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Assessing the impact of the Asian mussel *Arcuatula senhousia* in the recently invaded Oristano Lagoon-Gulf system (W Sardinia, Italy)

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ABSTRACT

In the marine environment, the introduction and spread of non-indigenous mussels may cause major modifications to native assemblages and alter the trophic flow within the food web. We analysed the impacts of the recently sighted Asian date mussel *Arcuatula* (=*Musculista*) *senhousia* on sediment features, native macrozoobenthic assemblages and the $\delta^{13}C$ and $\delta^{15}N$ values of dominant macrozoobenthic taxa in the Oristano Lagoon-Gulf system (western Sardinia, Italy). Results showed that the amount of variation generated by the occurrence of *Arcuatula senhousia* was lower than the intrinsic spatial variability in sediment features, macrozoobenthic assemblages and the $\delta^{13}C$ values of dominant deposit feeders (*Hediste diversicolor*, *Cirriphormia tentaculata*, *Haminoea navicula* and *Cyclope neritea*) of this system. In addition, $\delta^{13}C$ and $\delta^{15}N$ values of *A. senhousia* were found to be similar to those of co-occurring suspension feeders *Cerastoderma glaucum*, *Ruditapes decussatus* and *Scrobicularia plana*, indicating exploitation of common food resources. The overall lack of effects of *A. senhousia* may be dependent on the moderate densities encountered in our study area (<1000 individuals m^{-2}). We suggest that the low rate of new arrivals, owing to limited shellfish farming and maritime activities in the area, and unfavourable environmental conditions of the lagoons especially in summer (e.g. anoxia) which erode mussel populations, likely prevent *A. senhousia* from entering its expansion phase and impacting local benthic communities.

1. Introduction

Mussels are often introduced accidentally into new marine and freshwater environments. Over the past century, the Asian date mussel *Arcuatula* (=*Musculista*) *senhousia* (Benson in Cantor, 1842) has been introduced from Asia to the Pacific coast of North America, Australia, New Zealand and in the Mediterranean Sea (Crooks, 1996; Creese et al., 1997; Mistri, 2002). In the western Mediterranean Sea, *A. senhousia* was first discovered in the late 1980s in several lagoons of the Marseille area (Etang de Tau, Balaruc les Bains and Languedoc-Roussillon, Etang d'Or; Hoenselaar and Hoenselaar, 1989) and then found along the Italian coast. In particular, at the beginning of the 1990s it was sighted on the northern Adriatic coast (Ravenna and Sacca di Goro; Mistri et al., 2004) and in the late 1990s on both the north-western and north-eastern Tyrrhenian Sea (Gulf of Olbia on the Eastern coast of Sardinia and Leghorn harbour, respectively; Campani et al., 2004). Then, it was discovered in the Ionian Sea at the beginning of the 2000s (Mar Piccolo of Taranto; Apulian; Mastrototaro et al., 2003) and only in 2009 on the western coast of Sardinia (Gulf of Oristano; Cannas, 2010).

A. senhousia is a gregarious and fast-growing organism that lives semi-buried in the intertidal and shallow subtidal soft sediments of bays, estuaries and lagoons (Crooks, 1996; Mistri, 2002; Magni et al., 2006a). *A. senhousia* can influence the sediment features as well as the species composition and the distribution of abundances of local infauna through the creation of a structurally complex network composed of shells and byssus that modifies benthic habitat (i.e., ecosystem engineer effects). The shell's formation

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facilitates many small benthic invertebrates such as polychaetes, gastropods and crustaceans (Crooks and Khim, 1999), while larger organisms not able to live within or close to these structures, such as clams, can be inhibited (Creese et al., 1997; Crooks, 2001). In addition to structural effects, *A. senhousia* may influence the local infauna by altering the trophic interactions between benthic consumers and their food sources within the food webs. *A. senhousia* is a suspension feeder that filters suspended particles from the water column and may locally deplete food supplies to co-occurring bivalves (Crooks, 2001; Kushner, 2005). *A. senhousia* may also increase the availability of suspended material to benthic deposit feeders into the sediment. Mats created by *A. senhousia* typically raise a few millimetres above the surface sediments, and this biogenic structure alters the hydrodynamic features on flat bottoms favouring the trapping and deposition of suspended fine particles and labile detritus (Crooks, 1998; Crooks and Khim, 1999). *A. senhousia* may also increase the availability of suspended material to benthic deposit feeders through its biological activities of suspension feeding and biodeposition. During feeding, the undigested remains are ejected as mucus-bound faeces and pseudofaeces, and sink to the sediment surface (Newell, 2004; Strayer, 2014). This biodeposition is extremely important because biodeposits are mixed into the sediment and consumed by deposit feeders (Norkko et al., 2001). Finally, *A. senhousia* can store material within its body mass and this material accumulated during periods of growth may be released at death (Strayer, 2014).

Studies on dreissenid mussels (e.g. the zebra mussel *Dreissena polymorpha*) and other invasive freshwater bivalves (e.g. the Asian clam *Corbicula fluminea*) illustrate dramatic changes to the structure and energy base of the littoral food web following bivalve establishment (Higgins and Vander Zanden, 2010; Ozersky et al., 2012; Basen et al., 2013). The establishment of bivalves redirects energy and material from the water column to the littoral benthos through deposition of sestonic material, increasing benthic production (Higgins and Vander Zanden, 2010; Gergs et al., 2011; Ozersky et al., 2012). With regard to *A. senhousia*, while many studies have analysed the impact of *A. senhousia* on sediment properties and the abundances of resident fauna (e.g. Crooks, 1998, 2001; Mistri, 2002; Munari, 2008), no studies have investigated its ability to affect the transfer of phytoplankton from the first to the second trophic level of benthic food webs (i.e., to suspension and deposit feeders), both in native and non-native areas.

In this study, we investigated the ecological effects of *A. senhousia* that was recorded for the first time in the Santa Giusta and Marceddì lagoons of the Oristano Lagoon-Gulf system (western Sardinia, Italy) in 2009 (Cannas, 2010 and unpublished data). Firstly, in the Santa Giusta lagoon, we tested the effects of *A. senhousia* on the sediment features and macrozoobenthic assemblages. If the occurrence of *A. senhousia* affects the sediment features and the local infauna, we expected differences in the sediment features and the structure and species composition of macrozoobenthic assemblages between stations where *A. senhousia* was present and those where it was absent. Secondly, in the Marceddì lagoon, we tested some hypotheses regarding the role of *A. senhousia* on the benthic food web. In particular, we compared the $\delta^{13}C$ and $\delta^{15}N$ values of deposit feeders (DF) and sedimentary organic matter (SOM), which comprises the bulk of food sources for deposit feeders (Rodriguez-Graña et al., 2008; Riera, 2010), in the presence and absence of *A. senhousia*. If *A. senhousia* increases the availability of phytoplankton into the sediment for deposit feeders, we expected that DF and SOM would have more ^{13}C-depleted values, close to those of phytoplankton (France, 1995), in sites where *A. senhousia* is present than in those where it is absent. In addition, we compared the $\delta^{13}C$ and $\delta^{15}N$ values of *A. senhousia* to those of co-occurring suspension feeding bivalves. If they exploit common resources, we expected similar $\delta^{13}C$ and $\delta^{15}N$ values. Finally, because ontogenetic variability in food acquisition can occur in bivalves after the recruitment of the planktonic larvae (Veniot et al., 2003; Beninger et al., 2006; Cannuel and Beninger, 2007), we tested, where possible, whether differences in both $\delta^{13}C$ and $\delta^{15}N$ values exist between different sizes of *A. senhousia*.

2. Material and methods

2.1. Study area

The field work was conducted in the Santa Giusta and Marceddì lagoons, two eutrophic basins connected to the Gulf of Oristano (Fig. 1). The Santa Giusta lagoon has an area of 7.9 km^2, a mean depth of 1 m and is separated from the sea by a long-shore bar. Salinity ranges from 25‰ to 42‰, with a mean annual value of 30‰ (Sechi et al., 2001). The Santa Giusta lagoon is located in the plain of Pesaria, an agricultural area that is intensively cultivated with rice. During the last few decades, several human interventions have profoundly modified the lagoon ecosystem. An industrial port and an industrial canal communicating with the sea were built in the 1970s and a diversion canal for urban wastes was built in 1995. Although this canal was thought to reduce the trophic level of the lagoon, there is no evidence that the diversion system has stopped sewage from flowing into the lagoon (Sechi et al., 2001). As an example, a dystrophic event with anoxia and sulphide development occurred in the summer of 2004 causing a drastic reduction in macrozoobenthos and massive fish kill (Magni et al., 2008). The Marceddì lagoon has an area of 8 km^2 and a mean depth of 1.5 m. Salinity ranges from 23‰ to 42‰, with a mean annual value of 33‰ (Cannas, 2010). The Marceddì lagoon is located near the plain of Arborea, an area of intensive agricultural and zootechnical activities (Galiano et al., 2015), where of about 10,000 ha, 4500 ha are cultivated and 33,000 dairy cows are grazed. Until the early 1990s, mining was also present in the drainage basin of the Marceddì lagoon where high concentrations of heavy metals (Pb, Cd and Zn) in sediments have been found (Magni et al., 2006b).

2.2. Sample collection, processing and laboratory analysis

To study the effects of *A. senhousia* on sediment features and macrozoobenthic assemblages, sediment samples were collected in the Santa Giusta lagoon in December 2009 at three sites, according to a hierarchical sampling design described in Tataranni et al. (2009). There were twenty-seven samples at each site. Samples of macrozoobenthos were collected from the bare bottom with a box-corer (10 × 17 cm^2), sieved through a 0.5 mm mesh and preserved in 4% formaldehyde. At each sampling station, sediment cores (30 mm inner diameter) were also collected for the grain size analysis and the determination of organic matter (OM), water and bicarbonate contents.

In the laboratory, the surface layer (0–2 cm) of sediments was carefully sliced off each core. A sub-sample of ca. 4 g was suspended in 500 ml of distilled water and treated with hydrogen peroxide (H_2O_2, 4% solution) in order to eliminate organic matter before being wet sieved through a net of 64 μm. The sand fraction (>64 μm) remaining in the sieve was dried and weighed. Ten millilitres of suspension with the mud fraction (<64 μm) were then treated with Na-Hexametaphosphate 0.6% to avoid particle flocculation after a dilution to obtain a sediment concentration of ~0.5 mg ml^{-1}. The OM content in the sediments was determined from a sub-sample (about 1 g) by loss of ignition at 500 °C for 3 h. Water content in the sediment was quantified from a sub-sample (about 1 g) by loss of weight at 60 °C for 48 h. Carbonates