Palermo.

Calvo S, Barone R, Naselli-Flores L, Fradà Orestano C, Dongarrà G, Lugaro A, Genchi G. 1993. Limnological studies on lakes and reservoirs of Sicily. Naturalista sicil. 17 (suppl.): 1-292.

Colomba MS, Liberto F, Reitano A, Grasso R, Di Franco D, Sparacio I. 2013. On the presence of *Dreissena polymorpha* Pallas, 1771 and *Sinanodonta woodiana woodiana* (Lea, 1834) in Sicily (Bivalvia). Biodiversity Journal 4: 571-580.

Consoli N. 1928. Gl'interventi di piccola bonifica nella lotta contro la malaria in Sicilia. Rivista Sanitaria Siciliana 18, Francesco Sanzo e C., Industria Tipografica Editrice, Palermo, 108 pp.

Crescente V, Sperone E, Paolillo G, Bernabò I, Brunelli E, Tripepi S. 2014. Nesting ecology of the exotic *Trachemys scripta elegans* in an area of Southern Italy (Angitola Lake, Calabria). Amphibia-Reptilia 35: 366-370. DOI 10.1163/15685381-00002955.

D'Angelo S, Lo Valvo M. 2003. On the presence of the red swamp crayfish *Procambarus clarkii* (Girard, 1852) (Decapoda Cambaridae) in Sicily (Italy). Naturalista Siciliano 27: 325-327.

Deacon C, Samways MJ, Pryke JS. 2018. Artificial reservoirs complement natural ponds to improve pondscape resilience in conservation corridors in a biodiversity hotspot. PLoS ONE 13: e0204148. DOI 10.1371/journal.pone/0204148.

Deidun A, Sciberras A, Formosa J, Zava B, Insacco G, Corsini-Foka M, Crandall KA. 2018. Invasion by non-indigenous freshwater decapods of Malta and Sicily, central Mediterranean Sea. Journal of Crustacean Biology. DOI:10.1093/jcbiol/ruy076

De Meester L, Gómez A, Okamura B, Schwenk K. 2002. The monopolization hypothesis and the dispersal-gene flow paradox in aquatic organisms. Acta Oecologica 23: 121–135. DOI 10.1016/S1146-609X(02)01145-1

Duchi A. 2018. Indici di qualità ambientale ISECI e NISECI: proposta d'inserimento di *Tinca tinca* (Linnaeus, 1758) nelle comunità ittiche di riferimento della Sicilia. Biologia Ambientale 32: 57-60. DOI 10.30463/ao181.005.

Duggan IC, Payne RJ. 2017. Revisiting Elton's copepods: lake construction has altered the distribution and composition of calanoid copepods in the British Isles. Aquatic Invasions 12: 159-166. DOI 10.3391/ai.2017.12.2.04

Duggan IC, Pullan SG. 2017. Do freshwater aquaculture facilities provide an invasion risk for zooplankton hitchhikers? Biological Invasions 19: 307-314. DOI 10.1007/s10530-016-1280-5.

Duggan IC, Champion PD, MacIsaac HJ. 2018. Invertebrates associated with aquatic plants bought from aquarium stores in Canada and New Zealand. Biological Invasions 20: 3167-3178. DOI 10.1007/s10530-018-1766-4.

Ehrenfeld JG. 2010. Ecosystem consequences of biological invasions. Annual Review of Ecology, Evolution, and Systematics 41:59-80. DOI 10.1146/annurev-ecolsys-102209-144650.

Faranda F. 1977. Primo censimento delle aree destinabili ad acquacoltura in Sicilia. Atti Società Peloritana Scienze Fisiche, Matematiche e Naturali 23(Suppl.): 1-113

Faraone FP, Giacalone G, Canale DE, D'Angelo S, Favaccio G, Garozzo V, Giancontieri GL, Isgrò C, Melfi R, Morello B, Navarria F. 2017. Tracking the invasion of the red swamp crayfish *Procambarus clarkii* (Girard, 1852) (Decapoda Cambaridae) in Sicily: a "citizen science" approach. Biogeographia. The Journal of Integrative Biogeography 32: 25–29. DOI 10.21426/B632135512.

Ferrito V, Tigano C. 1995. The distribution of the ichthyofauna in the Simeto basin (Sicily). Cybium 19: 187-198.

Ficetola GF, Thuiller W, Padoa-Schioppa E. 2009. From introduction to the establishment of alien species: bioclimatic differences between presence and reproduction in the slider turtle. Diversity and Distributions 15: 108-116. DOI 10.1111/j.1472-4642.2008.00516.x.

Gandolfi G, Zerunian S, Torricelli P, Marconato A. 1991. I Pesci delle acque interne italiane. Ministero dell'Ambiente, Istituto Poligrafico e Zecca dello Stato, Roma, pp. 617.

Gherardi F (ed.). 2007. Biological invaders in inland waters: profiles, distribution and threats. Springer, Dordrecht, Netherlands

Giannetto S, Niutta P, Fioravanti ML, Canestri Trotti G. 1990. *Anguillicola crassus* in *Anguilla anguilla* in Calabria e Sicilia. XLIV Convegno della Società Italiana delle Scienze Veterinarie, Stresa, pp. 1225-1228.

Guggino Picone E, Grumignani M, Modica D. 1960. Diffusibilità dei laghetti collinari in Sicilia. Giuffrè Editore, Milano.

Havel JE, Lee CE, Vander Zanden MJ. Do reservoirs facilitate invasions into landscapes? BioScience 55: 518-525. DOI 10.1641/0006-3568(2005)055[0518:DRFIIL]2.0.CO;2.

Havel JE, Kovalenko KE, Magela Thomaz S, Amalfitano S, Kats LB. 2015. Aquatic invasive species: challenges for the future. Hydrobiologia 750: 147-170. DOI 10.1007/s10750-014-2166-0.

Hoffmann RC. 1995. Environmental change and the culture of common carp in medieval Europe. Guelph Ichthyology Reviews 3: 57-85.

Incagnone G, Marrone F, Barone R, Robba L, Naselli-Flores L. 2015. How do freshwater organisms cross the dry ocean? A review on passive dispersal and colonization processes with a special focus on temporary ponds. Hydrobiologia 750: 103-123. DOI 10.1007/s10750-014-2110-3.

Jeppesen E, Brucet S, Naselli-Flores L, Papastergiadou E, Stefanidis K, Nõges T, Nõges P, Attayde JL, Zohary T, Coppens J, Bucak T, Fernandes Menezes R., Sousa Freitas FR, Kernan M, Søndergaard M, Beklioğlu M. 2015. Ecological impacts of global warming and water abstraction on lakes and reservoirs due to change in water level and related changes in salinity. Hydrobiologia 750: 201-227. DOI 10.1007/s10750-014-2169-x.

Johnson PTJ, Olden JD, Vander Zanden MJ. 2008. Dam invaders: impoundments facilitate biological invasions into freshwaters. Frontiers in Ecology and the Environment 6: 357-363. DOI 10.1890/070156.

Kappas I, Mura G, Synefiaridou D, Marrone F, Alfonso G, Alonso M, Abatzopoulos TJ. 2017. Molecular and morphological data suggest weak phylogeographic structure in the fairy shrimp *Streptocephalus torvicornis* (Branchiopoda, Anostraca). Hydrobiologia 801: 21-32. DOI 10.1007/s10750-017-3203-6.

Ketmaier V, Marrone F, Alfonso G, Paulus K, Wiemann A, Tiedemann R, Mura G. 2012. Mitochondrial DNA regionalism and historical demography in the extant populations of *Chirocephalus kerkyrensis* (Branchiopoda: Anostraca). PLoS One 7(2): e30082. DOI 10.1371/journal.pone.0030082.

Korn M, Green AJ, Machado M, García-de-Lomas J, Cristo, M, Cancela da Fonseca L, Frisch D, Pérez-Bote JL, Hundsdoerfer AK. 2010. Phylogeny, molecular ecology and taxonomy of southern Iberian lineages of *Triops mauritanicus* (Crustacea: Notostraca). Organisms Diversity and Evolution, 10: 409-440. DOI 10.1007/s13127-010-0026-y

Letnic M, Webb JK, Jessop TS, Dempster T. 2015. Restricting access to invasion hubs enables sustained control of an invasive vertebrate. Journal of Applied Ecology 52: 341-347. DOI 10.1111/1365-2664.12390.

Leuven RSEW, Boggero A, Bakker ES, Elgin AK, Verreycken H. 2017. Invasive species in inland waters: from early detection to innovative management approaches. Aquatic Invasions 12: 269-273. DOI 10.3391/ai.2017.12.3.01.

Liberto F, Giglio S, Reitano A, Colomba MS, Sparacio I. 2010. Molluschi terrestri e dulciacquicoli di Sicilia della collezione F. Minà Palumbo di Castelbuono. Monografie Naturalistiche 2. Edizioni Danaus, Palermo.

Lillo F. 2008a. Xenopo liscio Xenopus laevis (Daudi, 1802) (Ordine Anura, Famiglia Pipidae). pp. 339-340 in: Massa B. (Ed.) Atlante della biodiversità della Sicilia: Vertebrati terrestri. Studi e Ricerche, 6, Arpa Sicilia, Palermo.

Lillo F. 2008b. Testuggine palustre dalle orecchie rosse *Trachemys scripta* (Schoepff, 1792). pp. 341-342 in: Massa B. (Ed.) Atlante della biodiversità della Sicilia: Vertebrati terrestri. Studi e Ricerche, 6, Arpa Sicilia, Palermo.

Lillo F, Marrone F, Sicilia A, Castelli G, Zava B. 2005. An invasive population of *Xenopus laevis* (Daudin, 1802) in Italy. Herpetozoa 18: 63-64.

Lomolino MV. 1990. The Target Area Hypothesis: the influence of island area on immigration rates of non-volant mammals. Oikos 57: 297-300. DOI 10.2307/3565957.

Lo Valvo M, Faraone FP, Giacalone G, Lillo F. 2017. Fauna di Sicilia. Anfibi. Monografie Naturalistiche 5. Edizioni Danaus, Palermo, 136 pp.

Maceda-Veiga A, Domínguez-Domínguez O, Escribano-Alacid J, Lyons J. 2014. The aquarium hobby: can sinners become saints in freshwater fish conservation? Fish and Fisheries 17: 860-874. DOI 10.1111/faf.12097.

Margaritora FG, Ferrara O, Vagaggini D. 2001. Predatory impact of the mosquitofish (*Gambusia holbrooki* Girard) on zooplanktonic populations in a pond at Tenuta di

Castelporziano (Rome, Central Italy). Journal of Limnology 60: 189-193. DOI 10.4081/jlimnol.2001.1.189.

Marrone F, Naselli-Flores L. 2011. Primo reperto di una lenticchia d'acqua alloctona in Sicilia: *Lemna minuta* Kunth (Araceae Lemnoideae). Naturalista sicil. 35: 179-185.

Marrone F, Naselli-Flores L. 2015. A review on the animal xenodiversity in Sicilian inland waters (Italy). Advances in Oceanography and Limnology 6: 2-12. DOI 10.4081/aiol.2015.5451.

Marrone F, Barone R, Naselli-Flores L. 2005. Cladocera (Branchiopoda: Anomopoda, Ctenopoda, and Onychopoda) from Sicilian inland waters: an updated review. Crustaceana 78: 1025-1039. DOI 10.1163/156854005775361043.

Marrone F, Barone R, Naselli-Flores L. 2006a. Ecological characterization and cladocerans, calanoid copepods and large branchiopods of temporary ponds in a Mediterranean island (Sicily, southern Italy). Chemistry and Ecology 22: S181-S190. DOI 10.1080/02757540600557827.

Marrone F, Castelli G, Naselli-Flores L. 2009. Sicilian temporary ponds: an overview of the composition and affinities of their crustacean biota. In: Fraga I Argiumbau P. (ed.) International Conference on Mediterranean Temporary Ponds. Proceedings & Abstracts. Consell Insular de Menorca. Recerca,14. Maó, Menorca. pp. 189-202.

Marrone F, Lo Brutto S, Arculeo M. 2011. Cryptic invasion in southern Europe: The case of *Ferrissia fragilis* (Pulmonata, Ancylidae) Mediterranean populations. Biologia 66: 484-490. DOI 10.2478/s11756-011-0044-z.

Marrone F, Castelli G, Barone R, Naselli-Flores L. 2006b. Ecology and distribution of Calanoid Copepods in Sicilian inland waters (Italy). Verh. Internat. Verein. Limnol., 29: 2150-2156. DOI 10.1080/03680770.2006.11903072.

Marrone F, Lo Brutto S, Hundsdoerfer AK, Arculeo M. 2013. Overlooked cryptic endemism in copepods: Systematics and natural history of the calanoid subgenus *Occidodiaptomus* Borutzky 1991 (Copepoda, Calanoida, Diaptomidae). Molecular Phylogenetics and Evolution 66: 190–202. DOI 10.1016/j.ympev.2012.09.016.

Marrone F, Sacco F, Kehlmaier C, Arizza V, Arculeo M. 2016. Some like it cold: the glossiphoniid parasites of the Sicilian endemic pond turtle *Emys trinacris* (Testudines, Emydidae), an example of 'parasite inertia'? Journal of Zoological Systematics and Evolutionary Research 54: 60-66. DOI 10.1111/jzs.12117.

Marrone F, Alfonso G, Stoch F, Pieri V, Alonso M, Dretakis M, Naselli-Flores L. 2019. An account on the non-malacostracan crustacean fauna from the inland waters of Crete, Greece, with the synonymization of *Arctodiaptomus piliger* Brehm, 1955 with *Arctodiaptomus alpinus* (Imhof, 1885) (Copepoda: Calanoida). Limnetica 38: 167-187. DOI: 10.23818/limn.38.01

Meineri E, Rodriguez-Perez H, Hilaire S, Mesleard F. 2014. Distribution and reproduction of *Procambarus clarkii* in relation to water management, salinity and habitat type in the Camargue. Aquatic Conservation: Marine and Freshwater Ecosystems 24: 312- 323. DOI 10.1002/aqc.2410.

Miracle MR, Alekseev V, Monchenko V, Sentandreu V, Vicente E. 2013. Molecular-genetic-based contribution to the taxonomy of the *Acanthocyclops robustus* group. Journal of Natural History 47: 863-888. DOI: 10.1080/00222933.2012.744432.

Monterosato TA. 1896. Note intorno alle Najadi siciliane. Naturalista Siciliano 15: 6 – 20.

Naselli-Flores L. 1999. Limnological aspects of Sicilian reservoirs: a comparative, ecosystemic approach. In: Tundisi JG, Straškraba M (eds), Theoretical reservoir limnology and its applications. International Institute of Ecology, Backhuys Publishers, Leiden, pp. 283-311.

Naselli-Flores L. 2003. Man-made lakes in Mediterranean semi-arid climate: the strange case of Dr Deep Lake and Mr Shallow Lake. Hydrobiologia 506-509: 13-21. DOI 10.1023/B:HYDR.0000008550.34409.06.

Naselli-Flores L. 2011. Mediterranean climate and eutrophication of reservoirs: limnological skills to improve management. In: Ansari AA, Sarvajeet SG, Lanza GR, Rast W (eds), Eutrophication: causes, consequences and control. Springer Science, pp. 131-142. DOI 10.1007/978-90-481-9625-8_6

Naselli-Flores L, Barone R. 2012. Phytoplankton dynamics in permanent and temporary Mediterranean waters: is the game hard to play because of hydrological disturbance? Hydrobiologia 698: 147-159. DOI 10.1007/s10750-012-1059-3

Naselli-Flores L, Lugliè A. 2014. Laghi artificiali dell'Italia meridionale e delle isole maggiori. Biologia Ambientale 28: 41-48.

Naselli-Flores L, Termine R, Barone R. 2016. Phytoplankton colonization patterns. Is species richness depending on distance among freshwaters and on their connectivity? Hydrobiologia 764: 103-113. DOI 10.1007/s10750-015-2283-4

Nentwig W (ed.). 2007. Biological Invasions. Ecological Studies 193. Springer, Berlin

Nunes AL, Tricarico E, Panov VE, Cardoso AC, Katsanevakis S. 2015. Pathways and gateways of freshwater invasions in Europe. Aquatic Invasions, 10: 359-370. DOI 10.3391/ai.2015.10.4.01.

Oertli, B. 2018. Editorial: Freshwater biodiversity conservation: the role of artificial ponds in the 21st century. Aquatic Conservation: Marine and Freshwater Ecosystems 28: 264-269. DOI 10.1002/aqc.2902

Ollivier QR, Maher DT, Pitfield C, Macreadie PI. 2018. Punching above their weight: Large release of greenhouse gases from small agricultural dams. Global Change Biology (in press) DOI: 10.1111/gcb.14477.

Padilla D, Williams S. 2004. Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems Frontiers in Ecology and Environment 2: 131-138. DOI 10.1890/1540-9295(2004)002[0131:BBWAAO]2.0.CO;2.

Patoka J, Bláha M, Kalous L, Vrabec V, Buřič M, Kouba A. 2016. Potential pest transfer mediated by international ornamental plant trade. Scientific Reports 6: 25896. DOI 10.1038/srep25896.

Peréz-Bote JL, Muñoz A, Romero AJ, Martin AB, Méndez E, López MT. 2004. Primer caso de depredación del cangrejo rojo americano *Procambarus clarkii* (Girard, 1853) (Crustacea: Decapoda: Astacidae) sobre *Triops cancriformis mauritanicus* (Ghigi, 1801) (Crustacea: Notostraca: Triopsidae) en lagunas temporales del suroeste ibérico. Boletín de la Sociedad Entomológica Aragonesa 35: 283-284.

Petralia E. 2008. Nutria o Castorino *Myocastor coypus* Molina 1782. pp. 63-64 in: Massa B. (Ed.) Atlante della biodiversità della Sicilia: Vertebrati terrestri. Studi e Ricerche, 6, Arpa Sicilia, Palermo.

Pimentel D (ed.). 2011. Biological invasions: economic and environmental costs of alien plant, animal, and microbe species. CRC Press, Boca Raton.

Philippi RA. 1844. Enumeratio molluscorum Siciliae cum viventium tum in tellure tertiaria fossilium, quae in itinere suo observavit. Vol 2, pp 1–303.

Prathvi R, Sheela I, Nalini RK. 2014. Ornamental fish exports from India: performance, competitiveness and determinants. International Journal of Fisheries and Aquatic Studies 1: 85-92.

Reitano A, Liberto F, Sparacio I, 2007. Nuovi dati su Molluschi terrestri e dulciacquicoli di Sicilia. 1° Contributo (Gastropoda Prosobranchia Neotaenioglossa; Gastropoda Pulmonata Basommatophora, Stylommatophora). Naturalista Siciliano 31: 311-330.

Ruggiero A, Céréghino R, Figuerola J, Marty P, Angélibert S. 2008. Farm ponds make a contribution to the biodiversity of aquatic insects in a French agricultural landscape. C.R. Biologies 331: 298-308. DOI 10.1016/j.crvi.2008.01.009.

Russo G, La Rocca S, Violani C, Zava B. 1999. Contributions to the knowledge of Sicilian freshwater fishes. II. Notes on some allochthonous species recently introduced. Doriana 7 (308): 1-7.

Russo G, Violani C, Zava B, 1997. Observations on population dynamics of *Rutilus rubilio* Cyprinidae in a man-made hypertrophic basin (Arancio Lake, southwest Sicily). Italian Journal of Zoology 65(Suppl.): 549-551. DOI 10.1080/11250009809386883.

Sahuquillo M, Miracle MR. 2013. The role of historic and climatic factors in the distribution of crustacean communities in Iberian Mediterranean ponds. Freshwater Biology 58: 1251-1266. DOI 10.1111/fwb.12124.

Schifani E, Viviano A, Viviano R, Marrone F, Naselli-Flores L. 2019. Different lineages of freshwater jellyfishes (Cnidaria, Olindiidae, *Craspedacusta*) invading Europe: another piece of the puzzle from Sicily, Italy. Limnology 20: 143-151. DOI 10.1007/s10201-018-0560-4.

Shurin JB. 2000. Dispersal limitation, invasion resistance, and the structure of pond zooplankton communities. Ecology 81: 3074–3086. DOI 10.1890/0012-9658(2000)081[3074:DLIRAT]2.0.CO;2.

Sicilia A, Turrisi F. 2008. Rospo comune *Bufo bufo* (Linnaeus, 1758). Pp. 269-270 in: Massa B. (Ed.) Atlante della biodiversità della Sicilia: Vertebrati terrestri. Studi e Ricerche, 6, Arpa Sicilia, Palermo.

Simberloff D, Martin JL, Genovesi P, Maris V, Wardle DA, Aronson J, Courchamp F, Galil B, García-Berthou E, Pascal M, Pyšek P, Sousa R, Tabacchi E, Vilà M. 2013. Impacts of biological invasions: what's what and the way forward. Trends in Ecology and Evolution 28:58-66. DOI 10.1016/j.tree.2012.07.013.

Stoch F, Valentino F, Volpi E. 1996. Taxonomic and biogeographic analysis of the *Proasellus coxalis*-group (Crustacea, Isopoda, Asellidae) in Sicily, with description of *Proasellus montalentii* n.sp. Hydrobiologia 317: 247-258. DOI 10.1007/BF00036474.

Stoch F, Naselli-Flores L. 2014. Acque temporanee: biodiversità, funzioni ecosistemiche, vulnerabilità e sensibilità ai cambiamenti climatici. Biologia Ambientale 28: 87-92.

Stoch F, Korn M, Turki S, Naselli-Flores L, Marrone F. 2016. The role of spatial environmental factors as determinants of large branchiopod distribution in Tunisian temporary ponds. Hydrobiologia 782: 37-51. DOI 10.1007/s10750-015-2637-y.

Strayer DL. 2010. Alien species in fresh waters: ecological effects, interactions with other stressors, and prospects for the future. Freshwater Biology 55 (suppl. 1):152–174. DOI 10.1111/j.1365-2427.2009.02380.x.

Tigano C, Ferrito V. 1986. Sulla presenza di *Rutilus rubilio* (Bp. 1837) in Sicilia (Pisces, Cyprinidae). Animalia 13: 109-124.

Tigano C, Ferrito V. 1996. I pesci delle acque interne e di estuarioAtti del Convegno su La Fauna degli Iblei tenuto dall'Ente Fauna Siciliana a Noto il 13 e 14 maggio 1995: 81-102.

Uzzani F. 2012. Laghetti collinari e dighe. Guida pratica per la progettazione, l'esercizio e la manutenzione. Dario Flaccovio Editore, Palermo.

Vamberger M, Stuckas H, Sacco F, D'Angelo S, Arculeo M, Cheylan M, Corti C, Lo Valvo M, Marrone F, Wink M, Fritz U. 2015. Differences in gene flow in a twofold secondary contact zone of pond turtles in southern Italy (Testudines: Emydidae: *Emys orbicularis galloitalica*, *E. o. hellenica*, *E. trinacris*). Zoologica Scripta 44: 233-249. DOI 10.1111/zsc.12102.

Vannini A, Bruni G, Ricciardi G, Platania L, Mori E, Tricarico E. 2018. *Gambusia holbrooki*, the ‘tadpolefish’: The impact of its predatory behaviour on four protected species of European amphibians. Aquatic Conservation Marine and Freshwater Ecosystems 28: 476-484. DOI 10.1002/aqc.2880.

Vecchioni L, Marrone F, Arculeo M, Arizza V. 2017. Are there autochthonous *Ferrissia* (Mollusca, Planorbidae) in the Palearctic? Molecular evidence of a widespread North American invasion of the Old World. The European Zoological Journal 84: 411-419. DOI 10.1080/24750263.2017.1350759.

Vecchioni L, Marrone F, Naselli-Flores L. 2019. On the occurrence and distribution of *Calanipeda aquaedulcis* Kritschagin, 1873 (Copepoda, Calanoida, Pseudodiaptomidae) in Sicily, Italy, with some notes on coexistence and species replacement in calanoid copepods. Advances in Oceanography and Limnology (accepted for publication).

Ventura M, Petrusek A, Miró A, Hamrová E, Buñay D, De Meester L, Mergeay J. 2014. Local and regional founder effects in lake zooplankton persist after thousands of years despite high dispersal potential. Molecular Ecology 23: 1014-1027. DOI 10.1111/mec.12656.

Vinarski MV. 2017. The history of an invasion: phases of the explosive spread of the physid snail *Physella acuta* through Europe, Transcaucasia and Central Asia. Biological Invasions 19: 1299-1314. DOI 10.1007/s10530-016-1339-3.

Zahar Y. 2011. Water Supply in Roman Carthage. HYDRIA PROJECT - Discover the wealth of the Mediterranean water management heritage. Volume: Collection, Storage & Distribution of Water in Antiquity Linking Ancient Wisdom to Modern Needs. http://www.hydriaproject.info/en/the-water-management-in-the-region-of-tunis-through-history/importance16. (accessed on May 20, 2019).

Zarfl C, Lumsdon AE, Berlekamp J, Tydecks L, Tockner K. 2015. A global boom in hydropower dam construction. Aquatic Sciences 77: 161-170. doi:10.1007/s00027-014-0377-0

Zettler ML, Richard D, 2003. Kurze Bemerkungen über Süsswassermollusken Siziliens unterbesonderer Berücksichtigung von *Theodoxus meridionalis* (Philippi, 1836). Malak. Abh. 21:29.38.

Figure 1. An example of Sicilian landscape with natural and man-made water-bodies. **A**: Synoptic vision of a hilly rural area in western Sicily. Man-made waterbodies are easily recognizable by their geometric shape; **B**: An excerpt from the previous image showing the occurrence of relic temporary swamps close to artificial water bodies and greenhouses covered with solar panels (February 2013); **C**: The same area in April 2016. The spreading of the greenhouses destroyed half of the natural swamps pre-occurring in the area; **D**: Temporary pond close to an urban center in southern Sicily (March 2003); **E**: The same after its reclamation due to "public utilities" works.

Taxa	Native range	First evidence in Sicily (century)	First reference(s) for Sicily	NLT	ALT	NLP	ALP	LOT
CNIDARIA **Hydrozoa**								
Craspedacusta sowerbii Lankester, 1880	E-PAL	XXI	Schifani et al. 2019				X	
NEMATODA **Secernentea**								
Anguillicola crassa Kuwahara, Niimi and Itagaki, 1974	E-PAL	XX	Giannetto et al., 1990					X
MOLLUSCA **Gastropoda**								
Potamopyrgus antipodarum (Gray, 1843)	AUS	XXI	Zettler and Richard, 2003			X		X
Radix auricularia (Linnaeus, 1758)	PAL	XIX	Aradas and Maggiore, 1841			X	X	X
Physella acuta (Draparnaud, 1805)	NEA	XIX	Philippi, 1844	X		X	X	X
Ferrissia californica (Rowell, 1863)	NEA	XXI	Marrone et al., 2011			X	X	
Helisoma duryi (Wheterby, 1879)	NEA	XXI	Zettler and Richard, 2003 (sub *Planorbella anceps* (Menke, 1830)). See also: Reitano et al., 2007			X	X	X
Melanoides tuberculata (Müller, 1774)	AFR & ORI	XXI	Reitano et al., 2007					X
Bivalvia								
Dreissena polymorpha (Pallas, 1711)	PAL	XXI	Colomba et al., 2013				X	
Sinanodonta woodiana (Lea, 1834)	E-PAL	XXI	Colomba et al., 2013				X	
ARTHROPODA **Crustacea**								
Daphnia ambigua Scourfield, 1947	NEA	XX	Calvo et al. 1993				X	
Daphnia parvula Fordyce, 1901	NEA	XX	Marrone et al. 2005				X	
Acanthocyclops americanus (Marsh, 1893)	NEA	XX	Calvo et al., 1993; Schifani et al., 2019				X	

			(sub *A. trajani* Mirabdullayey and Defaye, 2004)					
Neoergasilus japonicus (Harada, 1930)	E-PAL	XXI	Unpublished data				X	
Proasellus banyulensis (Racovitza, 1919)	PAL	XX	Stoch et al., 1996				X	X
Procambarus clarkii (Girard, 1852)	NEA	XXI	D'Angelo and Lo Valvo, 2003			X	X	X
Cherax destructor (Clark, 1836)	AUS	XXI	Deidun et al. 2018					X
Insecta								
Aedes albopictus (Skuse, 1894)	ORI	XXI	Liotta and Matranga, 2004, in: Bella et al. 2018		X			
CHORDATA **Osteichthyes**								
Micropterus salmoides Lacépède, 1802	NEA	XX	Tigano and Ferrito, 1996; See also: Russo et al., 1999				X	X
Perca fluviatilis Linnaeus, 1758	PAL	XX	Faranda et al., 1977				X	X
Carassius auratus (Linnaeus, 1758)	E-PAL	XX	Faranda et al., 1977			X		
Cyprinus carpio Linnaeus, 1758	PAL	XX	Faranda et al., 1977			X	X	X
Rutilus rubilio Bonaparte, 1837	PAL	XX	Faranda, 1977 (sub *Alosa fallax nilotica* (Geoffroy Saint-Hilaire, 1809). See also: Tigano and Ferrito, 1986				X	X
Tinca tinca (Linnaeus, 1758)	PAL	XIII	Bresc, 1986			X	X	X
Ameiurus melas (Rafinesque, 1820)	NEA	XX	Russo et al., 1999			X	X	X
Gambusia holbrooki Girard, 1859	NEA	XX	Consoli, 1928			X	X	X
Esox lucius Linnaeus, 1758	PAL	XX	Ferrito and Tigano, 1995				X	X
Oncorhynchus mykiss Walbaum, 1792	NEA	XX	Ferrito and Tigano, 1995					X
Salmo trutta Linnaeus, 1758 "aquaculture strain"	PAL	XX	Tigano and Ferrito, 1996					X
Amphibia								
Xenopus laevis (Daudin, 1802)	AFR	XX	Lillo et al. 2005				X	X
Sauropsida								
Emydidae	NEA	XXI	Lillo, 2008b and Unpublished data			X	X	X
Mammalia								
Myocastor coypus Molina, 1872	NEO	XX	Petralia, 2008					X

Table 1. Checklist and distribution patterns of the observed NIS. Based on available data, temporary lotic habitats do not host NIS and were thus excluded from the table. Moreover, man-made permanent lotic habitats are not present on the island. AFR: Afrotropical region; AUS: Australasian region; E-PAL: East-Palearctic region; NEA: Nearctic region; NEO: Neotropical region; ORI: Oriental region; PAL: Palearctic region. NLT: Natural, lentic, temporary water bodies; ALT: Artificial, lentic, temporary water bodies; NLP: Natural, lentic, permanent water bodies; ALP: Artificial, lentic, permanent water bodies; LOT: lotic water bodies.