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Rapid Communication

First record of *Sinanodonta woodiana* (Lea, 1834) in an artificial reservoir in the Molise region, Southeast Italy

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Abstract

The occurrence of the Chinese pond mussel *Sinanodonta woodiana* is reported for the first time in the Molise region (Southeast Italy). Details of the mussel's invasion history in Italy are also given. A total of 24 *S. woodiana* specimens were collected after a long drought period in October 2017 from an emerged beach on the southwest side of the Guardialfiera artificial lake and their main morphometric features were quantified. No young individuals were found, only large adults, whose survival could ensure population subsistence in more suitable environmental conditions. The present study provides evidence of a massive die-off affecting invasive bivalves during an extreme climatic event, producing decaying biomass with negative impacts on the water quality of the lake. Further investigations of the population dynamics of this species and the environmental quality of the water body are needed to develop an appropriate management plan in relation to the ecosystem services it delivers.

Key words: bivalves, invasive species, Chinese pond mussel, freshwater pond, Lake Guardialfiera

Introduction

The Chinese pond mussel *Sinanodonta (Anodonta) woodiana* (Lea, 1834) (Bivalvia: Unionidae) is an invasive freshwater species originating from Eastern Asia and the Amur Basin in Eastern Russia (Graf 2007). From its native area, the species has spread rapidly to Southeast Asia, Central and North America, and Europe, including Spain, France, Italy, Germany, Austria, Slovakia, Hungary, the Czech Republic, Poland, Croatia, Serbia, Romania, Moldova, Ukraine and Sweden (Cianfanelli et al. 2007 and literature cited therein; Benson 2011; Bogan et al. 2011; Lajtner and Crnčan 2011; Raković et al. 2016; Bolotov et al. 2016; Zieritz et al. 2018).

Sinanodonta woodiana is a broad and indiscriminate generalist. Fish restocking is recognized as the main vector of its introduction in Europe, as the mussel's parasitic larvae (glochidia) are carried by both indigenous European species (Douda et al. 2012, 2017) and non-indigenous fish species

such as the grass carp *Ctenopharyngodon idella* (Valenciennes), Prussian carp *Carassius auratus gibelio* (Bloch), silver carp *Hypophthalmichthys molitrix* (Valenciennes) and bighead carp *Hypophthalmichthys nobilis* (Richardson) (Lajtner and Crnčan 2011; Soroka et al. 2014). The mussel has also been intentionally introduced in Italy for the production of artificial pearls and other commercial purposes (Cianfanelli et al. 2007).

Sinanodonta woodiana is among the most threatening invaders of freshwater ecosystems: it is the largest mussel in European freshwaters and adapts to a variety of lentic (lakes, reservoirs) and lotic habitats (rivers, channels). In addition, *S. woodiana* may reduce the fitness of parasitized indigenous fish species (Douda et al. 2017) and, due to its high growth rate and reproductive potential, it can become both a direct and indirect competitor of indigenous bivalves (Benkő-Kiss et al. 2013; Donrovich et al. 2017).

The growing concern over the *S. woodiana* invasion requires continuous monitoring of its distribution, in particular at the margins of the species' range, in order to highlight expansion phenomena and to implement measures of prevention, control and eradication. In Italy (Supplementary material Table S1), *S. woodiana* was recorded for the first time at unspecified locations in the Emilia-Romagna and Latium regions between 1989 and 1999 (Malavasi et al. 1999). After 1999, other northern Italian regions (Piedmont, Veneto and Tuscany) were colonized via the hydrographic basins of the Po, Piave, Adige and Arno rivers (Manganelli et al. 1998; Kamburska et al. 2013). It was reported before 2003 in Veneto, in channels located between the cities of Verona and Rovigo (Niero 2003). Specimens ranging between 22 and 28 cm in size were reported in 2003 from the artificial Lake Gasparetti in the Marche region in central Italy (Solustri and Nardi 2006). During 2005, specimens of *S. woodiana* were recorded in the artificial Bilancino lake in Tuscany, together with other non-indigenous bivalve species such as *Dreissena polymorpha* (Pallas) (Lori and Cianfanelli 2006). In 2007, specimens ranging from 4 to 10 cm in size were collected in the Volturno river (Campania region), in an area subject to high anthropogenic pressure (De Vico et al. 2007). In the Lombardy region, data on the occurrence of the species are more recent. In February 2009, the presence of various cohorts of *S. woodiana* was reported for the first time in Lake Garda (Cappelletti et al. 2009), while during the period 2010–2012 the species was recorded in Lake Maggiore (Kamburska et al. 2013). In Sicily, *S. woodiana* was recorded for the first time by Zettlerand and Richard (2003), and the presence of large-sized specimens (19 cm maximum shell length) was reported in Lake Santa Rosalia in 2012 (Colomba et al. 2013). Episodic occurrences were reported in the San Giuliano and Cecita lakes in the Basilicata region during 2012 (Renda and Niero 2014). Stable populations of *S. woodiana* were found in ditches and

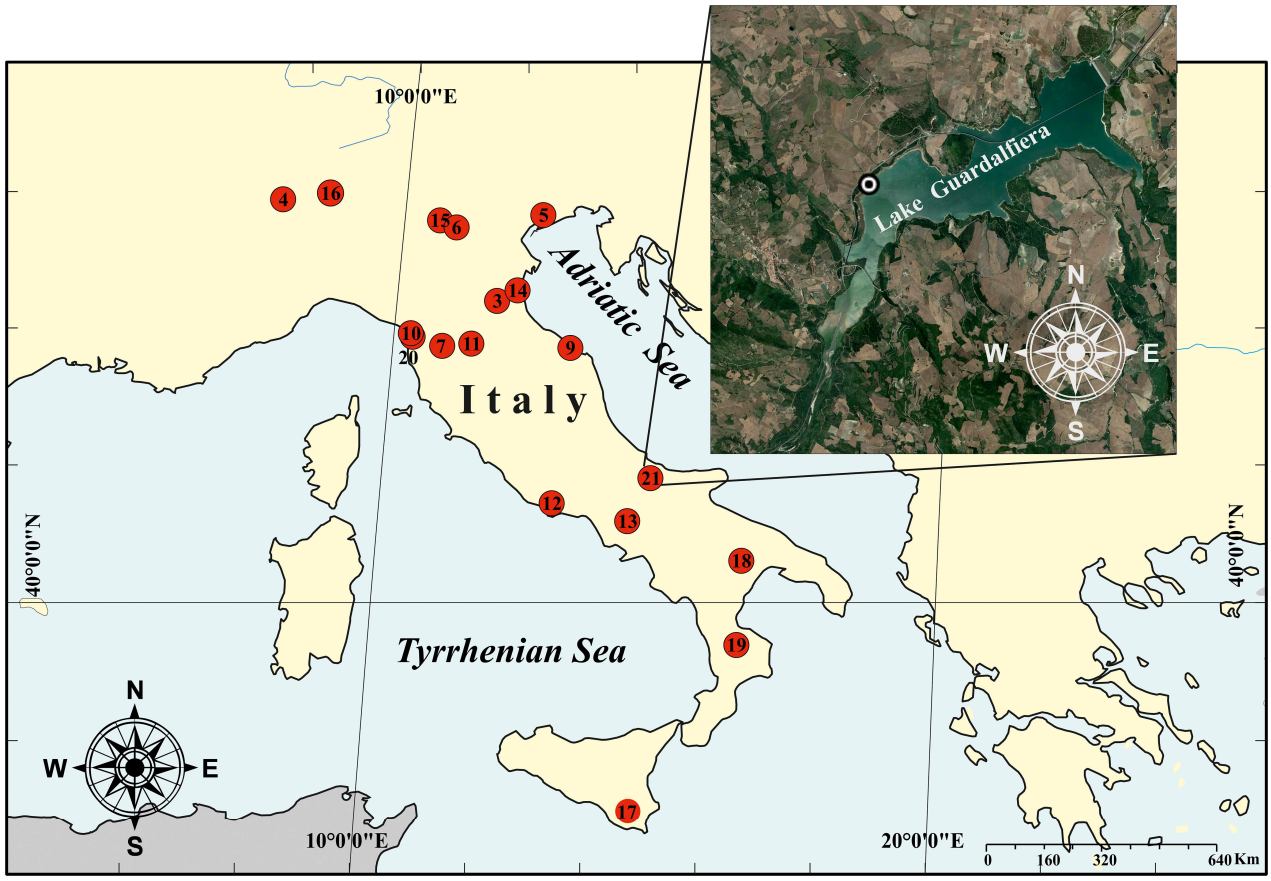

Figure 1. Study area (Lake Guardialfiera) and recorded locations of *S. woodiana* in Italy. See the Supplementary material Table S1 for the explanation of the location numbers.

channels in the Versilia district (Tuscany) in summer 2014 (Ercolini 2015). This study reports the first occurrence of *S. woodiana* in a lacustrine habitat located in the Molise region, providing evidence for its spread in Southeast Italy. In addition, it includes morphometric information on specimens collected after a long drought period (summer 2017).

Materials and methods

The study area is Lake Guardialfiera (41.809°N; 14.814°E), located in the Molise Region (SoutheastItaly), also known as the Liscione Dam (Figure 1). It is an artificial reservoir created in the early seventies by damming the Biferno river to supply drinking water to surrounding villages such as Larino, Campomarino, Casacalenda and Guardialfiera. The reservoir has a maximum surface area of 7.45 km^2, with depth ranging from 2 to more than 20 m, and sandy and stony substrata. According to local newspapers (http://www.ilgiornaledelmolise.it/2017/10/01/il-lago-del-liscione-invaso-da-vongole-giganti/) and social networks, the Chinese pond mussel, *Sinanodonta woodiana,* was observed for the first time in Lake Guardialfiera in September 2017 by tourists and local people.

The present study was carried out in October 2017, after an exceptional summer drought which dried out several hectares of the lake, documented

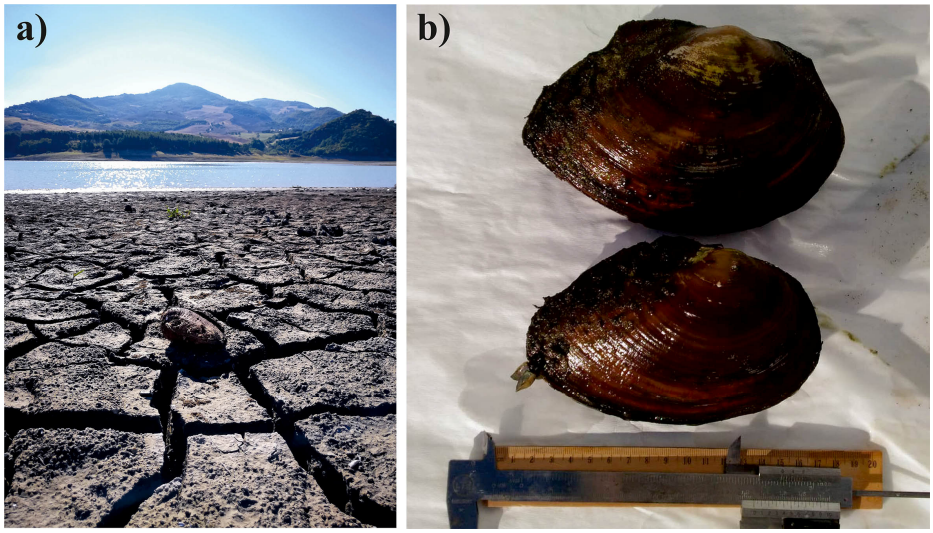

Figure 2. *Sinanodonta woodiana*: a) Lake Guardialfiera during the drought period and sample collection, 6th of October 2017; b) different specimen sizes classified in accordance with Spyra et al. (2012). Photographs by Nicola D'Emma.

by the "Molise Acque" regional company (Figure 2a). Between July and October 2017, the lake water level decreased by 4.5 m in only 60 days. Precipitation and temperature data were provided by the "Consorzio di Sviluppo Industriale della Valle del Biferno – COSIB".

Live bivalve specimens were collected by hand in an easily accessible location on the southwest side of the lake, close to the village of Guardialfiera (Figure 1). There, emerged clods (clumps of substratum material) were mostly dry and solid. The individuals were covered with wet cloths and transported to the laboratory, where the main biometric variables (shell length SL, height HL and width WL) were immediately measured to the nearest 0.1 mm and wet weight was obtained to the nearest 0.01 g. Based on shell length, specimens were classified into four size classes (Spyra et al. 2012): Young, with SL < 50 mm; Small 50 ≤ SL ≤ 100 mm; Medium 100 < SL ≤ 150 mm; and Large SL > 150 mm. An asymptotic equality test for unequal sample sizes (Feltz and Miller 1996) was used for testing the hypothesis that the coefficients of variation of biometric variables and wet weights were the same for the three size classes.

In addition, to evaluate the physiological state of the organisms, their Condition index (CI) was estimated. For this purpose, six individuals were chosen randomly, following conventional protocols and procedures adopted for bivalves (Cilenti et al. 2018), and used to calculate CI values in accordance with the equation suggested by Crosby and Gale (1990): CI = DMmeat(g)/DMshell(g), where DM=dry mass. Both shells and soft tissues were dried in an oven at 105 °C for 24 h and subsequently weighed.

Results and discussion

A total of 24 living individuals of *S. woodiana* were collected. Neither dead fish nor other indigenous bivalves were observed in the emerged clods. A few

Table 1. *Sinanodonta woodiana* biometric data collected in Lake Guardialfiera in October 2017. Size classes are in accordance with Spyra et al. (2012). The results of Feltz and Miller's (1996) asymptotic equality test (AE test in the table) for the coefficients of variation (calculated as the standard deviation/mean ratio) of the two size classes are also included; the R package *cvequality* (Marwick and Krishnamoorthy 2018) was used to run the test.

Size class	N. individuals	Length		Height		Width		Total WetWeight*	
		mean	SD	mean	SD	mean	SD	mean	SD
medium	10	128.50	14.7	48.60	6.1	86.70	12.6	271.82	91.25
large	14	164.50	8.3	59.57	5.1	106.93	6.7	450.24	80.21
all	24	149.50	21.3	55.00	7.7	98.50	13.8	372.67	122.9
AE test**		0.01		0.23		0.01		0.04	

* one large-sized individual excluded from calculations due to its anomalous total wet weight
** P-value reported

empty *S. woodiana* shells were found together with the 24 collected live specimens scattered across an area of about 500 m^2. Shell length of collected specimens ranged between 101 and 180 mm, shell height between 42 and 70 mm, and shell width between 61 and 114 mm. More than half of the specimens (N = 14) were large (ranging between 151 and 180 mm) while all the remaining individuals were of medium size (ranging between 101 and 142 mm) (Table 1, Figure 2b). With the exclusion of shell height, morphometric parameters of medium-sized individuals were characterized by a wider variability (higher SD) than that of large individuals (Table 1). Furthermore, asymptotic equality tests indicated that significant variations between size classes occurred only in terms of shell length or width and total wet weight, in agreement with the expectations of an allometric growth pattern (Dudgeon and Morton1983; Chen et al. 2015).

This is the first record of *S. woodiana* in the Biferno river catchment area and the Molise regionin general. The individuals collected were large and medium-sized, but it was not possible to determine the exact date of the species' introduction into Lake Guardialfiera. Fish may have represented the main vector of introduction of this species into the Lake, which has been colonized over the years by the non-indigenous *Carassius* spp. and *Cyprinus carpio carpio* (Linnaeus) (Costantini and Romano 2010).

Critical environmental variables, such as anomalously high water temperatures, may play a crucial role in the survival of young individuals (Kraszewski and Zdanowski 2007). The extended drought period and the high atmospheric temperatures recorded before and during the sampling time (Figure 3) could be responsible for the absence of young and small individuals. Indeed, the absence of small individuals may result from a range of factors. Higher mortality can be excluded, as small-sized empty shells were not collected. Furthermore, small individuals may have higher mobility, being able to move horizontally on the sediment surface and reach deeper areas (Monaco et al. 2016). The higher body mass of large and medium-sized specimens, coupled with their lower mobility and their ability to use alternative strategies for *in situ* survival (conserving water within the shell), may account for the observed size patterns.

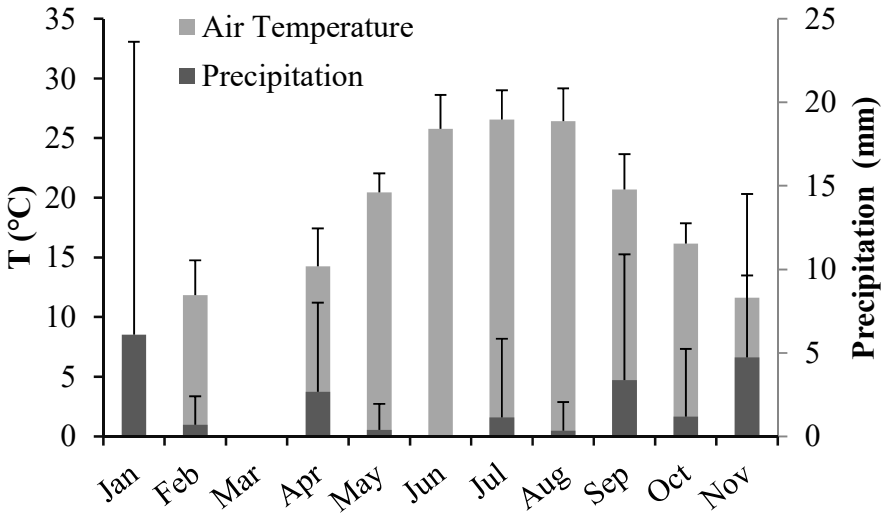

Figure 3. Monthly Climate data (means; bars represent standard deviations) during 2017 in the area surrounding Lake Guardialfiera.

Specimens' wet weight ranged from 153.74 g to 541.93 g. The condition index, calculated with reference to two large and four medium-sized individuals, ranged from 4.20 to 10.72 with a mean of 8.07 ± 2.4. Based on these preliminary data, we are not able to speculate regarding meat quality, due to the lack of comparable literature data. However, the considerable loss of water (estimated by the difference between the total wet weight and the wet tissue weight) indirectly suggested the ability of *S. woodiana* to survive for long periods under environmentally stressed conditions by relying on water reservoirs within the shell.

The ability of *S. woodiana* to invade freshwater environments, affecting the physical properties of colonized habitats (Douda et al. 2012) and altering them through various processes such as the capture of suspended material, production of faeces and biomagnification of pollutants (Douda et al. 2014), together with a great physiological tolerance to environmental variable changes and rapid growth, makes this species a threat to indigenous bivalves in Italian freshwater habitats. In our study, the partial drying up of the lake may have affected the population by killing larger individuals; nonetheless, the survival of adults may have ensured the survival of the population until the re-establishment of more suitable environmental conditions.

Indigenous bivalve species, represented in Italy by *Anodonta anatina* and *Anodonta cygnea*, could be almost completely replaced by *S. woodiana*, as has already occurred in Northern Italy (Emilia Romagna: Fabbri and Landi 1999; Veneto: Niero 2003) and in Poland (Najberek et al. 2011).

Specifically, in 1997, large-sized specimens (26 cm maximum shell length) of *S. woodiana* were found in the Emiliano-Romagnolo channel, after it dried up (Fabbri and Landi 1999). The high organic matter content in the sediments of this channel was recognized to be the trophic factor

responsible for the dominance of *S. woodiana* and the considerable decrease in abundance of the indigenous species *A. anatina* observed during the years 1998 and 1999 (Fabbri and Landi 1999). Donrovich et al. (2017) suggest that the dramatic decline in indigenous species might be related to competition from *S. woodiana* for hosts during larval stages. No quantitative information is available on the distribution and abundance of indigenous bivalves of the *Anodonta* genus, either in Lake Guardialfiera or the Biferno river. There is a need for further comparative studies to assess the ecological impact of *S. woodiana* on indigenous unionids and, in general, on the ecosystem services provided to Lake Guardialfiera. The lake is currently exploited for human activities (e.g., angling, recreational activities, crop irrigation, and abstraction of drinking waters). In theory, the species may paradoxically have positive effects, such as increasing the water clarity of the lake due to filtration, enhancing the deposition of organic and inorganic particulates in sediments as faeces and pseudo-faeces, or becoming an important food resource for fish species (Sousa et al. 2014 and references therein). All these changes may modify the entire ecosystem, having significant effects on fauna and flora composition and structure, as already observed for the zebra mussel (*Dreissena polymorpha*). However, the present study provides further confirmation of a massive die-off affecting invasive bivalves during an extreme climatic events (Ilarri et al. 2011; Sousa et al. 2012; Bódis et al. 2014). Indeed, during such events, *S. woodiana* mortality is caused by water quality deterioration (spikes in temperature associated with low oxygen), and the consequent biomass pulses provide a feedback loop that worsens the water quality even more. Due to the persistence of decaying carcasses in shallow benthic systems or in neighbouring terrestrial environments, the value of the lake shore for recreational purposes may consequently decrease. Particular attention should be paid in the future to extensive studies of lake water quality and *S. woodiana* population dynamics, to be used for developing management plans for the protection of the lacustrine habitat.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Records of *Sinanodonta woodiana* in Italy

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2019/Supplements/BIR_2019_Cilenti_etal_Table_S1.xlsx