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Monitoring of alien aquatic plants in the inland waters of Sicily (Italy)

Angelo Troia[1,*], Vincenzo Ilardi[2], Elisabetta Oddo[1]

[1] *Dipartimento STEBICEF (Scienze e Tecnologie Biologiche, Chimiche e Farmaceutiche), Università degli Studi di Palermo, Palermo, Italy*

[2] *Dipartimento DISTEM (Scienze della Terra e del Mare), Università degli Studi di Palermo, Palermo, Italy*

*Corresponding author, email angelo.troia@unipa.it

Abstract. Updated and reliable data on the presence and distribution of alien aquatic plant species in Sicily are lacking, and there is a need to fill this gap for a proper and efficient management of freshwater ecosystems and biodiversity. This paper reviews the available knowledge about alien aquatic vascular plants in the inland waters of Sicily (Italy). The aim is to provide an updated checklist, as a first step in the study of the impact of those plants on the native species and ecosystems of this Mediterranean island. The paper focuses on the strictly aquatic species (hydrophytes), excluding emergent macrophytes. Four species were listed, all of them free-floating and with American origin. Most of them occur within protected areas, and their introduction in the island appears to be anthropogenic. A set of functional traits of the alien species, such as relative growth rate, leaf mass per area, nitrogen and carbon content, were screened. These traits are useful for assessing the species invasive potential compared to native ones.

Keywords: alien species, aquatic plants, biodiversity, functional traits, hydrophytes, protected areas.

INTRODUCTION

Invasive alien species pose a major global threat to the conservation of biodiversity, causing the extinction of native species and modifying ecosystem functions: this is true also for aquatic habitats, particularly susceptible to invasion due to usually high disturbance regimes affecting these habitats and the easy dispersal of water plant propagules. In addition, aquatic environments are also difficult to monitor, and an early detection of introduction of a submerged species is seldom possible (Brundu 2015).

Mediterranean islands are particularly appreciated model systems for studying invasions due to the diversity of alien taxa, long history of species introductions and (usually) detailed floristic records (Hulme 2004; Lloret et al. 2005; Bjarnason et al. 2017; Chiarucci et al. 2017; Pasta et al. 2017).

The island of Sicily is one of the main hotspots of plant biodiversity, in the center of the Mediterranean basin (Médail and Diadema 2009), housing more than 3,000 wild plant species (Pignatti et al. 2017-2019) and being an ideal stage for research in ecology and evolution (e.g. Geraci et al. 2009, 2019; Minissale and Sciandrello 2016); it hosts different types of freshwater habitats, both lentic (coastal wetlands, temporary ponds, lakes, reservoirs) and lotic (springs, streams, permanent and seasonal watercourses) (Gianguzzi et al. 2016), with many endemic or endangered species occurring in aquatic habitats (cf. Bonanno and Veneziano 2011; Troia et al. 2012; Troia and Lansdown 2016; Sciandrello et al. 2016; Minissale et al. 2017).

In the last years new aquatic alien species, such as *Lemna minuta* Kunth (Marrone and Naselli-Flores 2011), and new populations of already reported ones, such as *Eichhornia crassipes* (Mart.) Solms (Ferro 2013), have been reported. Nevertheless, no recent and updated synthesis on the ecology and the distribution of the Sicilian alien aquatic flora is currently available.

Thus, the aims of this work were i) to compile data on the distribution of alien vascular plant species with special reference to their occurrence in protected areas, as a first step in the analysis of the effects of the alien species on the aquatic habitats of the island; ii) to compile data on some functional traits (such as relative growth rate, leaf area, leaf mass per area, nitrogen and carbon content) of the alien species, in order to allow predictions about their potential invasiveness of natural wetlands.

MATERIALS AND METHODS

In the literature, the term ‘‘water plant’’ has usually been applied rather arbitrarily in the case of plants occurring in and near the water (cf. Brundu 2015); here we refer to the classification of Chambers et al. (2008), framing the aquatic plants in four main groups: emergent macrophytes (plants that are rooted in submersed soils or soils that are periodically inundated, with foliage extending into the air), floating-leaved macrophytes (plants rooted to the lake or stream bottom with leaves that float on the surface of the water), submersed macrophytes (plants that grow completely submerged under the water, with roots or root analogs in, attached to, or closely associated with the substrate), and free-floating macrophytes (plants that typically float on or under the water surface). In particular, in this study we focused only on the vascular plants belonging to the last 3 types (“hydrophytes” according to Raunkiaer 1934), so excluding the not-strictly aquatic plants. In this sense, our three categories correspond to the three groups adopted by the European and Mediterranean Plant Protection Organisation (EPPO) (EPPO 2014).

Inland waters are here defined according to the Water Framework Directive (Directive 2000/60/EC), excluding transitional waters.

Finally, alien species are here defined as “plant taxa in a given area (…) whose presence there is due to intentional or unintentional human involvement, or which have arrived there without the help of people from an area in which they are alien” (Pyšek et al. 2004).

We consulted all available literature regarding the alien flora in Sicily, to prepare a list of the alien aquatic vascular plants reported for the island, with family names and order according to Smith et al. (2006) and Haston et al. (2009). In addition, databases and photographs from popular websites such as Acta Plantarum (www.actaplantarum.org) have been consulted to obtain recent data and cover under-represented geographic areas. Finally, the management plans for the “Natura2000 sites” (protected areas designated according to the European ‘Habitats’ Directive 92/43/CE, which mostly overlap with natural parks and reserves), available on the website of the Sicilia Region (http://www.artasicilia.eu/old_site/web/natura2000/index.html), were consulted, too.

We reviewed the scientific literature published in the last fifteen years (2006-2020) to screen the most relevant physiological traits that may aid in assessing the invasive potential of alien species compared to native ones. Literature search was made in the Scopus and Google Scholar databases, using as keywords the names of the species resulting from the list compiled as described in the previous paragraph.

RESULTS

Four aquatic alien species (Table 1), belonging to 3 genera and 3 different families, including both ferns (2 species) and angiosperms (2 species), are reported for Sicily.

About *Azolla*, the taxonomy of this genus “is difficult and controversial since the vegetative and some reproductive characters used to identify these species are highly variable, depending on the collection site and on the environmental conditions” (Pereira et al. 2011). In addition, nomenclatural reasons linked to the use of the name “Azolla caroliniana” created further confusion, so that the two species previously reported for Sicily (Romano et al. 1994) have been considered a single species in the last national Flora (Pignatti et al. 2017-2019). According to some recent studies (e.g. Evrard and van Hove 2004; Lastrucci et al. 2019), two different species occur in Sicily: *Azolla filiculoides* Lam. and *A. cristata* Kaulf. (= *A. carolinana* sensu Auct.) (Table 1).

Table 1. List of the alien aquatic vascular plants reported for Sicily.

Species	Family	Origin	Number of known populations in Sicily	Number of populations within a protected area	**References**
Azolla filiculoides Lam.	Salviniaceae	America (N&S)	3	2	Romano et al. 1994; Albano 2010; Giordana 2013
Azolla cristata Kaulf. (= *Azolla mexicana*) (= *Azolla caroliniana* Auct. non Willd.)	Salviniaceae	America (N&S)	2	2	Romano et al. 1994; Minissale and Sciandrello 2017
Lemna minuta Kunth	Araceae	America (N)	1	1	Marrone and Naselli-Flores 2011
Eichhornia crassipes (Mart.) Solms	Pontederiaceae	America (S)	3	2	Bartolo et al. 1976; Ferro 2013; Di Gregorio 2014

Table 2. Functional traits of the 4 alien aquatic species reported for Sicily.

	LA mm^2	LMA $mg\ mm^{-2}$	RGR $g\ g^{-1}\ d^{-1}$	NC %	CC %	
Azolla filiculoides	0.9-0.92	0.003-0.024	0.08-0.9	2.01-3.5	35.4-42.5	Brouwer et al. 2018; Cheng et al. 2010; Gufu et al. 2019; Lukàcs et al. 2017; Pierce et al 2012; Shaltout et al. 2012; Van Kempen et al. 2016
Azolla cristata (= *Azolla mexicana*) (= *Azolla caroliniana* sensu Auct.)			0.09-0.18	4.0		Hassan et al. 2020; Lizieri et al. 2011; Roberts et al. 2014; Rofkar et al. 2014
Lemna minuta	2.4-3.07	0.008-0.01	0.16	2.37-2.7	35.3-41	Pierce et al. 2012; Gérard & Triest 2014; Lukàcs et al. 2017
Eichhornia crassipes	3500-7300	0.05-0.07	0.002-0.045[(2)]	2.2-2.5	40	Henry-Silva et al. 2008; Fan et al. 2013; Wang et al. 2017; Eid & Shaltout 2017; Zahoor et al. 2018; Upadhyay & Pame 2019; Wauton & William-Ebi 2019

Abbreviations: LA, leaf area; LMA, leaf mass per area; RGR, relative growth rate; NC, nitrogen content; CC, carbon content.[(1)] average of different clones. [(2)] different nutrient availability or growth sites.

The presence in Sicily of another species, which we did not include here, *Halophila stipulacea* Asch. (Hydrocharitaceae) (Biliotti and Abdelahad 1990), is noteworthy; although it is a seagrass, native to the Indian Ocean and reported for the coasts of Sicily, it seems able to colonize also coastal ponds with salt or brackish water (Procaccini et al. 1999), potentially threatening protected areas such as “Saline di Trapani e Paceco”, “Stagnone di Marsala” and similar areas including saltworks and lagoons.

Table 1 shows that 4 out of 4 species are of American origin, all of them coming from warm, subtropical or tropical areas. This latter circumstance can be explained with the Mediterranean climate occurring in Sicily; the former one is probably to be linked to the reasons reported in the next paragraph. Interestingly, also the 10 alien hydrophytes reported for Sardinia (Mayoral et al. 2018) are American species.

Considering the geographic origin of the species, and their use in many human activities, it seems probable that *Homo sapiens* is the main vector of their introduction: all of these species are in fact commonly used as ornamental plants in gardens, fish tanks and aquaria, or as effective living elements in constructed wetlands (see Mazza et al. 2015).

All the aquatic alien species occurring in Sicily are free-floating species. Other alien aquatic species with a different growth-form potentially occurring in Sicily, for example the rooted *Elodea canadensis* Michx. and *Myriophyllum aquaticum* (Vell.) Verdc. (occurring in northern and central Italy), have not been found (till now at least), probably for climatic reasons.

Practically all the sites in which alien aquatic species were reported are located within protected areas (Table 1), i.e. natural parks and reserves or sites of the Natura2000 network (but also in an archaeological park). These areas include both coastal habitats (such as wetlands and river mouths) and lakes and ponds in the hills, not far from the coast.

Available literature from the last fifteen years often reported different traits for the alien species found in Sicilian wetlands. The functional traits that could be most widely compared among these species are reported in Table 2. We did not find recent data for *Azolla cristata* in our literature survey: considering the nomenclatural matters cited above, we included in Table 2 data for *A. caroliniana* (*sensu lato*). *Eichhornia crassipes* was the species with the highest leaf area and leaf mass per area (LMA) values. The lowest LMA values were reported for *Lemna minuta*, mainly reflecting the different leaf morphology between the species. Relative growth rate in *Eichhornia crassipes* was lower than the maximum RGR reported for the other species. Tissue nitrogen content was higher for the *Azolla* species, as predictable. Available data on carbon content, instead, were quite similar among the different species.

DISCUSSION

Comparing the number of alien aquatic plant species reported for Sicily with the total number of alien aquatic plant species in the EPPO list (Brundu 2015) - even if it does not include some of the species in our list - reveals that about 1/5 of that number have been found in Sicily, on a very limited area compared to the EPPO region currently including 50 countries (www.eppo.int). However in Sardinia, another Mediterranean island geologically different from Sicily but similar for climate and size, the number of alien hydrophytes is more than double (Mayoral et al. 2018).

The alien aquatic species here reported seem to be limited to few localities, so it seems they are not invasive; but really the feeling is that we have too scarce information – and scattered in time - to say something about their real status.

Our results show that aquatic alien species in Sicily have been reported almost exclusively from protected areas. This probably because protected areas are better studied and monitored, compared to other non-protected areas, and so they can function as 'sentinels' for monitoring the spread of invasive aquatic plant species. But this means also that: 1) the presence of (potentially invasive) alien species in protected areas must be managed (see for example threats and priorities for alien plant invasions in protected areas in Foxcroft et al. 2017); 2) Probably, other populations (and other species?) of alien plants could be already present in "secondary" and overlooked aquatic habitats, outside protected areas.

Usually, monitoring of invasive plant species focuses on terrestrial habitatas. During the preparation of the management plans of the Natura2000 sites in Sicily, that were made in the same period all over the island about 12 years ago, special attention to alien invasive species was asked by Regional Coordinators: only in one (Albano 2010) of the 25 examined plans a single aquatic invasive plant species is mentioned.

The situation we found in Sicily for aquatic alien species fits well (unfortunately) with the general lack of information on the presence and abundance of invasive aquatic plants in protected areas in all Mediterranean islands, as highlighted by Brundu (2013), who defined this a serious hindrance for management at international levels.

In the case of alien aquatic species in Sicily, we have seen that their introduction is generally linked to their use and release (intentional or not) by man. The release of alien species in natural habitats is generally prohibited by law, but in Italy, as in several other countries, this is not sufficient to avoid the diffusion of potentially invasive plants. While the impact of alien species on the native aquatic systems of Sicily is well known as regards the faunistic aspects (Marrone and Naselli-Flores 2015), it still has to be evidenced for floristic aspects.

The identification of a general set of functional traits favoring invasiveness may be controversial, as traits of invaders depend on many factors, among which reproductive strategies (Violle et al. 2007), ecological and physiological traits of native species and the environmental conditions of invaded habitats (Funk 2013). Generally, native species are the ones best adapted to a given habitat, but the arrival of alien, more competitive species may alter the ecosystem balance, especially when perturbations of that habitat occur. For terrestrial habitats, many studies have reported differences in morphological or physiological traits between native and invasive taxa, while others have not proved the predictability of invasiveness from these traits (Leffler et al. 2014).

In aquatic environments, an important factor determining invasiveness is nutrient availability. For example, experiments comparing competitiveness between *Lemna minuta* and *L. minor* found that the invasive species was dominant only under high levels of nutrient availability (Njambuya et al. 2011), and therefore invasion would increase with eutrophication, as reported also for *E. crassipes* (Coetzee et al. 2017) In mixed aquatic communities, plant density has been reported as another relevant factor affecting invasiveness, either through facilitation or competition, depending on the species (Silveira and Thiébaut 2020).

LMA is a trait central to the pattern of the leaf economic spectrum, which shows a negative correlation with photosynthetic rate across species (John et al. 2017). High values of LMA are typically found in slow growing species, while low values are common for fast growing species (Wright et al. 2004; Reich 2014). Most hydrophytes share low LMA values, a trait related to high resource acquisition strategies that may aid in competition (Pierce et al. 2012), so invasive species with lower LMA than native ones may be at advantage.

It is clear from this first analysis that updated and complete data on the presence of alien aquatic species in Sicily and on their competitiveness with native species are lacking, so there is the need to fill this gap for a proper and efficient management of ecosystems and biodiversity. Conservation of wetlands remains particularly challenging, given the importance of fresh water for human communities and the consequent pressure wetlands and water bodies are prone to, and this type of ecosystems can no longer be considered the "poor cousins" (Kingsford et al. 2016) of the other terrestrial ones.

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